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Essays on the elasticity of substitution between capital and labour and biased technological change

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ESSAYS ON THE ELASTICITY OF SUBSTITUTION BETWEEN CAPITAL AND LABOUR AND BIASED TECHNOLOGICAL CHANGE

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Summary

This study aims to contribute to a deeper understanding of the pivotal role played by the elasticity of substitution between capital and labour over a wide range of topics in economic literature and to estimate the elasticities of substitution and technological change biases, not only for the United States aggregate economy and industry-level, but also for the majority of OECD countries. Although there is no scarcity of studies estimating the elasticity of substitution, they are particularly focused on the United States aggregate economy, overlooking the heterogeneity that exists at the industry-level, and only a few of them cover other geographical scopes. Moreover, these studies are mostly based on a Constant Elasticity of Substitution (CES) production function which, as indicated by its name, is subject to the limitation that the elasticity of substitution assumes a constant value, although not necessarily unity (as the Cobb-Douglas function). It seems reasonable to admit, nevertheless, that the degree of substitutability between production factors can vary with changes in the capital intensity of production and consequently to evaluate the plausibility of a Variable Elasticity of Substitution (VES) functional form.

In order to explore these topics, this thesis comprises four essays, the first two consisting in a comprehensive critical appraisal of the literature on the elasticity of substitution and biased technological change, including the importance of factor substitution over a broad range of topics in economic theory, while the last two are empirically oriented.

The first essay begins by exploring the core concepts that will be used throughout the study, starting with the elasticity of substitution, a concept which was introduced independently by John R. Hicks and Joan Robinson in the 1930s, and its graphical representation, related to the shape of a given isoquant. Some of its mathematical properties include the symmetry with respect to the two factors of production, while the extensively adopted case of constant returns to scale in production implies that the elasticity of substitution is equal to the elasticity of labour productivity with respect to the wage rate (Allen's theorem). The concept of technological change and the possible directions of technological change are then presented, before exposing the well-known Diamond et al. (1978)'s impossibility theorem, according to which the bias of technological change cannot be identified simultaneously with the elasticity of substitution in the absence of *a priori* hypotheses on the structure of technological change.

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The quantitative exercises are performed with resort to CES and VES production functions, which are comprehensively surveyed in the first essay, ever since their introduction in the 1960s. We start by describing their properties and the particular parametric cases nested within each function, including the Cobb-Douglas, Leontief or linear production functions. In line with many economic studies, we will consider two estimation forms: either the log-linearized first-order conditions for profit maximization or the system approach, which presents important advantages, as it encompasses both optimizing behaviour and technology, in addition to improving parameter identification due to the inclusion of cross-equation parameter constraints.

Empirically, the CES production function has been extensively used to estimate the elasticity of substitution, either at the aggregate or at the sectoral or plant level. The prevailing conclusion, despite some exceptions, is a lower than unity elasticity of substitution, both for the United States of America and other geographical scopes, consequently rejecting the Cobb-Douglas assumption. In this regard, the technological change assumption plays an importante role, as restricting the analysis to the Hicks-neutral case will bias the elasticity of substitution estimates towards unity (see, in this respect, Antràs, 2004). When factor-augmenting technological change is taken into account, the prevailing conclusion is the finding of net labour-augmentation rates.

A recent development in this field involves the normalization of CES production functions, which implies expressing the production relations in an indexed number form and allows the joint identification of the elasticity of substitution and technological change parameters with less biased estimates than imposing *a priori* constraints on the structure of technological change. The existing studies, either considering individual or several heterogeneous countries, point to a lower than unity elasticity of substitution, a conclusion which is also prevalent at the United States industry-level (Young, 2013), while technological change is mainly net labour-augmenting.

The CES production function, as indicated by its denomination, restricts the elasticity of substitution to a constant value (albeit not necessarily unity as the Cobb-Douglas function), even if the relative supply of labour and capital changes in the economy. Consequently, several authors developed alternative functional forms for an economy's production function, which allow the value of the elasticity of substitution to be influenced by the economy's input ratio. Kadiyala (1972) suggested a general version for a Variable Elasticity of Substitution (VES) production function which includes, as special

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cases, the CES, the Lu and Fletcher (1968), the R. Sato and Hoffman (1968) and the Revankar (1971a) production functions, and which allows the application of the standard linear estimation methods for the profit maximization first-order conditions, under certain parametric restrictions. Despite its relatively limited empirical application since the 1970s, most studies agree that the VES production function is more realistic than the Cobb-Douglas and the CES production functions in many specifications and mainly point to lower than unity values of the elasticity of substitution. However, few studies estimated the annual rate of efficiency change and only at the expense of imposing a given neutrality assumption with non-unanimous conclusions. In line with the recent developments in the context of CES production functions, we extend the normalization procedure to the case of VES production functions, a procedure which may also alleviate the joint identification of the elasticity of substitution and the growth rates of factor-augmenting technological change.

Although many studies highlight the central role played by the elasticity of substitution in their models or within their streams of research, to the best of our knowledge none of them have recently attempted to survey the importance of factor substitution across a wide range of topics. Different values of this parameter can lead to significantly different conclusions, therefore highlighting the importance of its correct identification.

One of the topics directly affected by the magnitude of this parameter is the functional distribution of income. The capital share increases with capital intensity when the elasticity of substitution is greater than one, whereas an opposite conclusion is reached when the elasticity of substitution is lower than one. Although there is some debate in the literature, the majority of empirical studies estimate the elasticity of substitution to be less than one. This makes it challenging to attribute the recent decline in the labour share observed in many countries to an increase in capital intensity. The higher the elasticity of capital-labour substitution, the lower the impact of productivity on factor returns and the lower the impact of capital deepening on the wage-rental ratio. In the case of an elasticity of substitution below one, the relationship between output per capita and capital intensity is concave. Conversely, if the elasticity of substitution is higher than one, the relationship is convex. Empirical evidence from cross-country studies indicates that a concave relationship fits the data better. However, if the elasticity of substitution is lower than one, cross-country differences in productivity lead to significant and unrealistic

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differences in factor returns. This suggests that differences in total factor productivity (TFP) may be a significant source of cross-country differences in income per capita.

The welfare costs of taxation increase with the value of the elasticity of capital-labour substitution because the price elasticity of the demand functions for the productive factors increases with the value of the elasticity of substitution. Furthermore, a lower elasticity of substitution enhances the productivity gains from better resource allocation and increases the cross-country correlation between output per capita and the distortions that cause resource misallocation.

The elasticity of substitution also plays an important role in the labour market. Firstly, although not immediately apparent, the effect of unionisation on wages and employment depends on the elasticity of capital-labour substitution. Secondly, the impact of technological shocks on hours worked, unemployment and vacancies depends crucially on the nature of the productivity shock and the magnitude of the elasticity of substitution. The incorporation of a substantial capital-labour complementarity within a dynamic stochastic model enables the model to better reflect the cyclical properties of labour market variables in the United States. Furthermore, the lower the elasticity of substitution, the greater the impact of capital deepening on employment. Some authors have proposed that the prolonged period of elevated unemployment in Europe during the 1980s was a consequence of the implementation of capital-intensive technologies in a context where capital and labour were gross substitutes.

Capital-labour substitution is also crucial for some aspects of economic growth. Structural change can be driven by differences in the elasticity of substitution. Sectors with a higher elasticity of capital-labour substitution tend to intensify the use of the productive factor that is becoming more abundant, which can lead to sectoral differences in the growth rates of capital intensity. In the context of the neoclassical growth model, a higher elasticity of capital-labour substitution increases the speed of convergence if the economy is above its steady state, but reduces it otherwise. Furthermore, for any given capital intensity, a higher elasticity of capital-labour substitution boosts the growth of capital and output per worker during the transition to the balanced growth path. In the long run, both capital intensity and output per worker are increasing functions of the elasticity of substitution. Even in the absence of technological progress, it is possible to achieve perpetual growth if the elasticity of capital-labour substitution is sufficiently high. However, if the elasticity of capital-labour substitution is sufficiently low, it is also possible to experience a

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perpetual slowdown. In the neoclassical growth model, if the elasticity of substitution is not unitary, the existence of a balanced growth path necessitates solely labour-augmenting technological progress. An elasticity of substitution inferior to one ensures that the economy converges to a balanced growth path where technological change is exclusively labour-augmenting. While the results are contingent upon assumptions regarding preferences, technology, structure, and market distortions, the elasticity of capital-labour substitution represents a pivotal parameter for the emergence of multiple equilibria and complex dynamics in macroeconomic models.

In the third essay, we estimate the elasticities of substitution and the growth rates of factor-augmenting technological change for the United States between 1947 and 2014, both at the aggregate and at the industry-level, using CES and VES production functions and the associated first-order conditions, either by a single-equation approach or by a normalized system specification. In the case of VES production functions, we consider the two particular parameteric cases which allow, respectively, the log-linearization of the profit-maximization first-order conditions with respect to capital and to labour.

Data are taken from the KLEMS database, which combines information from the Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS). To check some potential data issues, different econometric tests were applied: first, to assess whether the regressors included in the model were endogenous, we employed the Durbin, Wu-Hausman, Wooldridge and the robust regression-based endogeneity tests, obtaining non-unanimous conclusions depending on the industry and production function specification. Serial correlation in the disturbance terms was tested using the Durbin-Watson and Breusch-Godfrey tests, finding that the no first-order serial correlation null was rejected at the aggregate level and for almost all industries; moreover, after the correction with the Prais-Winsten estimation procedure, the Durbin-Watson transformed statistics suggested that the error terms follow an AR(1) process for the majority of the industries and production function specifications. Finally, the Augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) unit root tests were performed in order to assess the stationarity of the variables used in the regressions; in this case, the variables in levels were almost always nonstationary but became stationary when taken at first differences, indicating integration of the same order and suggesting the possibility of a cointegrating relationship among the variables under study. However, both the Trace and the Maximum-Eigenvalue test results indicate that the variables used in the regressions

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for the aggregate economy are not cointegrated, a conclusion which is also prevalent at the industry-level.

In order to deal with the aforementioned potential issues (regressor endogeneity, serial correlation in the error terms and nonstationarity of the variables used in the estimations), different estimation methods were considered, including Ordinary Least Squares (OLS) with differenced data and a three-stage Generalized Instrumental Variables (GIV) approach in the case of the single-equation estimations, as well as the Nonlinear Seemingly Unrelated Regressions (NLSUR) and the Generalized Method of Moments (GMM) techniques in the case of system estimation.

According to our findings, irrespectively of the estimation method and production function specification used, the US aggregate elasticity of substitution is always lower than unity, which corresponds to the case of gross complementarity between the production factors. More precisely, it is most likely in the region of 0.6 (or even less according to most single-equation estimates), while VES parameter estimates indicate a reduced variation over time, suggesting a tendency towards the CES specification. Regarding the single-equation estimates, the highest elasticities of substitution are obtained from the labour first-order condition, confirming an empirical regularity found in previous studies, while the combination of the capital and labour first-order conditions (where the elasticity of substitution is the estimated coefficient of the factor-price ratio) yields the lowest results.

The vast majority of the 65 industries represented in the US National Income and Product Accounts (NIPAs) also exhibit lower than unity elasticities of substitution. Due to the inclusion of cross-equation restrictions, the confidence intervals using the normalized system approach are remarkably narrower and the estimates are not as low as in some of the single-equation methods, therefore never including the Leontief case. At the conventional 5% significance level, the Cobb-Douglas production function is a possibility for only one industry using the normalized CES production function, a figure that increases to between 8 and 14 industries using the different specifications of the normalized VES production function, which also do not reject the CES production function for between 8 and 17 industries; combining both results, the VES estimations suggest that only between a third and 40% of the overall number of industries may be characterized by a time-invariant elasticity of substitution. In the remaining cases, the elasticity of substitution is apparently variable and therefore disaggregated industry-level

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studies should consider alternative and more flexible functional forms rather than the conventional and widely used CES production function.

Technological change is estimated to be net labour-augmenting at the US aggregate level, irrespective of the production function specification, at an average rate of around 1.1% to 1.5%, resulting from a positive labour-augmentation rate, combined with a decline in the capital efficiency level, which is also the prevailing conclusion at the industry-level. However, these results are not uniform: for example, in some primary industries, there appears to be an increase in capital efficiency and net capital-augmentation is found particularly in a number of service industries.

In the fourth essay, we estimate the elasticities of substitution and factor augmentation rates for a set of 29 OECD countries for two purposes. On the one hand, we assess whether the gross complementarity or the gross substitutability hypothesis between production factors holds, as well as whether technological change is net labour-augmenting or net capital-augmenting. On the other hand, we assess the ability of factor-augmenting technological change, capital deepening and changes in the firm labour wedge to account for the evolution of the labour share and, in particular, for its decline. According to the neoclassical economic theory, the elasticity of substitution between capital and labour is a key variable in determining the response of functional distribution of income to these changes.

Data at the quarterly frequency are taken mainly from the OECD Quarterly National Accounts (QNA) database (as well as from the OECD Economic Outlook 110), and cover the longest time span for which all data are available for each country until the end of 2019 (before the Covid-19 pandemic), while the perpetual inventory method (PIM) is applied to construct the series of capital.

The labour share underwent considerable changes in most OECD countries in recent years, including marked declines in countries such as Australia and the United States or strong increases in some Eastern Europe and Baltic countries; however, the majority of the 29 OECD countries considered exhibited downward trends in their labour shares (17 out of 29), with the highest decline being recorded for Ireland, whose labour share declined by more than 26 percentage points since 1995. On the other hand, the capital-intensity ratio increased in all countries relative to its initial value, with rapid growth rates observed particularly in Eastern Europe countries (such as Poland), the Baltic countries, Finland and Ireland.

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Given its advantages, estimation is performed using the normalized system approach: system estimation allows the simultaneous incorporation of both optimizing behaviour (from the first-order conditions) and technology (from the production function), while the inclusion of cross-equation parameter constraints increases the degrees of freedom and may improve parameter identification. Normalization improves these benefits as it allows the presetting of some parameters, therefore alleviating the estimation of the elasticity of substitution and the growth rates of factor-augmenting technological change. In line with most of the recent literature in the field, we employ the NLSUR estimation technique as, since the first-order conditions are obtained from the same production function, it seems plausible to admit that their errors terms are correlated, so the equations might be seemingly unrelated. Moreover, we also consider the GMM estimation due to the widely discussed endogeneity issue within the production function framework.

The point estimates of the elasticity of substitution using the normalized CES production function, as well as the 95 percent confidence intervals, lie entirely below unity for all countries, corresponding to the case of gross complementarity between capital and labour. However, in a few cases the estimated elasticity of substitution is not far from unity (Greece, Hungary and Sweden, depending on the estimation method and production function used), and therefore the Cobb-Douglas possibility should not be completely discarded. The Leontief case (zero elasticity of substitution) is never obtained, with the lowest estimates being found for Poland, Germany and Norway. The estimated elasticity of substitution for the USA ranges between 0.70 (NLSUR) and 0.76 (GMM), which is not far from the result obtained in the previous essay and in previous studies focusing on this economy (notice that we are using a different database and considering a different time period). Besides Germany, whose substitution elasticity is estimated between 0.24 and 0.31, the largest European economies, United Kingdom, France and Italy, have estimates in the region of 0.45 to 0.55, while the estimates for Spain are between 0.71 and 0.72. Outside Europe, Australia, Canada and Japan have estimates comprised between 0.36 and 0.41 (with the only exception being Australia using the GMM method, whose result is 0.59).

Furthermore, our estimation results corroborate the net labour-augmentation hypothesis for practically all countries. One of the exceptions is precisely the Czech Republic, one of the countries which experienced an increase in the labour share. In a few countries, such as the United Kingdom or Germany, the rate of net labour-augmenting technological

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change was not sufficiently fast to generate a decline in the effective capital-labour ratio, which explains the observed labour share increases, as predicted by the neoclassical model. However, in the United States and Australia, two countries in which the labour share underwent a significant decline, the rate of net labour-augmenting technological change exceeded 3.50% and 2.25% per year, respectively.

We find that, on average, in OECD countries where the rate of decline in the labour share has been greater, the contribution of net labour-augmenting technological change has been larger, while the contribution of capital deepening has been smaller. Therefore, increases in labour productivity can be reconciled with the observed declines in the labour share across countries in a context of a gross complementarity between capital and labour, provided that technological change is in fact increasing the amount of effective labour relatively to effective capital. It also follows from our results that capital deepening has not contributed to reducing the labour share, but rather the opposite.

Our analysis shows that the perfect competition model with biased technological change accurately accounts for the evolution of the trend component of the labour share in the Anglo-Saxon countries of Australia, the United States and the United Kingdom and some European economies (Belgium, the Czech Republic, Ireland, Spain, and Sweden), but it does not in Canada, Japan, and most European countries, including the three largest economies in the euro area (Germany, France and Italy). In these countries the firm labour wedge might have played an important, even prominent, role in accounting for the evolution of the trend component of the labour share. Moreover, in many OECD countries, the firm labour wedge has been declining since around 2008, contributing to an increase or at least a stabilisation of the labour share.

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Resumo

Este estudo pretende contribuír a unha comprensión máis profunda do papel fundamental que xoga a elasticidade de substitución entre capital e traballo nunha ampla gama de temas da literatura económica e estimar as elasticidades de substitución e os sesgos do cambio tecnolóxico, non só para a economía agregada dos Estados Unidos e a nivel da súa industria, pero tamén para a maioría dos países da OCDE. Aínda que non hai escaseza de estudos que estimen a elasticidade de substitución, están especialmente centrados na economía agregada dos Estados Unidos, non analizando a heteroxeneidade que existe a nivel de industria, e só algúns deles abarcan outros ámbitos xeográficos. Ademais, estes estudos baséanse maioritariamente nunha función de produción de Elasticidade de Substitución Constante (CES) que, como indica o seu nome, está suxeita á limitación de que a elasticidade de substitución asume un valor constante, aínda que non necesariamente unitario (como a función Cobb-Douglas). Parece razoable admitir, con todo, que o grao de substituibilidade entre os factores de produción pode variar cos cambios na intensidade de capital da produción e, en consecuencia, avaliar a plausibilidade dunha forma funcional con Elasticidade de Substitución Variable (VES).

Para explorar estes temas, esta tese consta de catro ensaios, os dous primeiros que consisten nunha ampla avaliación crítica da literatura sobre a elasticidade de substitución e o cambio tecnolóxico sesgado, incluíndo a importancia da substitución de factores nunha ampla gama de temas da teoría económica, mentres que os dous últimos son orientados empíricamente.

O primeiro ensaio comeza explorando os conceptos fundamentais que se empregarán ao longo do estudo, empezando pola elasticidade de substitución, concepto que foi introducido de forma independente por John R. Hicks e Joan Robinson na década de 1930, e a súa representación gráfica, relacionada coa forma dunha dada isocuanta. Algunhas das súas propiedades matemáticas inclúen a simetría con respecto aos dous factores de produción, mentres que o caso amplamente adoptado de rendementos de escala constantes na produción implica que a elasticidade de substitución é igual á elasticidade da produtividade do traballo con respecto ao salario (Teorema de Allen). A continuación preséntase o concepto de cambio tecnolóxico e as súas posibles direccións, antes de expor o coñecido Teorema da Imposibilidade de Diamond et al. (1978), segundo o cal o sesgo do cambio tecnolóxico non pode identificarse simultaneamente coa elasticidade de substitución en ausencia de hipóteses *a priori* sobre a estrutura do cambio tecnolóxico.

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Os exercicios cuantitativos realízanse recorrendo ás funcións de produción CES e VES, que se analizan exhaustivamente no primeiro ensaio, desde a súa introdución na década de 1960. Comezamos describindo as súas propiedades e os casos paramétricos particulares incluídos dentro de cada función, incluíndo as funcións de Cobb-Douglas, Leontief ou de produción lineal. En liña con moitos estudos económicos, consideraremos dúas formas de estimación: ben as condicións de primeira orde log-linealizadas para a maximización do lucro ou o sistema de ecuacións, que presenta importantes vantaxes, xa que abarca tanto o comportamento optimizador como a tecnoloxía, ademais de mellorar a identificación de parámetros debido á inclusión de restricións cruzadas entre os parámetros das ecuacións.

Empíricamente, a función de produción CES utilizouse amplamente para estimar a elasticidade de substitución, xa sexa a nivel agregado ou a nivel sectorial ou de planta. A conclusión predominante, a pesar dalgunhas excepcións, é unha elasticidade de substitución inferior á unitaria, tanto para os Estados Unidos de América como para outros ámbitos xeográficos, polo que se rexeita o presuposto Cobb-Douglas. Neste sentido, a hipótese do cambio tecnolóxico xoga un papel importante, xa que restrinxir a análise ao caso neutro de Hicks sesgará as estimacións da elasticidade de substitución cara á unidade (véxase, a este respecto, Antràs, 2004). Cando se ten en conta o cambio tecnolóxico aumentativo dun factor, a conclusión predominante é o achado de taxas de progreso tecnolóxicas aumentativas do traballo en termos netos.

Un desenvolvemento recente neste campo consiste na normalización das funcións de produción CES, o que implica expresar as relacións de produción nunha forma de número indexado e permite identificar conxuntamente os parámetros da elasticidade de substitución e do cambio tecnolóxico con estimacións menos sesgadas que impoñendo restricións *a priori* á estrutura do cambio tecnolóxico. Os estudos existentes, que teñen en conta países individuais ou varios heteroxéneos, apuntan a unha elasticidade de substitución inferior á unitaria, unha conclusión que tamén prevalece ao nivel industrial dos Estados Unidos (Young, 2013), mentres que o cambio tecnolóxico aumenta principalmente o factor traballo en termos netos.

A función de produción CES, como indica a súa denominación, restrinxe a elasticidade de substitución a un valor constante (aínda que non necesariamente unitario como a función de Cobb-Douglas), aínda que a oferta relativa de traballo e capital cambie na economía. En consecuencia, varios autores desenvolveron formas funcionais alternativas

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para a función de produción dunha economía, que permiten que o valor da elasticidade de substitución se vexa influenciado pola relación entre os inputs da economía. Kadiyala (1972) suxeriu unha versión xeral para unha función de produción de Elasticidade de Substitución Variable (VES) que inclúe, como casos especiais, as funcións de produción CES, de Lu e Fletcher (1968), de R. Sato e Hoffman (1968) e de Revankar (1971a), e que permite a aplicación dos métodos estándar de estimación lineal para as condicións de primeira orde para maximización do lucro, baixo certas restricións paramétricas. A pesar da súa aplicación empírica relativamente limitada desde a década de 1970, a maioría dos estudos coinciden en que a función de produción VES é máis realista que as funcións de produción de Cobb-Douglas e CES en moitas especificacións e apuntan principalmente a valores inferiores á unidade para a elasticidade de substitución. Porén, poucos estudos estimaron a taxa anual de cambio da eficiencia e só a costa de impoñer unha determinada hipótese de neutralidade, con conclusións non unánimes. En consonancia cos desenvolvementos recentes no contexto das funcións de produción CES, estendemos o procedemento de normalización ao caso das funcións de produción VES, un procedemento que tamén pode facilitar a identificación conxunta da elasticidade de substitución e das taxas de crecemento do cambio tecnolóxico aumentativo dos factores.

Aínda que moitos estudos destaquen o papel central que xoga a elasticidade de substitución nos seus modelos ou dentro dos seus fluxos de investigación, polo que sabemos ningún deles intentou recentemente investigar a importancia da substitución de factores nunha ampla gama de temas. Os diferentes valores deste parámetro poden levar a conclusións significativamente diferentes, polo que se destaca a importancia da súa correcta identificación.

Un dos temas directamente afectados pola magnitude deste parámetro é a distribución funcional da renda. A participación do capital aumenta coa intensidade do capital cando a elasticidade de substitución é maior que un, mentres que se chega a conclusión contraria cando a elasticidade de substitución é inferior a un. Aínda que existe certo debate na literatura, a maioría dos estudos empíricos estiman que a elasticidade de substitución é inferior a un. Isto dificulta a atribución do recente descenso da participación laboral observado en moitos países a un aumento da intensidade de capital. Canto maior sexa a elasticidade de substitución capital-traballo, menor será o impacto da produtividade nos rendementos dos factores e menor será o impacto da profundización do capital na relación salario-aluguer. No caso dunha elasticidade de substitución inferior a un, a relación entre

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a produción per cápita e a intensidade de capital é cóncava. Por outra banda, se a elasticidade de substitución é superior a un, a relación é convexa. A evidencia empírica de estudos entre países indica que unha relación cóncava se adapta mellor aos datos. Non obstante, se a elasticidade de substitución é inferior a un, as diferenzas entre países na produtividade dan lugar a diferenzas significativas e pouco realistas nos rendementos dos factores. Isto suxire que as diferenzas na produtividade total dos factores poden ser unha fonte significativa de diferenzas na renda per cápita entre países.

Os custos de benestar da fiscalidade aumentan co valor da elasticidade de substitución capital-traballo porque a elasticidade prezo das funcións de demanda dos factores produtivos aumenta co valor da elasticidade de substitución. Ademais, unha menor elasticidade de substitución mellora as ganancias de produtividade derivadas dunha mellor asignación de recursos e aumenta a correlación entre países entre a produción per cápita e as distorsións que provocan a mala asignación dos recursos.

A elasticidade de substitución tamén xoga un papel importante no mercado laboral. En primeiro lugar, aínda que non dun xeito obvio, o efecto da sindicalización sobre os salarios e o emprego depende da elasticidade de substitución capital-traballo. En segundo lugar, o impacto dos choques tecnolóxicos sobre as horas traballadas, o desemprego e as prazas de traballo depende fundamentalmente da natureza do choque de produtividade e da magnitude da elasticidade de substitución. A incorporación dunha complementariedade substancial capital-traballo dentro dun modelo de dinámica estocástica permite que o modelo reflicta mellor as propiedades cíclicas das variables do mercado de traballo nos Estados Unidos. Ademais, canto menor sexa a elasticidade de substitución, maior será o impacto da profundización do capital no emprego. Algúns autores propuxeron que o prolongado período de desemprego elevado en Europa durante a década dos 80 foi consecuencia da implantación de tecnoloxías intensivas en capital nun contexto no que capital e traballo eran substitutos brutos.

A substitución capital-traballo tamén é crucial para algúns aspectos do crecemento económico. O cambio estrutural pode ser impulsado por diferenzas na elasticidade de substitución. Os sectores con maior elasticidade de substitución capital-traballo tenden a intensificar o uso do factor produtivo que se fai máis abundante, o que pode provocar diferenzas sectoriais nas taxas de crecemento da intensidade do capital. No contexto da teoría neoclásica do crecemento, unha maior elasticidade de substitución capital-traballo aumenta a velocidade de converxencia se a economía está por encima do seu estado

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estacionario, pero redúcea no caso contrario. Ademais, para calquera intensidade de capital, unha maior elasticidade de substitución capital-traballo impulsa o crecemento do capital e da produción por traballador durante a transición á senda de crecemento equilibrado. A longo prazo, tanto a intensidade de capital como a produción por traballador son funcións crecentes da elasticidade de substitución. Aínda en ausencia de progreso tecnolóxico, o crecemento perpetuo é posible se a elasticidade de substitución capital-traballo é suficientemente alta. Porén, se a elasticidade de substitución capital-traballo é suficientemente baixa, tamén é posible experimentar unha desaceleración perpetua. No modelo de crecemento neoclásico, se a elasticidade de substitución non é unitaria, a existencia dunha senda de crecemento equilibrado require unicamente un progreso tecnolóxico aumentativo do traballo. Unha elasticidade de substitución inferior a un garante que a economía converxa para unha senda de crecemento equilibrado onde o cambio tecnolóxico é exclusivamente aumentativo do traballo. Aínda que os resultados dependen de suposicións sobre preferencias, tecnoloxía, estrutura e distorsións do mercado, a elasticidade de substitución capital-traballo representa un parámetro fundamental para a aparición de equilibrios múltiples e dinámicas complexas nos modelos macroeconómicos.

No terceiro ensaio, estimamos as elasticidades de substitución e as taxas de crecemento do cambio tecnolóxico aumentativo dos factores para os Estados Unidos entre 1947 e 2014, tanto a nivel agregado como a nivel de industria, utilizando as funcións de produción CES e VES e as condicións de primeira orde asociadas, xa sexa por unha soa ecuación ou mediante unha especificación en sistema normalizado. No caso das funcións de produción VES, teremos en conta os dous casos paramétricos particulares que permiten, respectivamente, a log-linealización das condicións de primeira orde de maximización do lucro con respecto ao capital e ao traballo.

Os datos son extraídos da base de datos KLEMS, que combina información do Bureau of Economic Analysis (BEA) e do Bureau of Labor Statistics (BLS). Para comprobar algúns posibles problemas dos datos, aplicáronse diferentes probas econométricas: en primeiro lugar, para avaliar se os regresores incluídos no modelo son endóxenos, empregamos as probas de endoxenidade de Durbin, Wu-Hausman, Wooldridge e a baseada nunha regresión robusta, obtendo conclusións non unánimes dependendo da industria e da especificación da función de produción. Probouse a autocorrelación dos residuos mediante as probas de Durbin-Watson e Breusch-Godfrey, concluíndo que a hipótese nula

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de non correlación serial de primeiro orde foi rexeitada a nivel agregado e para case todas as industrias; ademais, tras a corrección co procedemento de estimación de Prais-Winsten, as estatísticas transformadas de Durbin-Watson suxiren que os termos de erro seguen un proceso AR(1) para a maioría das industrias e especificacións da función de produción. Por último, realizáronse as probas de raíz unitaria Augmented Dickey-Fuller (ADF) e Phillips-Perron (PP) para avaliar a estacionariedade das variables utilizadas nas regresións; neste caso, as variables en niveis eran case sempre non estacionarias pero quedaron estacionarias ao tomarse en primeiras diferenzas, indicando unha integración da mesma orde e suxerindo a posibilidade dunha relación de cointegración entre as variables obxecto de estudo. Non obstante, tanto os resultados da proba Trace como da Maximum-Eigenvalue indican que as variables utilizadas nas regresións para a economía agregada non están cointegradas, unha conclusión que tamén prevalece a nivel de industria.

Para tratar os problemas potenciais mencionados anteriormente (endoxeneidade do regresor, correlación en serie nos residuos e non estacionariedade das variables utilizadas nas estimacións), consideráronse diferentes métodos de estimación, incluíndo mínimos cadrados ordinarios (OLS) con datos diferenciados e un método de variables instrumentais xeneralizadas (GIV) en tres etapas, no caso das estimacións dunha única ecuación, así como o método das regresións non lineais aparentemente non relacionadas (NLSUR) e o método de momentos xeneralizado (GMM) no caso da estimación en sistema.

Segundo os nosos resultados, independentemente do método de estimación e da especificación da función de produción empregados, a elasticidade de substitución agregada dos EE. UU. é sempre inferior á unidade, o que corresponde ao caso de complementariedade bruta entre os factores de produción. Máis precisamente, é probable que estea na rexión de 0.6 (ou incluso menos segundo a maioría das estimacións dunha única ecuación), mentres que as estimacións dos parámetros VES indican unha variación reducida ao longo do tempo, o que suxire unha tendencia cara á especificación CES. No que se refire ás estimacións dunha única ecuación, as elasticidades de substitución máis altas obtéñense da condición de primeira orde do traballo, confirmando unha regularidade empírica atopada en estudos anteriores, mentres que a combinación das condicións de primeira orde do capital e do traballo (onde a elasticidade de substitución é o coeficiente estimado da relación de prezos dos factores) produce os resultados máis baixos.

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A gran maioría das 65 industrias representadas nas National Income and Product Accounts (NIPA) dos EE. UU. tamén presentan elasticidades de substitución inferiores á unitaria. Debido á inclusión de restricións cruzadas entre as ecuacións, os intervalos de confianza utilizando o sistema normalizado son notablemente máis estreitos e as estimacións non son tan baixas como nalgúns dos métodos dunha única ecuación, polo que o caso Leontief nunca está incluído. No nivel de significación convencional do 5%, a función de produción Cobb-Douglas é unha posibilidade só para unha industria usando a función de produción CES normalizada, unha cifra que aumenta a entre 8 e 14 industrias utilizando as diferentes especificacións das funcións de produción VES normalizadas, que tamén non rexeitan a función de produción CES para entre 8 e 17 industrias; combinando ambos os resultados, as estimacións da VES suxiren que só entre un terzo e o 40% do número total de industrias poden ser caracterizadas por unha elasticidade de substitución invariante no tempo. No resto dos casos, a elasticidade de substitución é aparentemente variable e, polo tanto, os estudos desagregados a nivel de industria deberían considerar formas funcionais alternativas e máis flexibles en lugar da convencional e amplamente utilizada función de produción CES.

Estímase que o cambio tecnolóxico ao nivel agregado dos EE. UU. sexa aumentativo do traballo en termos netos, independentemente da especificación da función de produción, a unha taxa media de entre o 1,1% e o 1,5%, como resultado dunha taxa de aumento positiva do traballo, combinada cun descenso do nivel de eficiencia de capital, que tamén é a conclusión predominante a nivel de industria. Non obstante, estes resultados non son uniformes: por exemplo, nalgunhas industrias primarias, observouse un aumento da eficiencia do factor capital, mentres que o cambio tecnolóxico aumentativo do capital en termos netos atopouse especialmente nun conxunto de industrias de servizos.

No cuarto ensaio, estimamos as elasticidades de substitución e as taxas de crecemento do cambio tecnolóxico aumentativo dos factores para un conxunto de 29 países da OCDE cunha dobre finalidade. Por unha banda, avaliamos a hipótese de complementariedade bruta ou de substituibilidade bruta entre os factores de produción, así como se o cambio técnolóxico é aumentativo neto do traballo ou aumentativo neto do capital. Por outra banda, avalíase a capacidade do cambio tecnolóxico aumentativo dos factores, da profundización do capital e dos cambios na cuña laboral da empresa para dar conta da evolución da participación do traballo e, en particular, do seu descenso. Segundo a teoría económica neoclásica, a elasticidade de substitución entre capital e traballo é unha

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variable clave para determinar a resposta da distribución funcional da renda a estes cambios.

Os datos de periodicidade trimestral tómanse principalmente da base de datos Quarterly National Accounts (QNA) da OCDE (así como do Economic Outlook 110 da OCDE) e abarcan o período de tempo máis longo para o cal todos os datos están dispoñibles para cada país ata finais de 2019 (antes da pandemia do Covid-19), mentres que se aplica o método do inventario perpetuo (PIM) para construír a serie de capital.

A participación do traballo na renda total sufriu cambios considerables na maioría dos países da OCDE nos últimos anos, incluíndo descensos notables en países como Australia e Estados Unidos ou fortes aumentos nalgúns países de Europa do Leste e Bálticos; non obstante, a maioría dos 29 países da OCDE considerados mostraron tendencias descendentes neste indicador (17 de 29), sendo o maior descenso rexistrado na Irlanda, cuxo valor diminuíu en máis de 26 puntos porcentuais desde 1995. Por outra banda, a intensidade do capital aumentou en todos os países en relación ao seu valor inicial, con taxas de crecemento rápidas observadas especialmente nos países da Europa do Leste (como Polonia), países Bálticos, Finlandia e Irlanda.

Dadas as súas vantaxes, a estimación realízase mediante o sistema normalizado: a estimación do sistema permite incorporar simultáneamente tanto o comportamento optimizador (a partir das condicións de primeira orde) como a tecnoloxía (a partir da función de produción), mentres que a inclusión de restricións de parámetros entre ecuacións aumenta os graos de liberdade e pode mellorar a súa identificación. A normalización mellora estes beneficios xa que permite a predeterminación dalgúns parámetros, aliviando así a estimación da elasticidade de substitución e das taxas de crecemento do cambio tecnolóxico aumentativo dos factores. En liña coa maior parte da literatura recente na materia, empregamos a técnica de estimación NLSUR xa que, dado que as condicións de primeira orde se obteñen a partir da mesma función de produción, parece plausible admitir que os seus termos de erro están correlacionados, polo que as ecuacións poden ser aparentemente non relacionadas. Ademais, tamén consideramos a estimación polo método GMM debido ao problema da endoxeneidade típicamente asociado á estimación da función de producción.

As estimacións puntuais da elasticidade de substitución utilizando a función de produción CES normalizada, así como os intervalos de confianza do 95 por cento, sitúanse totalmente por debaixo da unidade para todos os países, correspondente ao caso de

complementariedade bruta entre capital e traballo. Porén, nalgúns casos a elasticidade de substitución estimada non está lonxe da unidade (Grecia, Hungría e Suecia, dependendo do método de estimación e da función de produción utilizada), polo que non se debe descartar completamente a posibilidade da función Cobb-Douglas nestes países. Nunca se obtén o caso Leontief (elasticidade de substitución cero), sendo as estimacións máis baixas obtidas para Polonia, Alemaña e Noruega. A elasticidade de substitución estimada para os Estados Unidos oscila entre 0,70 (NLSUR) e 0,76 (GMM), o que non está moi lonxe do resultado obtido no ensaio anterior e dos estudos anteriores centrados nesta economía (nótese que estamos a utilizar unha base de datos diferente e a considerar un período de tempo diferente). Ademais da Alemaña, cuxa elasticidade de substitución se estima entre 0,24 e 0,31, as maiores economías europeas, Reino Unido, Francia e Italia, teñen estimacións na rexión de 0,45 a 0,55, mentres que as estimacións para España sitúanse entre 0,71 e 0,72. Fóra de Europa, Australia, Canadá e Xapón teñen resultados comprendidos entre 0,36 e 0,41 (a excepción de Australia cando usamos o método GMM, cuxo resultado é 0,59).

Ademais, os resultados das nosas estimacións corroboran a hipótese do progreso tecnolóxico aumentativo do traballo en termos netos para practicamente todos os países. Unha das excepcións é precisamente a República Checa, un dos países que experimentou un aumento da cota do traballo. Nalgúns países, como o Reino Unido ou Alemaña, a taxa de cambio tecnolóxico aumentativa do traballo en termos netos non foi suficientemente rápida para xerar un descenso da relación capital-traballo efectivo, o que explica os aumentos observados da cota de traballo, segundo o previsto polo modelo neoclásico. Non obstante, nos Estados Unidos e Australia, dous países nos que a participación laboral experimentou un descenso significativo, a taxa de cambio tecnolóxico aumentativo do traballo superou o 3,50% e o 2,25% ao ano, respectivamente.

Nos países da OCDE onde a taxa de descenso da participación laboral foi maior, atopamos que, en media, a contribución do cambio tecnolóxico aumentativo do traballo foi maior, mentres que a contribución da profundización do capital foi menor. Polo tanto, os aumentos da produtividade do traballo poden conciliarse cos descensos observados na cota de traballo entre os países nun contexto de complementariedade bruta entre o capital e o traballo, sempre que o cambio tecnolóxico estea de feito aumentando a cantidade de traballo efectivo en relación ao capital efectivo. Tamén se desprende dos nosos resultados

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que a profundización do capital non contribuíu a reducir a participación laboral, senón o contrario.

A nosa análise mostra que o modelo de competencia perfecta con cambio tecnolóxico sesgado explica con precisión a evolución da compoñente tendencial da participación laboral nos países anglosaxóns de Australia, Estados Unidos e Reino Unido e nalgunhas economías europeas (Bélxica, República de Irlanda, España e Suecia), pero non o fai en Canadá, Xapón e na maioría dos países europeos, incluíndo as tres economías máis grandes da zona do euro (Alemaña, Francia e Italia). Nestes países, a cuña laboral da empresa podería ter desempeñado un papel importante, incluso predominante, na contabilización da evolución do compoñente tendencial da participación laboral. Ademais, en moitos países da OCDE, a cuña laboral da empresa foi diminuíndo desde arredor de 2008, contribuíndo a un aumento ou, polo menos, a estabilización da participación laboral.

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Introduction

The concept of elasticity of substitution between capital and labour was introduced into economic literature in the early 1930s. Even though it was first used to explain how the functional distribution of income changes with an increase in the supply of any factor, it was soon recognized as a critical parameter in many economic studies, since different elasticity of substitution values can lead to substantially different conclusions, particularly depending on whether it is above, below or equal to unity.

The vast majority of empirical studies on the elasticity of substitution reject the Cobb Douglas assumption, mainly suggesting a lower than unity value of this parameter. Recent examples include Antràs (2004), Klump et al. (2007a), Jiang and León-Ledesma (2018) and Oberfield and Raval (2021), among others, and are mainly focused on the United States economy. Some studies also estimate this parameter for a group of countries (e.g. Mallick, 2012a; Karabarbounis and Neiman, 2014), but few studies attempt to compare the differences in the elasticity of substitution across the industry level of the country; exceptions include the empirical studies performed by Balistreri et al. (2003) or Young (2013).

The aforementioned studies are mainly based on a Constant Elasticity of Substitution (CES) production function (Arrow et al., 1961), which includes linear, Leontief and Cobb-Douglas functions as special cases. Contrary to the Cobb-Douglas production function, where the elasticity of substitution is always equal to one, in the CES production function this parameter can assume any values ranging between zero and infinity.

However, the use of a CES production function implies that, even if the relative supply of labour and capital changes in the economy, the elasticity of substitution remains constant. As a result, several authors developed other functional forms for an economy's production function, which allow the value of the elasticity of substitution to be influenced by the input ratio of the economy, instead of being constant along a given isoquant (e.g. Lu and Fletcher, 1968; R. Sato and Hoffman, 1968; Revankar, 1971a; Kadiyala, 1972). Among them, the Variable Elasticity of Substitution (VES) production function suggested by Kadiyala (1972) includes, as special cases, the CES production function, the Lu and Fletcher (1968), the R. Sato and Hoffman (1968) and the Revankar (1971a) production functions. Many of the empirical studies that have been performed suggest that the VES production function is more realistic than the Cobb-Douglas and the

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CES production functions in many specifications (e.g. R. Sato and Hoffman, 1968; Kazi, 1980; Karagiannis et al., 2005).

A recent development within this context is the normalization of CES production functions, which allows the joint identification of the elasticity of substitution and technological change parameters with less biased estimates than imposing *a priori* constraints on the structure of technological change, therefore allowing to circumvent the well-known Diamond et al. (1978)'s impossibility theorem (see, in this respect, Klump et al., 2012). In this study, we will show that the normalization procedure can also be extended to the VES production functions, a procedure which may also alleviate the identification issues in that case.

Furthermore, despite the almost century-old history of the elasticity of substitution in economic literature, period in which many studies have stressed the central role played this parameter in their models or have also estimated it for a diverse range of geographical and industrial scopes, to the best of our knowledge none of them recently attempts to survey the importance of factor substitution over a broad range of macroeconomic topics. It is our purpose to conduct a thorough literature review in order to provide a deeper understanding of how different substitution elasticity values can modify the conclusions of several economic models or the impact of many economic policies, therefore highlighting the importance of its correct identification.

Regarding the direction of technological change, several empirical studies found evidence of net labour-augmentation rates at the aggregate level for the United States economy (e.g. David and van de Klundert, 1965; Antràs, 2004; Chen, 2017). However, at a disaggregated two-digit industry level, to the best of our knowledge only Young (2013) estimated the rates of factor augmentation: although net labour-augmentation holds for the majority of the United States industries, results are not uniform, as a number of industries were found to be characterized by net capital-augmentation. Furthermore, even at the aggregated level, studies focusing on factor augmentation rates for other individual countries are still relatively scarce (e.g. Luoma and Luoto, 2010, for Finland or Stewart and Li, 2018, for Canada). In line with the recent developments in the area, it is our purpose to estimate the elasticities of substitution and factor augmentation rates for the United States aggregate economy, as well as for the 65 industries represented in the US National Income and Product Accounts (NIPAs) over a rather long time span, using the CES and VES production functions, in order to assess not only which is the more

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plausible functional form for each case, but also to evaluate how different are the aggregate and industry-level estimates and if our results are in line with the prevailing conclusions of a lower than unity elasticity of substitution and a net labour-augmentation rate.

Finally, even though a number of alternative explanations have been put forward in the literature, one of the topics which is influenced by different values of the elasticity of substitution and by the direction of technological change is the movement in the functional distributional of income over time. Several studies have already documented a decline in the labour's share in income in many OECD countries, particularly in more recent years, including the United States of America. In addition to estimating the elasticities of substitution and factor augmentation rates across the majority of OECD countries, we will also use these estimates to assess the performance of the neoclassical model in the explanation of the labour share variability across countries and over time.

In order to address the aforementioned research topics, this work is structured as follows. The first essay clarifies the concepts of the elasticity of substitution and technological change, before describing the CES and VES production functions that have been used in the literature, therefore representing the theoretical underpinnings of the analysis that will be performed in the following essays. Surveys of empirical work focusing on the identification of the elasticity of substitution and the direction of technological change are also provided. Moreover, the concept of normalization is also discussed in the context of CES production functions, and subsequently extended to the case of VES production functions.

The second essay surveys the relevant role played by the elasticity of substitution over a wide range of topics in economic literature, including factor income distribution, taxation and misallocation, the labour market, growth theory or equilibrium indeterminacy and complex dynamics.

The empirical studies are carried out in essays 3 and 4. In essay 3, we estimate the elasticities of substitution and rates of technological change for the United States between 1947 and 2014, both at the aggregate and at the industry-level. Estimations are performed either by a single-equation approach or by a normalized system specification and, in line with the recent literature on the field, different econometric methods are used to deal with some underlying issues of the data, including the Ordinary Least Squares using differenced data, the Two-Stage Least Squares (2SLS) and three-stage Generalized

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Instrumental Variables (GIV) approaches in the case of the former, and the Non-Linear Seemingly Unrelated Regression (NLSUR) and the Generalized Method of Moments (GMM) methods in the case of the latter. We assume that technology can be described either by a CES or a VES production function in order to assess whether economic studies should take into account more flexible functional forms rather than the more standard and extensively used CES specification.

Essay 4 is devoted to the estimation of the aggregate elasticities of substitution and factor augmentation rates for a set of 29 OECD countries, using the normalized CES system specification, for two purposes. On the one hand, we assess whether technological change is capital- or labour-biased, which implies assessing whether the gross complementarity or the gross substitutability hypothesis between capital and labour holds, and whether technological change is net labour-augmenting or net capital-augmenting. On the other hand, we assess the ability of the technological bias, capital deepening and changes in the firm labour wedge to account for the observed evolution of the labour share, which underwent considerable changes in most OECD countries in recent years.

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Objectives and methodology

The aim of this study is to review the existing theoretical and empirical literature on the concepts of elasticity of substitution and biased technological change and to discuss some of their estimation forms using Constant Elasticity of Substitution (CES) and Variable Elasticity of Substitution (VES) production functions, before testing their empirical application not only at the aggregate level, but also at a more disaggregated (industry) level. In particular, this study is aimed at providing answers to the following questions:

- What are the main results of the existing empirical studies using CES and VES production functions and what are the most recent developments on this matter?
- How can different values of the elasticity of substitution change the conclusions of several macroeconomic models or the impact of many economic policies?
- Are the United States industry-level technological change rates and elasticities of substitution different from the aggregate result and have they changed over time?
- Is technological change capital- or labour-biased across OECD countries?
- Can the neoclassical model with biased technological progress accurately predict the evolution of the labour share in OECD countries?
- What is the contribution of the technological change bias to the evolution of the labour share in OECD countries in recent decades?

In order to provide answers to the aforementioned questions, this thesis employs different methods. The first essays critically survey the existing literature on the field, clarifying some of the concepts that will be used throughout the study and providing some extensions to the existing works. We are also interested in surveying the importance of factor substitution across a wide range of macroeconomic topics which, despite the almost century-long history of the elasticity of substitution in economic literature, to the best of our knowledge has not been recently carried out, in order to incorporate some of the important recent developments on the matter.

The empirical studies are carried out in the last essays. We assume that technology can be described either by a CES or a VES production function. Estimations are performed either by a single-equation approach or by a normalized system specification and, in line with the recent literature on the field, different econometric methods are used to deal with some underlying issues of the data, including the Ordinary Least Squares using differenced data, the Two-Stage Least Squares (2SLS) and three-stage Generalized

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Instrumental Variables (GIV) approaches in the case of the former, and the Non-Linear Seemingly Unrelated Regression (NLSUR) and the Generalized Method of Moments (GMM) methods in the case of the latter. The econometric software Stata and EViews are used in the estimations. To detect potential data issues, different tests are applied, including the Durbin, Wu Hausman, Wooldridge and robust regression-based endogeneity tests, the Durbin-Watson and Breusch-Godfrey tests for serial correlation or the Augmented Dickey-Fuller and Phillips-Perron unit root tests to assess the stationarity of the variables.

Data are taken from different sources, including the KLEMS database, which combines information from the Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS), the OECD Quarterly National Accounts (QNA) database, the OECD Economic Outlook 110, or the Penn World Table 10.0. When necessary, to obtain data for the aggregate economy, we employ Törnqvist quantity indices to aggregate the volumes for the several industries, or apply the perpetual inventory method to construct the series of capital. Moreover, the Hodrick-Prescott filter can be applied to separate the trend from the cyclical component of a given variable; for example, in the particular case of the labour share, by paying attention to its trend component, we isolate the analysis from high-frequency fluctuations that could cause stochastic technological shocks.

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1. Elasticity of substitution and technological change using CES and VES production functions: a critical appraisal of the literature

1.1. Introduction

The concept of elasticity of substitution (σ) was first introduced in the early 1930s in the neoclassical production theory, representing a measure of the degree of substitutability between production factors. The estimation of this parameter became increasingly popular after the introduction of the Constant Elasticity of Substitution (CES) production function in the early 1960s; however, despite being clearly recognised as a critical parameter in a number of different economic topics, there is still no consensus on its magnitude (cf. Chirinko, 2008, who concluded that the weight of the evidence suggests a value in the range of 0.40–0.60, or Piketty, 2014, who argued that on the basis of historical data, this parameter could be estimated between 1.30 and 1.60). Different values of this parameter can modify the conclusions of several economic models or the impact of many economic policies, which are often dependent on whether capital and labour are in fact gross complements ($\sigma < 1$) or gross substitutes ($\sigma > 1$). Moreover, studies that do not allow for the possibility of non-neutral technological change may lead to biased estimates of the elasticity of substitution and are, consequently, misleading when technological change is factor-biased (David and van de Klundert, 1965; Antràs, 2004).

The aim of this essay is to review the existing theoretical and empirical literature on the concepts of elasticity of substitution and biased technological change and to discuss some of their estimation forms using Constant Elasticity of Substitution (CES) and Variable Elasticity of Substitution (VES) production functions. Despite being crucial parameters in many economic studies, whose conclusions are highly sensitive to the underlying assumptions on their real value, until recently their joint identification was considered to be problematic. In fact, recent work on the normalization of CES production functions combined with the system approach appears to have alleviated the estimation of the elasticity of substitution and the growth rates of factor-augmenting technological change. It is our purpose not only to review the existing literature on this subject, but also to extend it to the case of VES production functions, before testing its empirical application in the following essays.

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This essay is structured as follows. We start by clarifying the concept of elasticity of substitution, describing some of its mathematical properties and showing its graphical

representation (Section 1.2). Section 1.3 presents the concept of technological change, distinguishes between different types of neutrality and describes the possible directions of technological change, before exposing the issue of the simultaneous identification of the elasticity of substitution and the technological change bias. Section 1.4 provides a comprehensive survey of the economic literature on CES production functions, covering its foundations until the most recent developments on the concept of normalization, as well as a review of many existing empirical studies on the subject, a structure which is then replicated in section 1.5 for the case of VES production functions, including in this case the extension of the normalization procedure to this type of functions. Finally, Section 1.6 contains some concluding remarks.

1.2. The elasticity of substitution

1.2.1. The concept of elasticity of substitution

The elasticity of substitution (σ) is a measure of the degree of substitutability between production factors. More precisely, it can be defined either as *"a measure of the ease with which the varying factor can be substituted for others"* (Hicks, 1932, p. 117) or *"the degree to which the substitutability of one factor for another varies as the proportion between the factors varies"* (Lerner, 1933, p. 68).

The concept was introduced independently by John R. Hicks in *The Theory of Wages* (1932) and Joan Robinson in *The Economics of Imperfect Competition* (1933). According to Robinson's (1933) definition, the elasticity of substitution measures the percentage change in the factor input ratio, as a result of a percentage change in the marginal rate of technical substitution (MRTS), leaving output unchanged:

$$\sigma = \frac{\frac{d\left(\frac{K}{L}\right)}{\frac{K}{L}}}{\frac{dMRTS}{MRTS}} = \frac{d\ ln\left(\frac{K}{L}\right)}{d\ln MRTS'} \tag{1}$$

where $Y = F(K, L)$ is a production function relating output (Y) with capital (K) and labour (L). The marginal rate of technical substitution (MRTS), or the absolute value of the slope of the isoquant at a particular point, is given by:

$$MRTS = -\frac{dK}{dL} = -K' = \frac{\frac{\partial F}{\partial L}}{\frac{\partial F}{\partial K}} = \frac{F_L}{F_K}.$$

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Even though Hicks was the first to use this concept, Robinson's definition has become more popular in the literature (Chirinko, 2008). Notwithstanding, in certain conditions (namely in the case of two production factors, perfect competition and using a production function with constant returns to scale), the two definitions are identical (Kahn, 1933; Hicks, 1933; Hicks, 1963).[1]

1.2.2. Graphical representation

Lerner (1933) explained the concept graphically, showing that as the convexity of the isoquant increases, the elasticity of substitution decreases, therefore relating the elasticity of substitution to the shape of a given isoquant. If a small change in the marginal rate of technical substitution leads to a small (large) change in the factor input ratio, then the elasticity of substitution will assume a small (large) value and the isoquants will be relatively steep (flat). The higher the elasticity of substitution, the easier it will be to substitute between factors, leaving output unchanged. Moreover, it can be noted that if we assume that isoquants are convex to the origin, the marginal rate of technical substitution decreases with a decrease in the factor ratio (K/N), implying that the elasticity of substitution has to be positive.[2]

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[1] Hicks (1932) first introduced the concept while explaining how the functional distribution of income changed with an increase in the supply of any factor and formulated it in an appendix as $\sigma = \frac{F_L F_K}{Y F_{LK}}$, where $F_{KL} = \frac{\partial}{\partial K}\left(\frac{\partial F}{\partial L}\right)$. This concept was at the centre of a conceptual debate in the mid-1930s involving several authors, including Machlup, Pigou, Sweezy and Sraffa, among others (see in this respect Molina, 2005). For example, Kahn (1933) pointed out that the economic meaning of Hicks's definition was not clear, appearing to have been *"dictated by the requirements of algebra rather than of economics"* (Kahn, 1933, p. 72).

[2] The limiting cases are i) the case of perfect substitutes, which corresponds to the situation where the elasticity of substitution tends to infinity: output is left unchanged if one of the inputs is increased at the same rate that the other is decreased (the marginal rate of technical substitution does not change along a given isoquant); ii) the case of perfect complements, in which the elasticity of substitution is equal to zero: output is only left unchanged if inputs are used in a fixed proportion, so it is not possible to substitute one input by the other. A negative elasticity of substitution would imply that the marginal rate of technical substitution increases with a decrease in the factor ratio, which is the case of concave isoquants: for a given increase in one of factors and in order to keep output unchanged, the quantity used of the other input had to be increasing instead of decreasing.

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A graphical representation is provided in Figure 1.1. At point E_0, the marginal rate of technical substitution is given by the slope of the line tangent to that point (which is equal to the tangent of a_1), while the capital-labour ratio corresponds to the slope of line that connects E_0 to the origin (equal to the tangent of b_1). If we move to point E_1, the marginal rate of substitution decreases to the value of the tangent a_2, while the capital-labour ratio decreases to the value of the tangent b_2. Therefore, the elasticity of substitution corresponds to the limit, as the change in the marginal rate of technical substitution tends to zero, of the relative change of tangent a (from a_1 to a_2) divided by the relative change of tangent b (from b_1 to b_2).

[FIGURE 1.1]

1.2.3. Symmetry

Allen (1938) showed some important properties of the elasticity of substitution. Using the total differential of the marginal rate of technical substitution, equation (1) can be written as:

$$\sigma = \frac{MRTS}{KL}\frac{L\,MRTS + K}{MRTS\,\dfrac{\partial MRTS}{\partial K} - \dfrac{\partial MRTS}{\partial L}}. \qquad (2)$$

The derivatives of the marginal rate of technical substitution can be expressed in terms of the first and second-order partial derivatives[3] of the production function and so the elasticity of substitution becomes:

$$\sigma = -\frac{F_K F_L (K F_K + L F_L)}{KL(F_{KK}F_L^2 - 2F_{KL}F_K F_L + F_{LL}F_K^2)}. \qquad (3)$$

Equation (3) shows that the elasticity of substitution is symmetrical with respect to the two factors of production: its value is the same, whether we consider the substitution of capital for labour, or the substitution of labour for capital.

1.2.4. The elasticity of substitution and curvature

The "curvature"[4] of a particular isoquant at a given combination of labour and capital is:

[3] The second-order partial derivatives of the production function are: $F_{LL} = \frac{\partial}{\partial L}\left(\frac{\partial F}{\partial L}\right)$, $F_{KK} = \frac{\partial}{\partial K}\left(\frac{\partial F}{\partial K}\right)$ and $F_{KL} = \frac{\partial}{\partial K}\left(\frac{\partial F}{\partial L}\right)$. If the Clairaut-Schwarz theorem holds, the latter derivative is equal to $F_{LK} = \frac{\partial}{\partial \mathrm{L}}\left(\frac{\partial \mathrm{F}}{\partial \mathrm{K}}\right)$.

[4] Although referred to as "curvature" in the literature, this is in fact the second derivative of the isoquant.

$$\frac{d^2K}{dL^2} = MRTS\ \frac{\partial MRTS}{\partial K} - \frac{\partial MRTS}{\partial L}. \quad (4)$$

Comparing equations (2) and (4), we can conclude that the elasticity of substitution is inversely proportional to the "curvature" of the isoquant. This result confirmed mathematically that the smaller (larger) the value of the elasticity of substitution, the steeper (flatter) will be the isoquant.

However, de La Grandville (1997, 2009) pointed out that there was a confusion throughout the literature, as there is no relationship between the mathematical concept of curvature and the elasticity of substitution. To illustrate this ideia, we can consider two examples: first, considering a Cobb-Douglas production function, the elasticity of substitution is always equal to one along the isoquant,[5] while the second derivative is changing along the isoquant; also, in an arc of circle the curvature is constant in every point, while the elasticity of substitution varies from point to point. On the one hand, the curvature of a curve in a plane (k_p) is equal to:[6]

$$k_p = \frac{K''}{(1+K'^2)^{\frac{3}{2}}}. \quad (5)$$

On the other hand, the elasticity of substitution along the isoquant is given by equation (1) and can be written as:

[5] For example, considering the Cobb-Douglas production function $Y = AK^{\alpha}L^{\beta}$, the marginal rate of technical substitution is $MRTS = \frac{\beta}{\alpha}\frac{K}{L}$, so $ln\left(\frac{K}{L}\right) = ln\left(\frac{\alpha}{\beta}\right) + ln(MRTS)$. The elasticity of substitution is therefore equal to one: $\sigma = \frac{d\ ln\left(\frac{K}{L}\right)}{d\ ln\ MRTS} = 1$.

[6] Considering two points A and B of a given curve, with the slope of the tangent line at A equal to the tangent of angle θ, and the slope of the tangent line at point B equal to the tangent of angle $\theta + \Delta\theta$. The arc length between A and B is equal to Δs. Then, the average curvature of arc AB is equal to $\frac{\Delta\theta}{\Delta s}$, and the curvature at point A is equal to $k_p = \lim_{\Delta s \to 0} \frac{\Delta\theta}{\Delta s} = \frac{d\theta}{ds} = \frac{d\theta}{dL}\frac{dL}{ds}$. So, $tan(\theta) = K' = \frac{dK}{dL} \Rightarrow arctan(K') = \theta \Rightarrow \frac{d\theta}{dL} = \frac{K''}{1+K'^2}$, where K'' is the second derivative of the isoquant with respect to labour. Substituting this result and the arc lenght formula $ds = \sqrt{1+K'^2}dL \Leftrightarrow \frac{dL}{ds} = \frac{1}{\sqrt{1+K'^2}}$ into the curvature expression k_p yields equation (5).

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$$\sigma = \frac{\frac{d\left(\frac{K}{L}\right)}{\frac{K}{L}}}{\frac{d(K')}{K'}} = \frac{K'(K'L - K)}{LKK''}. \quad (6)$$

In addition to the clear difference between equations (5) and (6), the curvature and the elasticity of substitution cannot be compared because the curvature depends on measurement units (it is expressed in radians per unit of length), whereas the elasticity of substitution does not; moreover, the curvature concept has no economic interpretation, since the lenght of an isoquant arc has no economic meaning.

1.2.5. The case of constant returns to scale

Many economic studies focus on the particular case of constant returns to scale. In this case, denoting output per worker (or labour productivity) by y and the capital-labour ratio by k, we can write (assuming first-degree homogeneity):

$$\frac{Y}{L} = F\left(\frac{K}{L}, 1\right) = y = f(k).$$

Using Euler's theorem, the ratio of the marginal productivities of labour and capital (or the marginal rate of technical substitution) can then be expressed as a function of the capital-labour ratio:

$$\frac{F_L}{F_K} = \frac{y - ky'}{y'} = \frac{f(k) - kf'(k)}{f'(k)}.$$

Hence, applying logarithms and since $\frac{d\, ln\left(\frac{F_L}{F_K}\right)}{dk} = -\frac{f(k)f''(k)}{f'(k)[f(k)-kf'(k)]}$, from equation (1) the elasticity of substitution can be expressed as:

$$\sigma = \frac{d\, ln\, k}{d\, ln\, MRTS} = \frac{\frac{1}{k}}{\frac{d\, ln\, MRTS}{dk}} = -\frac{f'(k)[f(k) - kf'(k)]}{kf(k)f''(k)}. \quad (7)$$

This expression confirms the positive sign of the elasticity of substitution: since the marginal products of labour, $f(k) - kf'(k)$, and capital, $f'(k)$, are positive, and

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assuming diminishing marginal product (negative second derivative), the elasticity of substitution has to be greater than zero.[7]

Moreover, if we assume competitive labour and product markets, the real wage (w) equals the marginal product of labour:

$$w = \frac{\partial Y}{\partial L} = f(k) - kf'(k).$$

Differentiating this expression with respect the capital-labour ratio we get:

$$\frac{dw}{dk} = -kf''(k).$$

The elasticity of labour productivity with respect to the wage rate is then equal to the elasticity of substitution, a result known as the Allen's theorem (Allen, 1967):

$$\frac{\frac{dy}{y}}{\frac{dw}{w}} = \frac{dy}{dw}\frac{w}{y} = -\frac{f'(k)[f(k) - kf'(k)]}{kf''(k)f(k)} = \sigma. \quad (8)$$

1.3. Technological change and the elasticity of substitution

1.3.1. The concept and direction of technological change

Technological change can be understood as any shift in the production function (May, 1947; Solow, 1957; Rosenberg, 1963). It therefore describes a change in the amount of output that can be obtained using the same amount of inputs. Technological progress exists when the same amount of inputs yields a greater level of output, or when a given level of output is produced using fewer inputs.

The growth literature identifies three different types of neutral technological progress (Barro and Sala-i-Martin, 2004; Acemoglu, 2009). Considering a generic production function $\tilde{F}[K_t, L_t, A_t]$, where K_t and L_t are the capital and labour inputs, respectively, and A_t is the state of technology, technological progress is said to be Hicks-neutral if the technology term is a multiplicative constant in front of the production function $F[A_t]$. The marginal rate of substitution does not depend on A_t, but only on the capital-labour

[7] If the production function is homogeneous of degree h, $F(K, L) = L^h f(k)$, the elasticity of substitution could also be expressed as a function of the capital-labour ratio. In this case, $MRTS = \frac{hf(k) - kf\prime(k)}{f'(k)}$ and $\sigma = \frac{f'(k)[hf(k) - kf'(k)]}{k[(h-1)f'(k)^2 - hf(k)f''(k)]}$.

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ratio; Hicks neutrality therefore implies that the ratio of the marginal products remains unchanged at a constant capital-labour ratio (Uzawa, 1961; Sato and Beckmann, 1968). Technological progress simply renumbers isoquants without any change of their shape:

$$\tilde{F}[K_t, L_t, A_t] = A_t F[K_t, L_t].$$

Another possibility is the Solow-neutral technological progress (also called purely capital-augmenting, because a higher A_t is equivalent to the economy having more capital):

$$\tilde{F}[K_t, L_t, A_t] = F[A_t K_t, L_t].$$

Solow-neutrality implies that, for a given labour-output ratio, the relative input shares remain unchanged.

Technological progress can also be Harrod-neutral (also called purely labour-augmenting, because a higher A_t is equivalent to a corresponding increase in the labour force):

$$\tilde{F}[K_t, L_t, A_t] = F[K_t, A_t L_t].$$

Harrod-neutrality implies that, for a given capital-output ratio, the relative input shares remain unchanged.

Technological change can also be a combination of the previous cases:

$$\tilde{F}[K_t, L_t, A_t] = A_t^{HS} F[A_t^S K_t, A_t^H L_t],\ A_t = [A_t^{HS}, A_t^S, A_t^H], \quad (9)$$

where A_t^{HS}, A_t^S and A_t^H represent, respectively, the Hicks-neutral and the capital and labour efficiency parameters. If the capital (labour) efficiency parameter grows at a faster pace than the labour (capital) efficiency parameter, technological progress is net capital-augmenting (labour-augmenting).

Besides being factor-augmenting, technological change can also be factor-biased: it will be capital-biased if it increases the relative marginal product of factor capital compared to factor labour (Acemoglu, 2002, 2009) which, considering equation (9), corresponds to:

$$\partial \frac{\partial F/\partial K}{\partial F/\partial L} > 0. \quad (10)$$

Conversely, technological change will be labour-biased if this inequality holds in reverse, implying that technological change increases the relative marginal product of factor labour compared to factor capital.

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Capital-biased (labour-biased) technological change, which represents a labour-saving (capital-saving) innovation in the sense of Hicks,[8] corresponds to net capital-augmenting (labour-augmenting) technological progress, in the case that the elasticity of substitution is greater than one (David and van de Klundert, 1965; Drandakis and Phelps, 1966):

$$\frac{\dot{F_{K}}_t}{F_{K_t}} - \frac{\dot{F_{L}}_t}{F_{L_t}} = \frac{1-\sigma}{\sigma}\left[\frac{\dot{A_t^L}}{A_t^L} - \frac{\dot{A_t^K}}{A_t^K}\right], \tag{11}$$

where the overdots represent the derivatives with respect to time. On the other hand, for lower than unity values of the elasticity of substitution, capital-biased (labour-biased) technological change corresponds to net labour-augmenting (capital-augmenting) technological progress.

Assuming that technological progress takes the form of factor augmentation at a constant exponential rate, we can write:

$$A_t^K = A_0^K e^{(\zeta_{HS}+\zeta_S)t} = A_0^K e^{\zeta_K t},$$

$$A_t^L = A_0^L e^{(\zeta_{HS}+\zeta_H)t} = A_0^L e^{\zeta_L t},$$

where t represents a time trend, ζ_{HS}, ζ_S and ζ_H represent the growth rates of Hicks-neutral, Solow-neutral and Harrod neutral technological progress, respectively; $\zeta_K = \zeta_{HS+}\zeta_S$ and $\zeta_L = \zeta_{HS+}\zeta_H$ represent the growth rates of capital-augmenting and labour-augmenting technological progress, respectively, while $\zeta_K - \zeta_L = \zeta_S - \zeta_H \neq 0$ denotes net factor-augmenting technological progress (with $\zeta_K - \zeta_L > 0$ denoting net capital-augmentation and $\zeta_L - \zeta_K > 0$ denoting net labour-augmentation). The growth rate associated with each factor i (capital or labour) is therefore constant at rate ζ_i:[9]

$$\frac{\partial ln\,(A_t^i)}{\partial t} = \frac{\partial \zeta_i t}{\partial t} = \zeta_i.$$

[8] Hicks (1932) characterized inventions according to their relative impact on marginal factor productivities: an invention will be capital-saving (labour-saving) if it increases the marginal product of labour (capital) more than the marginal product of capital (labour), consequently increasing the demand for labour (capital).

[9] Some studies also consider more flexible forms for technological change, such as the Box-Cox transformation (Box and Cox, 1964), which includes a curvature parameter λ that determines the shape of the technological progress function. The growth rate of each factor is $g_i(t) = \zeta_i\left(\frac{t^{\lambda_i}-1}{\lambda_i}\right)$; in this case, $\lambda_i = 1$ yields the linear specification (constant growth rates).

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1.3.2. The identification of technological change and the elasticity of substitution

The bias of technological change cannot be identified simultaneously with the elasticity of substitution between factors in the absence of *a priori* hypotheses on the structure of technological change, a result known as the "impossibility" or "non-identification" theorem (Diamond and McFadden, 1965; Diamond et al., 1978). This means that more than one alternative production function could have generated some given time series data for a given economy, having an arbitrary elasticity of substitution or technological change bias at the observed points.

R. Sato (1970) provided a statement of this theorem. Considering a production function with factor-augmenting technological change $Y_t = F[A_t^K K_t, A_t^L L_t]$, under perfect competition and considering linear homogeneity, it is possible to estimate the rates of capital and labour efficiency growth for any functional form of the production function according to the following equations (for $\sigma \neq 1$):

$$\frac{\dot{A_t^K}}{A_t^K} = \frac{\sigma(\dot{r_t}/r_t) - (Y_t\dot{/}K_t)/(Y_t/K_t)}{\sigma - 1},$$

$$\frac{\dot{A_t^L}}{A_t^L} = \frac{\sigma(\dot{w_t}/w_t) - (Y_t\dot{/}L_t)/(Y_t/L_t)}{\sigma - 1},$$

where the overdots represent time derivatives and r_t and w_t represent, respectively, the rate of return to capital and the wage rate in period t. Therefore, we have three unknows ($\dot{A_t^K}/A_t^K$, $\dot{A_t^L}/A_t^L$ and the elasticity of substitution), but only two independent equations, making it impossible to estimate the rates of factor efficiency growth without specifying a given functional form for the production function (i.e., without identifying *a priori* the value of σ).

To circumvent this impossibility, researchers usually impose restrictive assumptions on the form of technological change, such as assuming some type of neutrality. For example, assuming Harrod-neutrality, the growth rate of capital efficiency would be equal to 0, making it possible to solve the previous system of equations.

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1.4. The Constant Elasticity of Substitution (CES) production function

1.4.1. Properties of the CES production function

The Constant Elasticity of Substitution (CES) production function was first introduced in the 1950s and since then has become one of the most used production functions. A general expression for the CES production function is:

$$Y_t = F(A_t^K K_t, A_t^L L_t) = \gamma\left[\delta(A_t^K K_t)^{\psi} + (1-\delta)(A_t^L L_t)^{\psi}\right]^{\frac{1}{\psi}}. \qquad (12)$$

The function contains five parameters: the efficiency parameter γ (which is neutral in the sense of Hicks), the distribution parameter δ (because for any given value of the elasticity of substitution it determines the functional income distribution[10]), the factor efficiency parameters A_t^K and A_t^L (which are assumed to be non-negative and whose variations over time can be interpreted as capital-augmenting and labour-augmenting technological progress) and the substitution parameter $\psi = (\sigma - 1)/\sigma$. The elasticity of substitution between capital and labour (σ) is constant and equal to $1/(1-\psi)$.

Depending on the value of the elasticity of substitution, the CES production function nests some particular cases: when the elasticity of substitution equals zero (or as $\psi \to -\infty$), there is no substitution between capital and labour and we have a Leontief function with fixed factor proportions, $Y_t = min(A_t^K K_t, A_t^L L_t)$; if the elasticity of substitution is equal to one (or as $\psi \to 0$), applying L'Hôpital's rule we obtain the Cobb-Douglas case, $Y_t = \gamma K_t^{\delta} L_t^{\delta}$; and when the elasticity of substitution tends to infinity (or when $\psi \to 1$), capital and labour are perfect substitutes and we have a linear production function, $Y_t = \gamma[\delta A_t^K K_t + (1-\delta) A_t^L L_t]$.

From the assumption of constant returns to scale, output per effective worker $\left(\frac{Y_t}{A_t^L L_t}\right)$ can be expressed as a function of the effective capital to effective labour ratio $\left(k_t = \frac{A_t^K K_t}{A_t^L L_t}\right)$:

$$\frac{Y_t}{A_t^L L_t} = F\left(\frac{A_t^K K_t}{A_t^L L_t}, 1\right) = f(k_t).$$

The CES production function (12) can therefore be written as:

[10] In competitive markets, the marginal rate of technical substitution equals the factor price ratio and therefore $\frac{w_t L_t}{r_t K_t} = \frac{1-\delta}{\delta}\left(\frac{A_t^K K_t}{A_t^L L_t}\right)^{-\psi}$.

$$f(k_t) = \gamma\left[\delta {k_t}^{\psi} + (1-\delta)\right]^{\frac{1}{\psi}}.$$

The previous function displays the usual properties of a production function, including positive and decreasing marginal productivities, as long as the following restrictions hold: $0 < \delta < 1$, $\gamma > 0$ and $\psi < 1$:

$$f'(k_t) = \frac{\gamma\delta {k_t}^{\psi-1}}{\left[\delta {k_t}^{\psi} + (1-\delta)\right]^{1-\frac{1}{\psi}}},$$

$$f''(k_t) = \frac{\gamma\delta(1-\delta) {k_t}^{\psi-2}(\psi-1)}{\left[\delta {k_t}^{\psi} + (1-\delta)\right]^{2-\frac{1}{\psi}}}.$$

The limits of the first derivatives of the CES production function depend on the value of ψ. If $0 < \psi < 1$ (which implies that the elasticity of substitution is greater than unity):

$$\lim_{k_t \to 0} f'(k_t) = +\infty,$$

$$\lim_{k_t \to +\infty} f'(k_t) = \gamma\delta^{\frac{1}{\psi}}.$$

On the other hand, for a negative ψ (or a lower than unity elasticity of substitution):

$$\lim_{k_t \to 0} f'(k_t) = \gamma\delta^{\frac{1}{\psi}},$$

$$\lim_{k_t \to +\infty} f'(k_t) = 0.$$

In both situations, one of the Inada conditions is violated: in the first case, the limit of the first derivative as the effective capital intensity goes to infinity is a positive constant (rather than zero), while in the second case, the marginal product tends to a positive constant (lower than infinity) as the effective capital intensity approaches zero.

The value of the elasticity of substitution also determines if products are gross complements ($\sigma < 1$) or gross substitutes ($\sigma > 1$). Acemoglu (2002) justifies the use of this terminology because an increase in the price of labour (holding constants its quantity and the price of capital) would lead to an increase (resp. decrease) in the demand for capital if and only if $\sigma > 1$ (resp. if $\sigma < 1$). Moreover, since the relative marginal products of capital and labour are given by:

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$$\frac{F_{K_t}}{F_{L_t}} = \frac{\delta}{1-\delta}\left(\frac{A_t^K}{A_t^L}\right)^{\frac{\sigma-1}{\sigma}}\left(\frac{K_t}{L_t}\right)^{-\frac{1}{\sigma}},$$

if the production factors are gross substitutes ($\sigma > 1$), a relative increase in capital-augmenting technological change increases the relative marginal product of capital and therefore, according to equation (10), the relative capital-augmenting technological change is also capital-biased. The opposite holds if the production factors are gross complements ($\sigma < 1$): in this case, the relative capital-augmenting technological change becomes labour-biased.[11]

1.4.2. Estimation forms

Linear single equation. The logarithmic form of the CES production function (12) is given by:

$$ln(Y_t) = ln(\gamma) + \frac{1}{\psi} ln\left[\delta(A_t^K K_t)^{\psi} + (1-\delta)(A_t^L L_t)^{\psi}\right].$$

Since the CES production function is non-linear in its parameters, the standard linear estimation techniques cannot be used to obtain them.[12] However, another important property of the CES production function is that, under perfect competition, the first-order conditions for profit maximization can be log-linearized into the following relationships:[13]

$$ln\left(\frac{Y_t}{K_t}\right) = \xi_0^K + \sigma\, ln(r_t) + (1-\sigma)\zeta_K t,$$

$$ln\left(\frac{Y_t}{L_t}\right) = \xi_0^L + \sigma\, ln(w_t) + (1-\sigma)\zeta_L t,$$

where $\xi_0^K = \sigma\, ln\left(\frac{1}{\delta}\right) + (1-\sigma)[ln(A_0^K) + ln(\gamma)]$ and $\xi_0^L = \sigma\, ln\left(\frac{1}{1-\delta}\right) + (1-\sigma)[ln(A_0^L) + ln(\gamma)]$.

Individually, each of these conditions allows the identification of the elasticity of substitution, but only of the respective technological progress term. Combining the two

[11] Notice that an increase in capital per worker (capital deepening) is inversely related to the relative marginal product of capital, but in this case for any value of the elasticity of substitution.

[12] Still, some studies employ non-linear techniques to estimate these parameters.

[13] We are assuming that technological progress takes the form of factor augmentation at a constant exponential rate, ζ_i: $A_t^i = A_0^i e^{\zeta_i t}$ and scaling, for simplicity, $A_0^i = 1$.

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expressions in a single equation, we would only be able to identify the bias in technological change:

$$ln\left(\frac{K_t}{L_t}\right) = (\xi_0^L - \xi_0^K) + \sigma\, ln\left(\frac{w_t}{r_t}\right) + (1-\sigma)(\zeta_L - \zeta_K)t.$$

The Kmenta approximation. Kmenta (1967) derived an approximation method that allows the estimation of the CES production functions with resort to linear estimation techniques, using the Taylor's formula for expansion around a fixed value. Applying natural logarithms to the CES production function (12) yields:

$$ln(Y_t) = ln(\gamma) + \frac{1}{\psi} f(\psi),$$

where $f(\psi) = ln\left[\delta(A_t^K K_t)^{\psi} + (1-\delta)(A_t^L L_t)^{\psi}\right]$. Expanding $f(\psi)$ using Taylor's formula around $f(\psi) = 0$:[14]

$$f(\psi) = \psi[\delta ln\,(A_t^K K_t) + (1-\delta) ln\,(A_t^L L_t)] + \frac{1}{2}\psi^2\delta(1-\delta)[ln(A_t^K K_t) - ln(A_t^L L_t)]^2 + \cdots$$

Disregarding the terms of third and higher orders and substituting $f(\psi)$ into the previous equation:

$$ln(Y_t) = ln(\gamma) + [\delta ln\,(A_t^K K_t) + (1-\delta) ln\,(A_t^L L_t)] + \frac{1}{2}\psi\delta(1-\delta)[ln(A_t^K K_t) - ln(A_t^L L_t)]^2.$$

Assuming that technological progress associated with factor *i* (capital or labour) grows at the constant rate ζ_i: $A_t^i = A_0^i e^{\zeta_i t}$ and scaling, for simplicity, $A_0^i = 1$, we get:

$$ln\left(\frac{Y_t}{L_t}\right) = ln(\gamma) + \delta\, ln\left(\frac{K_t}{L_t}\right) + \frac{1}{2}\psi\delta(1-\delta)\left[ln\left(\frac{K_t}{L_t}\right)\right]^2 + \delta\left[1 + \psi(1-\delta)\, ln\left(\frac{K_t}{L_t}\right)\right]\zeta_K t + (1-\delta)\left[1 - \psi\delta\, ln\left(\frac{K_t}{L_t}\right)\right]\zeta_L t + \frac{1}{2}\psi\delta(1-\delta)(\zeta_K - \zeta_L)^2 t^2.$$

Notice that in the case of the Hicks-neutral technological progress ($\zeta_K = \zeta_N = \zeta$), the last three terms can be simplified to ζt, therefore representing total factor productivity (TFP).

[14] Kmenta (1967) chose an expansion around $\psi = 0$ for its mathematical convenience, since the results of Arrow et al. (1961) pointed to values of ψ between -0.4 and 0.

If ψ does not deviate "too much" from zero as the approximation assumes (or alternatively, if σ does not deviate "too much" from unity), the multiplicative terms $\psi\delta(1-\delta)\,ln\left(\frac{K_t}{L_t}\right)\zeta_K\,t$ and $-\psi\delta(1-\delta)\,ln\left(\frac{K_t}{L_t}\right)\zeta_L t$ can be dropped without any significant loss of precision,[15] yielding the following equation to estimate:

$$ln\left(\frac{Y_t}{L_t}\right) = ln(\gamma) + \underbrace{\delta}_{a_0} \ln\left(\frac{K_t}{L_t}\right) \underbrace{+\frac{1}{2}\psi\delta(1-\delta)}_{a_1}\left[ln\left(\frac{K_t}{L_t}\right)\right]^2 + \underbrace{[\delta\zeta_K + (1-\delta)\zeta_L]}_{a_2} \mathrm{t} \underbrace{+\frac{1}{2}\psi\delta(1-\delta)(\zeta_K-\zeta_L)^2}_{a_3} t^2.$$

The previous equation has four parameters to estimate (δ, ψ, ζ_K and ζ_L), in addition to the constant term. The estimation of a_0 allows, from composite parameter a_1, the identification of the elasticity of substitution. However, if we try to identify the remaining parameters, we get:

for $\zeta_K > \zeta_L$: $\zeta_L = \widehat{a_2} - \delta\sqrt{\frac{\widehat{a_3}}{\widehat{a_1}}}$ and $\zeta_K = \widehat{a_2} + (1-\delta)\sqrt{\frac{\widehat{a_3}}{\widehat{a_1}}}$;

for $\zeta_L > \zeta_K$: $\zeta_L = \widehat{a_2} + \delta\sqrt{\frac{\widehat{a_3}}{\widehat{a_1}}}$ and $\zeta_K = \widehat{a_2} - (1-\delta)\sqrt{\frac{\widehat{a_3}}{\widehat{a_1}}}$.

Therefore, we can conclude that the Kmenta approximation cannot identify the direction of the bias in technological change, unless we have information on the signs and magnitudes of the technological progress components ζ_K and ζ_L (an alternative would be to impose the *a priori* restriction of Hicks-neutrality: $\zeta_K = \zeta_L$). Also the signs of estimates $\widehat{a_1}$ and $\widehat{a_3}$ must be the same (or constrained *a priori* to be the same).

As detailed in several studies, the Kmenta approximation suffers from some drawbacks. First, as previously shown, it is a truncated Taylor series, omitting several terms of the expansion, and it cannot be used to identify simultaneously the elasticity of substitution and the direction of the bias in technological change. Furthermore, Thursby and Lovell (1978) argued that it generates biased estimates in small samples and that some parameters (namely $ln(\gamma)$ and ψ) are generally estimated with large biases and mean square errors; moreover, as the sample size increases, the bias does not always tend to

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[15] As shown by León-Ledesma et al. (2010), the dropping of these terms is even more easily justified when using a normalized CES production function.

zero, therefore raising inconsistency issues. More recently, the Monte Carlo experiment by León-Ledesma et al. (2010) showed that the Kmenta approximation consistently underestimated the value of the elasticity of substitution, especially when it was far from unity.

System approach. An alternative estimation form is the system approach, which has been initially applied by Marschak and Andrews Jr. (1944) in a cross-sectional study and by Bodkin and Klein (1967), who simultaneous estimate a two equation system in a time-series framework. In the context of the CES production function, it consists in estimating the production function combined with one or two first-order conditions. Comparatively to a single-equation approach, there are important advantages: first, the system approach encompasses both optimizing behaviour (reflected by the first-order conditions) and technology (captured by the production function); also, by including cross-equation parameter constraints, the simultaneous equation estimation increases the degrees of freedom and may improve parameter identification (León-Ledesma et al., 2010).

1.4.3. Derivation of the CES production function

The CES production function has been derived in two alternative ways, which also correspond to the two different formulations of the definition of the elasticity of substitution. First, Arrow et al. (1961) showed that, under perfect competition, there is a log-linear relationship between the average productivity (or value added per unit of labour) and the real wage if and only if we have a CES production function with constant returns to scale; notice that this relationship corresponds to the integration of the definition shown in equation (8), $\sigma = \frac{dy}{dw}\frac{w}{y}$. The second derivation was put forward by Brown and De Cani (1963), who showed that a production function has a constant elasticity of substitution if and only if it is a CES production function; in this case, the authors started by the definition of the elasticity of substitution in the form of the non-linear second order differential equation shown in equation (6), $\sigma = \frac{K'(K'L-K)}{LKK''}$, which is homogeneous of any degree.

Arrow et al. (1961) started their analysis by estimating the relationship between the value added per unit of labour (y) and the wage rate (w), finding that the linear logarithmic relationship provided better regression results than the linear case (dropping time subscripts):

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$$ln(y) = ln(a) + b\, ln(w). \tag{13}$$

In competitive labour and product markets, the previous equation can be written as:[16]

$$ln(y) = ln(a) + b\, ln[y - ky'],$$

where $y = f(k)$ and $y' = f'(k)$, being $k = \frac{K}{L}$. Solving for y':

$$y' = \frac{dy}{dk} = \frac{y(1 - y^{\frac{1}{b}-1}a^{-\frac{1}{b}})}{k}.$$

Assuming that $\alpha = a^{-\frac{1}{b}}$ and $\psi = 1 - \frac{1}{b} = \frac{\sigma-1}{\sigma}$, this equation can be written as:

$$\frac{dk}{k} = \frac{dy}{y(1 - \alpha y^{-\psi})} = \frac{dy}{y} + \frac{\alpha y^{-\psi-1}}{1 - \alpha y^{-\psi}}\, dy.$$

Integrating the previous expression, we get (assuming that $-\frac{1}{\psi}\ln(\beta)$ is the integration constant):

$$ln(k) = ln(y) + \frac{1}{\psi}\ln\left(1 - \alpha y^{-\psi}\right) - \frac{1}{\psi}\ln(\beta).$$

Exponentiating and solving for per capita income, we obtain the CES production function in the intensive form:

$$y = \left(\beta k^{\psi} + \alpha\right)^{\frac{1}{\psi}},$$

which can also be written in the extensive form:

$$Y = \left(\beta K^{\psi} + \alpha L^{\psi}\right)^{\frac{1}{\psi}}. \tag{14}$$

The production function can be written in an alternative way, by setting $\alpha + \beta = \gamma^{\psi}$ and $\beta\gamma^{-\psi} = \delta$. In this case, the production function (14) becomes:[17]

$$Y = \gamma\left[\delta K^{\psi} + (1 - \delta)L^{\psi}\right]^{\frac{1}{\psi}}. \tag{15}$$

[16] Notice that, given Allen's theorem (equation (8)), we can see that b is equal to the elasticity of substitution (σ).

[17] Arrow et al. (1961) also point out this class of functions is known in the mathematical theory of elementary mean values (Hardy et al., 1934) as a mean value of order ψ.

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On the other hand, Brown and De Cani (1963) showed that the CES production function could also be obtained without the assumption of constant returns to scale. Using the definition of elasticity of substitution presented in equation (6), assuming that $L = e^u$ and taking the derivatives with respect to u:

$$\sigma K K'' + K K'(1-\sigma) - K'^2 = 0.$$

The order of this differential equation can be reduced by setting $p = K'$:

$$\sigma K \frac{dp}{dK} + K(1-\sigma) - p = 0.$$

The solution to the previous differential equation is given by (using $K^{-\frac{1}{\sigma}}$ as the integrating factor and denoting the constant of integration as c_0):

$$p = \frac{dK}{du} = K + c_0 K^{\frac{1}{\sigma}}.$$

Considering the case of a positive and non-unitary elasticity of substitution and since $\frac{dK}{du} = L\frac{dK}{dL}$, we have the following Bernoulli differential equation, with the derivative once again taken with respect to L:

$$K' - \frac{1}{L}K = \frac{c_0}{L}K^{\frac{1}{\sigma}}.$$

The solution to the previous equation is (c_1 is another constant of integration):

$$K^{1-\frac{1}{\sigma}} - c_1 L^{1-\frac{1}{\sigma}} = c_0.$$

From the previous expression, we can conclude that, as the elasticity of substitution tends to infinity, the isoquant tends to a straight line (the case of perfect substitutes). Moreover, to ensure that isoquants have negative slopes, the constant c_1 has to be negative.

To derive the production function, we set:

$$Y = F(K^{1-\frac{1}{\sigma}} - c_1 L^{1-\frac{1}{\sigma}}) = F(Z).$$

Using the Euler's theorem, the previous function will be homogeneous of degree h if:

$$hY = K\frac{\partial F}{\partial K} + L\frac{\partial F}{\partial L} = Z\left(1-\frac{1}{\sigma}\right)\frac{\partial F}{\partial Z}.$$

The solution to the previous equation contains an additional constant of integration (c_2):

$$Y = c_2 Z^{\frac{h}{\psi}} = c_2\left[K^{\psi} - c_1 L^{\psi}\right]^{\frac{h}{\psi}}.$$

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It can be noticed that setting $h = 1$ (linear homogeneity), $c_2 = \gamma(1 - c_1)^{-\frac{1}{\psi}}$ and $c_1 = 1 - \frac{1}{\delta}$ would lead to the Arrow et al. (1961) production function (15).

1.4.4. Specifications of the CES production function

The literature generally attributes the introduction of the CES production function to Arrow et al. (1961), who provided the first formal derivation of this function. However, as pointed by these authors, it was already used in previous papers by Solow (1956), as an example (in which he considered the particular case where the elasticity of substitution is equal to two), and by Swan, who deduced the constant elasticity of substitution property.[18] The first example came, however, from Dickinson (1954, p. 169), who showed *"a more general kind of national-income function, in which the factor shares are variable"*, compared to the Cobb-Douglas case.

Several alternative specifications of the CES production function have been put forward in the literature (Table 1.1), which are particular parametric cases of the production function (12).[19] As pointed by Whitaker (1964), Dickinson (1954) was led to the first chronological example by considering the class of production functions that could be written as $f(Y) = a_1 f(K) + a_2 f(L) + a_3$, and therefore it would be possible to get the Cobb-Douglas form or the CES production function in the case we consider $f(x) = ln\,(x)$ or $f(x) = x^{\psi}$, respectively. However, the economic significance of terms a_1, a_2 and a_3 is not explained. It can also be noted that Dickinson's (1954) production function would be linear homogeneous in the case that $a_3 = 0$. Solow's (1956) variant also contains a positive term a_4 whose economic meaning is not explained: it is either used as

[18] In this regard, see the ANU Inaugural Trevor Swan Distinguished Lecture (P. L. Swan, 2006, p. 12): *"While Trevor was at MIT he pointed out that a production function Solow was utilising had the constant elasticity of substitution, CES, property. In this way, the CES function was officially born. Solow and his coauthors publicly thanked Trevor for this insight (see Arrow; Chenery, Minhas, and Solow, 1961)."*

[19] Some authors have also extended the CES production function to more than two factors of production. Uzawa (1962) proposed the first extension to the case of n factors of production (denoted by x_i), assuming that the term attached to each factor of production is positive and showing that the partial elasticities of substitution between any two pairs of production factors are constant, identical for different pairs of factors and independent of factor prices ($Y = \left[a_1 {x_1}^{\psi} + a_2 {x_2}^{\psi} + \cdots + a_n {x_n}^{\psi}\right]^{\frac{1}{\psi}}$). Notice that, according to Uzawa (1962) and McFadden (1963), the generalization of the production function to more than two factors of production can only be obtained at the expense of strong restrictions on the values of the elasticity of substitution.

an "acceleration coefficient" in the Harrod-Domar model (similar to the Leontief production function), taking a_4 units of capital to produce one unit of output (combined with x units of labour), or as the capital coefficient in the Cobb-Douglas production function, measuring its relative factor share and therefore implying that $a_4 < 1$. Pitchford (1960) generalized T. W. Swan's (1956) model, using an expanded Solow's (1956) variant; in this case, the Cobb-Douglas production function was replaced by a constant elasticity of substitution production function, considering a_4 as the *"constant attached to capital"* (Pitchford, 1960, p. 497) and including a similar term a_5 attached to labour. This variant would be identical to the general CES production function (12) if we set $a_4 = \delta(\gamma A^K)^\psi$ and $a_5 = (1-\delta)(\gamma A^L)^\psi$, therefore implying, as indicated by Pitchford (1960), that the distribution terms depend on the elasticity of substitution.

[TABLE 1.1]

Two important limitations of the Arrow et al. (1961) production function are that the degree of homogeneity is constrained to unity and technological progress is restricted to the case of Hicks-neutrality. Brown and De Cani (1963) showed that the CES production function could be derived for any homogeneity degree h, while Ferguson (1965) included an additional technology parameter ζ in the production function (case *i*, for Hicks-neutral technological progress) and proposed an alternative CES production function with Harrod-neutral technological progress, including the parameter ζ_L (case *ii*). Both parameters ζ and ζ_L are assumed to be non-negative, since the American economy has not been characterized by *"technological retrogression"* (Ferguson, 1965, p. 303). David and van de Klundert (1965) found that technological progress in the United States of America (USA) between 1899 and 1960 has not been Hicks-neutral nor Harrod-neutral. In this vein, they proposed a new variant of the CES production function which includes two positive coefficients, A^K and A^L, that represent the efficiency levels of the capital and labour inputs, respectively, and whose variations over time are interpreted as capital-augmenting and labour-augmenting technological progress. There would be a capital-augmenting bias in technological progress if $\dot{A^K}/A^K > \dot{A^L}/A^L$ (where the overdots denote time derivatives), and a labour-augmenting bias if this inequality holds in reverse.

Despite the presence of the homogeneity parameter h in previous versions of the CES production function, Paroush (1966) proved that the Arrow et al. (1961)'s production

function could be extended to a case with homogeneity of degree h, with h not necessarily equal to one, using an analogous method that starts by the empirical relationship $ln(Y) = ln(a) + b\,ln(w) + cln(L)$, instead of equation (13).

More recently, the revival of interest in economic growth theory lead to the introduction of new variants of the CES production function. Barro and Sala-i-Martin (1995, 2004) included the Hicks-neutral technological progress parameter γ combined with two parameters, A^K and $(1 - A^K)$, that measure the efficiency of capital and labour. They justify the inclusion of these latter parameters because, as $\psi \to -\infty$, the shares of capital and labour in total product would approach A^K and $(1 - A^K)$, contrary to the standard Arrow et al. (1961)'s formulation, in which the output shares would be identical, approaching one-half. Ventura (1997)'s specification is a special case of David and van de Klundert (1965)'s variant, assuming $A^K = 1$. Other example is the variant used by Acemoglu (2002) and Antràs (2004), which does not incorporate the Hicks-neutral technological progress parameter γ, but includes both measures of factor efficiency, A^K and A^L, despite not being restricted to adding up to one as the Barro and Sala-i-Martin (1995, 2004) alternative. Finally, the formulation used by León-Ledesma et al. (2010), which is identical to equation (12), explicitly incorporates both Hicks-neutral and the efficiency levels of the capital and labour inputs.

1.4.5. Empirical studies

The CES production function has been widely used in empirical studies to estimate the elasticity of substitution, including studies at the sectoral (e.g. Balistreri et al., 2003) or plant level (Oberfield and Raval, 2021). The vast majority of them reject the Cobb-Douglas assumption for the United States (Table 1.2) and several other geographical scopes (Table 1.3), suggesting a lower than unity value of this parameter. One exception is Berndt (1976)'s paper, which has been cited in the literature as evidence in favour of the Cobb-Douglas functional form (e.g. Judd, 1987; Trostel, 1993). Willman (2002) found the same result for the Euro area (using the Solow-neutral specification for technological progress, which is considered the most reasonable result by the author), while some studies also point to substitution elasticities significantly above unity (e.g. Duffy and Papageorgiou, 2000, for a panel of 82 developed and developing countries, or Berthold et al., 2002, especially for Germany and France).

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[TABLES 1.2 AND 1.3]

The assumption for technological change of the CES production function plays an important role, as according to Antràs (2004), if the analysis is restricted to Hicks-neutral technological change, the estimate of the elasticity of substitution will be biased towards one. Within the studies that consider factor-augmenting technological change, the prevailing conclusion is that it is net labour-augmenting (e.g. Panik, 1976; Antràs, 2004; Lawrence, 2015).

1.4.6. Normalization

1.4.6.1 The concept of normalization and graphical representation

The importance of normalization of CES production functions stems from the seminal work of de La Grandville (1989), further elaborated by Klump and de La Grandville (2000), Klump and Preissler (2000) and de La Grandville and Solow (2006). According to Klump et al. (2012, p. 770), *"normalization essentially implies representing production relations in consistent indexed number form"*.

The concept of normalization starts from the observation that a family of CES production functions whose members are distinguished only by different elasticities of substitution needs a common benchmark point (Klump et al., 2007). Since the elasticity of substitution is calculated at a given point on one particular isoquant, it is defined as a point elasticity. In a CES production function, along a given isoquant or system of isoquants, the elasticity of substitution does not change; however, if the elasticity of substitution changes, the system of isoquants would also change. Normalization means the fixing of a baseline point characterized by a given level of production, factor inputs and marginal rate of technical substitution (or equivalently for per-capita production, capital deepening and factor income shares). In this baseline point, the isoquants of a CES production function with all parameters equal except the elasticity of substitution are tangents (Figure 1.2), with an inverse relationship being found between the elasticity of substitution and the second derivative of the normalized CES production function (Irmen and Klump, 2009). A family of normalized CES production functions is therefore understood as all production functions that share the same baseline point, being only distinguished by different elasticities of substitution (León-Ledesma et al., 2010; Klump et al., 2012).

[FIGURE 1.2]

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1.4.6.2. Derivation of the normalized CES production function

Analogously to the derivation of the standard CES production function, the normalized CES production function can be obtained through the same alternative ways (de La Grandville, 2009; Klump et al., 2012). For example, in a given point of time ($t = t_0$), we can measure the stock of capital (K_0) and labour (L_0), the income level (Y_0), the wage level (w_0), and the rental price of capital (r_0). Exponentiating equation (13) and solving for a:

$$a = y_0 w_0^{-b},$$

we can then identify constant α in the CES production function (14) (recalling that $\alpha = a^{-\frac{1}{b}}$, $b = \sigma$ and $\psi = 1 - \frac{1}{\sigma}$):

$$\alpha = \left(\frac{Y_0}{L_0}\right)^{\psi} (1 - \pi_0),$$

where π_0 represents the capital share in total income at time 0.

Also, since $Y_0 = F(K_0, L_0)$, we can also identify constant β:

$$\beta = \left(\frac{Y_0}{K_0}\right)^{\psi} \pi_0.$$

Replacing α and β in the Arrow et al. (1961) production function (14), we get the normalized CES production function:[20]

$$Y_t = Y_0 \left[\pi_0 \left(\frac{K_t}{K_0}\right)^{\psi} + (1 - \pi_0)\left(\frac{L_t}{L_0}\right)^{\psi}\right]^{\frac{1}{\psi}}.$$

Another possibility is to write the CES production function (12) as:

$$Y_t = \left[Y_0^{\psi}\gamma^{\psi}\delta(A_0^K)^{\psi}\left(\frac{Y_0}{K_0}\right)^{-\psi}\left(\frac{A_t^K K_t}{A_0^K K_0}\right)^{\psi} + Y_0^{\psi}\gamma^{\psi}(1-\delta)(A_0^L)^{\psi}\left(\frac{Y_0}{L_0}\right)^{-\psi}\left(\frac{A_t^L L_t}{A_0^L L_0}\right)^{\psi}\right]^{\frac{1}{\psi}}.$$

Hence, employing the first-order conditions for profit maximization in perfectly competitive markets yields the normalized CES production function (in this case also considering the technological change parameters):

[20] Alternatively, the normalized CES production function can be derived using the definition of the elasticity of substitution as a non-linear second-order differential equation, leading to the same result.

$$Y_t = Y_0 \left[\pi_0 \left(a_t^K \frac{K_t}{K_0} \right)^{\psi} + (1 - \pi_0) \left(a_t^L \frac{L_t}{L_0} \right)^{\psi} \right]^{\frac{1}{\psi}},$$

where $\pi_0 = \frac{r_0 K_0}{Y_0}$, $a_t^K = \frac{A_t^K}{A_0^K} = e^{\zeta_K (t - t_0)}$ and $a_t^L = \frac{A_t^L}{A_0^L} = e^{\zeta_L (t - t_0)}$.

The previous expression can be written in logarithmic form as:

$$ln(Y_t) = ln(Y_0) + \frac{1}{\psi} ln \left[\pi_0 \left(e^{\zeta_K (t - t_0)} \frac{K_t}{K_0} \right)^{\psi} + (1 - \pi_0) \left(e^{\zeta_L (t - t_0)} \frac{L_t}{L_0} \right)^{\psi} \right]. \quad (16)$$

Consequently, the normalized first-order conditions can also be log-linearized as their non-normalized counterparts:

$$ln \left(\frac{Y_t}{K_t} \right) = \xi_0^{NK} + \sigma \, ln(r_t) + (1 - \sigma) \zeta_K (t - t_0), \quad (17)$$

$$ln \left(\frac{Y_t}{L_t} \right) = \xi_0^{NL} + \sigma \, ln(w_t) + (1 - \sigma) \zeta_L (t - t_0), \quad (18)$$

where $\xi_0^{NK} = \sigma \, ln \left(\frac{1}{\pi_0} \right) + (1 - \sigma) ln \left(\frac{Y_0}{K_0} \right)$ and $\xi_0^{NL} = \sigma \, ln \left(\frac{1}{1 - \pi_0} \right) + (1 - \sigma) ln \left(\frac{Y_0}{L_0} \right)$.

1.4.6.3. The role of normalization

The normalized system approach in the estimation of CES production functions requires the choice of initial parameter values since one of the equations is non-linear. In the case of the non-normalized system of equations described in Section 1.4.2, there are no guidelines for choosing the initial parameters values of γ and δ, which can lead to serious estimation problems. In fact, at a particular point in time ($t = t_0$), corresponding to given baseline values of the capital (K_0) and labour stocks (K_0) and the income level (Y_0), they can be derived considering the system comprised by the CES production function (12) and the expression of the marginal rate of technical substitution in perfectly competitive markets, $(F_L / F_K)_0 = w_0 / r_0$: [21]

$$\gamma = Y_0 \left[\frac{{K_0}^{1-\psi} + {L_0}^{1-\psi} \left(\frac{F_L}{F_K} \right)_0}{K_0 + L_0 \left(\frac{F_L}{F_K} \right)_0} \right]^{\frac{1}{\psi}} = Y_0 \left[\frac{r_0 {K_0}^{\frac{1}{\sigma}} + w_0 {L_0}^{\frac{1}{\sigma}}}{r_0 K_0 + w_0 L_0} \right]^{\frac{\sigma}{\sigma - 1}},$$

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[21] For simplicity, we are assuming that $A_0^K = A_0^L = 1$.

$$\delta = \frac{{K_0}^{1-\psi}}{{K_0}^{1-\psi} + {L_0}^{1-\psi}\left(\frac{F_L}{F_K}\right)_0} = \frac{r_0 {K_0}^{\frac{1}{\sigma}}}{r_0 {K_0}^{\frac{1}{\sigma}} + w_0 {L_0}^{\frac{1}{\sigma}}}.$$

Looking at the previous expressions, we can conclude that these parameters are not "deep", as they depend on the elasticity of substitution (in addition to the magnitude of the normalized variables). Notice that the exception would be case where the stocks of capital and labour are equal and therefore $\gamma = \frac{Y_0}{K_0}$ and $\delta = \frac{r_0}{r_0 + w_0}$.

León-Ledesma et al. (2010) estimated normalized and non-normalized systems and concluded that the latter are attracted towards unity elasticities and that the bias in the estimated elasticity of substitution and technological change will increase the more the initial conditions depart from their true, theoretical values.

On the other hand, in the normalized system of equations (16)-(18), the parameters Y_0 and π_0 have a clear data-based intepretation and can be chosen prior to the estimation, allowing the reduction of freely estimated parameters by two and alleviating the estimation of the deep parameters, namely the elasticity of substitution and the growth rates of factor-augmenting technological progress (Klump et al., 2012). Moreover, since normalized functions belong to the same family, the estimated production function is suitable for comparative static analysis.

The results of Monte Carlo simulations performed by León-Ledesma et al. (2010) suggested that the best estimates of the elasticity of substitution and technological change rates were obtained using the system approach and that normalization increased those gains. Furthermore, the normalized system estimates were insensitive to the simultaneity bias and appeared robust to residual autocorrelation, variations of the sample size and alternative forms of technological progress (using a Box-Cox specification). The use of a normalized CES production function with a factor-augmenting specification in the context of system estimation results in markedly less biased estimates of the elasticity of substitution parameter than imposing *a priori* neutrality constraints, therefore allowing to circumvent the Diamond et al. (1978)'s impossibility theorem (Klump et al., 2012).

The definition of the normalization point is very important for the quality of the estimation results. Since the production functions do not hold exactly in every sample point (as actual data are stochastic rather than deterministic), Klump et al. (2012) state that an appealing procedure is to use sample averages (geometric for growing variables,

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such as capital and labour, and arithmetic for variables that are approximately stationary, such as the capital income share). However, as the CES production function is non-linear, the sample average of production may not coincide with the level of production implied by the production function using sample averages of each variable. Consequently, Klump et al. (2007) introduced an additional estimated parameter ξ, called the normalization constant and whose expected value is around one.[22] The normalization point is therefore defined as $Y_0 = \xi\bar{Y}$, $K_0 = \bar{K}$, $L_0 = \bar{L}$, $\pi_0 = \bar{\pi}$ and $t_0 = \bar{t}$, where the bar denotes the sample average (geometric in the case of the first three variables, and arithmetic in the case of the last two). As suggested by León-Ledesma et al. (2010) and Klump et al. (2012), a natural choice for the normalization constant is one. If the estimated values of the distribution parameter and the normalization constant deviate significantly from their initial values, the estimation results should be questioned. In this sense, normalization is also useful as a means for *a posteriori* validation of the estimated parameters.

1.4.6.4. Empirical studies

The normalized CES production function was first implemented empirically by Klump et al. (2007) and since then has been used in several empirical studies (Table 1.4). All of them point to estimates of the aggregate elasticity of substitution lower than one, thus rejecting the Cobb-Douglas assumption. Some studies consider groups formed by several (heterogeneous) countries (e.g. Klump et al., 2008; Mallick, 2012a), whereas others also study the industry-level (e.g. Young, 2013). The majority of the studies assumes that technological change is factor-augmenting. Moreover, Mallick (2012a) also found evidence of the positive effect of the elasticity of substitution on the growth rate at the cross-country level. Technological change is mainly net labour-augmenting; one of the exceptions is Jiang and León-Ledesma (2018)'s study, that estimated a normalized system allowing for a time-varying price markup, which also lead to a higher elasticity of substitution than in the constant markup case. It can also be observed that some studies reported a decline in the capital efficiency level (e.g. Luoma and Luoto, 2010; Mućk, 2017).[23]

[TABLE 1.4]

[22] Note that ξ would be exactly equal to 1 in the case of the log-linear Cobb-Douglas production function.

[23] Del Río and Lores (2019) found that the decline in the capital efficiency level explained the decline in the US labour share in a context of gross complementarity between labour and capital.

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1.5. The Variable Elasticity of Substitution (VES) production function

1.5.1. Properties of the VES production function

The CES production function, like its name indicates, is subject to the limitation that the elasticity of substitution assumes a constant value, although not necessarily unity (as the Cobb-Douglas case). It seems plausible to admit, however, that when the proportion between the factors varies, the degree of substitutability of one factor for another also varies. Following Kadiyala (1972), a general expression for a Variable Elasticity of Substitution (VES) including the factor efficiency parameters is given by:

$$Y_t = \gamma\left[\omega_{11}(A_t^K K_t)^{\psi} + 2\omega_{12}\left[(A_t^K K_t)^{\upsilon}(A_t^L L_t)^{(1-\upsilon)}\right]^{\psi} + \omega_{22}(A_t^L L_t)^{\psi}\right]^{\frac{1}{\psi}} \qquad (19)$$

where ω_{11}, ω_{12} and ω_{22} are non-negative and lower than unity, $\omega_{11} + 2\omega_{12} + \omega_{22} = 1$ and $0 \leq \upsilon \leq 1$ (and, as previously, $\psi < 1$). For simplicity, we can also express $\upsilon\psi = \psi_K$ and $(1-\upsilon)\psi = \psi_L$. The previous function includes other VES production functions proposed in the literature as particular parametric cases: if $\omega_{22} = 0$, it reduces to the Liu-Hildebrand (1965) / Nerlove (1967)[24], and Lu-Fletcher (1968) production functions; while if $\omega_{22} = 0$, $\psi_K = \psi - 1$ and $\psi_L = 1$ (which is equivalent to assuming $\upsilon = 1 - 1/\psi$) we obtain the Sato-Hoffman (1968) and Revankar (1971a) production functions. The CES production function (when $\omega_{12} = 0$) and the Cobb-Douglas case (when $\omega_{11} = \omega_{22} = 0$ or as $\psi \to 0$) are also included, as well as the Leontief case (when $\psi \to -\infty$) and the linear production function (when $\omega_{12} = 0$ and $\psi = 1$). Within the aforementioned particular parametric cases, it should be pointed out that, contrary to the Liu-Hildebrand (1965) / Nerlove (1967) and Lu-Fletcher (1968)'s VES productions functions, the Sato-Hoffman (1968) and Revankar (1971a) functions do not include the CES function as a special case. More recently, Del Río and Lores (2019) assumed the particular case where $\omega_{11} = 0$.

From the assumption of constant returns to scale , the VES production function (19) can be written as (where $k_t = \frac{A_t^K K_t}{A_t^L L_t}$):

$$f(k_t) = \gamma\left[\omega_{11} {k_t}^{\psi} + 2\omega_{12} {k_t}^{\upsilon\psi} + \omega_{22}\right]^{\frac{1}{\psi}}.$$

[24] The function was derived by Nerlove (1967) while formalizing the empirical evidence obtained by Liu and Hildebrand (1965).

The previous function displays the usual properties of a production function, including positive and decreasing marginal productivities of capital and labour, as long as $\psi < 1$:

$$f'(k_t) = \gamma {k_t}^{v\psi-1} \frac{\left[\omega_{11} {k_t}^{(1-v)\psi} + 2\omega_{12} v\right]}{\left[\omega_{11} {k_t}^{\psi} + 2\omega_{12} {k_t}^{v\psi} + \omega_{22}\right]^{1-\frac{1}{\psi}}},$$

$$f''(k_t) = \gamma {k_t}^{v\psi-2} \times \left[\frac{2\omega_{11}\omega_{12}[v(v\psi+1) + \psi(1-2v) - 1]{k_t}^{\psi} + 4\omega_{12}^2 v(v-1){k_t}^{v\psi}}{\left[\omega_{11} {k_t}^{\psi} + 2\omega_{12} {k_t}^{v\psi} + \omega_{22}\right]^{2-\frac{1}{\psi}}} \right.$$

$$\left. + \frac{\omega_{11}\omega_{12}(\psi-1){k_t}^{(1-v)\psi} + 2\omega_{12}\omega_{22} v(v\psi-1)}{\left[\omega_{11} {k_t}^{\psi} + 2\omega_{12} {k_t}^{v\psi} + \omega_{22}\right]^{2-\frac{1}{\psi}}} \right].$$

The limits of the first derivatives of the VES production function also depend on the value of ψ. If $0 < \psi < 1$:

$$\lim_{k_t \to 0} f'(k_t) = +\infty,$$

$$\lim_{k_t \to +\infty} f'(k_t) = \gamma {\omega_{11}}^{\frac{1}{\psi}}.$$

On the other hand, for a negative ψ (or a lower than unity elasticity of substitution):

$$\lim_{k_t \to 0} f'(k_t) = \gamma {\omega_{11}}^{\frac{1}{\psi}},$$

$$\lim_{k_t \to +\infty} f'(k_t) = 0.$$

Similarly to the CES production function, one of the Inada conditions is violated in both situations: for a positive and lower than unity ψ, as the effective capital intensity intensity goes to infinity, the first derivative tends to a positive constant (greater than zero), while for the same happens for a negative ψ, but in this case when the effective capital intensity approaches zero (instead of infinity).

The output elasticity for capital is given by:

$$s(k_t) = \frac{f'(k_t)}{f(k_t)} k_t = \frac{\omega_{11} {k_t}^{(1-v)\psi} + 2\omega_{12} v}{\omega_{11} {k_t}^{(1-v)\psi} + 2\omega_{12} + \omega_{22} {k_t}^{-v\psi}}.$$

Hence, using equation (7), the elasticity of substitution between capital and labour is equal to:

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$$\sigma(k_t) = \left[1 - \left(\frac{\omega_{11}(1-\upsilon)\psi}{\omega_{11} + 2\omega_{12}\upsilon k_t^{-(1-\upsilon)\psi}} + \frac{\omega_{22}\upsilon\psi}{\omega_{22} + 2\omega_{12}(1-\upsilon)k_t^{\upsilon\psi}}\right)\right]^{-1},$$

which varies with the input ratio along the same isoquant. As previously mentioned, when $\omega_{11} = \omega_{22} = 0$, we are in the Cobb-Douglas case and the elasticity of substitution is equal to 1, while if $\omega_{12} = 0$, we are in the CES case and the elasticity of substitution is equal to $(1 - \psi)^{-1}$. In all other cases, the elasticity of substitution is not constant. Also note that, since k_t is always positive, the sign of ψ determines the value of the elasticity of substitution: if $\psi < 0$, the elasticity of substitution is lower than unity (the case previously referred to as gross complementarity between capital and labour), whereas when $0 < \psi < 1$, the elasticity of substitution is greater than unity (gross substitutability).

The previous expression can also be written as:

$$\sigma(k_t) = \frac{1}{1 - \frac{\psi}{2} + R},$$

where

$$R = \frac{\omega_{11}\omega_{12}\psi(1-\upsilon)[1-2(1-\upsilon)]k_t^{\upsilon\psi} + \omega_{12}\omega_{22}\psi\upsilon(1-2\upsilon)k_t^{-(1-\upsilon)\psi}}{\left[\omega_{11} + 2\omega_{12}\upsilon k_t^{-(1-\upsilon)\psi}\right]\left[\omega_{22} + 2\omega_{12}(1-\upsilon)k_t^{\upsilon\psi}\right]}$$
$$+ \frac{2\omega_{12}^2\psi\upsilon(1-\upsilon)k_t^{\psi(2\upsilon-1)} - \omega_{11}\omega_{22}\frac{\psi}{2}}{\left[\omega_{11} + 2\omega_{12}\upsilon k_t^{-(1-\upsilon)\psi}\right]\left[\omega_{22} + 2\omega_{12}(1-\upsilon)k_t^{\upsilon\psi}\right]}.$$

To study the behaviour of the elasticity of substitution for different capital intensity levels, an additional simplifying assumption can be made: by setting $\upsilon = 0.5$, the previous VES production function loses one parameter and is no longer a generalization of the Sato-Hoffman / Revankar production function, but it becomes more easily workable while maintaining its essential characteristics (Kadiyala, 1972). In this case, the previous equation is reduced to:

$$R = \frac{-\frac{\psi}{2}(\omega_{11}\omega_{22} - \omega_{12}^2)}{\left[\omega_{11} + \omega_{12}k_t^{-\frac{\psi}{2}}\right]\left[\omega_{22} + \omega_{12}k_t^{\frac{\psi}{2}}\right]}$$

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The extrema of R are obtained when $k_t = \left(\frac{\omega_{11}}{\omega_{22}}\right)^{\frac{1}{\psi}}$. Assuming that $\omega_{11}\omega_{22} - \omega_{12}^2 > 0$, the sign and behaviour of R will depend on ψ: for positive values of ψ (which is the only

case that is able to generate higher than or equal to unity values of the elasticity of substitution), the function is monotone decreasing until that effective capital intensity level and becomes monotone increasing thereafter; the elasticity of substitution is consequently comprised between:

$$\sigma_{min\ (0<\psi<1)} = \frac{1}{1-\frac{\psi}{2}}$$

and

$$\sigma_{max\ (0<\psi<1)} = \frac{1}{1-\frac{\psi}{2}-\frac{\frac{\psi}{2}(\omega_{11}\omega_{22}-\omega_{12}^2)}{(\sqrt{\omega_{11}}\sqrt{\omega_{22}}+\omega_{12})^2}}.$$

On the other hand, for negative values of ψ, the R function starts increasing with the effective capital intensity level, reaching its maximum at $k_t = \left(\frac{\omega_{11}}{\omega_{22}}\right)^{\frac{1}{\psi}}$ and decreasing thenceforth. Accordingly, the elasticity of substitution varies between:

$$\sigma_{min\ (\psi<0)} = \frac{1}{1-\frac{\psi}{2}-\frac{\frac{\psi}{2}(\omega_{11}\omega_{22}-\omega_{12}^2)}{(\sqrt{\omega_{11}}\sqrt{\omega_{22}}+\omega_{12})^2}}$$

and

$$\sigma_{max\ (\psi<0)} = \frac{1}{1-\frac{\psi}{2}}.$$

Notice that, to ensure that the elasticity of substitution is greater than or equal to zero, it must be guaranteed that:

$$\psi \leq \frac{(\sqrt{\omega_{11}}\sqrt{\omega_{22}}+\omega_{12})^2}{\omega_{11}\omega_{22}+\omega_{12}\sqrt{\omega_{11}}\sqrt{\omega_{22}}}$$

The particular cases where $\omega_{11} = 0$ and $\omega_{22} = 0$ are characterized by opposite behaviours of the elasticity of substitution when the ratio of effective capital to effective labour varies. On the one hand, in the particular case where $\omega_{11} = 0$ (Del Río and Lores, 2019), the first derivative of the elasticity of substitution with respect to the ratio of effective capital to effective labour is equal to:

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$$\frac{d\sigma(k_t)}{dk_t} = -\frac{2\omega_{12}\omega_{22}v^2(1-v)\psi^2 {k_t}^{v\psi-1}}{\left[\omega_{22}(1-v\psi)+2\omega_{12}(1-v){k_t}^{v\psi}\right]^2}$$

which is always negative, implying that the elasticity of substitution is a decreasing function of the ratio of effective capital to effective labour. The elasticity of substitution reaches its maximum at $k_t = 0$, being equal to:

$$\sigma_{max} = \frac{1}{1-v\psi}.$$

On the other hand, considering the case where $\omega_{22} = 0$ (Liu and Hildebrand, 1965; Nerlove, 1967; Lu and Fletcher, 1968), we obtain:

$$\frac{d\sigma(k_t)}{dk_t} = \frac{2\omega_{11}\omega_{12}v(1-v)^2\psi^2 {k_t}^{-(1-v)\psi-1}}{\left[\omega_{11}[1-(1-v)\psi]+2\omega_{12}v{k_t}^{-(1-v)\psi}\right]^2},$$

which is always positive, implying that the elasticity of substitution is an increasing function of the ratio of effective capital to effective labour. Accordingly, the lowest value of the elasticity of substitution corresponds to the situation where $k_t = 0$, being equal to:

$$\sigma_{min} = \frac{1}{1-(1-v)\psi}.$$

1.5.2. Estimation forms

The logarithmic form of the VES production function (19) is given by:

$$ln(Y_t) = ln(\gamma) + \frac{1}{\psi} ln\left[\omega_{11}\left(A_t^K K_t\right)^{\psi} + 2\omega_{12}\left[\left(A_t^K K_t\right)^{v}\left(A_t^L L_t\right)^{(1-v)}\right]^{\psi} + \omega_{22}\left(A_t^L L_t\right)^{\psi}\right].$$

Analogously to the CES production function, the VES production function is non-linear in its parameters. Under perfect competition, the first-order conditions for profit maximization are:

$$ln\left(\frac{Y_t}{K_t}\right) = -\frac{\psi}{1-\psi}[ln(\gamma) + ln(A_t^K)] + \frac{1}{1-\psi} ln(r_t) - \frac{1}{1-\psi} ln\left[\omega_{11} + 2\omega_{12}v\left(\frac{A_t^K K_t}{A_t^L L_t}\right)^{-(1-v)\psi}\right],$$

$$ln\left(\frac{Y_t}{L_t}\right) = -\frac{\psi}{1-\psi}[ln(\gamma) - ln(A_t^L)] + \frac{1}{1-\psi} ln(w_t) - \frac{1}{1-\psi} ln\left[\omega_{22} + 2\omega_{12}(1-v)\left(\frac{A_t^K K_t}{A_t^L L_t}\right)^{v\psi}\right].$$

If we set $\omega_{12} = 0$, we are in the CES case and both conditions are log-linear.

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Moreover, the first-order condition with respect to capital can be log-linearized by setting $\omega_{11} = 0$, the same happening with the first-order condition with respect to labour by setting $\omega_{22} = 0$:[25]

$$ln\left(\frac{Y_t}{K_t}\right) = \xi_0^{VK} + \xi_1^{VK}\, ln(r_t) + \xi_2^{VK} t + \xi_3^{VK} ln\left(\frac{K_t}{L_t}\right),$$

$$ln\left(\frac{Y_t}{L_t}\right) = \xi_0^{VL} + \xi_1^{VL}\, ln(w_t) + \xi_2^{VL} t + \xi_3^{VL} ln\left(\frac{K_t}{L_t}\right),$$

where $\xi_0^{VK} = -\frac{1}{1-\psi}\left[\psi ln(\gamma) + ln(2\omega_{12}\upsilon) + \psi[\upsilon ln(A_0^K) + (1-\upsilon) ln(A_0^L)]\right]$, $\xi_0^{VL} = -\frac{1}{1-\psi}\left[\psi ln(\gamma) + ln[2\omega_{12}(1-\upsilon)] + \psi[\upsilon ln(A_0^K) + (1-\upsilon) ln(A_0^L)]\right]$, $\xi_1^{VK} = \xi_1^{VL} = \frac{1}{1-\psi}$, $\xi_2^{VK} = \xi_2^{VL} = -\frac{\psi}{1-\psi}[\upsilon\zeta_K + (1-\upsilon)\zeta_L]$, $\xi_3^{VK} = \frac{(1-\upsilon)\psi}{1-\psi}$ and $\xi_3^{VL} = -\frac{\upsilon\psi}{1-\psi}$.

Each of these conditions allows the identification of parameters υ and ψ, but requires *a priori* assumptions on the nature of technological change to identify the factor augmentation rates. Identification is possible, for example, under the assumption of one of the three aforementioned types of neutrality: Hicks-neutrality ($\zeta_L = \zeta_K = \zeta$), Harrod-neutrality ($\zeta_K = 0$) or Solow-neutrality ($\zeta_L = 0$).

Alternatively, the system approach can also be applied to the estimation of the VES production function, estimating the production function combined with one or two first-order conditions.

1.5.3. Derivation of the VES production function

The particular parametric cases of the VES production function (19) were derived in the literature in two alternative ways: first, Nerlove (1967) extended Arrow et al. (1961)'s log-linear relationship between the average productivity and the real wage to include the stock of capital, a relationship that exists in the unique case of a VES production function[26]; later, R. Sato and Hoffman (1968) showed that the elasticity of substitution is a linear function of the capital-labour ratio if and only if we have a VES production function.

[25] We are again assuming constant growth rates of factor efficiency, $A_t^K = A_0^K e^{\zeta_K t}$ and $A_t^L = A_0^L e^{\zeta_L t}$.

[26] Nerlove (1967) described this procedure, whose origin goes back to an unpublished work of Bruno (1962). Later, Lu and Fletcher (1968) derived a similar VES production function starting from the same relationship, but using a different mathematical procedure.

As described in section 1.4.3, Arrow et al. (1961) derived the CES production function by estimating the relationship between the value added per unit of labour (y) and the wage rate (w), independently from the stock of capital. However, if this assumption does not hold, we may obtain biased estimates and, in this vein, Nerlove (1967) began the derivation of the VES production function from a similar relationship, but which included additionally the stock of capital per worker (k):

$$ln(y) = ln(a) + b\, ln(w) + g\, ln(k).$$

In competitive labour and product markets, the previous equation can be written as:

$$ln(y) = ln(a) + b\, ln[y - ky'] + g\, ln(k).$$

Assuming $z = \frac{k}{y}$ and rearranging we obtain:

$$k^{\frac{1-2b-g}{b}} dk = a^{\frac{1}{b}} z^{\frac{1-2b}{b}} dz.$$

Integration of the previous expression yields (c_3 is a constant of integration):

$$\frac{b k^{\frac{1-b-g}{b}}}{1-b-g} = \frac{b a^{\frac{1}{b}} z^{\frac{1-b}{b}}}{1-b} + c_3.$$

Substitution of $z = \frac{k}{y}$ and simplification leads to the VES production function in the intensive form:

$$y = \left[\beta_{LH} k^{\psi} + \alpha_{LH} k^{m\psi}\right]^{\frac{1}{\psi}},$$

where $\psi = 1 - \frac{1}{b}$, $\beta_{LH} = \frac{-c(1-b)}{b a^{\frac{1}{b}}}$, $\alpha_{LH} = \frac{1-b}{(1-b-g) a^{\frac{1}{b}}}$ and $m = \frac{g}{1-b}$. In the extensive form:

$$Y = \left[\beta_{LH} K^{\psi} + \alpha_{LH} (K^m L^{1-m})^{\psi}\right]^{\frac{1}{\psi}}.$$

Notice that this expression is equivalent to the general case (19) if we set $\omega_{11} = \beta_{LH}$, $2\omega_{12} = \alpha_{LH}$, $\omega_{22} = 0$, $\gamma = A^K = A^L = 1$ and $\upsilon = m$. Using equation (7), the elasticity of substitution is variable and equal to (π represents the capital share):

$$\sigma = \frac{1}{1 - \psi + \frac{m\psi}{\pi}},$$

which is equal to 1 if $g = m = 0$ and $\psi = 0$ (Cobb-Douglas case) and $(1-\psi)^{-1}$ if $g = m = 0$ and $\psi \neq 0$ (CES production function case).

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Another possibility was put forward by R. Sato and Hoffman (1968), who started the derivation of a VES production function from the definition of the elasticity of substitution as a linear function of the capital-labour ratio:[27]

$$\sigma(k) = a_{SH} + b_{SH}k. \tag{20}$$

Rearranging the definition of elasticity of substitution given in equation (7) and substituting the previous expression:

$$\frac{d\ ln\ MRTS}{MRTS} = \frac{dk}{k(a_{SH} + b_{SH}k)}.$$

Integration of which and simplification leads to (c_4 is a constant of integration):

$$MRTS = c_4 \left(\frac{k}{a_{SH} + b_{SH}k}\right)^{\frac{1}{a_{SH}}}.$$

Using the definition of marginal rate of technical substitution, we obtain after some manipulation (with $y' = dy/dk$):

$$\frac{dy}{y} = \frac{dk}{k + c_4 \left(\frac{k}{a_{SH} + b_{SH}k}\right)^{\frac{1}{a_{SH}}}}.$$

Integration of which and further simplification yields (where c_5 is another constant of integration):

$$y = c_5 e^{\int \frac{dk}{k + c_4 \left(\frac{k}{a_{SH} + b_{SH}k}\right)^{\frac{1}{a_{SH}}}}}.$$

R. Sato and Hoffman (1968) then work empirically with the special case where $a_{SH} = 1$.[28] In this case, the previous equation becomes (with an additional constant of integration c_6):

[27] R. Sato and Hoffman (1968) also derived another alternative approach, considering the elasticity of substitution as a linear function of time, resulting in a production function which they characterized as a "shifting CES".

[28] In this case, equation (20) becomes $\sigma = 1 + b_{SH}k$, which is the same definition used by Revankar (1971a) to derive his VES production function. Notice also the following domain restriction for this function: for a negative b_{SH} (implying a lower than unity elasticity of substitution), $\sigma > 0$ is only verified as long as $k < -\frac{1}{b_{SH}}$.

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$$y = c_5 e^{\int \frac{dk}{k + c_4\left(\frac{k}{1+b_{SH}k}\right)}} = c_5 e^{ln\left[c_6 k^{\frac{1}{1+c_4}}(1+c_4+b_{SH}k)^{\frac{c_4}{1+c_4}}\right]}.$$

And therefore R. Sato and Hoffman (1968)'s VES production function can be written in the intensive form as:

$$y = c_5 c_6 k^{\frac{1}{1+c_4}}[1 + c_4 + b_{SH}k]^{\frac{c_4}{1+c_4}} = \left[\beta_{SH}k^{\psi} + \alpha_{SH}k^{\psi-1}\right]^{\frac{1}{\psi}},$$

where $\psi = \frac{1+c_4}{c_4}$, $\beta_{SH} = b_{SH}(c_5 c_6)^{\psi}$ and $\alpha_{SH} = (1 + c_4)(c_5 c_6)^{\psi}$. Hence, in the extensive form:

$$Y = \left[\beta_{SH}K^{\psi} + \alpha_{SH}K^{\psi-1}L\right]^{\frac{1}{\psi}}. \tag{21}$$

The previous expression becomes equivalent to the general production function (19) by setting $\omega_{11} = \beta_{SH}$, $2\omega_{12} = \alpha_{SH}$, $\omega_{22} = 0$, $\gamma = A^K = A^L = 1$, $\psi_K = \psi - 1$ and $\psi_L = 1$ (notice that, since $\psi < 1$ and contrary to the Liu-Hildebrand / Nerlove function, it is not possible to choose the particular case where $\psi_K = \psi_L$). The production function (21) can also be written as:

$$Y = \alpha_{SH}^{\frac{1}{\psi}} K^{\frac{\psi-1}{\psi}}\left[L + \frac{\beta_{SH}}{\alpha_{SH}}K\right]^{\frac{1}{\psi}} = \alpha_{SH}^{\frac{1}{\psi}} K^{\frac{\psi-1}{\psi}} L^{\frac{1}{\psi}}\left[1 + \frac{\beta_{SH}}{\alpha_{SH}}\frac{K}{L}\right]^{\frac{1}{\psi}}.$$

Finally, using equation (20):

$$Y = \alpha_{SH}^{\frac{1}{\psi}} K^{\frac{\psi-1}{\psi}} L^{\frac{1}{\psi}}\left[\sigma(k) - \frac{1}{\psi}b_{SH}\frac{K}{L}\right]^{\frac{1}{\psi}}.$$

Therefore, this production function can be decomposed into the Cobb-Douglas case $\left(\alpha_{SH}^{\frac{1}{\psi}} K^{\frac{\psi-1}{\psi}} L^{\frac{1}{\psi}}\right)$ and a second term $\left[\sigma(k) - \frac{1}{\psi}b_{SH}\frac{K}{L}\right]^{\frac{1}{\psi}}$, which is dependent on the variable elasticity of substitution, adjusting its value from unity.

An alternative approach, which to the best of our knowledge has not been put forward in economic literature, consists in starting the derivation of a VES production function from a relationship between the value added per unit of labour, the stock of capital per worker and the rental price of capital (r), instead of the wage rate:

$$ln(y) = ln(a) + b\, ln(r) + g\, ln(k).$$

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In competitive labour and product markets, the previous equation can be written as:

$$ln(y) = ln(a) + b\ ln(y') + g\ ln(k),$$

which is equivalent to:

$$y = a\left(\frac{dy}{dk}\right)^{b} k^{g}.$$

Rearranging the previous expression:

$$k^{-\frac{g}{b}}dk = a^{\frac{1}{b}}y^{-\frac{1}{b}}dy.$$

Integration of the previous expression yields (c_7 is a constant of integration):

$$\frac{k^{1-\frac{g}{b}}}{1-\frac{g}{b}} = a^{\frac{1}{b}}\frac{y^{1-\frac{1}{b}}}{1-\frac{1}{b}} + c_7.$$

Rearranging the previous expression and denoting $\psi = 1 - \frac{1}{b}$, $\beta_1 = \frac{-c_7(b-1)}{ba^{\frac{1}{b}}}$, $m_1 = \frac{b-g}{b-1}$ and $\alpha_1 = \frac{(b-1)}{(b-g)a^{\frac{1}{b}}}$:

$$y = \left[\alpha_1 k^{m_1\psi} + \beta_1\right]^{\frac{1}{\psi}}.$$

In the extensive form, this VES production function becomes:

$$Y = \left[\alpha_1 K^{m_1\psi}L^{(1-m_1)\psi} + \beta_1 L^{\psi}\right]^{\frac{1}{\psi}}.$$

Notice that this expression is equivalent to the general case (19) if we set $\omega_{11} = 0$, $2\omega_{12} = \alpha_1$, $\omega_{22} = \beta_1$, $\gamma = A^K = A^L = 1$ and $\upsilon = m_1$. Using equation (7), the elasticity of substitution is variable and equal to:

$$\sigma = \frac{1}{1 - \psi - \frac{\psi(m_1 - 1)}{1 - \pi}},$$

which is equal to 1 if $\psi = 0$ (Cobb-Douglas case) and $(1-\psi)^{-1}$ if $g = m_1 = 1$ and $\psi \neq 0$ (CES production function case).

1.5.4. Alternative functions with variable elasticity of substitution

Alternatively to the general VES production (19) or its particular parametric cases, some studies have been performed with resort to the transcendental production function (e.g., Lovell, 1968, 1973; Bairam, 1989, 1990), to the constant marginal share (CMS)

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production function developed by Bruno (1968) or to the Sobelow production function, taking advantage of their variable elasticity of substitution property.

The transcendental production function. This production function can be written as:

$$Y = \gamma_T e^{\lambda_T} K^{\alpha_T} L^{1-\alpha_T} e^{\beta_T \frac{K}{L}},$$

where $0 < \alpha_T < 1$, $\gamma_T > 0$ and $0 < \alpha_T + \beta_T \frac{K}{L} < 1$. In this case, the marginal rate of technical substitution is equal to:

$$MRTS = \frac{K}{L}\left[\frac{1}{\alpha_T + \beta_T \frac{K}{L}} - 1\right].$$

And, using equation (1), the elasticity of substitution is given by:

$$\sigma = 1 - \frac{\beta_T \frac{K}{L}}{\left(\alpha_T + \beta_T \frac{K}{L}\right)^2 - \alpha_T},$$

which varies with the capital-labour ratio. Notice that this function can be reduced to the Cobb-Douglas case in the case that $\beta_T = 0$, but it does not include the linear production function as a special case. Moreover, as pointed by Lovell (1968), this function possesses an "uneconomic region": when $\beta_T \neq 0$, there is a region of capital-labour ratio values with negative marginal products of capital and labour.[29]

The constant marginal share (CMS) production function. The CMS production function can be expressed as:

$$Y = \gamma_C e^{\lambda_T} K^{\alpha_C} L^{1-\alpha_C} - m_C L,$$

where $0 \leq \alpha_C < 1$ and $\gamma_C > 0$. In this case, the marginal rate of technical substitution is equal to:

$$MRTS = \left(\frac{1-\alpha_C}{\alpha_C}\right)\frac{K}{L} - \frac{m_C}{\gamma_C e^{\lambda_T} \alpha_C}\left(\frac{K}{L}\right)^{1-\alpha_C}.$$

And, according to equation (1), the elasticity of substitution is given by:

[29] If $\beta_T > 0$, the marginal product of labour will be negative when if $\frac{K}{L} > \frac{1-\alpha_T}{\beta_T}$, whereas if $\beta_T < 0$, the marginal product of capital will be negative if $\frac{K}{L} > -\frac{\alpha_T}{\beta_T}$.

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$$\sigma = 1 - \left(\frac{\alpha_C m_C}{1-\alpha_C}\right)\frac{L}{Y},$$

which varies with the level of output per worker: as output per worker increases, the elasticity of substitution approaches one. This function can be reduced to the Cobb-Douglas case in the case that $m_C = 0$ and to the linear production function if $\alpha_C = 1$. It can be noted that, to ensure a non-negative value of the marginal product of labour for all inputs values, the parameter m_C has to be lower than or equal to zero, which implies higher than or equal to unity values for the elasticity of substitution.

The Sobelow production function.[30] This production function can be written as:

$$Y = A_S K + B_S K^{\alpha_S} L^{1-\alpha_S},$$

where $0 < \alpha_S < 1$ and $A, B > 0$. In this case, the marginal rate of technical substitution is equal to:

$$MRTS = \frac{(1-\alpha_S)B_S\left(\frac{K}{L}\right)^{\alpha_S}}{A_S + \alpha_S B_S\left(\frac{K}{L}\right)^{\alpha_S - 1}}.$$

And, accordingly, the elasticity of substitution is equal to:

$$\sigma = \frac{A_S K + \alpha_S B_S\left(\frac{K}{L}\right)^{\alpha_S}}{\alpha_S A_S\left(\frac{K}{L}\right) + \alpha_S B_S\left(\frac{K}{L}\right)^{\alpha_S}}.$$

Similarly to the CMS production function, the elasticity of substitution implied by this production function cannot assume all positive values, being restricted to the higher than unity situation (since α_S is positive and lower than one).

1.5.5. Empirical studies

Contrary to CES production function, the VES function enjoyed a relatively limited empirical application since the 1970s (Table 1.5). The majority of the studies are focused on the United States and point to lower than unity values of the elasticity of substitution, either in the context of time-series (e.g. Revankar, 1971b; Bairam, 1990 for the Soviet

[30] This production function was named "Sobelow" by Sala-i-Martín (1994) as it is a combination of the functions used in the Solow (1956, $A_S = 0$) and Rebelo (1991, $B_S = 0$) models. The function itself was first considered by Kurz (1968) and later reintroduced by L. E. Jones and Manuelli (1990, 1997) in the endogenous growth literature.

economy; Del Río and Lores, 2019) or cross-section studies (e.g. Revankar, 1971a; Zellner and Ryu, 1998). Higher than unity values of the elasticity of substitution are also found for some industries within the sample (e.g. Nerlove, 1967, for 9 out of 15 industries; Roskamp, 1977, for 7 out of 35 German industries), or even for the total economy (e.g. Bairam, 1989, for the Japanese economy) or a group of countries (Karagiannis et al., 2005, for 82 countries). Some studies also find a wider variability of results when using the VES than in the CES (e.g. Nerlove, 1967; Lu and Fletcher, 1968). Few studies estimate the annual rate of efficiency change: using a Hicks-neutral specification, Lovell (1968) and Bairam (1989) point to positive annual rates (between 1 and 2%) for the United States and the Soviet economies, while Karagiannis et al. (2005) obtain the opposite conclusion (-1.5 to -1.2%) for a group of 82 countries; Revankar (1971b) estimated technological progress to be net-capital augmenting for the American economy at the average rate of 0.1%.

[TABLE 1.5]

A prevailing conclusion is that the Cobb-Douglas and/or the CES production functions can be rejected in favour of the VES, which provides a better fit for the data under analysis (e.g. Diwan, 1970; Kazi, 1980; Del Río and Lores, 2019). However, some studies do not formally test the most adequate function (e.g. Tsang and Yeung, 1976; Roskamp, 1977) or find it difficult to reach a conclusion (e.g. Zellner and Ryu, 1998).

1.5.6. Normalization

Similarly to Figure 1.2, a family of VES production functions can be understood as all VES production function that share the same baseline levels of the capital (K_0) and labour (L_0) stocks and income level (Y_0), being distinguished by different values of the elasticity of substitution at the point of normalization; moreover, since the elasticity of substitution is now variable along a given isoquant, normalization in the context of VES production functions also implies fixing that baseline level for the elasticity of substitution (σ_0, i.e., the value of the elasticity of substitution that corresponds to the baseline capital-intensity level), whereas the actual elasticity of substitution can subsequently change over time.

The normalized general VES production function obtained from (19) can be written as:

$$Y_t = Y_0 \left[\beta_{11} \left(\frac{A_t^K K_t}{A_0^K K_0} \right)^{\psi} + \beta_{12} \left(\frac{A_t^K K_t}{A_0^K K_0} \right)^{\upsilon\psi} \left(\frac{A_t^L L_t}{A_0^L L_0} \right)^{(1-\upsilon)\psi} + \beta_{22} \left(\frac{A_t^L L_t}{A_0^L L_0} \right)^{\psi} \right]^{\frac{1}{\psi}},$$

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where $\beta_{11} = \omega_{11}\gamma^{\psi}\left(\frac{A_0^L L_0}{Y_0}\right)^{\psi}\left(\frac{A_0^K K_0}{A_0^L L_0}\right)^{\psi}$, $\beta_{12} = 2\omega_{12}\gamma^{\psi}\left(\frac{A_0^L L_0}{Y_0}\right)^{\psi}\left(\frac{A_0^K K_0}{A_0^L L_0}\right)^{\upsilon\psi}$ and $\beta_{22} = \omega_{22}\gamma^{\psi}\left(\frac{A_0^L L_0}{Y_0}\right)^{\psi}$. The previous normalized parameters do not have a clear empirical correspondence, as they depend on the parameters that are going to be estimated, making it difficult to prefix them before estimation.

The first-order conditions for capital and labour establish that the real rental prices of capital and labour ($r_t = \frac{R_t}{P_t}$ and $w_t = \frac{W_t}{P_t}$, respectively) equal their marginal productivities. Therefore, the normalized first-order conditions for capital and labour are

$$r_t = \left(\frac{\frac{Y_t}{Y_0}}{\frac{K_t}{K_0}}\right)^{1-\psi} \frac{Y_0}{K_0}\left(\frac{A_t^K}{A_0^K}\right)^{\psi}\left[\beta_{11} + \upsilon\beta_{12}\left(\frac{A_t^K K_t}{A_0^K K_0}\right)^{(\upsilon-1)\psi}\left(\frac{A_t^L L_t}{A_0^L L_0}\right)^{(1-\upsilon)\psi}\right]$$

and

$$w_t = \left(\frac{\frac{Y_t}{Y_0}}{\frac{L_t}{L_0}}\right)^{1-\psi} \frac{Y_0}{L_0}\left(\frac{A_t^L}{A_0^L}\right)^{\psi}\left[(1-\upsilon)\beta_{12}\left(\frac{A_t^K K_t}{A_0^K K_0}\right)^{\upsilon\psi}\left(\frac{A_t^L L_t}{A_0^L L_0}\right)^{-\upsilon\psi} + \beta_{22}\right].$$

Evaluating the capital and labour shares at the normalization point we obtain $\pi_0 = \beta_{11} + \upsilon\beta_{12}$ and $1 - \pi_0 = (1-\upsilon)\beta_{12} + \beta_{22}$. Hence, as $\pi_0 + (1-\pi_0) = 1$, we can conclude that $\beta_{11} + \beta_{12} + \beta_{22} = 1$.

Assuming that technological change is represented by factor augmentation at constant exponential rates $\frac{A_t^K}{A_0^K} = a_t^K = e^{\zeta_K(t-t_0)}$ and $\frac{A_t^L}{A_0^L} = a_t^L = e^{\zeta_L(t-t_0)}$, the logarithmic forms of the normalized VES production function and the first-order conditions for profit maximization can be expressed as:

$$ln(Y_t) = ln(Y_0) + \frac{1}{\psi} ln\left[(\pi_0 - \upsilon\beta_{12})\left(a_t^K \frac{K_t}{K_0}\right)^{\psi} + \beta_{12}\left(a_t^K \frac{K_t}{K_0}\right)^{\upsilon\psi}\left(a_t^L \frac{L_t}{L_0}\right)^{(1-\upsilon)\psi} + [1 - \pi_0 - (1-\upsilon)\beta_{12}]\left(a_t^L \frac{L_t}{L_0}\right)^{\psi}\right],$$

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$$ln\left(\frac{Y_t}{K_t}\right) = \frac{\psi}{\psi-1} ln\left(\frac{Y_0}{K_0}\right) + \frac{\psi}{\psi-1}\zeta_K(t-t_0) + \frac{1}{1-\psi} ln(r_t)$$
$$+ \frac{1}{\psi-1} ln\left[\upsilon\beta_{12} e^{(\upsilon-1)\psi(\zeta_K-\zeta_L)(t-t_0)} \left(\frac{\frac{K_t}{K_0}}{\frac{L_t}{L_0}}\right)^{(\upsilon-1)\psi} + (\pi_0 - \upsilon\beta_{12})\right]$$

and

$$ln\left(\frac{Y_t}{L_t}\right) = \frac{\psi}{\psi-1} ln\left(\frac{Y_0}{L_0}\right) + \frac{\psi}{\psi-1}\zeta_L(t-t_0) + \frac{1}{1-\psi} ln(w_t)$$
$$+ \frac{1}{\psi-1} ln\left[(1-\upsilon)\beta_{12} e^{\upsilon\psi(\zeta_K-\zeta_L)(t-t_0)} \left(\frac{\frac{K_t}{K_0}}{\frac{L_t}{L_0}}\right)^{\upsilon\psi} + 1 - \pi_0 - (1-\upsilon)\beta_{12}\right],$$

with the elasticity of substitution being (where $k_t = \frac{A_t^K K_t}{A_t^L L_t}$):

$$\sigma(k_t) = \left[1 - \frac{(1-\upsilon)\psi(\pi_0-\upsilon\beta_{12})}{(\pi_0-\upsilon\beta_{12})+\upsilon\beta_{12}k_t^{(\upsilon-1)\psi}} - \frac{\upsilon\psi(1-\pi_0-(1-\upsilon)\beta_{12})}{(1-\pi_0-(1-\upsilon)\beta_{12})+(1-\upsilon)\beta_{12}k_t^{\upsilon\psi}}\right]^{-1},$$

which in the normalization point is

$$\sigma_0 = \left[1 - \frac{(1-\upsilon)\psi(\pi_0 - \upsilon\beta_{12})}{\pi_0} - \frac{\upsilon\psi[(1-\pi_0)-(1-\upsilon)\beta_{12}]}{1-\pi_0}\right]^{-1}.$$

Consequently, $\beta_{12} = \left(1 - \frac{\frac{\sigma_0-1}{\sigma_0}}{\psi}\right)\frac{\pi_0(1-\pi_0)}{\upsilon(1-\upsilon)}$, implying that if $\sigma_0 > 1$, then $0 < \psi < 1$, whereas if $\sigma_0 < 1$, then $\psi < 0$.

In the estimation of the previous equations, an identification problem arises, that is, unique numerical estimates of the structural parameters cannot be obtained from the estimated reduced-form coefficients. This problem stems from the fact that a particular reduced-form equation can be compatible with different hypotheses, making it difficult to conclude which one is being investigated (Gujarati and Porter, 2009). More precisely, the VES production function generates the CES specification in three parametric cases: (i) when $\beta_{11} = 0$ and $\upsilon = 1$, implying that $\beta_{12} = \pi_0$ and $\beta_{22} = 1 - \pi_0$; (ii) when $\beta_{22} = 0$ and $\upsilon = 0$, implying that $\beta_{12} = 1 - \pi_0$ and $\beta_{11} = \pi_0$; or also (iii) when $\beta_{12} = 0$, implying that $\beta_{11} = \pi_0$ and $\beta_{22} = 1 - \pi_0$. On the other hand, the Cobb-Douglas case is obtained under two possibilities: (i) when $\beta_{11} = 0$ and $\beta_{22} = 0$, implying that $\beta_{12} = 1$; or (ii) when $\psi \to 0$.

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Different parametric solutions are therefore compatible with the same set of data and consequently the estimation of the previous equations without any additional restrictions may be problematic (the solution of the problem is not identified). In addition to the rates of technological progress, the parameters to estimate are υ, β_{12} and ψ. We must set two of these three parameters to have the solution of the equation system perfectly identified. Accordingly, we can estimate the following production functions under several parameter restrictions:

(i) *CES production function* ($\beta_{12} = 0$). In this case, $\upsilon = 1$, implying that $\beta_{22} = 1 - \pi_0$ and $\beta_{11} = \pi_0$. Under these restrictions, the production function is CES and, in addition to the rates of technological progress, we can estimate ψ. The elasticity of substitution is constant, $\sigma = (1 - \psi)^{-1}$;

(ii) *VES$_L$ production function* ($\beta_{11} = 0$). In this case, $\beta_{12} = \frac{\pi_0}{\upsilon}$ and, since $\beta_{12} + \beta_{22} = 1$, $\beta_{22} = \frac{\upsilon - \pi_0}{\upsilon}$, with $\upsilon > \pi_0$, which is needed to guarantee that $\beta_{22} > 0$. Given ψ estimated in (i), i we can estimate υ. This production function can be expressed as:

$$Y_t = Y_0 \left[\frac{\pi_0}{\upsilon} \left(\frac{A_t^K}{A_0^K} \frac{K_t}{K_0} \right)^{\upsilon\psi} \left(\frac{A_t^L}{A_0^L} \frac{L_t}{L_0} \right)^{(1-\upsilon)\psi} + \left(1 - \frac{\pi_0}{\upsilon} \right) \left(\frac{A_t^L}{A_0^L} \frac{L_t}{L_0} \right)^{\psi} \right]^{\frac{1}{\psi}},$$

with the elasticity of substitution in the point of normalization being equal to:

$$\sigma_0 = \left[1 - \frac{\psi(\upsilon - \pi_0)}{1 - \pi_0} \right]^{-1};$$

(iii) *VES$_K$ production function* ($\beta_{22} = 0$). In this case, $\beta_{12} = \frac{1-\pi_0}{1-\upsilon}$ and, since $\beta_{12} + \beta_{11} = 1$, $\beta_{11} = \frac{\pi_0 - \upsilon}{1-\upsilon}$, with $\upsilon < \pi_0$, which is needed to guarantee that $\beta_{11} > 0$. Given ψ estimated in (i), we can estimate υ. This production function can be expressed as:

$$Y_t = Y_0 \left[\frac{\pi_0 - \upsilon}{1 - \upsilon} \left(\frac{A_t^K}{A_0^K} \frac{K_t}{K_0} \right)^{\psi} + \frac{1 - \pi_0}{1 - \upsilon} \left(\frac{A_t^K}{A_0^K} \frac{K_t}{K_0} \right)^{\upsilon\psi} \left(\frac{A_t^L}{A_0^L} \frac{L_t}{L_0} \right)^{(1-\upsilon)\psi} \right]^{\frac{1}{\psi}},$$

while the elasticity of substitution in the normalization point becomes equal to:

$$\sigma_0 = \left[1 - \frac{\psi(\pi_0 - \upsilon)}{\pi_0} \right]^{-1};$$

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(iv) *VES production function.* Given ψ estimated in (i) and the arithmetic average of υ estimated in (ii) and (iii), we can estimate β_{12}.

1.6. Concluding remarks

The elasticity of substitution between capital and labour was first introduced almost a century ago and has been recognized as a critical parameter in a wide range of economic topics. Different values of this parameter can lead to significantly different conclusions, therefore highlighting the importance of its correct identification. However, until recently, the joint identification of the elasticity of substitution and biased technologic change was considered to be problematic in light of the well-known "impossibility" or "non-identification" theorem.

Recent developments in this area involve the normalization of the CES production function, which was first introduced in its standard non-normalized specification more than sixty years ago, and since then has been widely used in several economic studies. Combined with the system approach, the normalization procedure allows the estimation of the elasticity of substitution and factor augmentation rates with less biased estimates than imposing *a priori* constraints on the structure of technological change.

Despited being considered more realistic than the CES production function, functional forms with variable elasticity of substitution have enjoyed a relatively limited empirical application since the 1970s. Similarly to the empirical studies that employ CES production functions, their main focus is the United States aggregate economy and point to lower than unity values of the elasticity of substitution, therefore rejecting the Cobb-Douglas specification. When factor-augmenting technological change is taken into account, technological change is found to be net labour-augmenting, mainly in the case of CES production productions. Moreover, in this essay, we have shown that the normalization procedure can also be extended to the case of different VES production functions, a framework which consequently has not been empirically tested. Consequently, one of the following essays aims at estimating the elasticities of substitution and rates of technological change not only for the United States aggregate economy, but also at a highly disaggregated industry-level and over a rather long time span, allowing us to evaluate the most plausible functional form for each industry and, in particular, whether the elasticity of substitution should be treated as constant or time varying.

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1.7. Tables and Figures

Table 1.1: Specifications of CES production functions with two production factors

Author(s)	Specification
Dickinson (1954)	$Y = [(a_1K)^{\psi} + (a_2L)^{\psi} + a_3{}^{\psi}]^{\frac{1}{\psi}}$
Solow (1956)	$Y = [a_4K^{\psi} + L^{\psi}]^{\frac{1}{\psi}}$
Pitchford (1960)	$Y = [a_4K^{\psi} + a_5L^{\psi}]^{\frac{1}{\psi}}$
Arrow et al. (1961)	$Y = \gamma[\delta K^{\psi} + (1-\delta)L^{\psi}]^{\frac{1}{\psi}}$
Brown and De Cani (1963)	$Y = c_2\left[K^{\psi} - c_1L^{\psi}\right]^{\frac{h}{\psi}}$
Ferguson (1965)	i) $Y = \gamma e^{\zeta t}[\delta K^{\psi} + (1-\delta)L^{\psi}]^{\frac{h}{\psi}}$ ii) $Y = \gamma\left[\delta K^{\psi} + (1-\delta)\left(e^{\zeta_L t}L\right)^{\psi}\right]^{\frac{h}{\psi}}$
David and van de Klundert (1965)	$Y = [(A^K K)^{\psi} + (A^L L)^{\psi}]^{\frac{1}{\psi}}$
Paroush (1966)	$Y = \gamma[\delta K^{\psi} + (1-\delta)L^{\psi}]^{\frac{h}{\psi}}$
Barro and Sala-i-Martin (1995, 2004)	$Y = \gamma[\delta(A^K K)^{\psi} + (1-\delta)[(1-A^K)L]^{\psi}]^{\frac{1}{\psi}}$
Ventura (1997)	$Y = [K^{\psi} + (A^L L)^{\psi}]^{\frac{1}{\psi}}$
Acemoglu (2002) and Antràs (2004)	$Y = [\delta(A^K K)^{\psi} + (1-\delta)(A^L L)^{\psi}]^{\frac{1}{\psi}}$
León-Ledesma et al. (2010)	$Y = \gamma\left[\delta(A^K K)^{\psi} + (1-\delta)(A^L L)^{\psi}\right]^{\frac{1}{\psi}}$

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Table 1.2: Empirical studies of the aggregate elasticity of substitution using a CES production function in the USA

Author(s)	Period	Assumption about technological change	Estimation method	Estimated aggregate elasticity of substitution	Estimated annual rate of efficiency change		
					Hicks-neutral: $\widehat{\zeta_L} = \widehat{\zeta_K}$	Labour-augmenting: $\widehat{\zeta_L}$	Capital-augmenting: $\widehat{\zeta_K}$
Arrow et al. (1961)	1909-1949	Hicks-neutral	OLS, Si	0.57	1.83		
Brown and De Cani (1963)	1890-1918 1919-1937 1938-1958 1890-1958	Factor-augmenting	OLS, Si	0.35 0.08 0.11 0.44	Net labour-augmenting ($\zeta_L - \zeta_K = 0.48$) Net labour − augmenting ($\zeta_L - \zeta_K = 0.62$) Net labour-augmenting ($\zeta_L - \zeta_K = 0.36$) Not indicated*		
Ferguson (1965)	1929-1963	i) Hicks-neutral ii) Harrod-neutral	OLS, Si	0.67	i) 1.50	ii) 1.50	
David and van de Klundert (1965)	1899-1960	Factor-augmenting	OLS, Si	0.32		2.23	1.51
Bodkin and Klein (1967)	1909-1949	Hicks-neutral	NMLE, Sy	0.47 to 0.68	1.37 to 1.49		
Wilkinson (1968)	1899-1953	Factor-augmenting	2SLS, Sy	0.50	Net labour-augmenting ($\zeta_L - \zeta_K = 0.51$)		
Sato (1970)	1909-1960	Factor-augmenting	LR, Si	0.52		1.93 to 2.06	0.73 to 1.74
Panik (1976)	1929-1966	Factor-augmenting	CO, Si	0.76	Net labour-augmenting ($\zeta_L - \zeta_K = 0.27$)		
Berndt (1976)	1929-1968	Hicks-neutral	OLS and 2SLS; Si and Sy	0.96 to 1.25	?		
Kalt (1978)	1929-1967	Factor-augmenting	CO and SUR, Si and Sy	0.76		2.2	-0.69 to 0.01

Levy (1990)	1948-1983 (quarterly data)	Hicks-neutral	RATS FLS, Si	0.42	?		
Bolt and van Els (2000)	1971-1996 (quarterly)	Hicks-neutral	ECM, Si	0.82	0.60		
Berthold et al. (2002)	1970-1995 (semi-annual)	Harrod-neutral	SUR, Sy	1.15		?	
Balistreri et al. (2003)	1947-1998	Hicks-neutral	CO and COI, Si	0.95 to 1.22	?		
Antràs (2004)	1948-1998	i) Hicks-neutral ii) Factor-augmenting	OLS, FGLS, GIV and STSP, Si and Sy	i) 0.94 to 1.02 ii) 0.64 to 0.89	i) ? ii) Net labour-augmenting ($\zeta_L - \zeta_K = 3.08$ to 3.15)	1.85 to 1.90	-1.56 to -1.34
Chirinko et al. (2011)	1972-1991	Hicks-neutral	OLS and GIV based on IDE, Si	0.40	?		
Lawrence (2015)	i) 1947-1979 ii) 1980-2010 iii) 1999-2010	Factor-augmenting	PW, Si	0.76 0.54 0.71	i) Net labour-augmenting ($\zeta_L - \zeta_K = 3.90$) ii) Net labour-augmenting ($\zeta_L - \zeta_K = 3.80$) iii) Net capital-augmenting ($\zeta_L - \zeta_K = -0.10$)		
Chen (2017)	1958-2005	Factor-augmenting	OLS and CF, Si	0.51	Net labour-augmenting ($\zeta_L - \zeta_K = 5.30$)		
Semieniuk (2017)	1960-2010	Hicks-neutral	OLS, FGLS and COI, Si	0.36 to 0.51	?		
Oberfield and Raval (2021)	1972-2007	Factor-augmenting	OLS with FE and GIV, Si	0.50 to 0.70		?	?

Notes: Some studies do not cover the whole USA economy. * Information obtained from Klump et al. (2007b). 2SLS = Two-Stage Least Squares; CF = Control Function approach; CO = Cochrane–Orcutt estimation; COI = Cointegration; ECM = Error Correction Model; FE = Fixed Effects; FGLS = Feasible Generalized Least Squares; GIV = Generalized Instrumental Variables; IDE = Interval-Difference Estimator; LR = Linear Regression; NMLE = Non-linear Maximum Likelihood Estimation; OLS = Ordinary Least Squares; PW = Prais-Winsten estimation; RATS FLS = RATS' Filtered Least Squares; STSP = Saikkonen's (1991) Two-Step Procedure; SUR = Seemingly Unrelated Regression. Si = Single Equation; Sy = System of Equations.

Table 1.3: Empirical studies of the aggregate elasticity of substitution that use a CES production function in other countries

Author(s)	Geographical scope	Period	Assumption about technological change	Estimation method	Estimated aggregate elasticity of substitution	Estimated annual rate of efficiency change		
						Hicks-neutral: $\widehat{\zeta_L} = \widehat{\zeta_K}$	Labour-augmenting: $\widehat{\zeta_L}$	Capital-augmenting: $\widehat{\zeta_K}$
Rosefielde and Lovell (1977)	USSR (Mining, Manufacturing and Power)	1950-1974	Hicks-neutral	2SLNL, Si	0.16 to 0.19	1950-1954: 0.28 to 0.49 1960-1964: 3.36 to 3.82 1970-1974: 6.44 to 7.13		
Rusek (1989)	Czechoslovakia (15 industries)	1971-1985	Hicks-neutral	NLLS, Si	0.10	2.09		
Easterly and Fischer (1995)	USSR	1950-1987	Hicks-neutral	NLLS, Si	0.37	1950-1959: 1.09 1960-1969: 1.10 1970-1979: 1.16 1980-1987: 1.09		
Andersen et al. (1999)	17 OECD countries	1966-1996	Hicks-neutral	i) OLS and ii) DOLS, Si	i) 1.12 and ii) 0.26	?		
Bolt and van Els (2000)	i) Austria ii) Belgium iii) Germany iv) Denmark v) Finland vi) France vii) Italy viii) Netherlands ix) Sweden x) UK xi) Japan	1971-1996 (quarterly)	Hicks-neutral	ECM, Si	i) 0.24 ii) 0.78 iii) 0.53 iv) 0.61 v) 0.34 vi) 0.73 vii) 0.52 viii) 0.27 ix) 0.68 x) 0.60 xi) 0.30	i) 2.30 ii) 3.20 iii) 2.70 iv) 2.20 v) 3.40 vi) 3.50 vii) 3.20 viii) 2.30 ix) 2.70 x) 1.80 xi) 2.60		
Duffy and Papageorgiou (2000)	82 countries	1960-1987	Hicks-neutral	NLLS, GMM, OLS with FE and TE, Si	1.60	-1.07		

Ripatti and Vilmunen (2001)	Finland	1975-1999 (quarterly)	Factor-augmenting	COI, Sy	0.60		1980-1989: 7.63 1990-1994: 3.55 1995-1999: -1.25	1980-1989: -1.42 1990-1994: -0.23 1995-1999: 20.39
Berthold et al. (2002)	i) Germany ii) France	1970-1995 (semi-annual)	Harrod-neutral	SUR, Sy	i) 1.45 ii) 2.06		?	
Willman (2002)	Euro area	1971-1997 (quarterly)	i) Harrod-neutral ii) Hicks-neutral iii) Solow-neutral	NLLS and NL3SLS, Sy	i) 0.40 to 0.70 ii) 0.70 to 0.90 iii) 0.90 to 1.10	ii) 1.33 to 1.41	i) 1.81 to 2.06	iii) 4.51 to 5.01
Masanjala and Papageorgiou (2004)	i) 98 countries ii) 90 countries	i) 1960-1985 ii) 1960-1995	Harrod-neutral	OLS and NLLS, Si	i) 1.19 to 1.54 ii) 1.13 to 1.37		?	
McAdam and Willman (2004)	Germany	1983-1999 (quarterly)	Hicks-neutral	NLLS, Sy	1983-1990: 0.68 to 0.70 1991-1999: 1.14 to 1.19	1.50		
Karabarbounis and Neiman (2014)	59 countries	1975-2012	Factor-augmenting	RR, Si	1.25		?	0.90
Oberfield and Raval (2014)	i) Chile ii) Colombia iii) India (manufacturing)	i) 1986-1996 ii) 1981-1991 iii) 2000-2003	Factor-augmenting	OLS with FE and GIV, Si	i) 0.84 ii) 0.84 iii) 1.11		?	?
Semieniuk (2017)	i) UK ii) France iii) Germany iv) Australia v) Canada vi) Japan vii) Italy	1970-2010	Hicks-neutral	OLS, FGLS and COI, Si	i) 0.08 to 0.33 ii) 0.16 to 0.52 iii) 0.16 to 0.33 iv) 0.26 to 0.59 v) 0.18 to 0.47 vi) 0.41 to 0.96 vii) 0.30 to 1.38	?		

Notes: Some studies do not cover the whole economy of each country. 2SLNL = Two-step linear-non-linear procedure; COI = Cointegration; DOLS = Differenced Ordinary Least Squares; ECM = Error Correction Model; FE = Fixed Effects; FGLS = Feasible Generalized Least Squares; GMM = Generalized Method of Moments; NL3LS = Non-linear Three-Stage Least Squares; NLLS = Non-linear Least Squares; OLS = Ordinary Least Squares; RR = Robust Regression; TE = Time Effects. Si = Single Equation; Sy = System of Equations.

Table 1.4: Empirical studies of the elasticity of substitution using a normalized CES production function

Author(s)	Geographical scope	Period	Assumption about technological change	Estimation method	Estimated aggregate elasticity of substitution	Estimated annual rate of efficiency change		
						Hicks-neutral: $\widehat{\zeta_L} = \widehat{\zeta_K}$	Labour-augmenting: $\widehat{\zeta_L}$	Capital-augmenting: $\widehat{\zeta_K}$
Klump et al. (2007a)	USA	1953-1998	Factor-augmenting	NLSUR, Sy	0.50 to 0.60		1.50 to 1.70	0.40
Klump et al. (2008)	Euro area	1971-2005 (quarterly)	Factor-augmenting	NLSUR, Sy	0.70		1971-1997: 1.45 1997-2005: -3.08	1971-1997: 0.56 1997-2005: 4.06
Luoma and Luoto (2010)	Finland	1902-2004	Factor-augmenting	BAE, Si	0.45		2.90	-0.70
Mallick (2012a)	90 countries	1950-2000	Hicks-neutral	NLLS, Si	0.34	?		
Young (2013)	USA	1960–2005	Factor-augmenting	OLS, GIV, DOLS and GMM, Si and Sy	0.18 (norm.) to 0.62 (non-norm.)		6.10	3.50
Herrendorf et al. (2015)	USA	1947-2010	Factor-augmenting	NFG3SLS, Sy	0.84		2.2	-1.0 (not significant)
Kreuser et al. (2015)	South Africa	1994-2012	Factor-augmenting	FGNLS, Sy	1.32		-1.96	5.0
León-Ledesma et al. (2015)	USA	1952-2009	Factor-augmenting	NLSUR, NL3SLS, FIML and GMM, Sy	0.44 to 0.72		2.0	0.2 to 0.5
Mućk (2017)	12 advanced economies	1980-2006	Factor-augmenting	FGNLS, Si and Sy	0.70		2.60 to 2.80	-3.40 to -3.10
Stewart and Li (2018)	Canada	1961–2012	Factor-augmenting	NLSUR, Sy	0.92 to 2.22		-5.30 to 3.30	-3.40 to 10.70
Jiang and León-Ledesma (2018)	USA	1950-2014	Factor-augmenting	NLSUR and NL3SLS, Sy	0.82 to 0.86		0.50 to 1.00	4.00 to 5.90

Notes: BAE = Bayesian Estimation; DOLS = Differenced Ordinary Least Squares; FGNLS = Feasible Generalized Non-linear Least Squares; FIML = Fully Information Maximum Likelihood; GIV = Generalized Instrumental Variables; GMM = Generalized Method of Moments; NFG3SLS = Non-linear Feasible Generalized Three-Stage Least Squares; NL3SLS = Non-linear Three-Stage Least Squares; NLLS = Non-linear Least Squares; NLSUR = Non-linear Seemingly Unrelated Regression; OLS = Ordinary Least Squares; Si = Single Equation; Sy = System of Equations.

Table 1.5: Empirical studies of the elasticity of substitution using a VES production function

Author(s)	Geographical scope	Sector	Period	Assumption about technological change	Estimation method	Estimated aggregate elasticity of substitution (σ) and annual rate of efficiency change (ζ)	Comparative conclusion
Nerlove (1967)	USA	Two-digit manufacturing industries	1957	-	LR**, Si	$0.60 < \sigma < 0.92$ for 4 industries; $0.98 < \sigma < 1.00$ for 2 industries; $1.06 < \sigma < 2.15$ for 9 industries	The VES production function provides a greater variability of results, which are sensitive to the equation specification and data used
Lu and Fletcher (1968)	USA	17 two-digit manufacturing industries	1957	Hicks-neutral	OLS, Si	Wider range of the VES estimates (vs CES, which are in the neighbourhood of 1)	The CES production function was rejected in 7 to 9 industries
R. Sato and Hoffman (1968)	i) USA ii) Japan	Private non-farm sectors	i) 1909-1960 ii) 1930-1960	Hicks-neutral	LR, Si	?	Overall impression that the VES functions are more realistic (vs CES)
Lovell (1968)*	USA	16 two-digit manufacturing industries	1949-1963	Hicks-neutral	LR, Si	$0.4 < \sigma < 0.8$ for 15 industries; $2.2 < \sigma < 2.5$ for 1 industry; $\zeta = 1.72$ to 1.88 (average), ranging between -2.13 and 3.78)	VES presents some advantages over the CES and Cobb-Douglas functions
Bruno (1968)*	Israel	i) manufacturing ii) total private economy	1953-1964	Asymptotically neutral	OLS and NLR, Si	?	Contrary to the CMS function, the CES and Cobb-Douglas functions either failed to give sensible results or produced internal contradictions
Diwan (1970)	USA	273-346 random manufacturing firms	1955-1957	Factor-augmenting	OLS, Si	Higher σ estimates in the case of the VES than in the CES: ($0.78 < \sigma_{VES} < 1.09$ vs $0.64 < \sigma_{CES} < 0.95$)	Estimates point to the VES rather than to the CES production function
Revankar (1971a)	USA	12 two-digit manufacturing industries	1957	-	?	$\sigma < 1$ (for 5 industries)	The Cobb-Douglas was rejected in favour of the VES production function for 5 out of 12 industries
Revankar (1971b)	USA	Private non-farm sector	1929-1953	Factor-augmenting	SUR, Sy	$\sigma = 0{,}53$ Net capital-augmenting $\zeta_K - \zeta_L = 0.1$	The Cobb-Douglas function was rejected in favour of the VES production function
Lovell (1973)*	USA	Manufacturing sector	1947-1968	Hicks-neutral	OLS, Si	$\sigma = 0.47$	The CES function outperforms the VES in tests of descriptive accuracy and predictive power

Roskamp (1977)	West Germany	Manufacturing	1950-1960	-	LR, Si	$\sigma = 0$ (for 3 industries) $0 < \sigma < 1$ (for 16 industries) $1 < \sigma < 2.83$ (for 7 industries) $\sigma < 0$ (for 9 industries)	Not tested
Kazi (1980)	India	Manufacturing industries	1973-1975	-	OLS, Si	$0.42 < \sigma < 1.51$ (two-digit industries) $0.48 < \sigma < 1.12$ (three-digit industries)	The Cobb-Douglas and CES functions are rejected in favour of the VES for most industries
Bairam (1989)*	Japan	Total economy	1878-1939	Hicks-neutral	OLS and CO, Si	$\sigma > 1$, with a positive trend $\sigma = 1.63$ (on average) $\zeta = 3.6$	The Cobb-Douglas production function is rejected in favour of the VES
Bairam (1990)*	USSR	i) Total economy ii) Manufacturing	1950-1975	Hicks-neutral	OLS and MLE, Si	i) 1950-1955: $\sigma = 0.75$; $\zeta = 1.7$ 1956-1961: $\sigma = 0.65$; $\zeta = 1.4$ 1962-1975: $\sigma = 0.44$; $\zeta = 1.1$ ii) 1950-1955: $\sigma = 0.70$; $\zeta = 5.6$ 1956-1961: $\sigma = 0.56$; $\zeta = 5.2$ 1962-1975: $\sigma = 0.23$; $\zeta = 4.8$	The Cobb-Douglas production function is rejected in favour of the VES
Zellner and Ryu (1998)	USA (25 states)	Transportation equipment	1957	-	MLE and BE, Si	States with extreme and mean values of K/L: Michigan ($\sigma < 0$), Maine ($0.61 < \sigma < 0.65$) and Kansas ($0.84 < \sigma < 0.86$)	Large standard errors make it difficult to reach a conclusion with respect to Cobb-Douglas and VES production functions
Karagiannis et al. (2005)	82 countries	Total economy	1960-1987	Hicks-neutral	NLLS, Si	$\sigma > 1$ $\zeta = -1.5$ to -1.2	The Cobb-Douglas production function is rejected in favour of the VES
Del Río and Lores (2019)	USA	Total economy and 65 industries	1947-2014	Factor-augmenting	DOLS, Si	$\sigma < 1$ $\zeta_L > 0$ and $\zeta_K < 0$	The VES production function provides a better fit than the CES
Bellocchi and Travaglini (2023)	i) France ii) Germany iii) Italy iv) Spain v) UK vi) USA	Total economy	1980-2020	Hicks-neutral	GIV, 2 SLS and ARDL, Si	$\sigma < 1$. Exceptions: Italy (perfect competition) and USA (VES, imp. competition). ζ: i) -0.55 to 0.15; ii) 0.22 to 0.36; iii) -2.05 to -0.39; iv) -0.37 to -0.20; v) -0.06 to 0.61; vi) -0.90 to -0.57	Contrary to the VES, the CES σ estimates are likely to be biased

Notes: *Studies that use an alternative VES production function to the specified in equation (19); ** Implied from Liu and Hildebrand (1965) regressions. 2SLS = Two-Stage Least Squares; ARDL = Autoregressive Distributed Lag cointegration technique; BE = Bayesian Estimation; CO = Cochrane–Orcutt estimation; DOLS = Differenced Ordinary Least Squares; GIV = Generalized Instrumental Variable procedure; LR = Linear Regression; MLE = Maximum Likelihood Estimation; NLLS = Non-linear Least Squares; NLR = Non-Linear Regression; OLS = Ordinary Least Squares; SUR = Seemingly Unrelated Regression. Si = Single Equation; Sy = System of Equations.

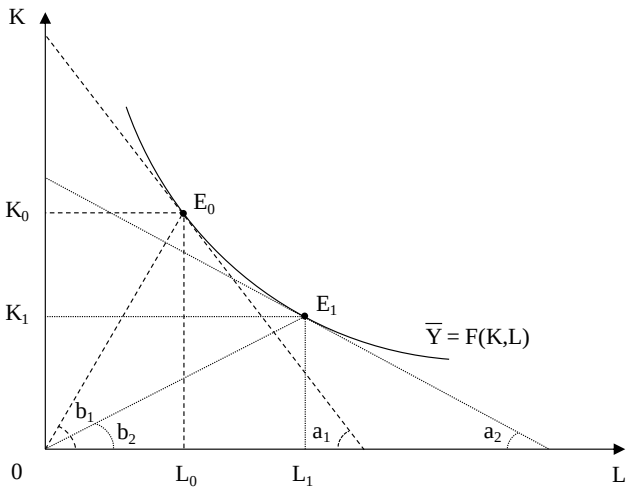

Figure 1.1: Geometrical illustration of the elasticity of substitution.

Source: de La Grandville (2009)

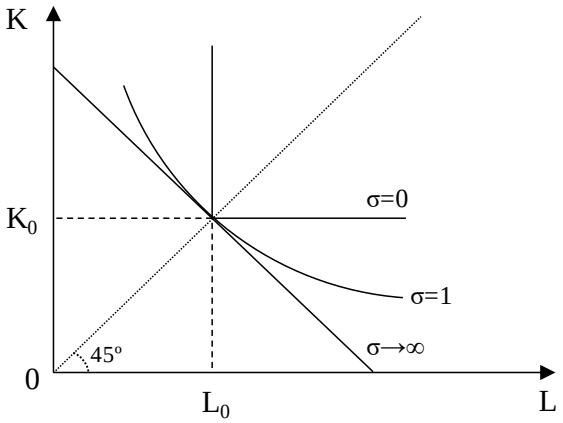

Figure 1.2: Isoquants of normalized CES production functions.

Source: Miyagiwa and Papageorgiou (2003); Klump et al. (2012)

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2. The role of the elasticity of capital-labour substitution in macroeconomics

2.1. Introduction

In the neoclassical production theory, the elasticity of capital-labour substitution is a measure of the degree of substitutability between the two factors of production.[31] The concept was introduced independently by John R. Hicks in *The Theory of Wages* (1932) and Joan Robinson in *The Economics of Imperfect Competition* (1933). As defined by Robinson (1933), the elasticity of capital-labour substitution, σ, is the ratio of the percentage change in capital-labour ratio to the percentage change in Marginal Rate of Technical Substitution (MRTS). For a canonical production function, $Y = F(K, L)$, relating output (Y) to capital (K) and labour (L), the elasticity of capital-labour substitution is given by:

$$\sigma = \frac{d\ ln\left(\frac{K}{L}\right)}{d\ ln\ MRTS}$$

where $MRTS = \frac{F_L}{F_K}$. In a perfectly competitive market, $\frac{F_L}{F_K} = \frac{W}{R}$, where W and R are the rental prices of capital and labour, respectively, and the elasticity of substitution measures the percentage change in the two inputs used in response to a percentage change in their rental prices. Hicks (1932) introduced the concept while explaining how the functional distribution of income changes with an increase in the supply of any factor and formulated it in an appendix as:

$$\sigma = \frac{F_L F_K}{Y F_{LK}}$$

Although Hicks was the first to use this concept, Robinson's definition has become more popular in the literature. However, under certain conditions (namely, two factors of production, perfect competition and constant returns to scale), the two definitions are identical (Kahn, 1933; Hicks, 1933, 1963).

Lerner (1933) explained the concept graphically, showing that as the convexity of the isoquant increases, the elasticity of substitution decreases, thus relating the elasticity of

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[31] For the sake of brevity, we will henceforth often simply use the term "elasticity of substitution".

substitution to the shape of a given isoquant. If a small change in the MRTS leads to a small (large) change in the factor input ratio, then the elasticity of substitution will take a small (large) value and the isoquants will be relatively steep (flat). The higher the elasticity of substitution, the easier it is to substitute between factors with no change in output. Furthermore, if we assume that the isoquants are convex to the origin, the MRTS decreases as the factor ratio decreases, implying that the elasticity of substitution is positive.[32] The value of the elasticity of substitution determines whether productive factors are gross complements ($\sigma < 1$) or gross substitutes ($\sigma > 1$).

A graphical representation is given in Figure 2.1. At point E_0, the MRTS is given by the slope of the line tangent to that point (which corresponds to the tangent a_1), while the capital-labour ratio corresponds to the slope of the line connecting E_0 to the origin (which corresponds to the tangent b_1). If we move to point E_1, the MRTS falls to the value of the tangent a_2, while the capital-labour ratio falls to the value of the tangent b_2. The elasticity of substitution therefore corresponds to the limit (as the change in the MRTS approaches zero) of the relative change in the tangent a (from a_1 to a_2) divided by the relative change in the tangent b (from b_1 to b_2).

[FIGURE 2.1]

Many empirical studies use different functional forms to estimate the elasticity of capital-labour substitution (see Chirinko, 2008, for a review, or Knoblach et al., 2020, for a meta-regression analysis), among which the widely used Constant Elasticity of Substitution (CES) production function, including studies at the sectoral level (e.g. Balistreri et al., 2003) or at the plant level (Oberfield and Raval, 2021). A recent development in this field involves the normalization of CES production functions, which implies expressing the production relations in an indexed number form and allows the joint identification of the elasticity of factor substitution and the parameters of technological change with less biased estimates than imposing *a priori* constraints on the structure of technological change (see Klump et al., 2012, for a review). The vast majority of them reject the Cobb-Douglas assumption for the United States (e.g. Klump et al., 2007; Chirinko, 2008; León-Ledesma et al., 2015; Chen, 2017) and several other

[32] A negative elasticity of substitution would imply that the MRTS increases as the factor ratio decreases, which is the case with concave isoquants: for a given increase in one of the factors, and for output to remain unchanged, the quantity of the other input would have to increase rather than decrease.

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geographical scopes (e.g. Klump et al., 2008; Semieniuk, 2017), suggesting a value of less than one for this parameter. An exception is the work of Berndt (1976), which has been cited in the literature as evidence in favour of the Cobb-Douglas functional form (e.g. Judd, 1987; Trostel, 1993). A few studies have obtained estimates of the elasticity of capital-labour substitution higher than unity (e.g. Berthold et al., 2002; Karabarbounis and Neiman, 2014), although this is not the prevailing empirical conclusion.

Nevertheless, despite its almost century-long history in the economic literature, during which numerous studies have emphasised the central role of the elasticity of capital-labour substitution in their models or have also estimated it for a wide range of geographical and industrial contexts, to the best of our knowledge none of them have recently attempted to survey the importance of factor substitution across a wide range of macroeconomic issues.[33] Morrissett (1953) is an exception that is now seventy years old. More recently, Mallick (2012b) reviews the importance of the elasticity of capital-labour substitution, but his focus is solely on economic growth. In this survey, our aim is to conduct a macroeconomic literature review in order to provide a deeper understanding of how different values of the elasticity of capital-labour substitution can alter the conclusions of several macroeconomic models or the impact of many economic policies, thus reinforcing the importance of its correct identification.

The remainder of this essay is organised as follows. Section 2.2 discusses the importance of the elasticity of substitution for the neoclassical theory of production and income distribution. In Section 2.3, we undertake a review of the role that the elasticity of substitution plays in determining the magnitude of the effects of market distortions on

[33] Our review focuses strictly on the substitution between labour and capital. It therefore excludes an issue that has been widely analysed in the macroeconomic literature: the complementarity between skilled labour and capital. The capital-skill complementarity hypothesis was formulated by Griliches (1969, 1970). Bergström and Panas (1992) estimated the elasticity of substitution between skilled labour and capital and found that the result of complementarity between the two was very robust to different specifications of the production function. The capital-skill complementarity hypothesis has been widely used to explain the rise in the skill premium and wage inequality (see Krusell et al., 2000). The fundamental idea is straightforward: the expansion of capital intensity increases the demand for skilled workers to a greater extent than that for unskilled workers, given that the former are more complementary to capital than the latter. This leads to an increase in the wage of skilled workers relative to that of unskilled workers.

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efficiency. Section 2.4 is dedicated to the analysis of the relevance of the elasticity of substitution in determining labour market variables. The role of the elasticity of capital-labour substitution in growth theory is discussed in Section 2.5. The elasticity of capital-labour substitution plays a key role in macroeconomic models with multiple equilibria and complex dynamics. This issue is explored in Section 2.6. Finally, a summary is provided in Section 2.7.

2.2. Production and functional income distribution

Output, *Y*, is produced using capital, *K*, and labour, *L*, according to a neoclassical production function with constant returns to scale, $Y = AF(QK, ZL)$ where A is Total Factor Productivity (TFP), Q is the efficiency of capital and Z is the efficiency of labour (hence, ZL is efficient labour and QK is efficient capital). Therefore, (i) output per unit of efficient labour, $y = Y/ZL$, is a function of the ratio of efficient capital to efficient labour, $y = Af(k)$ where $k = QK/ZL$. Under perfect competition, (ii) the real wage per unit of efficient labour efficiency, *w*, is equal to the marginal productivity of efficient labour, $w = A[f(k) - kf'(k)]$, and (iii) the rental price of efficient capital, r, is equal to the marginal productivity of efficient capital, $r = Af'(k)$.[34] Differentiation of (i)-(iii) yields:

$$\frac{dy}{y} = \frac{dA}{A} + \pi(k)\frac{dk}{k}, \tag{22}$$

$$\frac{dw}{w} = \frac{dA}{A} + \frac{\pi(k)}{\sigma(k)}\frac{dk}{k}, \tag{23}$$

and

$$\frac{dr}{r} = \frac{dA}{A} - \frac{1 - \pi(k)}{\sigma(k)}\frac{dk}{k}. \tag{24}$$

where $\pi(k) = \frac{kf\prime(k)}{f(k)}$ is the capital share and $\sigma(k) = -\frac{f\prime(k)[f(k)-kf\prime(k)]}{kf\prime\prime(k)f(k)}$ is the elasticity of substitution. In the following, we will write π and σ instead of $\pi(k)$ and $\sigma(k)$. We will only use the latter two expressions when we consider it necessary to emphasize that both the capital share and the elasticity of substitution generally depend on the ratio of efficient capital to efficient labour.

[34] It follows from (i)-(iii) that factor payments exhaust output (implying that factor shares add up to 1), $y = rk + w$.

As noted above, the concept of elasticity of substitution between capital and labour was first introduced by Hicks (1932, p. 117) to study how the functional distribution of income changes with an increase in the supply of any factor: *"an increase in the supply of any factor will increase its relative share (i.e., its proportion of the National Dividend) if its "elasticity of substitution" is greater than unity"*. Arrow et al. (1961) estimated an elasticity of substitution of less than 1 for the US economy and attributed the decline in the US capital share in the 1950s to the increase in capital intensity.

It is easy to show that for values of the elasticity of capital-labour substitution less (greater) than one, an increase in the ratio of efficient capital to efficient labour leads to a decrease (increase) in the capital share (assuming that the returns to factors are determined by their marginal productivities), whereas for values of the elasticity of substitution equal to one (the Cobb-Douglas case), an increase in the ratio of efficient capital to efficient labour has no effect on factor income shares. The ratio of efficient capital to efficient labour refers to capital intensity multiplied by the relative efficiency of the two factors. It must therefore be emphasised that changes in the factor income distribution depend on the evolution of capital intensity, K/L, and on the evolution of the relative factor efficiency, Q/Z, i.e., on the bias of technological progress.

Given that the ratio of the capital share to the labour share is $s = \frac{rk}{w}$, then $\frac{d\,s}{s} = \frac{d\,r}{r} + \frac{d\,k}{k} - \frac{d\,w}{w}$. Using (23) and (24), it follows from the previous equation that

$$\frac{d\,s}{s} = \frac{\sigma - 1}{\sigma}\frac{d\,k}{k}. \tag{25}$$

Therefore, the capital share increases (decreases) with the ratio of efficient capital to efficient labour when $\sigma > 1$ ($\sigma < 1$). Alternatively, the labour share decreases (increases) with the ratio of efficient capital to efficient labour when $\sigma > 1$ ($\sigma < 1$). The wage rate increases with the ratio of efficient capital to efficient labour ($\frac{dw}{dk} = -kf''(k) > 0$), and therefore the capital share will also increase (decrease) with the wage rate if $\sigma > 1$ ($\sigma < 1$) or, alternatively, the labour share will also decrease (increase) with the wage rate if $\sigma > 1$ ($\sigma < 1$) . When the elasticity of substitution is equal to one (the Cobb-Douglas case), changes in the ratio of efficient capital to efficient labour have no impact on the functional distribution of income.

Since $\frac{d\,k}{k} = \frac{d\,K/L}{K/L} + \frac{d\,Q}{Q} - \frac{d\,Z}{Z}$, it follows from (25) that

$$\frac{d\,s}{s} = \frac{\sigma - 1}{\sigma}\frac{d\,K/L}{K/L} + \Sigma,$$

where $\Sigma = \frac{\sigma-1}{\sigma}\left(\frac{dQ}{Q} - \frac{d\,Z}{Z}\right)$ is the technological change bias. If $\Sigma > 0$, then technological change is capital biased because, given the relative supply of both factors, it increases the capital share, but if $\Sigma < 0$, then technological change is labour biased because, given the relative supply of both factors, it increases the labour share.

To our knowledge, Blanchard (1998) was the first to report a decline in the labour share in several European countries. Some other studies have found evidence of a significant decline in the labour share in many countries (see, for example, Azmat et al., 2012, Elsby et al., 2013, Rodriguez and Jayadev, 2013, Karabarbounis and Neiman, 2014, del Río and Lores, 2019, and Bellocchi et al., 2023).

In a context where capital and labour are gross substitutes, Karabarbounis and Neiman (2014) attributed the decline in the labour share to capital deepening driven by the decrease in the relative price of investment goods, while Piketty and Zucman (2014) attributed it to the increase in the capital-output ratio.[35] The common factor underlying these conclusions is a greater than unity elasticity of substitution combined with an increase in capital intensity.

Alternatively, the explanation for the declining labour share has been linked to a decrease in the ratio of efficient capital to efficient labour, as the elasticity of substitution is less than one, which has been the predominant conclusion in empirical studies. This is the argument put forward, for example, by Lawrence (2015): despite the increase in capital intensity, the ratio of efficient capital to efficient labour (i.e. the ratio that takes into account technological bias) has fallen as a result of faster labour-augmenting technological change in the industries that account for most of the decline in the US labour share. Del Río and Lores (2019) show that the decline in the US labour share has been driven by a large decline in capital efficiency leading to a significant decline in the ratio of efficient capital to efficient labour. In the fourth essay, we find that technological change was capital biased in most OECD countries and that the bias for capital was, on average, higher in countries where the decline of the labour share has been higher. Using micro data on the cross-section of plants, Oberfield and Raval (2021) also find that the

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[35] From (22) and (25), it follows that $\frac{ds}{s} = \frac{\sigma-1}{\sigma}\frac{1}{1-\pi}\left(\frac{dy}{y} - \frac{dk}{k} + \frac{dA}{A}\right)$.

decline in the US labour share is related to the bias of technological change and that explanations based solely on variations in factor supply over time have difficulty explaining it.

It follows from equation (22) that the relationship in logs between k and y is strictly concave when $\sigma < 1$, it is strictly convex when $\sigma > 1$, and it is linear when $\sigma = 1$ (see Figure 2.2). The reason is that for values of the elasticity of capital-labour substitution lower (resp. higher) than one, the capital share is an increasing (resp. decreasing) function of the ratio of efficient capital to efficient labour, and it is constant when the elasticity of substitution is equal to one. Consequently, if $\sigma < 1$ (resp. $\sigma > 1$), capital deepening leads to a large (resp. small) increase in output per unit of efficient labour when the ratio of efficient capital to efficient labour is low, whereas capital deepening leads to a small (resp. large) increase in output per unit of efficient labour when the ratio of efficient capital to efficient labour is high.

[FIGURE 2.2]

Caselli (2005) finds that a concave shape accurately fits the cross-country relationship between output per worker and capital intensity (both variables in logs). Using a CES production function, he performs a development accounting exercise for a sample of 94 countries to assess the relative contribution of differences in technological efficiency and differences in factor endowments. Irrespective of whether the relative efficiency of capital and labour is the same as in the United States, or whether it differs because countries had access to the same 'menu' of technologies and chose the relative efficiency of capital and labour that maximised output, the conclusion is that as the elasticity of capital-labour substitution declines, the explanatory power of observed differences in endowments increases (or, in other words, the explanatory power of differences in technological efficiency declines). In the first case (all countries using the same technology), the perfect fit was obtained for an elasticity of substitution of 0.5 (in this case, almost all of the variation in per capita income across countries was due to differences in factor endowments, as opposed to about 35 to 40% in the Cobb-Douglas case and only 25% when the elasticity of substitution was 1.5), while in the second case (all countries choose their appropriate technology) the best results (in terms of the explanatory power of differences in factor endowments) were obtained when the elasticity of substitution tends to zero (the Leontief case), as opposed to an explanatory power of about 30% in the Cobb-Douglas case and 20% when the elasticity of substitution is 1.5.

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From equations (22)-(24) it follows that:

$$\frac{dr}{r} = \left(1 + \frac{1-\pi}{\pi\sigma}\right)\frac{dA}{A} - \frac{1-\pi}{\sigma\pi}\frac{dy}{y} \tag{26}$$

and

$$\frac{dw}{w} = \left(1 - \frac{1}{\sigma}\right)\frac{dA}{A} + \frac{1}{\sigma}\frac{dy}{y}. \tag{27}$$

It follows from the previous equations that the higher the output per unit of efficient labour, the lower the rental price of capital and the higher the wage. Furthermore, the higher the elasticity of capital-labour substitution, changes in output per unit of efficient labour result in smaller changes in both rental prices.

Cross-country differences in the rates of return to productive factors and the evolution of the wage-rental ratio can be better understood if the usual hypothesis of a unitary elasticity of substitution between capital and labour is abandoned. Mankiw (1995) argued that the neoclassical theory of production and distribution generates enormous differences in the return to capital in the absence of differences in TFP, even when the elasticity of substitution is high. However, if capital flows freely between countries, differences in the rate of return on capital should not be excessive. According to Mankiw (1995), this implies, on the one hand, that neoclassical theory must allow for significant differences in TFP in order to account for the observed differences in capital income across countries and, on the other hand, that greater than unity values of the elasticity of substitution appear to be more consistent with the empirical evidence on cross-country differences in the rates of return to productive factors.

Mankiw's argument can be illustrated with a few simple examples. From equation (26), assuming that there are no differences in TFP, it follows that $r = y^{-\frac{1-\pi}{\sigma\pi}}$. Therefore, assuming that the capital share is one third in both poor and rich countries, if per capita income in poor countries is 10 times lower than in rich countries and the elasticity of capital-labour substitution is one, it follows that the returns to capital in poor countries should be about 100 times larger than in rich countries. Even if the elasticity of substitution is 4, returns to capital in poor countries should be about 3 times higher than in rich countries. This difference increases markedly as the elasticity of substitution becomes smaller than 1: for example, if the elasticity of substitution is 0.5, which is an empirically plausible value, the difference reaches 10,000 times.

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Given the arguments of Caselli (2005) and Mankiw (1995), it can be concluded that the neoclassical theory of production and distribution needs to incorporate important differences in TFP across countries in order to account for the enormous differences in output per worker observed. Let's see why. With an elasticity of capital-labour substitution lower than one, the cross-country relationship between capital intensity and output per worker can be accurately adjusted by the model, but it would entail an unrealistic difference in the rates of return of productive factors in the absence of differences in TFP. However, with a sufficiently high elasticity of capital-labour substitution, differences in the rates of return could be reasonable in the absence of differences in TFP, but the model would fail to fit the observed cross-country relationship between capital intensity and output per worker.

Using equation (23), Chari et al. (2012) argue that the effects of opening markets to foreign capital inflows are consistent with either a large increase in TFP induced by liberalisation or, if the impact of liberalisation was mainly through capital deepening, with an elasticity of capital-labour substitution significantly less than one. In particular, they argue that in a sample of 25 emerging market economies, the average annual growth rate of real wages in manufacturing increased by a factor of three about three years after opening stock markets to foreign capital inflows, while no such development was observed in a control group of countries that did not liberalise. If liberalisation had no impact on TFP, the observed increases in the growth rate of wages are consistent with the model only if the elasticity of substitution is substantially less than one.

From (23) and (24), it follows that:

$$\frac{dw}{w} - \frac{dr}{r} = \frac{1}{\sigma}\frac{dk}{k}.$$

Accordingly, the lower is the elasticity of capital-labour substitution, the higher will be the impact of capital deepening on the evolution of the wage-rental ratio. This result is true in a closed economy, in a Heckscher-Ohlin model with two commodities or under factor price equalization of international trade. However, Dornbusch et al. (1980), who considered a version of the Heckscher-Ohlin model with a continuum of goods, shown that an increase in a country's capital-labour ratio will raise the wage-rental ratio when the elasticities of capital-labour substitution are equal to or less than unity, but with high elasticities of substitution, that regularity is no longer assured.

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2.3. Taxation and misallocation

Studies of the effects of changes in tax policy have a long tradition in the economic literature. For example, Hall and Jorgenson (1967) studied the effectiveness of tax policy on investment behaviour using a Cobb-Douglas production function; subsequent studies (Eisner and Nadiri, 1968; Coen, 1969; Eisner, 1969, 1970) pointed to lower than unity values of the elasticity of capital-labour substitution, implying substantially lower estimates of tax policy effects.

The value of the elasticity of substitution between capital and labour is key to assessing the distortionary effects of taxation on productive factors, since the higher is the elasticity of substitution, the higher is the price elasticity of factor demands and, consequently, the greater the distortionary effect of taxes.

If the capital demand is subject to a tax rate of τ, then the capital demand is given by $r(1+\tau) = Af'(k)$. Upon differentiation of the previous equation, the following result is obtained:

$$\frac{d\,k}{k} = \frac{\sigma}{1-\pi}\frac{d\,A}{A} - \frac{\sigma}{1-\pi}\left[\frac{d\,r}{r} + \frac{d\,(1+\tau)}{1+\tau}\right].$$

Consequently, the greater the elasticity of substitution, the more detrimental a capital tax will be to capital intensity.

Chamley (1981) evaluated the welfare costs of capital taxation in the Ramsey model and concluded that these costs depend mainly on the elasticity of substitution between capital and labour.[36] Furthermore, when the elasticity of substitution is less than two, they are almost proportional to the value of the elasticity of substitution. Lucas (1990) carried out a quantitative analysis of changes in capital taxation for the US economy and found that the effects of a reduction in the capital tax rate (either in terms of capital accumulation or welfare) increase significantly with the value of the elasticity of substitution. He found that for a unitary elasticity of substitution (compared to the case with an elasticity of capital-labour substitution of 0.60), the effect of a tax cut on capital accumulation is multiplied by 1.70 and the effect on welfare is almost doubled. Chirinko (2002) presents a review of general equilibrium models that evaluate welfare changes resulting from various tax reforms and finds that, in four of the five studies reviewed, larger welfare

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[36] Judd (1987) also evaluates the welfare costs of capital taxation in the Ramsey model.

gains are associated with higher values of the elasticity of substitution. The studies examined are Harberger (1959), Ballard et al. (1985), Engen et al. (1997), an earlier version of Roeger et al. (2002) and Altig et al. (2001); it is only in this last study that the sensitivity of welfare changes to the elasticity of capital-labour substitution is relatively small.

Consider an infinite-lived household with the following intertemporal utility function, $U = \int_0^\infty e^{-\rho t}\left(log\ c_t - \frac{h_t^{1+v}}{1+v}\right)dt$, which is common in both growth and economic fluctuation models. In this function, c represents consumption per worker, h represents hours worked per worker, ρ is the intertemporal discount rate, and $1/v > 0$ is the Frisch elasticity of labour supply. The consumption-labour condition determining the labour supply is given by the following equation:

$$\frac{c}{y}h^{1+v} = (1-\pi)(1-\tau),$$

where τ is a tax rate on labour income. For the sake of simplicity, temporary subscripts have been ignored.

Prescott (2004) attributed the low number of hours worked by Europeans relative to Americans and Japanese to the negative impact of the high tax burden on labour income in Europe relative to the United States or Japan. However, his analysis assumed a unitary elasticity of substitution between capital and labour and did not analyse how changes in the elasticity of substitution affected his results. Prescott (2004) assumes a Cobb-Douglas production function, which implies that the labour share, $1-\pi$, is constant. However, if we assume a CES production function, then we can express output per capita as follows:

$$y = A\left[ak^{\frac{\sigma-1}{\sigma}} + (1-a)h^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}},$$

where $0 < a < 1$, $A > 0$, and $\sigma > 0$ is the elasticity of capital-labour substitution. Furthermore, the labour share is

$$1-\pi = (1-a)\left[a\left(\frac{k}{h}\right)^{\frac{\sigma-1}{\sigma}} + (1-a)\right]^{-1}.$$

In this case, an increase in the tax rate on labour income results in a reduction in hours worked. If capital and labour are gross complements (i.e. $\sigma < 1$), then the labour share, $1-\pi$, also falls, which mitigates the initial fall in hours worked, but, if capital and labour

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are gross substitutes (i.e. $\sigma > 1$), then the labour share, $1 - \pi$, increases, which strengthens the initial fall in hours worked.

The impact of taxation on the mobility of productive factors has also deserved the attention of economic research, which has found that the elasticity of capital-labour substitution plays a key role. This is because the greater the elasticity of substitution, the greater the mobility of capital, which is generally assumed in the literature to be able to move between jurisdictions. McLure (1970) shows that the effect of taxing either capital or labour depends on the ease of substituting the untaxed factor for the taxed one. This substitution effect accentuates capital outflows when capital is taxed, but when labour is taxed, this factor substitution offsets some or all of the tendency for capital to leave the taxing jurisdiction. Wilson (1986) shows that the substitutability between capital and labour must be sufficiently high to ensure the existence of tax competition between states. As Wilson (1986) points out, the intuition here is that the degree of factor substitution is closely related to the responsiveness of investment decisions to property taxation, and that state governments can be expected to hold down tax rates if capital is sufficiently mobile.[37]

There is an extensive literature attributing a large part of the cross-country differences in output per capita to the misallocation of resources across firms (see the seminal work of Hsieh and Klenow, 2009). Misallocation occurs because distortions prevent some firms from exploiting highest marginal returns. As pointed out by Mallick and Maqsood (2023), the extent of distortions in factor markets and the resulting misallocation depends crucially on the specification of the production function and, in particular, on the value of the elasticity of capital-labour substitution.[38]

In equilibrium, the efficient allocation of resources across firms necessitates that each firm equalise the MRTS between capital and labour to the rental-wage ratio. Market distortions that result in the misallocation of resources across firms create a wedge that separates the MRTS from the rental-wage ratio. Assuming a CES production function, output per worker is given by $y = A\left[ak^{\frac{\sigma-1}{\sigma}} + 1 - a\right]^{\frac{\sigma}{\sigma-1}}$ (hours worked are assumed to be constant and equal to 1), and capital intensity of a firm is given by

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[37] See also Wilson (1987, 1991) and Wilson and Wildasin (2004).

[38] Restuccia and Rogerson (2017) analyse the causes and costs of misallocation.

$$\frac{r}{w}(1+\tau) = \frac{a}{1-a}k^{-\frac{1}{\sigma}},$$

where τ is the inefficiency wedge. The larger τ is, the greater the inefficiency in resource allocation. The relative capital intensity between two companies i and j, $\hat{k} = \frac{k_i}{k_j}$, is given by

$$1 + \hat{\tau} = \hat{k}^{-\frac{1}{\sigma}},$$

where $1 + \hat{\tau} = \frac{1+\tau_i}{1+\tau_j}$ is the relative inefficiency wedge.

The previous equation describes a decreasing relationship between the relative capital intensity and the relative inefficiency wedge. Figure 2.3 shows this relationship for both a low (0.5) and a high (1.5) value of the elasticity of substitution: for any relative capital intensity value, the lower the elasticity of substitution, the greater the inefficiency wedge. Moreover, the lower the elasticity of substitution, the greater the productivity gains derived from reallocating capital across firms.

[FIGURE 2.3]

Mallick and Maqsood (2023) examine the role of the elasticity of substitution in resource misallocation both analytically and empirically using cross-country firm-level survey data. They find that, relative to $\sigma = 1$, the output gains from reallocating resources are 28 per cent higher when $\sigma = 0.5$, while they are 6 per cent lower when $\sigma = 1.5$. They also find that distortions are negatively related to a country's economic development when $\sigma < 1$, but not strongly when $\sigma = 1$.

2.4. Labour

Both the value of the elasticity of capital-labour substitution and the capital share play a crucial role in the response of hours worked per worker to technological shocks. Consider an economy with L workers. The intertemporal utility function of a worker is $U = \int_0^\infty e^{-\rho t}\left(log\ c_t - \frac{h_t^{1+v}}{1+v}\right)dt$, where $1/v > 0$ is the Frisch elasticity of labour supply, ρ is the intertemporal discount rate, c is consumption per worker, and h are hours worked per worker. Output per hour worked given by $y = Zf(k)$, where $k = \frac{QK}{ZhL}$ is capital per hour worked adjusted by the relative efficiency of capital and labour, Q and Z. A worker equals the marginal rate of substitution of labour for consumption to the real wage per hour

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worked, (i) $ch^{v} = w$, where (ii) $w = Z(f(k) - kf'(k))$ is the wage rate per hour worked, which equals the marginal productivity of labour. Using that $\frac{\mathrm{d}\, k}{k} = \frac{d\, Q}{Q} - \frac{\mathrm{d}\, Z}{Z} + \frac{d\, K/L}{K/L} - \frac{d\, h}{h}$, differentiation of (i) and (ii) yields,

$$v\frac{d\, h}{h} = \frac{d\, w}{w} - \frac{d\, c}{c},$$

and

$$\frac{\mathrm{d}\, w}{w} = \frac{\sigma - \pi}{\sigma}\frac{d\, Z}{Z} + \frac{\pi}{\sigma}\frac{\mathrm{d}\, Q}{Q} + \frac{\pi}{\sigma}\left(\frac{d\, K/L}{K/L} - \frac{d\, h}{h}\right),$$

From the two previous equations, it follows that:

$$\frac{d\, h}{h} = \frac{\pi}{v\sigma + \pi}\frac{d\, Q}{Q} + \frac{\sigma - \pi}{v\sigma + \pi}\frac{d\, Z}{Z} + \frac{\pi}{v\sigma + \pi}\frac{d\, \frac{K}{L}}{\frac{K}{L}} - \frac{1}{v\sigma + \pi}\frac{d\, c}{c}.$$

Therefore, as pointed out by Cantore, León-Ledesma et al. (2014) the response of hours worked depends on the factor-augmenting nature of shocks and the elasticity of substitution both in a Real Business Cycle (RBC) and a New Keynesian (NK) sticky-price model. In particular, the relative size of the capital share and the elasticity of substitution are crucial in determining the sign and the magnitude of the response. Looking at the postwar US economy, Cantore et al. (2017) later verified that the response of hours worked to technology shocks has increased over time, which can be attributed to the observed increase in the elasticity of substitution; this parameter increased towards the end of the sample (but remained below unity), leading to changes in the sign and magnitude of the response of hours.

As pointed out by Freeman and Medoff (1982), the elasticity of substitution is an important determinant of the price elasticity of demand for labour and hence of the negative effects of wage rigidities on employment. Looking at equation (23) and assuming that A, Z, and Q are constant, it follows that

$$\frac{dl}{l} = -\frac{\sigma}{\pi}\frac{dw}{w} + \frac{d\, K/N}{K/N},$$

where N is population and $l = \frac{L}{N}$ is the employment rate. The previous equation implies that, other things being equal, the higher the elasticity of substitution, the higher the

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elasticity of derived demand and the greater the displacement of labour for a given wage increase.

In sectors where the elasticity of capital-labour substitution is high, unions are likely to be relatively weak and able to win only small wage increases or, if they win large increases, they will have to pay a high price in terms of job losses. However, in sectors where the elasticity is low, unions may be able to win a substantial wage premium at little cost in terms of employment. Diewert (1974) shows that the higher is the elasticity of substitution, the higher is the trade-off employment-wage that the trade union confronts. As argued by Freeman and Medoff (1981), the effect on employment of a higher elasticity of substitution when wages are the result of collective bargaining is a priori ambiguous, because although a wage increase is more damaging to employment, unions also have less incentive to raise wages. Johnson and Mieszkowski (1970) show that the elasticity of substitution in the unionised sector is a key parameter in determining the impact of collective bargaining on the earnings of non-unionised workers and on the efficiency of the economy.

Fernández-de-Córdoba and Moreno-García (2006) analyse the results of union games and find that a certain degree of complementarity between capital and labour is required for unemployment to exist, and that the lower the elasticity of substitution, the more labour unemployment is observed in the union equilibrium. Chang and Hung (2016) develop an infinite-horizon macroeconomic model where wages are the result of collective bargaining and workers can adjust their hours of work. They find that as the elasticity of substitution increases, the impact of unionisation on growth, income inequality, employment and hours worked becomes less pronounced, but the negative impact of deunionisation on the labour income share is reinforced.

The elasticity of capital-labour substitution also plays a key role in the relationship between the employment rate and capital deepening. Consider that the wage rate per unit of effective labour, w, is based on average labour productivity, y, and the employment rate, l. Thus,

$$w = \mu y l^{\beta},$$

where $\mu > 0$ and $\beta > 0$. Using (22) and (23), from differentiation of the previous equation, it follows that:

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$$\frac{dl}{l} = \frac{\pi}{\beta}\frac{1-\sigma}{\sigma}\frac{dk}{k}.$$

Therefore, given the capital share, if the elasticity of substitution is lower (resp. higher) than 1, capital deepening leads to an increase (resp. decrease) of the employment rate.

This idea can be observed in Rowthorn (1999)'s model of unemployment determination in the presence of trade unions and monopolistic product markets, according to which capital deepening reduces the unemployment level if the elasticity of capital-labour substitution is lower than unity, implying that measures to stimulate investment can therefore exert an important effect on unemployment reduction; this conclusion differs from the model developed by Layard et al. (1991) who considered Cobb-Douglas production functions (elasticity of substitution equal to one), implying that long-run unemployment is independent of capital accumulation. Caballero and Hammour (1998) assume a putty-clay technology with an *ex-ante* elasticity of substitution higher than one and argue that the adoption of more capital-intensive technologies in an attempt at appropriating rents of specific investments contributed to increased unemployment in Europe in the 1980s. Blanchard (1998) also analyses the causes of high European unemployment assuming an elasticity of substitution of one or more than one and argues that the persistence of high European unemployment in the 1980s may have been caused by the shift to more capital-intensive technologies. Kaas and von Thadden (2003) incorporate a wage-bargaining structure to an overlapping generations model and show that values of the elasticity of capital-labour substitution below unity add persistence, tend to preserve stability and lead to empirically plausible adjustment patterns.

The matching model developed by Mortensen and Pissarides (1994) has become the mainstream theory of equilibrium unemployment. However, Shimer (2005) has shown that the standard matching model, driven by neutral productivity shocks, is unable to match the volatility of labour market variables observed in the US data and does not generate an amplification of unemployment and vacancies. Choi and Ríos-Rull (2009) show that the dynamic macroeconomic matching model fails to reproduce the dynamic empirical response of the labour market variables to technological shocks, but they also show that a CES production function performs better than a Cobb-Douglas, especially in reproducing the response of the labour share. Schubert (2011), in a dynamic macroeconomic matching model of a small open economy, finds that the lower the elasticity of substitution, the smaller the negative effects of neutral technological shocks

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on unemployment, output and welfare. In a stochastic dynamic macroeconomic matching model with deep habits and different types of technological shocks, Di Pace and Villa (2016) show that capital-labour complementarity and unemployment benefits play a key role for explaining the amplification in unemployment and job vacancies. They find that capital-augmenting productivity account for a large part of fluctuations in labour market variables over the medium and long term when the elasticity of substitution takes empirically plausible values lower than one.[39] The reason is that an expansionary capital-augmenting productivity innovation increases labour demand by more than the demand for capital when factors are gross complements. This implies that capital-augmenting productivity innovations can have a large effect on vacancy creation and the demand for hours. Cantore, Levine and Melina (2014) analyse the effects of a government spending expansion in a dynamic stochastic model with deep habits and find that an empirically plausible elasticity of capital-labour substitution of less than one allows the model to generate jobless recoveries of the kind the US economy is experiencing after the Great Recession.

2.5. Growth

The linkage between the elasticity of substitution, being treated as a parameter of an aggregate CES production function, and growth in the neoclassical economy of Solow (1956) has been analysed by de La Grandville (1989) and Klump and de La Grandville (2000). They conclude that the degree of factor substitution is a powerful driver of economic growth because, for any given capital intensity, a higher elasticity of substitution leads to a higher growth rate and output per worker during the transition, as well as to higher steady-state levels of capital intensity and output per worker. The hypothesis that the growth rate increases with the value of the elasticity of substitution was tested by Mallick (2012a) at the cross-country level and by Yuhn (1991) for South Korea.

The equation of motion for the Solow growth model (dropping time subscripts) is[40]

$$\frac{dk}{k} = s\frac{y}{k} - (\delta + \gamma + n), \tag{28}$$

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[39] Investment-specific and matching efficiency innovations also play a significant role.

[40] The Solow model assumes that technological progress is purely augmenting the efficiency of labour.

where s, γ, δ and n are, respectively, the savings rate, the rate of technological progress, the depreciation rate and the rate of population growth. Along a balanced growth path, the capital-output ratio is constant and given by (the asterisks denote steady-state levels): $\frac{k^*}{y^*} = \frac{s}{\delta+\gamma+n}$.

Assume a CES production function, $y = A\left[ak^{\frac{\sigma-1}{\sigma}} + 1 - a\right]^{\frac{\sigma}{\sigma-1}}$, where $0 < a < 1,\ A > 0$, and $\sigma > 0$ is the elasticity of substitution. The partial derivative of the average productivity of capital (in logs) with respect to the elasticity of capital-labour substitution is:

$$\frac{\partial\, ln\left(\frac{y}{k}\right)}{\partial\sigma} = -\frac{1}{\sigma(\sigma-1)}\left[ln\left(\frac{y}{Ak}\right) + \frac{(1-a)k^{-\frac{\sigma-1}{\sigma}}\, ln(k)}{a + (1-a)k^{-\frac{\sigma-1}{\sigma}}}\right].$$

Using that $\pi = a\, A^{\frac{\sigma-1}{\sigma}}\left(\frac{y}{k}\right)^{-\frac{\sigma-1}{\sigma}}$ and $1 - \pi = (1-a)A^{\frac{\sigma-1}{\sigma}}\, y^{-\frac{\sigma-1}{\sigma}}$, after a little algebra it follows that:

$$\frac{\partial\, ln\left(\frac{y}{k}\right)}{\partial\sigma} = \frac{1}{(\sigma-1)^2}\left[(1-\pi)ln\left(\frac{1-\pi}{1-a}\right) + \pi ln\left(\frac{\pi}{a}\right)\right],$$

which, given the strict concavity of the logarithmic function is always positive. Since the logarithmic transformation is strictly increasing, then $\frac{\partial\left(\frac{y}{k}\right)}{\partial\sigma} > 0$. Therefore, (i) for any capital intensity value, the greater the elasticity of substitution, the greater output per worker. According to the motion equation (28), and given that the production function establishes a strictly increasing relationship between capital intensity and output per worker, (ii) the greater the elasticity of capital-labour substitution, the higher the growth rate of capital intensity and output per worker for any capital intensity value. Moreover, (iii) in the steady state, capital intensity and, consequently, output per worker are both an increasing function of the elasticity of capital-labour substitution (see Figure 2.4).

[FIGURE 2.4]

Extending this analysis to other growth models, Klump (2001) and Xue and Yip (2012) confirmed the positive relationship between the elasticity of substitution and the steady-state values of the capital intensity (and hence on the steady-state level of per capita income) in the Ramsey–Cass–Koopmans model as long as the steady-state value

of the capital intensity is higher than its baseline value. Miyagiwa and Papageorgiou (2003), however, extended the analysis to the Diamond's (1965) overlapping generations model and concluded that this model does not exhibit the monotonic relationship between the elasticity of substitution for capital and output per worker either in the transition or in the steady state (in particular, in a country with a sufficiently high elasticity of substitution, further increases in this parameter would reduce output per worker both in the transition and in the steady-state). Irmen and Klump (2009) reconcile the previous findings by pointing out that the positive growth effects of a high elasticity of substitution arise as long as the propensity to save out of capital income exceeds the propensity to save out of wage income. Papageorgiou and Saam (2008) analyse the impact of the elasticity of substitution on growth under different saving hypotheses and two-level CES production functions. Miyagiwa and Papageorgiou (2007) present a multi-sector growth model in which the elasticity of substitution is endogenously determined and varies positively with the level of economic development. Their results confirm the conjecture that a country with a higher elasticity of substitution experiences higher capital and output per worker both in the transition and in the steady-state.

The first papers on the speed of convergence in the single-sector neoclassical growth model were based on the Cobb-Douglas production function where the elasticity of capital-labour substitution is equal to one (e.g. R. Sato, 1963, 1964; Conlisk, 1966; K. Sato, 1966). An exception is Ramanathan (1975), who considered a CES production function in a two-sector model and found that the elasticity of capital-labour substitution played a central role in the speed of convergence of the model.

In the Solow growth model, the speed of convergence, λ, is:

$$\lambda = (\delta + \gamma + n)(1 - \pi^*) ,$$

where π^* is the steady-state capital share. If the elasticity of substitution is unitary, then the capital share is constant and independent of the elasticity of substitution and, consequently, so is the speed of convergence. However, if the elasticity of substitution differs from unity, then the capital share and hence the speed of convergence depend on the elasticity of capital-labour substitution.

Assume a normalized CES production function, $y = \left[\pi_0 k^{\frac{\sigma-1}{\sigma}} + 1 - \pi_0\right]^{\frac{\sigma}{\sigma-1}}$. The relation between the steady-state capital share and the baseline capital share (in logs) is:

$$ln\,(\pi^*) = ln\,(\pi_0) + \frac{\sigma - 1}{\sigma} ln\left(\frac{k^*/k_0}{y^*/y_0}\right).$$

The derivative of the previous expression with respect to the elasticity of capital-labour substitution is given by:

$$\frac{\partial ln\,(\pi^*)}{\partial \sigma} = \frac{1}{\sigma^2} ln\left(\frac{k^*/k_0}{y^*/y_0}\right).$$

Given that the CES production is strictly concave (i.e., k/y increases with the value of k), it follows from the definition of λ and the previous equation that:

$$\frac{\partial\,\lambda}{\partial \sigma} = -\frac{\delta + \gamma + n}{\sigma^2}\pi^* ln\left(\frac{k^*/k_0}{y^*/y_0}\right)\begin{cases} > 0 \Leftrightarrow k^* < k_0 \\ = 0 \Leftrightarrow k^* = k_0 \\ < 0 \Leftrightarrow k^* > k_0 \end{cases}$$

Therefore, if the baseline capital intensity is higher (resp. lower) than the steady-state value of the capital intensity, then a higher elasticity of substitution increases (resp. decreases) the speed of convergence. Klump and Preissler (2000) derived this result.

More recently, the earlier conclusion that we presented for the Solow model has also been verified for the Ramsey-Cass-Koopmans model (Klump, 2001; Klump and Saam, 2008; Xue and Yip, 2012; Gómez, 2018). Ventura (1997) demonstrated the negative impact of a higher elasticity of substitution on the speed of convergence in the Ramsey model, although he restricted his analysis to an elasticity of capital-labour substitution less than unity. Turnovsky (2002, 2008) simulated a one-sector neoclassical model for different values of the elasticity of substitution and found that the speed of convergence is strongly and negatively related to changes in the elasticity of substitution. Also, in the Diamond overlapping generations model, a higher elasticity of capital-labour substitution generates a higher speed of convergence when the steady-state capital intensity is not greater than its baseline value, while for the opposite scenario a higher elasticity of capital-labour substitution has an uncertain effect on the speed of convergence (Xue and Yip, 2012). Considering a one-sector endogenous growth model, Gómez (2020) showed that a higher elasticity of capital-labour substitution is associated with a faster speed of convergence to the balanced growth path; moreover, comparing the convergence of two economies to the same balanced growth path, a higher elasticity of substitution is associated with a higher speed of convergence in the case of the CES and Sobelow technologies, while no effect is found for the Revankar's (1971) VES production function.

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The value of the elasticity of capital-labour substitution is related to the possibility of either perpetual growth, as recognised in the seminal work of Solow (1956), or perpetual slowdown.[41] Using a CES production function, Solow (1956) found that with a sufficiently high elasticity of substitution his model could exhibit perpetual growth (see also Pitchford, 1960). The reason why a sufficiently high elasticity of substitution could generate perpetual growth was pointed out by Brown (1968): the higher is the elasticity of substitution, the easier is for the additional capital to be substituted for labour, leading to an almost equal increase in both factors. With constant returns to scale, the simultaneous growth of both factors counteracts the brake on growth imposed by the diminishing marginal productivity of capital.

More recently, de La Grandville (1989) derived the critical value of the elasticity of capital-labour substitution that determines the possibility of perpetual growth (even in the absence of technological progress) in the Solow growth model with a CES production function. Karagiannis et al. (2005) have also derived a similar result for the case of Revankar's (1971) production function with variable elasticity of substitution. Irmen (2011) showed that a higher elasticity of substitution boosts long-run economic growth regardless of how aggregate savings are generated, as long as they grow at the same rate as aggregate output. More recently, the positive relationship between the elasticity of capital-labour substitution and long-run growth in the one-sector convex endogenous-growth model has been confirmed by Gómez (2020), for different production function specifications (CES, VES and Sobelow cases).

Assuming that $\gamma = 0$, from the equation of motion of capital intensity, (28), it follows that the economy exhibits perpetual growth if $\lim_{k\to+\infty}\left(s\frac{y}{k}\right) > \delta + n$. Considering a CES production function, if the elasticity of substitution is less than 1, then the previous limit is 0, but, if it is greater than 1, then it is $sAa^{\frac{\sigma}{\sigma-1}}$. Therefore, if $sAa > \delta + n$ then there exists $\sigma > 1$, such that $sAa^{\frac{\sigma}{\sigma-1}} > \delta + n$ and capital per capita grows indefinitely even without technological progress (see Figure 2.5).

[FIGURE 2.5]

[41] Solow (1956) and Swan (1956) showed that the unstable equilibrium of the Harrod-Domar growth model depends critically on the assumption of zero substitution between labour and capital.

Moreover, given that the growth rate of the capital intensity is related to the growth rate of output per worker by equation (22), and that when $k \to +\infty$ the capital share approaches one when $\sigma > 1$, then income per worker also grows indefinitely. The critical value of the elasticity of capital-labour substitution that produces perpetual growth when $sAa > \delta + n$ is

$$\sigma_M = \left[1 - \frac{ln(a)}{ln\left(\frac{\delta + n}{sA}\right)}\right]^{-1} > 1.$$

Duffy and Papageorgiou (2000) estimate an elasticity of capital-labour substitution greater than one for a sample of 82 countries, but they also point out that the estimated coefficient values suggest that the conditions for perpetual growth are not present.

Mallick (2010) provides the critical value of the elasticity of substitution for perpetual slowdown in both the Solow and Ramsey models. He also shows that the equilibrium growth path defined by a singular point in the form of a saddle path exists and is locally stable if the elasticity of capital-labour substitution lies between two critical values.

Assuming that $\gamma = 0$, it follows from the equation of motion for capital intensity, (28), that the economy exhibits perpetual slowdown when $\lim_{k \to 0} \left(s\frac{y}{k}\right) < \delta + n$. Considering a CES production function, if the elasticity of capital-labour substitution is greater than 1, then the previous limit is ∞, but, if it is less than 1, then it is $sAa^{\frac{\sigma}{\sigma-1}}$. Therefore, if $sA < \delta + n$, then there exists $\sigma > 1$, such that $sAa^{\frac{\sigma}{\sigma-1}} < \delta + n$ and capital intensity decreases indefinitely (see Figure 2.6).

[FIGURE 2.6]

Moreover, given that the growth rate of the capital intensity is related to the growth rate of income per worker by equation (22), and that if $\sigma < 1$ the capital share approaches one when $k \to 0$, then output per worker also falls indefinitely. The critical value of the elasticity of capital-labour substitution that causes a perpetual slowdown when $sA < \delta + n$ is

$$\sigma_m = \left[1 - \frac{ln\, a}{ln\left(\frac{\delta + n}{sA}\right)}\right]^{-1} < 1.$$

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Economic growth entails systematic changes in the composition of production. In particular, it involves a steady decline in the share of agriculture in output and employment. This process of structural change was emphasised by Clark (1940) and Kuznets (1966).

Much work has shown that structural change can be driven both by mechanisms related to preferences and by mechanisms related to technologies. In this regard, Alvarez-Cuadrado et al. (2017) have recently pointed to sectoral differences in the elasticity of capital-labour substitution as an important driving force of structural change. Alvarez-Cuadrado et al. (2017) show that when the flexibility to combine capital and labour differs across sectors, the sector with a higher elasticity of capital-labour substitution tends to become more intensive in the input that is becoming more abundant, and consequently the growth rates of sectoral capital-labour ratios may differ. Their quantitative analysis shows that differences in sectoral factor substitutability may have been an important driver of structural change out of agriculture in the United States.

The mechanism highlighted by Alvarez-Cuadrado et al. (2017) can be illustrated with a simple example. Suppose that the economy consists of two intermediate sectors, $i = 1,2$, where e_1 and $1 - e_1$ are the employment shares in sector 1 and sector 2, respectively. The production function in each intermediate sector is CES, $y_i = A\left[ak_i^{\frac{\sigma_i - 1}{\sigma_i}} + 1 - a\right]^{\frac{\sigma_i}{\sigma_i - 1}}$. The two sectors differ in the elasticity of capital-labour substitution, $\sigma_1 \neq \sigma_2$. Both intermediate goods are one-to-one perfect substitutes in the production of the final good, $y = y_1 e_1 + y_2(1 - e_1)$, which means that the scale of production in both intermediate sectors remains undefined. Therefore, an exogenous value of e_1 between 0 and 1 is assumed. The efficient allocation of resources implies that the marginal rate of substitution between capital and labour is equal in both sectors, $(s_1 k)^{\frac{1}{\sigma_1}} = (s_2 k)^{\frac{1}{\sigma_2}}$, where $s_i = \frac{k_i}{k}$ is the capital intensity in sector i relative to the aggregate capital intensity. From the resource constraint for capital, $k = k_1 e_1 + k_2(1 - e_1)$, it follows that $s_2(1 - e_1) = 1 - s_1 e_1$. Therefore, the efficiency condition can be rewritten as

$$\left(\frac{1 - s_1 e_1}{1 - e_1}\right)^{-\frac{\sigma_1}{\sigma_2}} s_1 = k^{\frac{\sigma_1 - \sigma_2}{\sigma_2}}.$$

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Figure 2.7 shows the efficiency condition for any value of e_1. It follows that, given e_1, if $\sigma_1 > \sigma_2$ (resp. $\sigma_1 < \sigma_2$), then an increase in aggregate capital intensity leads to an increase (resp. decrease) in the capital intensity of sector 1. Thus, the more flexible sector intensifies the use of the factor that is becoming more abundant.

[FIGURE 2.7]

In the neoclassical growth model, if the elasticity of substitution is not unitary, the existence of a balanced growth path requires only labour-augmenting technological progress. An elasticity of substitution lower than one guarantees that economy converges to a balanced growth path where technological change is purely labour augmenting.

Technological progress can be directed towards increasing capital efficiency or labour efficiency. If the capital (resp. labour) efficiency grows at a faster pace than the labour (resp. capital) efficiency parameter, technological progress is net capital-augmenting (resp. labour-augmenting). Taking into account that $k = QK/ZL$, $\pi = rk/y$, and $1 - \pi = w/y$, it follows from equations (22)-(25) that:

$$\frac{d(1-\pi)}{1-\pi} - \frac{d\pi}{\pi} = \frac{\sigma - 1}{\sigma}\left[\frac{dZ}{Z} - \frac{dQ}{Q} + \frac{dL}{L} - \frac{dK}{K}\right].$$

Consequently, as pointed out by David and van de Klundert (1965), when the elasticity of capital-labour substitution departs from unity, it is possible to distinguish between capital and labour-augmenting technological change, but when the elasticity of substitution equals one (the Cobb-Douglas case), the bias of technological change cannot be empirically determined.

The first studies on the direction of technological change can be traced back to the induced innovation literature of the 1960s, which linked technological change with the evolution of relative factor prices. For example, Drandakis and Phelps (1966) proposed a model based on Kennedy's (1964) theory of induced innovations, in which the long-run constancy of factor shares is explained by purely labour-augmenting technological change and the stability of the equilibrium is only ensured by an elasticity of capital-labour substitution less than one. The theory of induced innovations stems from the seminal work of Hicks (1932), who argued that technological change would allow the substitution of the factor that had become relatively more expensive.

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More recently, Acemoglu (2003) presented a microeconomic model of technological change that allows for both labour- and capital-augmenting innovations (see also Funk,

2002). The main conclusion of the model is that, as long as the elasticity of substitution is less than one, long-run technological change will be purely labour-augmenting, but along the transition path the economy will experience net capital-augmenting technological change. Acemoglu (2003) argues that, for a higher relative share of capital, there will be an increased demand for capital-using technologies; if the elasticity of substitution is less than one, these new technologies will reduce the capital share and the economy will move towards the balanced growth path, where the income shares are stable.

Considering that $k = QK/ZL$ and $y = Y/ZL$ and assuming that A remains constant, then it follows from equation (22) that

$$\frac{d\,Y/L}{Y/L} = (1-\pi)\frac{dZ}{Z} + \pi\frac{dQ}{Q} + \pi\frac{d\,K/L}{K/L}.$$

Along a balanced growth path, the capital share remains constant and output and capital per worker grow at a constant rate equal to the rate of labour-augmenting technological change. It follows from the previous equation that along a balanced growth path $\frac{dQ}{Q} = 0$ and the economy should only invest resources in increasing labour efficiency. However, along the transition to the balanced growth path, the economy might find it profitable to invest resources in increasing the efficiency of capital if the capital share is sufficiently high. According to the previous equation, when the capital share is high (resp. low), technological innovation aimed at increasing output per worker should be directed to increasing Q (resp. Z). As shown in Section 2.2, if the elasticity of capital-labour substitution is less (resp. greater) than one, the capital share decreases (resp. increases) as the ratio of efficient capital to efficient labour increases.

Suppose that the elasticity of substitution is less than one. If $k < k^*$, then $\pi > \pi^*$ and, along a transition path, technological innovation aimed at increasing output per worker should be directed at increasing capital efficiency. According to the Solow model (see equation (28), if $k < k^*$, then capital intensity will increase, leading to a decrease in the capital share, and consequently less resources should be invested in increasing Q and more in increasing Z. This will continue until $\pi = \pi^*$, when the economy returns to the balanced growth path, where technological progress is purely labour-augmenting. The previous conclusion also holds when $k > k^*$ and hence $\pi < \pi^*$. In this case, along a transition path, more resources than in the steady-state should be invested in increasing

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labour efficiency, Z. According to the Solow model, if $k > k^*$, then capital intensity will decrease, leading to an increase in the capital share (as $\sigma < 1$) and fewer resources should be invested in increasing Z. This will continue until $\pi = \pi^*$ when the economy returns to the balanced growth path.

Consequently, when the elasticity of capital-labour substitution is lower than one, transitional dynamics will take the economy towards the balanced growth path where technological change is purely labour-augmenting, but if the elasticity of substitution is greater than one, the path is unstable.[42]

However, while the induced innovations literature of the 1960s and Acemoglu (2003) find that convergence to a steady-state with only labour-augmenting technological change depends on an elasticity of capital-labour substitution strictly smaller than unity, Irmen and Tabaković (2017) develop an infinite-horizon macroeconomic model with endogenous labour- and capital-augmenting technological change and find that the saddle-path stability of the equilibrium does not depend on the elasticity of capital-labour substitution. Irmen (2018) is sceptical about the ability of the literature on the endogenous choice of the direction of technological change to provide a satisfactory answer to why technological progress in the long run is purely labour-augmenting. He argues that the main finding of the existing literature on the endogenous choice of capital- and labour-augmenting technological change is mainly an artifact of its underlying analytical structure.

2.6. Equilibrium indeterminacy and complex dynamics

In their seminal work, Benhabib and Farmer (1994) show that large positive factor externalities can lead to equilibrium indeterminacy in the Ramsey model of optimal growth. They use a Cobb-Douglas production function in their analysis, implicitly assuming a unitary elasticity of capital-labour substitution between capital and labour. Reichlin (1986) and Benhabib and Laroque (1988) show that in overlapping generations models with endogenous labour supply equilibrium, indeterminacy and complex dynamics can arise for low values of the elasticity of substitution (always lower than the capital share of output), which seems empirically implausible. De Vilder (1996) and Pintus et al. (2000) illustrate the emergence of a Hopf bifurcation and the existence of

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[42] See Stiglitz (2014).

chaotic equilibria for low values of the elasticity of substitution.[43] In the Woodford's (1986) model, which is a canonical model for dealing with financial constraints, Grandmont et al. (1998) show that indeterminacy can occur, but for rather low elasticities of factor substitution. Becker and Foias (1987) considered agents with different discount factors in addition to borrowing constraints in the Ramsey model and found that the model can exhibit complex dynamics for a low elasticity of capital-labour substitution.[44]

The works cited in the previous paragraphs point in one direction: with constant or slightly increasing returns to scale, equilibrium indeterminacy and complex dynamics arise when the elasticity of capital-labour substitution between capital and labour is very low, which is empirically implausible. A whole series of subsequent works attempted to delimit the range of the elasticity of substitution for which complex dynamics emerge under different assumptions on preferences, technologies and market frictions.

Pintus (2004) showed that, in comparison to the configuration of constant input utilization, considering variable utilization in the Ramsey model reduces the actual possibilities of factor substitution and, consequently, the range of input substitution elasticities that are compatible with endogenous fluctuations. Nishimura and Venditti (2004a) found that a sufficiently small elasticity of substitution is a necessary condition for local indeterminacy in the Ramsey model of exogenous growth, but they assumed that the instantaneous utility function is linear. Under general formulations of both preferences and technology in the one-sector Ramsey model, Pintus (2006) showed that indeterminacy and sunspots may occur when externalities are small, provided that the elasticity of capital-labour substitution is greater than one, and that both concavity of utility for consumption is small enough and labour supply is close to indivisible. In the two-sector Ramsey model, Guo and Lansing (2009) and Photphisutthiphong and Weder (2012) restricted their analysis to a loglinear instantaneous utility function and found that, for empirically plausible values of the elasticity of substitution below one, equilibrium indeterminacy requires a higher degree of increasing returns to scale than when the elasticity of substitution is unity. Wong and Yip (2010) assumed that the elasticity of substitution between capital and labour depends on aggregate capital intensity and

[43] The overlapping generations model is prone to complex dynamics (see Grandmont, 1985).

[44] Sorger (1994) showed that under the standard assumptions of strictly concave and time-additive utility functions and a strictly concave production function, the Ramsey model with borrowing constraints can exhibit equilibrium indeterminacy and periodic equilibria.

showed that multiple equilibria can then occur for empirically plausible values of the elasticity of substitution (less than one or slightly greater than one). Magris (2012) showed that multiple equilibria can arise in a two-sector growth model with aggregate and sector-specific externalities for empirically plausible elasticities of substitution (including the unitary one). In a two-sector model, Nishimura and Venditti (2004b) showed that when the elasticity of substitution is less (resp. greater) than one, local indeterminacy is more likely to occur with low (resp. high) capital depreciation. Garnier et al. (2007) discussed the role of the elasticity of capital-labour substitution on the local determinacy properties of the steady state in a two-sector economy with CES technologies and sector-specific externalities. Lloyd-Braga et al. (2006) considered a Ramsey one-sector model with non-separable homothetic preferences, endogenous labour and productive external effects arising from average capital and labour. They showed that sunspot fluctuations are consistent with empirically plausible values of the elasticity of capital-labour substitution (including the Cobb-Douglas specification).

In an overlapping generations model with endogenous labour supply, Cazzavillan (2001) considered increasing returns due to externalities and showed that multiple stationary equilibria as well as equilibrium indeterminacy arise when the size of externalities is arbitrarily small and the elasticity of capital-labour substitution is large. Dos Santos Ferreira and Lloyd-Braga (2005) showed that with Cournotian competition, free entry and exit of firms and the consequent variability of markups, existence of endogenous fluctuations becomes compatible with any level of the elasticity of capital-labour substitution, even when market power is arbitrarily small.

In the Woodford's (1986) model with financial constraints, Cazzavillan et al. (1998) and Barinci and Chéron (2001) include increasing returns to scale and show that endogenous fluctuations occur even when the elasticity of factor substitution is arbitrarily large. Barinci (2001) considers two classes of infinitely lived agents with heterogeneous general preferences and shows that Hopf cycles emerge for a wide range of elasticities of substitution, including the unitary one. Lloyd-Braga and Modesto (2007) include labour unions and unemployment into Woodford's (1986) model and find that for an elasticity of capital-labour substitution higher than one, the occurrence of equilibrium indeterminacy with small externalities becomes more likely when union power is stronger. However, if the elasticity of capital-labour substitution is lower than one, as union power increases, indeterminacy requires higher externalities. Dufourt et al. (2008)

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incorporate imperfectly insured unemployment into Woodford's (1986) model and show that equilibrium indeterminacy always prevails in the case of a unitary elasticity of capital-labour substitution and that Flip and Hopf bifurcations occur for lower than one empirically plausible elasticities of capital-labour substitution.

Another source of equilibrium indeterminacy in growth models is the balanced-budget rule. In a Ramsey model of optimal growth where the government finances its spending with distortionary taxes, Schmitt-Grohé and Uribe (1997) show that equilibrium indeterminacy can arise under a balanced-budget rule for a unity elasticity of capital-labour substitution and empirically plausible values of the other parameters. However, Ghilardi and Rossi (2014) show that the probability of equilibrium indeterminacy is greatly reduced for less than one empirically plausible values of the elasticity of capital-labour substitution, when the other model parameters are set to empirically plausible values. Xue and Yip (2013) identify two channels through which the elasticity of substitution affects indeterminacy: a direct efficiency effect and an indirect distributional effect. They show that when the economy has a lower capital intensity than in the steady state, a larger elasticity of substitution increases equilibrium determinacy. They warn of the importance of using a normalized CES production function in the analysis. In a model with fiscal constraints à la Woodford (1986), Gokan (2006) examines the effect of a given increase in government spending financed by labour taxation and shows that multiple equilibria and Flip and Hopf bifurcations can emerge for both high and low values of the elasticity of capital-labour substitution. In the same framework, Xue and Yip (2014) show that this indeterminacy can only occur under capital income taxation when the elasticity of substitution is very low, while indeterminacy under labour income taxation does not depend on the elasticity of capital-labour substitution. Using a type of preferences that includes different degrees of income effects, Nourry et al. (2013) find for both higher and lower than one values of the elasticity of capital-labour substitution that nonlinear consumption taxation can generate equilibrium indeterminacy for high values of the elasticity of intertemporal substitution in consumption if the tax rate is countercyclical with respect to consumption. Abad et al. (2017) assume non-separable preferences and that government spending is financed by a tax on labour income. They find that the lower bound on the tax on labour income for which equilibrium indeterminacy can arise decreases with the elasticity of capital-labour substitution.

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2.7. Summary

The concept of the elasticity of capital-labour substitution between capital and labour was first introduced almost a century ago to study the functional distribution of income. Since then, it has been recognised as a critical parameter in a wide range of economic issues. Different values of this parameter can lead to significantly different conclusions, thus highlighting the importance of its correct identification.

The elasticity of capital-labour substitution is a key parameter for the functional distribution of income. The capital share increases with capital intensity when the elasticity of substitution is greater than one, whereas an opposite conclusion is reached when the elasticity of substitution is lower than one. Although there is some debate in the literature, the majority of empirical studies estimate the elasticity of substitution to be less than one. This makes it challenging to attribute the recent decline in the labour share observed in many countries to an increase in capital intensity. The higher the elasticity of capital-labour substitution, the lower the impact of productivity on factor returns and the lower the impact of capital deepening on the wage-rental ratio. In the case of an elasticity of substitution below one, the relationship between output per capita and capital intensity is concave. Conversely, if the elasticity of substitution is higher than one, the relationship is convex. Empirical evidence from cross-country studies indicates that a concave relationship fits the data better. However, if the elasticity of substitution is lower than one, cross-country differences in productivity lead to significant and unrealistic differences in factor returns. This suggests that differences in total factor productivity (TFP) may be a significant source of cross-country differences in income per capita.

The welfare costs of taxation increase with the value of the elasticity of capital-labour substitution because the price elasticity of the demand functions for the productive factors increases with the value of the elasticity of substitution. Furthermore, a lower elasticity of substitution enhances the productivity gains from better resource allocation and increases the cross-country correlation between output per capita and the distortions that cause resource misallocation.

The elasticity of substitution also plays an important role in the labour market. Firstly, although not immediately apparent, the effect of unionisation on wages and employment depends on the elasticity of capital-labour substitution. Secondly, the impact of technological shocks on hours worked, unemployment and vacancies depends crucially on the nature of the productivity shock and the magnitude of the elasticity of substitution.

The incorporation of a substantial capital-labour complementarity within a dynamic stochastic matching model enables the model to better reflect the cyclical properties of labour market variables in the United States. Furthermore, the lower the elasticity of substitution, the greater the impact of capital deepening on employment. Some authors have proposed that the prolonged period of elevated unemployment in Europe during the 1980s was a consequence of the implementation of capital-intensive technologies in a context where capital and labour were gross substitutes.

Capital-labour substitution is also crucial for some aspects of economic growth. Structural change can be driven by differences in the elasticity of capital-labour substitution. Sectors with a higher elasticity of capital-labour substitution tend to intensify the use of the productive factor that is becoming more abundant, which can lead to sectoral differences in the growth rates of capital intensity. In the context of the neoclassical growth model, a higher elasticity of capital-labour substitution increases the speed of convergence if the economy is above its steady state, but reduces it otherwise. Furthermore, for any given capital intensity, a higher elasticity of capital-labour substitution boosts the growth of capital and output per worker during the transition to the balanced growth path. In the long run, both capital intensity and output per worker are increasing functions of the elasticity of substitution. Even in the absence of technological progress, it is possible to achieve perpetual growth if the elasticity of capital-labour substitution is sufficiently high. However, if the elasticity of capital-labour substitution is sufficiently low, it is also possible to experience a perpetual slowdown. In the neoclassical growth model, if the elasticity of substitution is not unitary, the existence of a balanced growth path necessitates solely labour-augmenting technological progress. An elasticity of substitution inferior to one ensures that the economy converges to a balanced growth path where technological change is exclusively labour-augmenting. While the results are contingent upon assumptions regarding preferences, technology, structure, and market distortions, the elasticity of capital-labour substitution represents a pivotal parameter for the emergence of multiple equilibria and complex dynamics in macroeconomic models.

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2.8. Figures

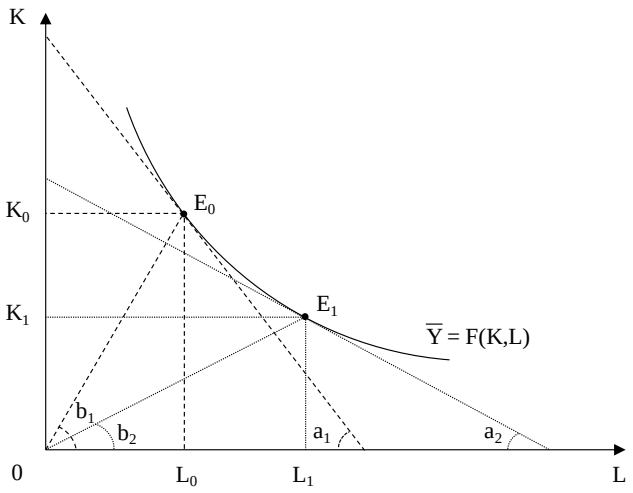

Figure 2.1: Geometrical illustration of the elasticity of substitution

Source: de La Grandville (2009)

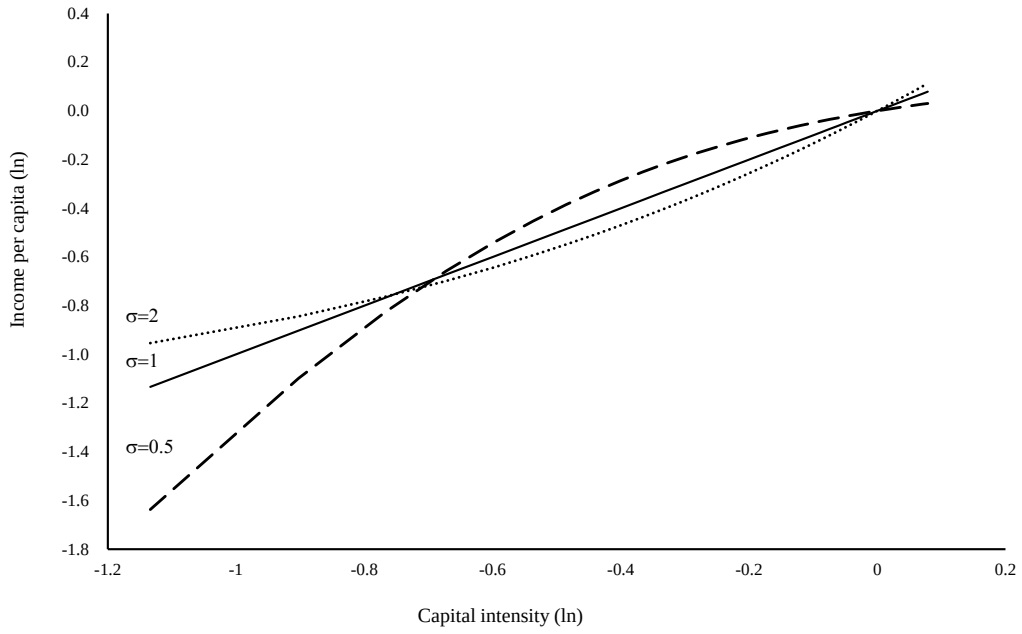

Figure 2.2: Capital intensity, income per capita and elasticity of substitution

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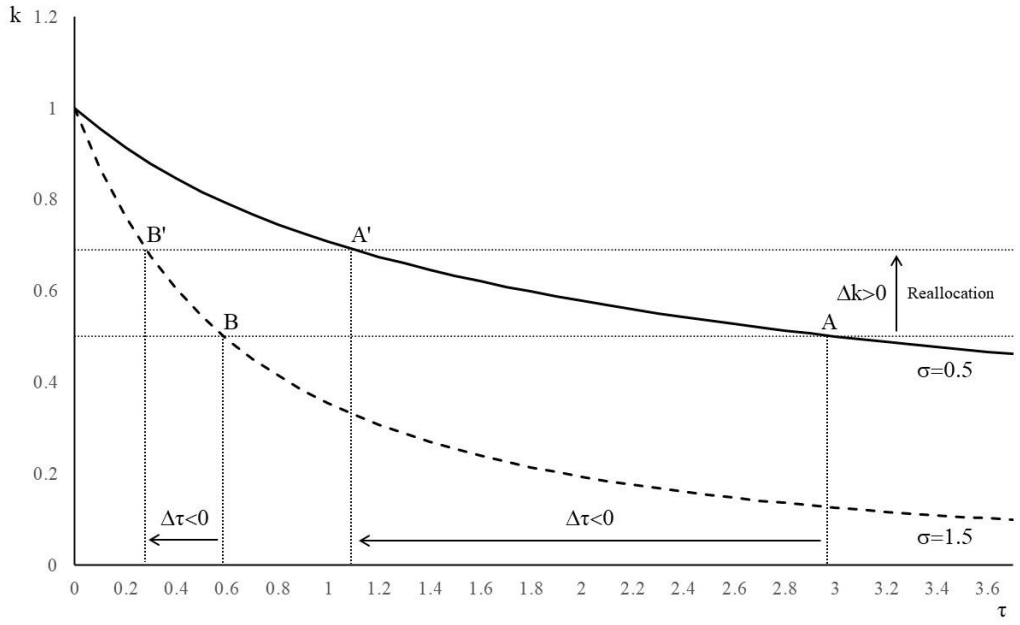

Figure 2.3: Resource misallocation

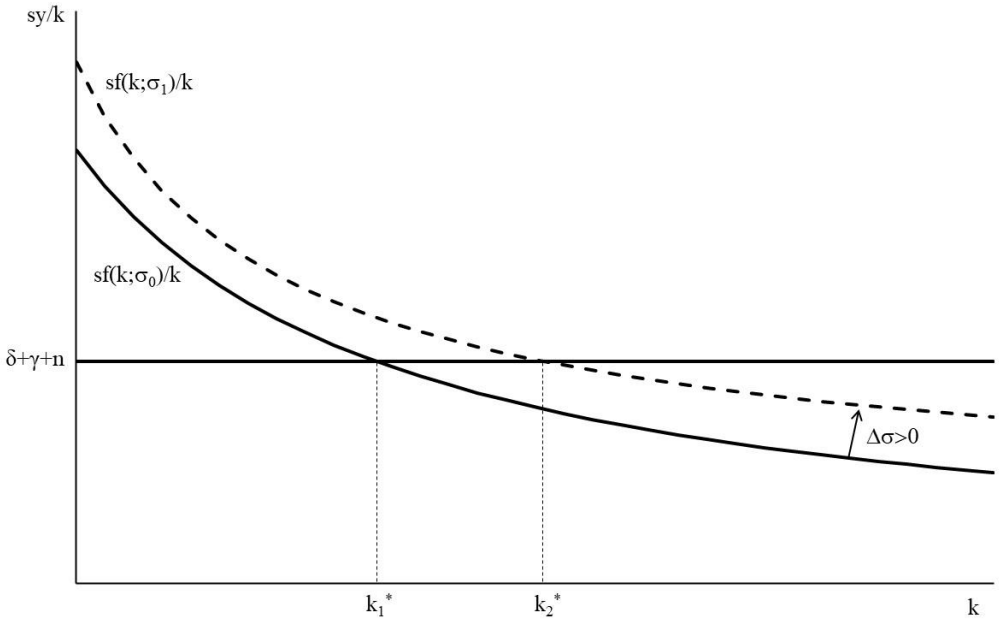

Figure 2.4: Capital deepening and the elasticity of substitution (Solow model)

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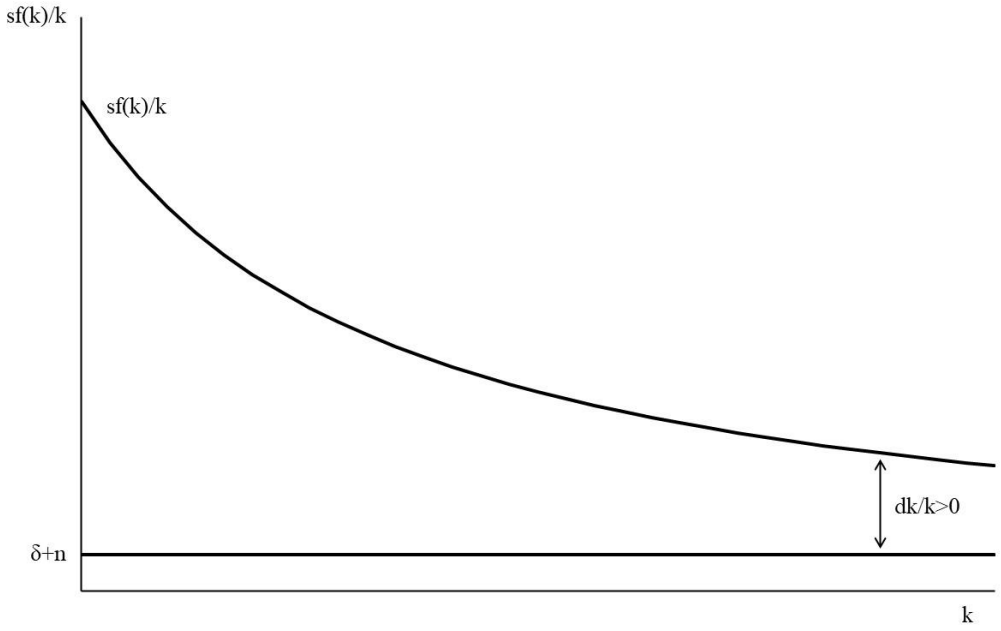

Figure 2.5: Perpetual growth in the Solow model

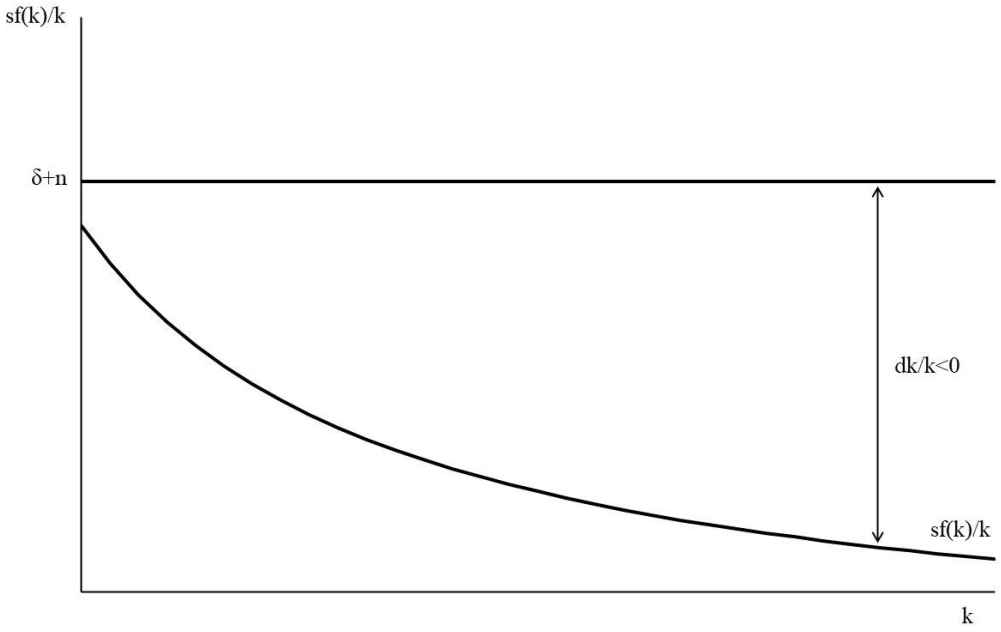

Figure 2.6: Perpetual slowdown in the Solow model

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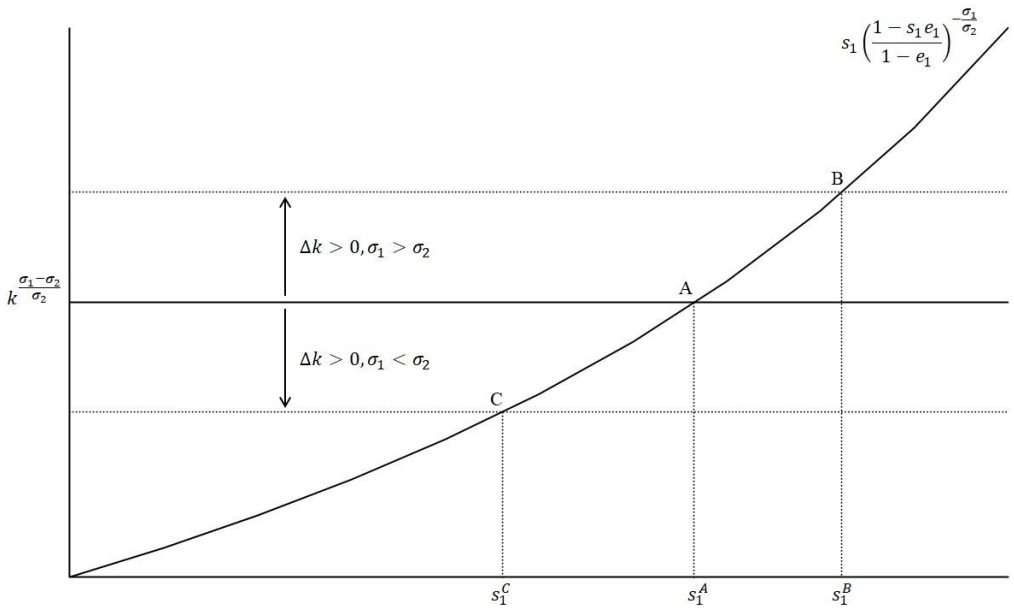

Figure 2.7: Efficiency condition for any value of e_1

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3. Elasticities of substitution and factor augmentation rates: the case of the USA, 1947-2014

3.1. Introduction

The elasticity of substitution between capital and labour plays a pivotal role in economic literature, covering a wide range of topics, including production and functional income distribution (Hicks, 1932; Mankiw, 1995; Caselli, 2005), taxation and resource misallocation (Lucas, 1990; Chirinko, 2002; Mallick and Maqsood, 2023), labour (Freeman and Medoff, 1982; Rowthorn, 1999; Cantore et al., 2017), growth theory (Solow, 1956; Klump and Preissler, 2000; Klump, 2001) or equilibrium indeterminacy and complex dynamics (Nishimura and Venditti, 2004a, 2004b; Xue and Yip, 2013).

The CES production function has been widely used in empirical studies to estimate both the elasticity of substitution and factor augmentation rates (see, in this respect, sections 1.4.5 and 1.4.6.4). However, as its name indicates, this function constrains the elasticity of substitution to a fixed value, albeit not necessarily unity (as the Cobb-Douglas function). On the other hand, the VES production function, which admits the time-varying hypothesis of this parameter, enjoyed a relatively limited empirical application, despite having already been used in some studies, particularly in the 1970s (section 1.5.5). As pointed out by Kazi (1980, p. 169), a VES production function can reduce the upward bias resulting from the estimation of a CES because the latter *"includes part of the variation due to K/L in the average product"*.

Recently, many studies have focused on the system approach which, combined with normalization, facilitates the joint identification of the elasticity of substitution and the direction of technological change, allowing to circumvent the well-known "impossibility" or "non-identification" theorem (Diamond and McFadden, 1965; Diamond et al., 1978). Moreover, even studies that resort to the CES production function are predominantly focused on the aggregate economy, overlooking a more disaggregated level of analysis. Therefore, in this essay, we aim to estimate the elasticities of substitution and the rates of technological change for the United States (US) between 1947 and 2014, both at the aggregate and at the industry-level. The empirical framework relies on CES and VES production functions and the associated first-order conditions. Estimation is performed either by a single-equation approach or by a normalized system specification. In line with the recent developments in the area, a novel contribution of this study, which to the best of our knowledge has not been performed in the literature, is the estimation of the VES production function parameters using the normalized

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system approach. One of the particular cases that can be obtained from the VES production function estimation is precisely the CES production function, and therefore its estimation will allow us to discuss the time-invariant hypothesis of the substitution elasticity parameter that has been widely assumed by economic studies.

This essay is structured as follows. Section 3.2 describes the CES and VES production functions and the associated first-order conditions that represent our empirical model, while Section 3.3 details the econometric techniques that will be used in the estimations. Section 3.4 characterizes the database and analyses the main properties of the data. The estimation results are then presented and discussed in section 3.5, while the last section of the essay provides a synthesis of the main results found and of the corresponding implications for economic studies.

3.2. Empirical model

We assume that each industry and the aggregate economy's production technology can be described either by a CES production function

$$Y_t = F(A_t^K K_t, A_t^L L_t) = \gamma\left[\delta(A_t^K K_t)^{\psi} + (1-\delta)(A_t^L L_t)^{\psi}\right]^{\frac{1}{\psi}},$$

where the elasticity of substitution is constant and equal to $(1-\psi)^{-1}$, or by a VES production function

$$Y_t = \gamma\left[\omega_{11}(A_t^K K_t)^{\psi} + 2\omega_{12}\left[(A_t^K K_t)^{\upsilon}(A_t^L L_t)^{(1-\upsilon)}\right]^{\psi} + \omega_{22}(A_t^L L_t)^{\psi}\right]^{\frac{1}{\psi}}, \qquad (29)$$

where the elasticity of substitution changes with the effective capital-labour ratio $k_t = A_t^K K_t / A_t^L L_t$:

$$\sigma(k_t) = \left[1 - \left(\frac{\omega_{11}(1-\upsilon)\psi}{\omega_{11} + 2\omega_{12}\upsilon {k_t}^{-(1-\upsilon)\psi}} + \frac{\omega_{22}\upsilon\psi}{\omega_{22} + 2\omega_{12}(1-\upsilon){k_t}^{\upsilon\psi}}\right)\right]^{-1}.$$

Technological change is represented by factor augmentation at constant exponential rates $A_t^K = A_0^K e^{\zeta_K t}$ and $A_t^L = A_0^L e^{\zeta_K t}$. For simplicity, the components of technological progress are scaled so that $A_0^K = A_0^L = 1$.

Considering the CES production function, the log-linear first-order conditions for profit maximization can be expressed as (henceforth named CES_1, CES_2 and CES_3):

$$CES_1: yk_t = \xi_0^K + \sigma rp_t + (1-\sigma)\zeta_K t,$$

$$CES_2: yl_t = \xi_0^L + \sigma wp_t + (1-\sigma)\zeta_L t,$$

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$$\text{CES}_3\text{: } kl_t = (\xi_0^L - \xi_0^K) + \sigma wr_t + (1-\sigma)(\zeta_L - \zeta_K)t,$$

where $\xi_0^K = \sigma\, ln\left(\frac{1}{\delta}\right) + (1-\sigma)[ln(A_0^K) + ln(\gamma)]$ $\xi_0^L = \sigma\, ln\left(\frac{1}{1-\delta}\right) + (1-\sigma)[ln(A_0^L) + ln(\gamma)]$, whereas *yk*, *yl*, *kl*, *rp*, *wp* and *wr* represent, respectively, the natural logarithms of *Y/K*, *Y/L*, *K/L*, *R/P*, *W/P* and *W/R*. The first equation (CES_1) represents the log-linear first-order condition with respect to capital, the second (CES_2) represents the log-linear first-order condition with respect to labour, while the third (CES_3) corresponds to the difference between the first and the second equations. Individually, each of the equations allows the estimation of the elasticity of substitution, but only of the respective technological progress term (in the case of CES_1 and CES_2) or the overall bias in technological change (in the case of CES_3).

In order to apply the standard log-linear estimation methods, the VES production function (29) will be considered in the particular parametric cases where $\omega_{11} = 0$ (Del Río and Lores, 2019) and $\omega_{22} = 0$ (Liu and Hildebrand, 1965; Nerlove, 1967; Lu and Fletcher, 1968). The former can be written as (subsequently VES_L):

$$\text{VES}_\text{L}\text{: } Y_t = \gamma\left[2\omega_{12}\left[(A_t^K K_t)^{\upsilon}(A_t^L L_t)^{(1-\upsilon)}\right]^{\psi} + \omega_{22}(A_t^L L_t)^{\psi}\right]^{\frac{1}{\psi}}.$$

In this case, the CES production function would be obtained if $\upsilon = 1$ and the linear first-order condition for profit maximization is equal to (henceforth VES_1):

$$\text{VES}_1\text{: } yk_t = \xi_0^{VK} + \xi_1^{VK} rp_t + \xi_2^{VK} t + \xi_3^{VK} kl_t,$$

where $\xi_0^{VK} = -\frac{1}{1-\psi}[\psi ln(\gamma) + ln(2\omega_{12}\upsilon)]$, $\xi_1^{VK} = \frac{1}{1-\psi}$, $\xi_2^{VK} = -\frac{\psi}{1-\psi}[\upsilon\zeta_K + (1-\upsilon)\zeta_L]$ and $\xi_3^{VK} = \frac{(1-\upsilon)\psi}{1-\psi}$.

On the other hand, the latter can be expressed as (subsequently VES_K):

$$\text{VES}_\text{K}\text{: } Y_t = \gamma\left[\omega_{11}(A_t^K K_t)^{\psi} + 2\omega_{12}\left[(A_t^K K_t)^{\upsilon}(A_t^L L_t)^{(1-\upsilon)}\right]^{\psi}\right]^{\frac{1}{\psi}}.$$

The CES production function would be obtained if $\upsilon = 0$ whereas the linear first-order condition is (henceforth VES_2):

$$\text{VES}_2\text{: } yl_t = \xi_0^{VL} + \xi_1^{VL} wp_t + \xi_2^{VL} t + \xi_3^{VL} kl_t,$$

where $\xi_0^{VL} = -\frac{1}{1-\psi}\left[\psi ln(\gamma) + ln[2\omega_{12}(1-\upsilon)]\right]$, $\xi_1^{VL} = \frac{1}{1-\psi}$, $\xi_2^{VL} = -\frac{\psi}{1-\psi}[\upsilon\zeta_K + (1-\upsilon)\zeta_L]$ and $\xi_3^{VL} = -\frac{\upsilon\psi}{1-\psi}$.

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In addition to the separate estimation of the previous first-order conditions, we also consider the normalized system approach. The importance of normalization of CES production functions stems from the seminal work of de La Grandville (1989), further elaborated by Klump and de La Grandville (2000), Klump and Preissler (2000) and de La Grandville and Solow (2006). According to Klump et al. (2012, p. 770), *"normalization essentially implies representing production relations in consistent indexed number form"*. The normalized CES production function is equal to:

$$Y_t = Y_0 \left[\pi_0 \left(a_t^K \frac{K_t}{K_0} \right)^{\psi} + (1 - \pi_0) \left(a_t^L \frac{L_t}{L_0} \right)^{\psi} \right]^{\frac{1}{\psi}},$$

where $\pi_0 = \frac{r_0 K_0}{Y_0}$, $a_t^K = \frac{A_t^K}{A_0^K} = e^{\zeta_K (t - t_0)}$ and $a_t^L = \frac{A_t^L}{A_0^L} = e^{\zeta_L (t - t_0)}$.

The definition of the normalization point is especially important for the quality of the estimation results. Following Klump et al. (2012), we use sample averages (geometric for growing variables, such as capital and labour, and arithmetic for variables that are approximately stationary, such as the capital income share) to set the normalization point. However, as the CES production function is non-linear, the sample average of production may not coincide with the level of production implied by the production function using sample averages of each variable. Consequently, Klump et al. (2007) introduced an additional estimated parameter ξ, called the normalization constant and whose expected value is around one.[45] The normalization point is therefore defined as $Y_0 = \xi \bar{Y}$, $K_0 = \bar{K}$, $L_0 = \bar{L}$, $\pi_0 = \bar{\pi}$ and $t_0 = \bar{t}$, where the bar denotes the sample average (geometric in the case of the first three variables, and arithmetic in the case of the last two). As suggested by León-Ledesma et al. (2010) and Klump et al. (2012), a natural choice for the normalization constant is one. If the estimated values of the distribution parameter and the normalization constant deviate significantly from their initial values, the estimation results should be questioned. In this sense, normalization is also useful as a means for *a posteriori* validation of the estimated parameters.

Accordingly, the natural logarithm of the normalized CES production function together with the normalized first-order conditions can be expressed as:

$$yp_t - \overline{yp} = ln\,(\xi) + \frac{1}{\psi} ln \left[\bar{\pi} \left(e^{\zeta_K (t - \bar{t})} \frac{K_t}{\bar{K}} \right)^{\psi} + (1 - \bar{\pi}) \left(e^{\zeta_L (t - \bar{t})} \frac{L_t}{\bar{L}} \right)^{\psi} \right],$$

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[45] Note that ξ would be exactly equal to 1 in the case of the log-linear Cobb-Douglas production function.

$$yk_t - \overline{yk} = -\sigma\left[ln(\bar{\pi}) + \overline{yk}\right] + (1-\sigma)\, ln(\xi) + \sigma\, rp_t + (1-\sigma)\zeta_K(t-\bar{t}),$$

$$yl_t - \bar{y}l = -\sigma\left[ln(1-\bar{\pi}) + \bar{y}l\right] + (1-\sigma)\, ln(\xi) + \sigma wp_t + (1-\sigma)\zeta_L(t-\bar{t}),$$

where *yp* represents the natural logarithm of *Y*.

A similar procedure will also be applied to each of the particular parametric cases of the VES production function. In order to overcome the identification problem discussed in section 1.5.6, we will assume the value of ψ obtained with the normalized CES production function estimation and, from parameter υ estimates, we will then analyse whether the elasticity of substitution changes over time or whether it is time-invariant, either corresponding to the CES specification (i.e., when υ is equal to 1 or to 0, respectively in the cases of the VES_L and VES_K equations), or to the Cobb-Douglas case (i.e., when υ is equal to the capital share in the point of normalization). Therefore, in the first case, $\omega_{11} = 0$ (VES_L production function), we will estimate the system comprised by the natural logarithm of the normalized production function, together with the normalized first-order conditions:

$$yp_t - \overline{yp} = ln(\xi) + \zeta_L(t-\bar{t}) + \frac{1}{\psi} ln\left[\left(\frac{\bar{\pi}}{\upsilon}\right) e^{\upsilon\psi(\zeta_K-\zeta_L)(t-\bar{t})} \left(\frac{K_t}{\bar{K}}\right)^{\upsilon\psi} \left(\frac{L_t}{\bar{L}}\right)^{(1-\upsilon)\psi} + \left(1-\frac{\bar{\pi}}{\upsilon}\right)\left(\frac{L_t}{\bar{L}}\right)^{\psi}\right],$$

$$yk_t - \overline{yk} = \frac{1}{\psi-1}\left[\overline{yk} + \psi ln(\xi) + ln(\bar{\pi})\right] + \frac{\psi}{\psi-1}[\upsilon\zeta_K + (1-\upsilon)\zeta_L](t-\bar{t}) + \frac{1}{1-\psi} ln(rp_t) + \frac{\psi}{\psi-1}(\upsilon-1)\left(kl_t - \bar{k}l\right),$$

$$yl_t - \bar{y}l = \frac{1}{\psi-1}\left[\bar{y}l + \psi ln(\xi)\right] + \frac{\psi}{\psi-1}\zeta_L(t-\bar{t}) + \frac{1}{1-\psi} ln(wp_t) + \frac{1}{\psi-1} ln\left[\bar{\pi}\left(\frac{1-\upsilon}{\upsilon}\right) e^{\upsilon\psi(\zeta_K-\zeta_L)(t-\bar{t})} \left(\frac{\frac{K_t}{\bar{K}}}{\frac{L_t}{\bar{L}}}\right)^{\upsilon\psi} + 1 - \frac{\bar{\pi}}{\upsilon}\right].$$

For a given value of ψ (other than zero), the CES production function is obtained if $\upsilon = 1$, whereas the Cobb-Douglas case corresponds to the particular case where $\upsilon = \pi_0$ (which implies that $\sigma_0 = 1$). The elasticity of substitution (σ_0) in the point of normalization (i.e., the one that corresponds to the baseline capital-intensity level, since the elasticity of substitution is now variable along a given isoquant) is equal to $\sigma_0 = \left[1 - \frac{\psi(\upsilon-\pi_0)}{1-\pi_0}\right]^{-1}$, with $\upsilon > \pi_0$.

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On the other hand, the case where $\omega_{22} = 0$ (VES_K production function) yields the following system for estimation:

$$yp_t - \overline{yp} = ln(\xi) + \zeta_K(t - \bar{t}) +$$

$$\frac{1}{\psi} ln\left[\left(\frac{\bar{\pi} - \upsilon}{1 - \upsilon}\right)\left(\frac{K_t}{\bar{K}}\right)^{\psi} + \left(\frac{1 - \bar{\pi}}{1 - \nu}\right) e^{(\upsilon-1)\psi(\zeta_K - \zeta_L)(t-\bar{t})}\left(\frac{K_t}{\bar{K}}\right)^{\upsilon\psi}\left(\frac{L_t}{\bar{L}}\right)^{(1-\upsilon)\psi}\right],$$

$$yk_t - \overline{yk} = \frac{1}{\psi - 1}\left[\overline{yk} + \psi ln(\xi)\right] + \frac{\psi}{\psi - 1}\zeta_K(t - \bar{t}) + \frac{1}{1 - \psi} ln(rp_t)$$

$$+ \frac{1}{\psi - 1} ln\left[\left[\frac{\upsilon - \upsilon\bar{\pi}}{1 - \upsilon}\right] e^{(\upsilon-1)\psi(\zeta_K - \zeta_L)(t-\bar{t})}\left(\frac{\frac{K_t}{\bar{K}}}{\frac{L_t}{\bar{L}}}\right)^{(\upsilon-1)\psi} + \frac{\bar{\pi} - \upsilon}{1 - \upsilon}\right],$$

$$yl_t - \bar{yl} = \frac{1}{\psi - 1}\left[ln(1 - \bar{\pi}) + \bar{yl} + \psi ln(\xi)\right] + \frac{\psi}{\psi - 1}[\upsilon\zeta_K + (1 - \upsilon)\zeta_L](t - \bar{t})$$

$$+ \frac{1}{1 - \psi} ln(wp_t) + \frac{\psi\upsilon}{\psi - 1}\left(kl_t - \bar{kl}\right).$$

For a given value of ψ (other than zero), the CES production function is obtained if $\upsilon = 0$, whereas the Cobb-Douglas case corresponds to the particular case where $\upsilon = \pi_0$ (which implies that $\sigma_0 = 1$). The elasticity of substitution in the point of normalization is now equal to $\sigma_0 = \left[1 - \frac{\psi(\pi_0 - \upsilon)}{\pi_0}\right]^{-1}$, with $\upsilon < \pi_0$.

Parameter υ estimates will therefore allow us to discuss the time-invariant hypothesis of the substitution elasticity parameter that has been widely assumed by economic studies, as well as, together with the ψ estimate obtained from CES production function estimations, to check whether there is evidence in favour of the Cobb-Douglas specification.

3.3. Estimation methods

Several econometric techniques have been used in the literature to estimate the elasticity of substitution and the technological change bias. Our approach in this matter starts by following Young (2013) and to consider the following methods for the linearized variants of the first-order conditions (single-equation estimation): (i) Ordinary Least Squares (OLS) as a baseline; (ii) OLS using differenced data; (iii) a Two-Stage Least Squares (2SLS) approach and (iv) a three-stage Generalized Instrumental Variables (GIV) approach. In turn, the normalized system estimation is performed by the (v) Non-Linear Seemingly Unrelated Regression (NLSUR) and

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the (vi) Generalized Method of Moments (GMM) methods. The econometric software Stata and EViews are used in the estimations.

The choice of the previous methods is related to three underlying issues of the data: regressor endogeneity, serial correlation in the error terms and nonstationarity of the variables used in the estimations.

The endogeneity problem within the production function framework has been widely discussed in the literature (e.g. Petrin et al., 2004; Ackerberg et al., 2006; Horrace et al., 2016). It can be related to a number of factors, such as input measurement errors, unobservable factors to the econometrician (omitted variable bias) or simultaneity between the variables. To account for this problem, we use instrument-based estimators, such as the 2SLS, where the instrumental variables are lagged dependent and independent variables. More precisely, we use (when applicable) the first lags of the natural logarithms of the real wage and the real rental price of capital, normalized labour, capital stocks and log-output, and the time trend (León-Ledesma et al., 2015).

The issue of serial correlation arises when the disturbance terms are not independent, i.e., they are correlated with each other, which violates one of the assumptions of the classical model (Durbin and Watson, 1950; Gujarati and Porter, 2009). In this regard, we also estimate the log-linearized first-order conditions using the three-stage GIV approach developed by Fair (1970) and used more recently by Antràs (2004) and Young (2013) in the estimation of the production function parameters. This procedure accounts not for endogeneity (first stage), but also for serial correlation, as it uses a Feasible Generalized Least Squares (FGLS) treatment with AR(1) correlation in the third stage (Young, 2013; Wooldridge, 2016), and can be summarized as follows:

i) first, estimate a two-stage least squares regression, using lagged dependent and independent variables as instruments, denoting $\varepsilon_{j,t}$ as the error term from the estimation of each equation j;

ii) second, estimate ρ from an AR(1) regression of the first-stage residuals: $\hat{\varepsilon}_{j,t} = \rho\hat{\varepsilon}_{j,t-1} + \nu_t$;

iii) third, use the estimated $\hat{\rho}$ to obtain the GIV coefficients by running the following regressions (the first three corresponding to the CES_1, CES_2 and CES_3 equations, and the last two corresponding to the VES_1 and VES_2 equations, respectively):

$$yk_t - \hat{\rho}yk_{t-1} = (1-\hat{\rho})\xi_0^K + \hat{\rho}(1-\sigma)\zeta_K + \sigma(rp_t - \hat{\rho}rp_{t-1}) + (1-\hat{\rho})(1-\sigma)\zeta_K t + \varepsilon_{1,t}^{GIV};$$

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$$yl_t - \hat{\rho} yl_{t-1} = (1-\hat{\rho})\xi_0^L + \hat{\rho}(1-\sigma)\zeta_L + \sigma(wp_t - \hat{\rho} wp_{t-1}) + (1-\hat{\rho})(1-\sigma)\zeta_L t + \varepsilon_{2,t}^{GIV};$$

$$kl_t - \hat{\rho} kl_{t-1} = (1-\hat{\rho})(\xi_0^L - \xi_0^K) + \hat{\rho}(1-\sigma)(\zeta_L - \zeta_K) + \sigma(wr_t - \hat{\rho} wr_{t-1}) +$$

$$(1-\hat{\rho})(1-\sigma)(\zeta_L - \zeta_K)t + \varepsilon_{3,t}^{GIV};$$

$$yk_t - \hat{\rho} yk_{t-1} = (1-\hat{\rho})\xi_0^{VK} + \hat{\rho}\xi_2^{VK} + \xi_1^{VK}(rp_t - \hat{\rho} rp_{t-1}) + \xi_2^{VK}(1-\hat{\rho})t +$$

$$\xi_3^{VK}(kl - \hat{\rho} kl_{t-1}) + \varepsilon_{4,t}^{GIV};$$

$$yl_t - \hat{\rho} yl_{t-1} = (1-\hat{\rho})\xi_0^{VL} + \hat{\rho}\xi_2^{VL} + \xi_1^{VL}(wp_t - \hat{\rho} wp_{t-1}) + \xi_2^{VL}(1-\hat{\rho})t +$$

$$\xi_3^{VL}(kl - \hat{\rho} kl_{t-1}) + \varepsilon_{5,t}^{GIV}.$$

Finally, nonstationarity arises when the variables used in the regression display strong trends, showing no tendency to revert to their mean levels. In a nonstationary time series process, the probability distributions are not constant over time and classical estimation techniques could lead to spurious regressions (Granger and Newbold, 1974; Wooldridge, 2016). Moreover, hypothesis testing will be biased towards the rejection of the null hypothesis (Rao, 1994). Differentiation is required to achieve stationarity of the variables and therefore we also estimate each equation using OLS regressions of differenced data knowing, however, that long-run information (in levels) is being sacrificed.[46] The equations to estimate are (again, the first three corresponding to the CES_1, CES_2 and CES_3 equations, and the last two corresponding to the VES_1 and VES_2 equations, respectively):

$$\Delta yk_t = (1-\sigma)\zeta_K + \sigma \Delta rp_t + \varepsilon_{1,t}^D,$$

$$\Delta yl_t = (1-\sigma)\zeta_L + \sigma \Delta wp_t + \varepsilon_{2,t}^D,$$

$$\Delta kl_t = (1-\sigma)(\zeta_L - \zeta_K) + \sigma \Delta wr_t + \varepsilon_{3,t}^D,$$

$$\Delta yk_t = \xi_2^{VK} + \xi_1^{VK} \Delta rp_t + \xi_3^{VK} \Delta kl_t + \varepsilon_{4,t}^D,$$

$$\Delta yl_t = \xi_2^{VL} + \xi_1^{VL} \Delta wp_t + \xi_3^{VL} \Delta kl_t + \varepsilon_{5,t}^D,$$

where $\Delta x_t = x_t - x_{t-1}$ for any x_t. It can be noticed that the estimates of the technological progress terms are obtained from the constant term in the case of the CES production function,

[46] Therefore the conclusions obtained with this method should be interpreted with particular caution, as economic theory assumes that *"quantities entering the production function are long-run variables; that is, variables that have been adjusted to their optimal levels without incurring costly frictions"* (Chirinko, 2008, p. 674). These long-run values are often referred to as "frictionless" in the economic literature (e.g. Caballero, 1999; King and Thomas, 2006; Karanassou et al., 2007).

whereas in the case of the VES production functions they can only be individually computed from the constant term after imposing one neutrality assumption.

The results from the aforementioned single-equation methods may hold some caveats: for example, several studies find that the elasticity of substitution estimated from the labour first-order condition systematically exceeds that estimated from the capital first-order condition (e.g. Berndt, 1976; Kalt, 1978; Antràs, 2004; León-Ledesma et al., 2010; Young, 2013)[47]; moreover, the obtained estimates may be biased due to business cycle effects which can affect relative factor input prices (see, in this respect, McKinnon, 1962, and David and van de Klundert, 1965). These problems may be alleviated through system estimation: Berthold et al. (2002) estimated a two-equation system which, however, did not include the production function; later, León-Ledesma et al. (2010) used Monte Carlo analysis to compare the performance of different estimation approaches, finding that the joint estimation of the production function with the first-order conditions is superior to single-equation approaches, particularly when combined with normalization.

We follow this procedure and estimate the equation systems described in the previous section for the CES, VES_L and VES_K production functions, using the NLSUR and GMM estimation methods. Since both first-order conditions are obtained from the same production function, it seems plausible to admit that their errors terms are correlated, so the equations might be seemingly unrelated (Berthold et al., 2002); furthermore, we also consider the GMM estimator which takes into account the potential endogeneity bias.

The non-linearity of the normalized systems requires furthermore the choice of initial parameter values. For the CES case, we follow Young (2013) and estimate the capital and labour first-order conditions CES_1 and CES_2 by OLS as a two-equation system; the resulting estimates are then set as initial values in the system estimation. In the VES cases, for the parameters υ and ψ, we estimate the linear first-order conditions VES_1 and VES_2 by the differenced OLS and GIV methods and use the average of the estimates as the initial values[48]; in turn, the initial

[47] Berndt (1991) suggested that this fact can be related to the lower substitutability of the capital stock in the short run (when capital is partially fixed).

[48] Sometimes, these estimates fell outside of the economic meaningful ranges – in these cases, we selected values near the closest possible option.

values of the technological change parameters are set according to the estimates obtained in the normalized CES system.[49] In all cases, the initial value of the normalization constant is set to 1.

3.4. Data

The estimation is performed for the United States aggregate economy as well as for the 65 industries represented in the US National Income and Product Accounts (NIPAs), which are listed in Table 3.1.1 (as well as Table 3.1.2 and Table 3.1.3). Data are taken from the KLEMS database, which combines information from the Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS), and covers the period from 1947 to 2014 (see Jorgenson et al., 2018).[50] Key features of the KLEMS framework are the inclusion of both quality-adjusted labour and capital inputs (Jorgenson and Stiroh, 2000; Jorgenson, 2018): in the case of labour, individual data are collected from both the US Census of Population and annual Current Population Surveys, accounting for heterogeneity across several characteristics of individual workers, such as age, gender or educational attainment; then, instead of using the total number of hours as the measure of the flow of labour services, hours worked for differentiated labour groups are combined into a constant quality index of the labour input, where the weights are the respective hourly compensations.[51] In the case of capital, constant quality indices are also obtained at the industry level, using the rental prices of the different capital inputs as weights, which makes it possible to incorporate differences in inflation, depreciation rates and tax structures between different types of assets.

[TABLES 3.1.1, 3.1.2 AND 3.1.3]

[49] In a few cases, to obtain estimates or to improve the estimation fit, the initial values had to be adjusted: for example, the estimate of ψ in one of the equations was set as the initial value for the other equation, or the technological change estimates obtained with one method were used as the initial values for the other method.

[50] The database is available online at http://www.worldklems.net/ and contains industry-level data for output, inputs and productivity. The acronym KLEMS stands for the primary inputs of capital (K) and labour (L), as well as the intermediate inputs of energy (E), materials (M) and services (S). Based on the growth accounting framework (Jorgenson and Griliches, 1967), it was originally developed by Jorgenson et al. (1987) and represented the first database which included the aforementioned annual time series information for all the US industries (see, in this respect, Jorgenson, 2018). The dataset used in the estimations builds on previous work from Jorgenson et al. (2005) for the US economy for the period 1977-2000 (although at a less detailed industry-level), and has been updated for the period 1947-2014 in the 2017 release.

[51] Note that, if we do not control for differences in labour quality, such as schooling differences, we may obtain biased estimates (Ho and Jorgenson, 1999; Young, 2013; Grossman et al., 2018).

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The variables used in our estimations are the KLEMS real stocks of capital (K_t) and labour (L_t), while the real rental price of capital and the real wage are obtained by dividing, respectively, the nominal rental prices of capital (R_t) and labour (W_t) by the implicit price index of gross output (P_t). Since the output included in the database is gross (incorporating the value of intermediate inputs), we calculate real value added (Y_t), deflating nominal gross value added by the implicit price index of gross output.[52] To obtain annual data for the aggregate economy, we follow Del Río and Lores (2019) and employ Törnqvist quantity indices to aggregate the volumes from the 65 industries (see, in this respect, O'Mahony and Timmer, 2009). The variables *yk*, *yl*, *kl*, *rp*, *wp* and *wr* are then computed for each industry and the aggregate economy and their summary statistics are displayed in Table 3.1.1, Table 3.1.2 and Table 3.1.3.

To assess whether the regressors included in the model are endogenous, we first perform the Durbin (1954) and Wu-Hausman (Wu, 1974; Hausman, 1978) endogeneity tests based on 2SLS regressions with lagged dependent and independent variables (Table 3.2.1). At the conventional 5% significance level, the exogeneity null is rejected for more than half of the 65 industries, with the exception of the CES_2 and VES_2 specifications, where this hypothesis is only rejected for 30 and 31 industries, respectively. If we increase the significance level to 10%, the regressors appear to be endogenous in more than half of the industries for every specification; in the CES_1, CES_3 and VES_1 cases, more than two-thirds of the industries reject the exogeneity hypothesis. At the aggregate level, however, there is only evidence of endogeneity at the 10% level in the CES_2, CES_3 and VES_1 specifications. Furthermore, we also report the results from Wooldridge's (1995) robust test and from a robust regression-based test (Table 3.2.2): at the 5% significance level, the exogeneity null is rejected for fewer industries, but still for more than half of the cases in the CES_1, CES_3 and VES_1 specifications (compared to 40% and 46% of the industries in the CES_2 and VES_2 equations). Also, for the aggregate economy, these tests corroborate the evidence of endogeneity only in the CES_2, CES_3 and VES_1 specifications and at the 10% significance level.

[TABLES 3.2.1 AND 3.2.2]

To test for serial correlation in the disturbance terms, we start by performing the Durbin-Watson test based on OLS single-equation regressions (Durbin and Watson, 1950). The null hypothesis of no serial correlation is almost always rejected, both at the 5% and 1% significance levels

[52] Nominal gross value added is equal to the sum of capital (nominal rental price of capital multiplied by the real stock of capital) and labour incomes (nominal price of the labour input multiplied by the real stock of labour).

(Table 3.3.1). [53] Furthermore, we perform the Breusch-Godfrey test, which can detect autocorrelation of higher orders (Breusch, 1978; Godfrey, 1978). The null of no first-order serial correlation is rejected at the aggregate level and for almost all industries up to order five (Table 3.4.1 and Table 3.4.2).[54]

Assuming that the errors follow a first-order autoregressive process, AR(1), we apply the Prais-Winsten estimation procedure (Prais and Winsten, 1954) and compute the Durbin-Watson statistics (Table 3.3.2). The no serial correlation null is not rejected at the aggregate level, being only rejected for a minority of industries, particularly in the CES_2 and VES_2 specifications where only 6 industries reject this hypothesis at the 5% significance level (and only 5 and 4 industries at the 1% significance level, respectively). In the CES_3 specification, however, the null hypothesis is still rejected for 23 industries at the 5% level (a figure that increases to 32 industries at the 1% level, approximately half of the industries).

[TABLES 3.3.1, 3.3.2, 3.4.1 AND 3.4.2]

Finally, in order to assess the stationarity of the variables used in the regressions, we perform the Augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1979, 1981) and the Phillips-Perron (PP) (Phillips and Perron, 1988) unit root tests. As expected when looking at their behaviour over time (see, for example, Figure 3.1 which depicts the variables for the aggregate economy), the variables in levels are almost always nonstationary, that is, the null hypothesis of the existence of a unit root is not rejected at the 1% significance level (Table 3.5.1 and Table 3.6.1). More precisely, the ADF unit root test only suggests stationarity for between 2 industries (in the case of the *yl* and *wp* variables) and 8 industries (in the case of the *wr* variable) and never for the aggregate economy, whereas, in the case of the PP unit root test, stationarity is only detected for between 1 industry (in the case of the *yk* variable) and 14 industries (in the case of the *wr* variable) and also never for the aggregate economy. However, when taken at first differences, almost all of the variables become stationary (Table 3.5.2 and Table 3.6.2), indicating that integration of the same order [I(1)] is a prevailing feature of the data. A cointegrating relationship may therefore exist among the variables under study.

[53] Only a minority of industries does not reject the no serial correlation null hypothesis: 4 industries in the CES_1 specification, 2 industries in the CES_2, 3 industries in the VES_1 (4 at the 1% significance level) and 2 industries in VES_2 (6 at the 1% significance level). For the aggregate economy, the null is rejected for all specifications.

[54] We only report the tables for 1 and 5 lags for the sake of saving space. The other tables are available upon request.

[FIGURE 3.1]

[TABLES 3.5.1, 3.5.2, 3.6.1 AND 3.6.2]

Two or more variables are cointegrated if, despite being individually nonstationary, one or more linear combinations of them is stationary, that is, it tends to revert towards its mean value in the long-run (Dickey et al., 1991). To test for the cointegration of the series, we employ the Johansen cointegration test (Johansen, 1988, 1991; Johansen and Juselius, 1990),[55] which is preceded by the estimation of the number of lags for an unrestricted VAR model. In line with the previous empirical model, we consider the following combinations of variables: *(yk rp)*, *(yl wp)*, *(kl wr)*, *(yk rp kl)* and *(yl wp kl)*. Using the Schwarz information criterion, the lag order of the vast majority of the econometric specifications is set to 1; in the remaining cases it is either set to 2, particularly in several industries for the *(kl wr)* combination, or to 3 lags (Table 3.7.1, Table 3.7.2 and Table 3.7.3).

[TABLES 3.7.1, 3.7.2 AND 3.7.3]

Both the Trace and the Maximum-Eigenvalue test results mainly indicate no cointegration at the 5% level for the majority of the industries: for the CES first-order conditions, this outcome is obtained for between 44 and 46 industries (Table 3.8.1, Table 3.8.2 and Table 3.8.3), while for the VES_1 specification (Table 3.8.4) there is no evidence of cointegration for 37 (Trace Test) or 40 industries (Maximum-Eigenvalue test); the VES_2 linear first-order condition is the only specification where cointegration is found for approximately half of the industries (Table 3.8.5). This notwithstanding, the null hypothesis of no cointegration vectors is never rejected for the aggregate economy for every econometric specification, always suggesting no cointegration at the 10% significance level or better.

[TABLES 3.8.1, 3.8.2, 3.8.3, 3.8.4 AND 3.8.5]

Despite some exceptions, the prevailing evidence is that the variables used in the regressions are nonstationary but also not cointegrated, a result always verified for the aggregate economy, and which confirms that the use of classical estimation techniques, such as OLS, would lead to spurious regressions. In fact, if the means and variances change over time, the computed statistics of a regression model will be also dependent on time, and consequently, they will not

[55] This method is used instead of the Engle and Granger (1987) approach, as it is able to detect more than one cointegrating relationship. Another difference between the two tests is that the Johansen test derives maximum likelihood estimators of the cointegration vectors, whereas the Engle and Granger procedure estimates the cointegrating regression using the OLS technique, and tests the residuals for a unit root using the ADF test.

converge to the population values as the sample increases to infinity (see, in this respect, Rao, 1994).

3.5. Estimation results

The CES production function has been widely used in the literature to estimate the aggregate elasticity of substitution, particularly in the case of the US economy (see, in this respect, Section 1.4.5). Studies at the industry level, however, have been relatively scarcer and therefore we start this section by presenting the results of the aggregate level estimates, which facilitate the comparison with the bulk of the literature, before presenting the industry-level conclusions. We then adopt a similar procedure for the case of the VES production function, a function that enjoyed a substantially lower empirical application.

3.5.1. CES estimation results

Aggregate economy estimates. Looking at the single-equation aggregate estimates using the CES production function (Table 3.9), the first important conclusion is that, irrespective of the estimation method used, the elasticity of substitution is always lower than unity, which corresponds to the case of gross complementarity between the production factors. This result is in line with the majority of the studies surveyed in the first essay; exceptions include Berndt (1976) and Balistreri et al. (2003)'s estimations, that suggest the possibility of a unity elasticity of substitution (the Cobb-Douglas case).

Moreover, the elasticity of substitution estimates from the CES_2 equation are higher than those obtained from the CES_1 and CES_3 cases. In fact, estimates obtained from the CES_2 equation lie in the range of 0.51 to 0.67, whereas in the other cases they are comprised between 0.22 and 0.46. Once again, this result confirms an empirical regularity found in previous studies (e.g. Berndt, 1976; Kalt, 1978; Antràs, 2004; León-Ledesma et al., 2010; Young, 2013). Our estimates also suggest an additional conclusion, since the elasticities of substitution obtained from the CES_1 equation are higher than those obtained from the CES_3 equation: with the exception of the 2SLS method, where both results are very similar (between 0.36 and 0.37), the CES_1 estimates are in the region of 0.41-0.46, whereas the CES_3 results lie between 0.22 and 0.34.

[TABLE 3.9]

The results obtained from the normalized system approach (Table 3.10) confirm the gross complementarity result, as the elasticity of substitution is estimated at around 0.6 (more precisely, 0.59 or 0.62, respectively, using the NLSUR or the GMM estimator), a result which

is in line with other studies for the US economy (e.g. Klump et al., 2007; León-Ledesma et al., 2015). Notice that, as expected, the estimated normalization constant is almost indistinguishable from unity in both cases.

[TABLE 3.10]

Regarding the aggregate factor augmentation estimates, the estimates obtained from the CES_3 equation, which suggest net labour-augmentation at an annual rate of 1.7% to 1.8%, are not far from the obtained by the difference of the estimates between the CES_2 and the CES_1 equations. It should be emphasized, however, that according to the separate estimates obtained from each equation, the growth rates of capital-augmenting and labour-augmenting technological progress show opposite behaviours: while the former is negative irrespective of the estimation method used (around -0.3% to -0.5% annually), the latter is always positive (between 1.2 and 1.4% per year).

Normalized system estimates are very similar, with an annual rate of net labour-augmentation of 1.34% (GMM) or 1.36% (NLSUR), resulting from labour-augmenting technological progress at an annual rate of nearly 1.3% and a negative rate of capital-augmenting technological progress, but with a lower absolute magnitude (-0.08% or -0.05% per year in the cases of NLSUR and GMM, respectively).

The finding of net labour-augmenting technological change is a prevailing conclusion in the studies that consider factor-augmenting technological change (e.g. Young, 2013; León-Ledesma et al., 2015). Negative rates of capital-augmenting technological progress were also found not only in previous studies of the US economy (Antràs, 2004; Del Río and Lores, 2019), but also in studies with different geographical scopes (e.g. Luoma and Luoto, 2010, for the Finnish economy or Mućk, 2017, for 12 advanced economies, which however also included the US).[56]

Industry-level elasticities of substitution. An important contribution of this study is the estimation of the elasticities of substitution and technological change for the 65 industries represented in the US NIPAs.

[56] Note that Jiang and León-Ledesma (2018) attributed this conclusion to the assumption of constant markups, which have in fact increased in the US since the 1980s. The estimation of factor-augmenting technological progress using a CES production function with a time-varying markup lead to a positive capital-augmentation rate, larger than the labour-augmenting rate, therefore resulting in net capital-augmentation.

We start the estimation using the OLS method as a baseline (Table 3.11.1). The majority of the estimates are statistically significant at the 5% level or better[57] and, among these industries, only a minority shows implausible (negative) values for the elasticity of substitution. Within the 95 percent confidence interval, the Cobb-Douglas hypothesis of a unitary elasticity of substitution is only admitted for one industry simultaneously for the three equations (industry 41), while the Leontief hypothesis (elasticity of substitution equal to zero) is never obtained in simultaneous (nonetheless, in four industries this hypothesis is not rejected by two of the equations). For only two or three industries, depending on the equation, the estimate is greater than unity; this notwithstanding, for only one of them (industry 46), the confidence intervals for all the three equations present higher than unity values (despite also including lower than unity values in the CES_1 case). In the remaining cases (the majority of the industries: 58, 57 and 48 significant cases, respectively in the CES_1, CES_2 and CES_3 equations), the elasticity of substitution is lower than unity, corresponding to the gross complementarity hypothesis. In general, the highest estimates are obtained from the CES_2 equation, while those obtained from the CES_3 equation are notoriously lower.

[TABLE 3.11.1]

The aforementioned characteristics of the data imply, however, that the OLS estimators may be biased or spurious depending on each particular industry. We therefore proceed our analysis by performing the 2SLS industry-level estimation to account for the endogeneity issue (Table 3.11.2). The elasticity of substitution estimates are slightly higher than in the OLS case, but the overall conclusions prevail: the majority of the estimates are statistically significant at the 5% level, very few present negative values for the elasticity of substitution[58], while no industry reveals a null elasticity of substitution. The Cobb-Douglas hypothesis is not rejected using the three equations in simultaneous for only 2 industries (industries 34 and 56), although at the expense of high standard errors or despite the point estimate not being statistically significant in one of the equations. Even though the majority of the confidence intervals lie entirely below unity, suggesting that capital and labour are gross complements, the 2SLS method is the one that generates more higher than unity point estimates of the elasticities of substitution (7 in the

[57] Only 3, 5 or 11 industries in the CES_1, CES_2 and CES_3 equations, respectively, are not statistically significant and the estimate of industry 39 in the case of CES_2 and industry 45 in the case of the CES_3 are only significant at the 10% significance level.

[58] This is the estimation method, however, that generates more significant negative values for the elasticities of substitution: 3 for the CES_1, 2 for the CES_2 and 6 for the CES_3 equation.

CES_1 equation, 8 in the CES_2 and 3 in the CES_3); industries 41 and 46 are the only ones that admit that capital and labour may be gross substitutes in the three equations. Another particularity of this method's estimates is that, on average, the estimated elasticities of substitution from the CES_1 equation (0.60) are closer to the obtained from the CES_2 equation (0.64, the highest average value using the single-equation method), which nonetheless still presents the highest values.

[TABLE 3.11.2]

In addition to the endogeneity issue, we have also performed GIV estimations which include an additional component to account for serial correlation in the residuals. As an intermediate step in the GIV estimations (second stage), we estimate an AR(1) regression of the 2SLS residuals, whose coefficients are presented on Table 3.11.3 and which are almost all statistically significant (depending on the equation, there are only 4 to 6 industries whose coefficients are not statistically significant). The substitution elasticities estimated from GIV regressions are then displayed in Table 3.11.4. Similarly to the previous methods, the estimated coefficients are almost always statistically significant, but are now noticeably lower in the three equations. A striking feature is that in practically all industries the point elasticity of substitution is lower than unity: with the exception of the CES_2 results, where two industries show higher than unity point estimates (industry 37, which also admits the Cobb-Douglas case in its confidence interval, and industry 40) and two others have a small part of their confidence intervals also above unity (industries 13 and 36), in the remaining cases (including all the CES_1 and CES_3 significant estimates), the results point to gross complementarity between labour and capital. Contrary to the previous methods, three industries now admit the Leontief possibility within the 95 percent confidence interval for the three equations in simultaneous (industries 33, 57 and 65).

[TABLES 3.11.3 AND 3.11.4]

The lowest elasticity of substitution estimates are obtained from the differenced OLS method (Table 3.11.5), with an average of 0.32, 0.46 and 0.09 (Table 3.12), respectively in equations CES_1, CES_2 and CES_3 (corresponding to a value-added share-weighted average of 0.34, 0.39 and 0.07). This conclusion is similar to the obtained by Young (2013), which is attributed *"to the discarding of longer-run information in the levels of variables in favour of shorter-term information in the changes"* (Young, 2013, p. 881). Once again, almost all industries show lower than unity values for the elasticity of substitution, with only two higher than unity point

estimates being obtained in the CES_2 equation (industries 16 and 40, the only whose confidence interval lies entirely above unity). The Cobb-Douglas production function is only admitted for 10 industries using the CES_2 equation or 1 industry using the CES_1 equation, while the Leontief case is not rejected for two industries in simultaneous (industries 57 and 61). Some industries present very low values for the elasticity of substitution especially in the CES_3 equation, where twenty-nine industries present figures lower than 0.05, while the four industries that show significant negative values are nonetheless very close to zero (in the range of -0.08 to -0.02). Also notice that the OLS estimates based on differenced data using the CES_3 equation have the particularity of generating markedly less significant estimates than the other methods and equations (only 65% of the estimates are significant, when generally more than 80% or 90% of significant estimates are obtained). Similarly to the other single-equation methods, the elasticity of substitution estimates obtained from the CES_3 equation are notoriously lower than those from CES_1 and CES_2 equations; even so, in relative terms, this is the estimation method that generates the largest difference between them, as the industry average of the elasticities of substitution estimates obtained from the CES_3 equation represent less than 20% of the corresponding value from the CES_2 equation.

[TABLES 3.11.5 AND 3.12]

Finally, the normalized system estimates are presented in Table 3.13 and are all statistically significant. A prominent feature is that almost all of the point estimates are below unity; the only exceptions are industries 40 and 46, using both the NLSUR or the GMM methods, and industry 41 with the GMM method (in this case, however, the NLSUR estimate is very close to unity at 0.98[59]). Note that these are service industries which frequently presented a similar conclusion using the single-equation approach. The confidence intervals are now remarkably narrower, which can attributed to the imposition of cross-equation restrictions (Young, 2013) and, as such, the Cobb-Douglas case is only admitted in one industry at the 5% significance level (industry 5) or in 3 industries at the 1% significance level (industries 5, 6 and 38), in both cases using the GMM method, while the Leontief case is never obtained within the 95 percent confidence interval (nor within the 99 percent confidence interval). Moreover, the normalized system approach does not generate such low elasticity of substitution values as some of the previous single-equation methods – the lowest point estimates are 0.08 and 0.09 in the case of

[59] Using the GMM method, industry 56 also has a very close to unity point estimate of the elasticity of substitution (0.99), which however falls to 0.67 when applying the NLSUR procedure.

the NLSUR method (industries 23 and 57, respectively), while, in the case of the GMM method, industries 23 and 54 have an estimated elasticity of substitution of 0.04; in the remaining cases, the estimated elasticities of substitution are always greater than 0.10.

[TABLE 3.13]

The simple average of the industry-level estimates (Table 3.14) yields a value of 0.48 in the case of the NLSUR method (a little lower than the 0.59 estimated for the aggregate economy), while in the case of GMM method the industry-level average is almost identical to the aggregate economy estimate (0.62), whereas the value-added share weighted averages of the industries' elasticities of substitutions are fairly lower (0.38 in the case of the NLSUR method and 0.48 in the case of the GMM method).

[TABLE 3.14]

To summarize, quite irrespectively of the estimation method used, perfect complementarity between labour and capital is a prevailing feature of the US data, both at the aggregate and at the industry-level. The Cobb-Douglas production function is only a possibility for a reduced number of industries, while the Leontief case is only admitted in some single-equation methods. Moreover, in the single-equation approach, the labour first-order condition systematically produces higher estimates, confirming an empirical regularity found in previous studies.

Industry-level factor augmentation rates. The CES production function first-order conditions allow us to obtain, separately, three different estimates: from the estimation of CES_1 and CES_2 expressions we can compute, respectively, ζ_K and ζ_L, the point estimates of the growth rates of capital-augmenting and labour-augmenting technological progress, whereas from CES_3 equation we can determine the point estimate of the net labour-augmentation rate, $\zeta_L - \zeta_K$ (or net capital-augmentation, in the case that this difference is negative). The estimation results and the underlying calculations are displayed in Table 3.15.1 to Table 3.15**.4**. On the other hand, from the normalized system approach, the rates of capital- (ζ_K) and labour- (ζ_L) augmentation are obtained directly from the estimation (i.e. without the need of any further calculations), and the difference $(\zeta_L - \zeta_K)$ corresponds to the difference between these point estimates.

Table 3.15.1 reports the OLS estimates which predominantly suggest net labour-augmentation (in approximately 90% of the US industries). The majority of the industries display negative rates of capital-augmentation (44 industries, or 38 out of the 55 industries whose coefficients where obtained from significant estimates) and positive rates of labour-augmentation (54 industries, or 46 out of the 55 industries with significant estimates); however, note that there

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are also industries which show precisely the opposite conclusion (e.g. industries 2 and 35) or where both rates have the same sign (e.g. industry 1, where both rates are positive, or industry 37 where both rates are negative). The industry average of factor augmentation growth rates is higher, in absolute terms, than the results obtained for the aggregate economy: considering only the results obtained from significant estimates, we obtain an average of -0.7% for the growth rate of capital-augmentation (-1.0% if all results are considered), 1.7% for growth the rate of labour-augmentation (1.5%) and 2.8% for the net labour-augmentation rate (5.7%).

[TABLE 3.15.1]

The 2SLS method corroborates the finding of net labour-augmentation for the majority of the US industries (Table 3.15.2). In fact, 51 industries display positive and significant rates of net labour-augmentation (6 more industries are not statistically significant but also show a positive sign), at an average rate of 3.0% (2.8% if all results are considered). Once again, a negative growth rate of capital-augmenting technological progress appears to characterize the majority of the industries (41 industries), combined with a positive growth rate of labour-augmenting technological progress (52 industries).

[TABLE 3.15.2]

When the GIV method is implemented (Table 3.15.3), the same conclusions hold, now with 56 industries with significant positive rates of net labour-augmentation (plus 3 more which are not statistically significant), at an average rate of 3.1% (2.9% if all results are considered). These results constrast with the conclusion obtained by Young (2013), who found that only 18 out of the 35 industries analysed in his study were characterized by net labour-augmentation. Using this technique, even more industries present negative growth rates of capital-augmenting technological progress (44 significant industries at an average rate of -1.8%, and an additional 4 results obtained from coefficients which are not statistically significant) and positive ones of labour-augmenting technological progress (43 significant industries at an average rate of 1.7%, plus 10 more whose coefficients are not statistically significant).

[TABLE 3.15.3]

The results obtained from the OLS regressions of differenced variables (Table 3.15.4) generate the lowest number of significant estimates, particularly in the CES_1 and CES_2 equation, where the growth rates of only 30 or 22 industries, respectively, are calculated from a significant term (remember that technological progress is now being computed from the constant term). Even so, considering only these or all industries would lead to the same overall conclusion: in the

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majority of the industries, net labour-augmentation rates are found (at an average rate of 3.2%, or 2.7% considering all industries), capital-augmenting technological progress grows at a negative rate (at an average of -1.6%, or -1.0% considering all industries) while the growth rate of labour-augmenting technological progress is positive (at an average rate of 2.6%, or 1.5% considering all industries).

[TABLE 3.15.4]

The normalized system results confirm the single-equation conclusions (Table 3.13): either using the NLSUR or the GMM method, net labour-augmentation characterizes most of US industries. More precisely, considering only the significant results, this is the case of either 45 (NLSUR method) or 40 industries (GMM method), at an average rate of, respectively, 1.9% or 2.0%[60] (or 50 and 43 industries if all results are considered at an average rate of, respectively, 1.8% or -0.6%). Only 12 industries present the opposite conclusion (or 15 and 22 industries, respectively using the NLSUR or the GMM, if all the results are considered), which are mainly service industries (e.g. industries 47, 49, 51 or 52). Negative rates of capital-augmenting technological progress are found for 45 or 42 industries, in the case of the NLSUR or the GMM method, respectively (42 or 36 of which are statistically significant), while 53 or 44 industries, respectively, show positive rates of labour-augmenting technological progress (with 50 or all of the 44 results being statistically significant).

As a general conclusion, net labour-augmentation is found for the majority of the US industries in the period under analysis, that is, technological change is predominantly labour-augmenting, but not purely labour-augmenting, analogously to the aggregate economy result. This entails some repercussions for the neoclassical growth model, as the stability of the growth equilibrium or the existence of steady-state growth requires technological change to be strictly labour-augmenting or Harrod-neutral along the equilibrium growth path (Uzawa, 1961; Schlicht, 2006; Jones and Scrimgeour, 2008). Moreover, in an endogenous growth model with biased technological change, Acemoglu (2003) showed that, as long as capital and labour are gross complements (which we found to be case for the majority of the US industries), long run technological change will be purely labour-augmenting (despite the fact that, along the transitional path, there will be also capital-augmenting technological change).[61] Furthermore, a

[60] Excluding some outliers.

[61] In the case of gross substitutes, the balanced growth path would be unstable (explosive growth or consumption growing asymptotically faster than capital).

decline in capital efficiency at the industry-level was also found previously for the US economy: Herrendorf et al. (2015) obtained a significant negative estimate for the manufacturing sector, but a positive result for agriculture; notice that, within the primary sector of the economy, this positive result was also found in our study for industry 1 (farms), as well as for industry 2 (forestry, fishing and related activities); in the case of the latter, its magnitude is even reflected in a net capital-augmentation result.

3.5.2. VES estimation results

Aggregate economy estimates. The single-equation estimation results for the US aggregate economy using the two particular parametric cases of the VES production function are presented in Table 3.16. The first important point to notice is that, using the VES_1 equation, in the OLS and 2SLS methods the estimated parameter υ lies outside of the economic meaningful range $(0 \leq \upsilon \leq 1)$, although they include the CES possibility within the 95% confidence interval $(\upsilon = 0)$. In the remaining cases, the point estimates of υ are between 0 and 1 and statistically significant at the 10% level or better, ranging between 0.4 and 0.51 in the VES_1 equation or between 0.32 and 0.42 in the VES_2 equation. In both functions, the estimated ψ is always negative (and mostly lower than -1), implying that the elasticity of substitution is always lower than unity (corresponding to the case of gross complementarity between capital and labour), and never including the Cobb-Douglas possibility in the 95% confidence intervals.

[TABLE 3.16]

A distinctive feature of our study is the estimation of the VES production function applying the normalized system approach, which combines the normalized production function with the associated (linear and non-linear) first-order conditions, therefore offering important theoretical advantages (see, in this respect, sections 1.5.2 and 1.5.6). The estimates are presented in Table 3.17 and, as expected, the estimated normalization constant is very close to unity. An important conclusion is that the estimated parameter υ is not far from unity in the case of the VES_L function, and zero in the VES_K function; these particular cases are always included within the 95% confidence interval,[62] which suggests that, for the aggregate economy, the VES production function tends to the CES specification, where the elasticity of substitution is time-invariant.

[TABLE 3.17]

[62] Note, however, that in the case of the VES_K function, the parameter υ estimates are only statistically significant at the 10% level.

Moreover, chi-square test statistics (Table 3.18) clearly confirm the rejection of the Cobb-Douglas hypothesis ($\upsilon = \pi_0$) for both VES specifications and for both methods (NLSUR and GMM). The implied σ_0 results are in the region of 0.63 to 0.67 in the case of the NLSUR method, and fall to around 0.53 and 0.54 in the case of the GMM method, which, as expected (since we are assuming the same ψ), are not far from the substitution elasticities obtained with the CES production function (0.59 and 0.62, respectively).

[TABLE 3.18]

To identify the factor augmentation rates, the single-equation approach requires *a priori* assumptions on the nature of technological change. In this case, we assume three different types of neutrality: Hicks-neutrality ($\zeta_L = \zeta_K = \zeta$), Harrod-neutrality ($\zeta_K = 0$) and Solow-neutrality ($\zeta_L = 0$). The estimates and implied coefficients of technological change are reported in Table 3.16. The factor augmentation rates are almost always positive for the US aggregate economy: with the exception of those obtained with the OLS and 2SLS methods for the VES_1 equation (the methods which generated point estimates of υ outside of the economic meaningful range), the growth rate of the Hicks-neutral technological change parameter is comprised between 0.46% and 0.83%; under the assumption of Harrod-neutrality, the growth rate of labour-augmenting technological progress ranges between 0.88% and 1.29%; finally, in the case of Solow-neutrality, the implied growth rates of capital-augmenting technological progress show a wider range, between 0.91% and 2.62%, constituting the main difference from the CES single-equation results, where the estimated capital-augmenting growth rates were always negative.

The normalized system approach does not require the imposition of the aforementioned restrictive assumption on the nature of technological change, allowing to identify biased technological change and therefore yielding our preferred estimates (Table 3.17). In this case, the estimates are close to the ones obtained with the CES production function (which is not surprising since the parameter υ estimates suggest that both functions tend to the CES case): the growth rates of capital-augmenting technological progress are only significant for the GMM method and are either -0.17% or -0.15%, while the labour-augmenting technological progress growth rates (for both methods) range between 1.18% to 1.37%, resulting in net labour-augmentation at an annual rate of approximately 1.12% and 1.26% in the case of the NLSUR method (considering, however, the non-significant capital-augmenting estimates, one of which is inclusively slightly positive), or around 1.5% in the case of GMM method.

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Industry-level estimates of ψ and υ. The estimation of the VES production function parameters at the industry-level has only been performed by a reduced number of studies and with already a large temporal distance, dating predominantly from the 1960s and 1970s (e.g. Nerlove, 1967; Revankar, 1971). Similarly to the previous section, we start our estimations using the OLS technique, whose results are presented in Table 3.19.1. Several industries show point estimates outside of the economic meaningful ranges: either the computed ψ is higher than unity (6 cases in the VES_1 equation or 2 cases in the VES_2) or the value of parameter υ is not comprised between 0 and 1 (20 cases in the VES_1 equation or 24 cases in the VES_2), whereas in two industries these conditions overlap for the VES_1 equation. Regarding the 41 industries in the case of the VES_1 equation or the 39 industries in the case of the VES_2 equation whose point estimates are included within the economic meaningful values, the parameter ψ is always negative, confirming a lower than unity elasticity of substitution. The 95 percent confidence intervals for υ include the CES possibility for 15 industry in the case of the VES_1 equation and 24 industries in the case of the VES_2, 4 of which in simultaneous by both functions (industries 6, 13, 26 and 64), while the Cobb-Douglas possibility is more frequent in the VES_2 estimation (6 industries include the case $\psi = 0$ in the 95 percent confidence interval, whereas in the VES_1 estimation this result is only obtained for industry 44).

[TABLE 3.19.1]

The lowest number of industries with economic meaningful point estimates is obtained using the 2SLS method (Table 3.19.2), where only approximately half of the industries generate estimates within the economic meaningful range (30 or 31 industries in the VES_1 and VES_2 equations, respectively). This is also the only single-equation method which generates an industry with a positive point estimate of ψ and where the value of υ is simultaneously between 0 and 1 (industry 42), pointing to a higher than unity elasticity of substitution between capital and labour, but only in the case of the VES_1 equation and despite the fact that the estimate of ξ_3^{VK} is not statistically significant.[63] In the remaining cases, the estimates suggest a lower than unity elasticity of substitution (negative ψ). This is also the method where the Cobb-Douglas production function is more often included in the 95 percent confidence intervals, with 12 and 14 industries being found with the VES_1 and VES_2 specifications, respectively, two of which in simultaneous using both functions (industries 3 and 31). Like in the OLS method, the CES

[63] In the case of industry 53, the estimate of ψ is also between 0 and 1 and the estimate of υ is not very far from unity (1.06), but the underlying estimated coefficients are not statistically significant.

production function is more recurrent under the VES_2 equation than in the VES_1 (23 vs. 16 industries, respectively), but again only in the case of industries 3 and 31 there is an agreement between both equations.

[TABLE 3.19.2]

Similarly to the CES single-equation estimation, an intermediate step in the GIV estimations is the estimation of AR(1) regressions of the 2SLS residuals, whose coefficients are presented on Table 3.19.3 and which are almost all statistically significant at the 5% level of better (there are only 6 to 8 industries whose coefficients are not statistically significant, respectively in the VES_1 and VES_2 equations[64]). The GIV estimations are then presented in Table 3.19.4 and show more industries with estimates included within the economic meaningful values than the previous methods (51 or 45 industries using, respectively, the VES_1 and VES_2 equations), all of which pointing to a lower than unity elasticity of substitution (negative ψ). The Cobb-Douglas production function is only a possibility for 5 industries under the VES_2 specification, whereas the CES production function is also more frequent using this equation (30 industries vs. 9 industries in the case of the VES_1 equation), with this latter result being obtained for 5 industries in simultaneous using both equations (for industries 2, 6, 13, 26 and 38).

[TABLES 3.19.3 AND 3.19.4]

The largest number of point estimates included within the economic meaningful range using the VES_1 equation is obtained through the differenced OLS technique (Table 3.19.5: 58 industries vs. 40 in the VES_2 specification), all of which point to a lower than unity elasticity of substitution (negative ψ). This is also the method that generates more industries where the CES production function is a possibility, in particular with the VES_2 specification as a result of the low ξ_3^{VL} parameter estimates (41 industries vs. 5 industries with the VES_1). The Cobb-Douglas possibility is admitted for 9 industries, again in the VES_2 equation.

[TABLE 3.19.5]

The value-added weighted averages of the industry-level results for ψ range between -13.60 (OLS with differenced variables) and -1.55 (2SLS) in the VES_1 equation, whereas in the VES_2 equation they are comprised between -11.81 and -6.67, with the exception of the OLS method with differenced variables (-27.78), which tends to imply the lowest parameter values (Table 3.20). On the other hand, the computed values for υ tend to be comprised within a relatively

[64] Note that, among them, one of the coefficients is significant at the 10% level for the VES_2 equation.

narrower range: either between 0.28 and 0.33 in the VES_1 specification (excluding the 2SLS method), or between 0.28 and 0.43 using the VES_2 first-order condition (excluding the OLS method).

[TABLE 3.20]

One particular result that arises from the previous estimations is the possibility of production functions where output would become only a function of effective labour (when parameter υ tends to zero using the VES_1 first-order condition) or only a function of effective capital (when parameter υ tends to one using the VES_2 first-order condition), particularly as a result of high ψ estimates (in absolute terms). The former result is obtained relatively more often than the latter; examples include industry 61 (particularly in the first case), or industry 45 (particularly in the second case).

The normalized system approach, in general, yields a high number of estimates within the economic meaningful values (Table 3.21.1 and Table 3.21.2): in fact, the majority of parameter υ estimates are statistically significant (the exceptions are only 5 to 11 industries, depending on the production function and estimation method used) and only sometimes fall outside of the $[0; 1]$ interval (at the 95% confidence level), a result which is more frequently found with the VES_L specification when using the GMM technique (for 22 industries, comparatively to between 10 and 14 industries in the remaining cases). The implied values for β_{12} and σ_0 are then presented in Table 3.21.3, some of which fall outside of the economic meaningful range as a consequence of the underlying estimates.

[TABLES 3.21.1, 3.21.2 AND 3.21.3]

Looking at the results, it is important to evaluate how many industries could be characterized by constant elasticity of substitution specifications, namely the CES or Cobb-Douglas production functions (the Leontief possibility, $\psi \to -\infty$, was already previously discarded by the normalized CES production function estimations). According to the chi-square test (Table 3.22), the Cobb-Douglas specification ($\upsilon = \pi_0$) is not rejected for between 8 and 14 industries at the 5% significance level (or for between 12 and 19 industries at the 1% significance level), depending on the production function and estimation technique used. Furthermore, the CES specification ($\upsilon = 1$ in the case of the VES_L function, or $\upsilon = 0$ in the case of the VES_K function) is not rejected for between 8 and 17 industries at the 5% significance level (or for between 9 and 21 industries at the 1% significance level – Table 3.23). Taking into account that there may be industries which simultaneously admit the Cobb-Douglas and CES specification

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from parameter υ estimates, and considering also the cases where the confidence intervals of ψ include the Cobb-Douglas possibility, there are between 22 and 26 industries which do not reject that the elasticity of substitution is time-invariant within the 95 percent confidence interval (or between 28 and 34 industries within the 99 percent confidence interval).

[TABLES 3.22 AND 3.23]

The remaining industries could be described by a VES_L or VES_K production function if parameter υ estimates are comprised between π_0 and 1 in the case of the former, or between 0 and π_0 in the case of the latter. For the VES_L function, discarding the 23 or 27 estimates which to do not comply with this restriction at the 5% significance level (resp. 20 or 23 industries at the 1% significance level), there are either 14 or 19 industries that are consistent with this specification (resp. 12 or 14 industries at the 1% significance level), whereas for the VES_K function, discarding the 22 estimates which to do not comply with this restriction at the 5% significance level (resp. 17 or 19 industries at the 1% significance level), there are either 17 or 21 industries that are consistent with this specification (resp. 14 or 18 industries at the 1% significance level). Among these, there are industries which simultaneously admit the VES_L and the VES_K specifications (for example, industries 27 or 55), which suggests that they could be described by a more general VES production function, such as the one described in equation (29). Besides, there are industries where parameter υ estimates admit the constancy of the substitution elasticity parameter using the VES_L (resp. VES_K) specification, whereas the other specification suggests its time variability, indicating that the better performing specification for that particular industry is most likely the VES_K (resp. VES_L) production function (this is the case, for example, of industry 50 or industry 2, respectively).

Consequently, in line with the aggregate economy result, there are a number of industries where a time-invariant elasticity of substitution is not rejected (approximately between a third and 40% of the overall figure using the conventional 95 percent confidence interval); in the remaining cases, the elasticity of substitution is apparently variable and therefore the functional form of the production function should not be *a priori* restricted to the CES or to the Cobb-Douglas specifications. There are a number of reasons why the sectoral elasticities of substitution can change over time (see also Hicks, 1963, and Klump and Preissler, 2000). To name a few, changes in the relative prices of factors which may lead to inter-sectoral reallocation of production, the adoption of new methods of production (either determined by technological innovations or knowledge spillovers from firms within the same sector or also from other sectors) which can make it easier or more convenient to substitute one factor for the

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other, changes in the sectoral institutional framework, as powerful trade unions may be associated with low sectoral elasticities of substitution (Maki and Meredith, 1987), or the degree of openness to trade, as it has already been discussed (despite for the case of small open economies) that an open economy production function is generally associated with a higher elasticity of substitution than a closed economy (Azariadis, 1996; Ventura, 1997).

Industry-level factor augmentation rates. As previously mentioned, the single-equation approach requires restrictive assumptions on the nature of technological change (i.e., Hicks-, Harrod-or Solow-neutrality). Consequently, the industry-level estimates and the implied technological change coefficients are presented in Table 3.24.1 to Table 3.24.4). Conversely, the normalized system approach allows the direct estimation of the capital- and labour-augmentation rates without making any additional assumption (reported in Table 3.21.1 and Table 3.21.2); in this case, since both are obtained from the same estimation, we can also determine the underlying growth rates of net factor augmentation.

Table 3.24.1 reports the OLS results. The implied growth rates of the technological change parameters are mostly positive in the case of Hicks-neutrality and Harrod-neutrality, a result found for between 45 and 53 industries, using any of the functions. In the case of Solow-neutrality, however, only 33 industries in the case of the VES_1 equation, or 28 industries in the case of the VES_2 equation, show positive growth rates of capital-augmenting technological progress.

[TABLE 3.24.1]

The overall picture looks very similar in the case of the 2SLS and GIV estimations (Table 3.24.2 and Table 3.24.3, respectively). Even so, in the case of the 2SLS method, the Harrod-neutrality assumption generates the highest number of industries with positive rates of labour-augmenting technological change (56 in the case of the VES_1 specification and 49 in the case of the VES_2). Under the assumption of Solow-neutrality, negative capital-augmenting growth rates are also found for the majority of the industries (35 or 42 industries, respectively in the VES_1 or VES_2 function). Regarding the GIV technique, the growth rate of the Hicks-neutral and labour-augmenting technological change are positive for, respectively, 48 and 49 industries in the case of the VES_1 equation and 44 industries in the case of the VES_2 specification. An important difference lies on the capital-augmentation growth rates under Solow-neutrality in the VES_1 case, which are now positive for the majority of the industries (for 40 industries vs. 31 industries using the VES_2 specification).

[TABLES 3.24.2 AND 3.24.3]

The results from the OLS regressions of differenced variables are in line with the previous methods (Table 3.24.4): we can observe that the VES_1 specification generates more positive coefficients than the VES_2 equation irrespective of the technological change assumption (48 to 54 industries vs. 31 to 45 industries, respectively), with a lower than half overall figure of positive results being found only for the Solow-neutrality assumption under the VES_2 specification.

[TABLE 3.24.4]

Similarly to the verified for the aggregate economy, the Solow-neutrality assumption tends to generate higher estimates in absolute terms, with the highest industry-level average being obtained from this method (Table 3.20). Moreover, it can also be noticed that sometimes the average of the implied industry-level coefficients are negative: for example, when all industries are considered, this is the case of the labour-augmenting growth rate using the VES_2 equation and the OLS method or the growth rate of the Hicks-neutral technological change parameter using the VES_1 equation and the 2SLS method.

The normalized system approach allows the joint identification of the factor augmentation growth rates without the need to make any neutrality assumption. The results are presented in Table 3.21.1 and Table 3.21.2 and show that between 33 and 40 industries, depending on the production function and estimation method used, display negative rates of capital-augmenting technological change (or, considering only the significant estimates, between 29 and 36 industries, which nonetheless represent a slightly higher share of the total number of industries with an average of 60%), whereas between 45 and 50 industries have positive rates of labour-augmenting technological change (or between 42 to 48 industries considering only significant estimates, representing more than 70% the total number of industries). It follows that the majority of the industries is characterized by net labour-augmentation, a result found for between 39 and 46 industries (or between 33 and 39 industries considering only significant estimates, which represent more than two thirds of the total number of industries). Similarly to the conclusions obtained with the CES production function, many of the exceptions are service industries (e.g. industries 47 or 49 to 52).

Lastly, note that the average of the industry-level net labour-augmentation rates is always negative except in the estimation of the VES_K production function using the NLSUR method (Table 3.25). These results are largely influenced not only by estimates which fall outside of

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the economic meaningful range, but also by outliers, some of which stem from the finding of more industries where the Cobb-Douglas specification is a possibility than in the estimation of the normalized CES production function, therefore making it more difficult to empirically determine the bias of technological change. However, if we consider the medians or the averages excluding the outliers, the results become very similar: the medians are in the range of 1.71% to 2.22% (vs. 2.08% and 2.37% in the case of the normalized CES), while the average of the significant values excluding outliers is comprised between 1.60% and 1.93% (vs. 1.94% and 2.03% in the case of the normalized CES). Net labour-augmentation is therefore the prevailing conclusion at the industry-level using either of the VES production function specifications, which is in line with both the aggregate economy and the CES production function results.

[TABLE 3.25]

3.6. Concluding remarks

The elasticity of substitution between capital and labour and the bias in technological change are crucial parameters in many economic studies and, until recently, their joint identification was problematic. In this essay, we estimated these parameters using not only the conventional single equation approach, but also the normalized system approach which highly alleviates the identification issues.

The estimation is performed for the US aggregate economy, but also at the industry-level, for a relatively long time span (from 1947 to 2014). According to our findings, the US aggregate elasticity of substitution is most likely around 0.6 (or even less according to most single-equation estimates) and shows a reduced variation over time, which is confirmed by parameter estimates suggesting that the VES production function tends to the CES specification. However, even if lower than unity elasticities of substitution also characterize the vast majority of the US industries, this is not the case for the time-invariance of their values, which only appears to be a feature of less than half of the total number of industries. Disaggregated industry-level studies therefore require the use of production functions with more flexible functional forms than the widely used CES production function.

Technological change is found to be net labour-augmenting at the aggregate level, at an average rate of around 1.1% to 1.5%, resulting from a positive labour-augmentation rate, combined with a decline in the capital efficiency level, which is also the prevailing conclusion at the industry-level. Given the gross complementarity between capital and labour, this means that

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technological change is, in general, capital biased. Models that consider technological progress to be purely labour-augmenting should therefore be interpreted with some caution; this is also the case of some industry-level studies as the previous conclusions are not uniform: for example, in some primary industries, there appears to be an increase in capital efficiency and net capital-augmentation is found particularly in a number of service industries.

The analysis performed provides rather clear results regarding the identification of the elasticity of substitution and the direction of technological change for the US economy and the 65 industries represented in the NIPAs. Still, it should be noted that it is based on given technological specifications (either CES or VES production functions, or the assumption of constant factor-augmenting growth rates) which surely have an impact on the estimation results.

Lastly, it would be important to replicate this analysis in other countries for comparative purposes: in particular, it would be enlightening to test whether the tendency towards a time-invariant elasticity of substitution at the aggregate level is also reproduced for other technologically advanced countries, such as those in the European Union, the United Kingdom or Japan.

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3.7. Tables and Figures

Table 3.1.1: Summary statistics of regression variables: *yk* and *rp*

Industry		*yk*			*rp*		
		Mean	St. Dev.	$\Delta_{1947\text{-}2014}$	Mean	St. Dev.	$\Delta_{1947\text{-}2014}$
AG	Aggregate	0.9841	0.0890	-0.2164	0.1524	0.1235	-0.2589
1	Farms	0.3376	0.2040	0.2885	-0.2886	0.3195	0.5672
2	Forestry, fishing and related activities	1.2219	0.3000	-0.8240	0.4462	0.4985	-1.4196
3	Oil and gas extraction	0.1867	0.3331	-0.0768	-0.0707	0.3255	0.1338
4	Mining except oil and gas	0.1116	0.2856	-0.7175	-0.6794	0.4318	-0.0868
5	Support activities for mining	0.8929	0.3883	-0.2840	-0.0635	0.3687	0.1926
6	Utilities	0.7383	0.2572	-0.3675	0.4001	0.2781	-0.2899
7	Construction	2.2512	0.2539	-0.7124	-0.1266	0.3012	0.1654
8	Wood products	1.9810	0.2395	-0.9188	0.5375	0.3355	-0.8369
9	Nonmetallic mineral products	1.5896	0.3345	-0.7700	0.5720	0.4628	-0.7266
10	Primary metals	1.7091	0.4280	-1.2292	0.6912	0.5621	-1.0251
11	Fabricated metal products	1.6259	0.2771	-0.7690	0.2533	0.2053	-0.5151
12	Machinery	1.8417	0.4865	-1.2955	0.8674	0.6494	-1.3914
13	Computer and electronic products	-0.1215	0.5552	0.5805	-1.5420	0.9437	2.0303
14	Electrical equipment appliances and components	1.2884	0.4174	-1.3794	0.4605	0.5709	-1.6317
15	Motor vehicles bodies and trailers and parts	2.1749	0.4055	-0.8455	1.1444	0.4904	-0.3451
16	Other transportation equipment	1.2814	0.4496	-0.5033	0.1911	0.5285	0.0146
17	Furniture and related products	2.8194	0.3511	-0.8535	0.8971	0.2949	-0.6395
18	Miscellaneous manufacturing	1.0371	0.1908	-0.8311	-0.3696	0.2731	0.3586
19	Food and beverage and tobacco products	0.5041	0.1576	-0.1376	-0.3005	0.1610	-0.0042
20	Textile mills and textile product mills	1.6906	0.1442	-0.0371	0.1744	0.2278	-0.2626
21	Apparel and leather and allied products	2.7857	0.5709	-1.5157	1.2926	0.6367	-1.0188
22	Paper products	0.9813	0.2567	-0.7500	0.1274	0.2941	-0.8795
23	Printing and related support activities	1.9231	0.2932	-0.9275	0.0614	0.2763	-0.2207
24	Petroleum and coal products	0.2094	0.3827	-0.9021	-0.2653	0.4767	-0.4211
25	Chemical products	0.8052	0.3264	-0.7559	0.2616	0.2670	-0.4067
26	Plastics and rubber products	1.2284	0.2174	-0.8846	0.2443	0.2688	-0.8921
27	Wholesale Trade	1.3936	0.3145	-0.9939	0.2181	0.3338	-0.8481
28	Retail Trade	1.9195	0.3557	-1.0312	0.2649	0.3270	-0.9530
29	Air transportation	1.3092	0.2492	0.6017	0.2732	0.2670	0.1421
30	Rail transportation	0.9089	0.1521	-0.2642	-0.1644	0.2690	0.1372
31	Water transportation	-0.1851	0.2596	0.7931	-0.8255	0.3445	0.7957

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Industry		*yk*			*rp*		
		Mean	St. Dev.	$\Delta_{1947\text{-}2014}$	Mean	St. Dev.	$\Delta_{1947\text{-}2014}$
32	Truck transportation	1.4952	0.2027	0.2743	0.0674	0.2285	-0.2752
33	Transit and ground passenger transportation	0.7512	0.2688	0.6991	0.0499	0.2359	-0.2455
34	Pipeline transportation	0.9035	0.3213	0.8368	0.4269	0.3859	1.1987
35	Other transportation and support activities	1.0149	0.3662	1.0891	0.1152	0.2428	0.2852
36	Warehousing and storage	0.7500	0.3928	0.9869	-0.9341	0.7128	0.4611
37	Publishing industries (includes software)	1.1099	0.2591	-0.7970	0.0825	0.1346	-0.2338
38	Motion picture and sound recording industries	0.6963	0.2299	-0.8907	0.2630	0.2773	-0.9377
39	Broadcasting and telecommunications	0.7198	0.2207	-0.8296	0.1464	0.1550	-0.3082
40	Information and data processing services	2.9529	1.3744	-4.3204	2.2496	1.5782	-4.7410
41	Federal Reserve banks, credit intermediation and related activities	1.7266	0.7289	-1.8715	1.1161	0.7557	-2.0760
42	Securities, commodity contracts and investments	4.0519	1.3972	-3.0458	2.1140	1.6295	-4.8938
43	Insurance carriers and related activities	2.2224	1.0491	-2.7637	1.0092	0.9559	-2.1576
44	Funds, trusts and other financial vehicles	0.1011	0.5580	1.5456	-0.4734	0.4729	1.5070
45	Real estate	-0.0063	0.0555	0.1890	-0.0628	0.0465	0.1723
46	Rental and leasing services and lessors of intangible assets	1.3719	0.6340	-2.0982	1.1537	0.6305	-2.0216
47	Legal services	2.0903	0.4277	-1.1363	1.1937	0.7663	-2.0095
48	Computer systems design and related services	3.8655	1.0651	-2.2394	2.5626	1.6677	-4.4629
49	Miscellaneous professional scientific and technical services	2.4881	0.4547	-1.4645	1.4704	0.8580	-2.8121
50	Management of companies and enterprises	3.1192	0.7335	-2.1325	2.0706	1.3831	-3.7150
51	Administrative and support services	2.7446	0.5590	-0.8878	1.3164	0.9499	-1.9374
52	Waste management and remediation services	0.8002	0.2774	1.0164	0.1120	0.3513	0.2573
53	Educational services	3.0527	0.4621	-1.3758	1.1904	0.8087	-2.6821
54	Ambulatory health care services	2.7531	0.6771	-2.1277	0.5871	0.9218	-2.6796
55	Hospitals, nursing and residential care facilities	2.4390	0.5113	-1.7007	0.9549	1.0981	-3.2085
56	Social assistance	2.9859	0.4764	-0.4645	0.7662	0.6266	-1.5592
57	Performing arts, spectator sports, museums and related activities	1.2853	0.3795	0.8437	0.4027	0.4539	-0.5529
58	Amusement, gambling and recreation industries	1.6266	0.1901	-0.3114	0.6848	0.3587	-0.8083
59	Accommodation	1.1441	0.1498	-0.2684	0.0602	0.2192	-0.0711
60	Food services and drinking places	1.5216	0.0945	-0.3405	-0.4505	0.3828	0.1523
61	Other services except government	1.5938	0.2492	-0.6324	-0.6278	0.6869	1.7105
62	Federal General government	1.0046	0.2450	-0.5537	0.5124	0.3389	-0.8820
63	Federal Government enterprises	1.1590	0.4622	-1.6896	0.6601	0.5125	-1.8133
64	S&L Government enterprises	0.7958	0.2865	-0.5101	0.4119	0.3819	-0.6710
65	S&L General Government	0.9828	0.0723	0.1028	0.2530	0.1982	-0.2303

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Table 3.1.2: Summary statistics of regression variables: *yl* and *wp*

Industry		*yl*			*wp*		
		Mean	St. Dev.	$\Delta_{1947\text{-}2014}$	Mean	St. Dev.	$\Delta_{1947\text{-}2014}$
AG	Aggregate	0.1923	0.3012	0.9664	-0.3813	0.3316	1.0034
1	Farms	0.0424	0.6720	2.0893	-0.7644	0.5666	1.7154
2	Forestry, fishing and related activities	0.6783	0.2063	-0.1992	0.0187	0.1986	0.3466
3	Oil and gas extraction	1.6557	0.2116	0.6539	0.1157	0.3393	-0.1599
4	Mining except oil and gas	0.5704	0.4688	1.0882	-0.1001	0.2999	0.0648
5	Support activities for mining	0.0093	0.4115	1.5131	-0.5149	0.3975	1.2888
6	Utilities	0.9819	0.2512	0.9776	-0.2754	0.2879	0.8126
7	Construction	0.1527	0.1770	0.6160	0.0405	0.1752	0.4802
8	Wood products	-0.0160	0.2772	0.8647	-0.2918	0.2807	0.8334
9	Nonmetallic mineral products	0.2554	0.2382	0.7856	-0.2046	0.2816	0.7570
10	Primary metals	0.2077	0.1987	0.6115	-0.2683	0.2048	0.4539
11	Fabricated metal products	0.0960	0.2753	0.7512	-0.2047	0.2324	0.6590
12	Machinery	0.0083	0.3765	1.1414	-0.4831	0.4662	1.2104
13	Computer and electronic products	-1.9241	1.4728	4.2133	-2.2685	1.3404	3.6564
14	Electrical equipment appliances and components	-0.0477	0.3692	0.8487	-0.6434	0.4720	1.0742
15	Motor vehicles bodies and trailers and parts	0.6439	0.3824	1.5049	0.1801	0.3453	1.1467
16	Other transportation equipment	0.0009	0.3195	1.1850	-0.4194	0.3172	0.9002
17	Furniture and related products	-0.1311	0.2911	0.9064	-0.2990	0.2521	0.8572
18	Miscellaneous manufacturing	-0.3958	0.5529	1.7667	-0.7034	0.4606	1.4174
19	Food and beverage and tobacco products	0.2904	0.3923	1.1286	-0.3157	0.3346	0.9930
20	Textile mills and textile product mills	-0.2267	0.4785	1.5565	-0.4794	0.4767	1.6499
21	Apparel and leather and allied products	-0.2391	0.3812	1.2241	-0.5025	0.3985	0.8980
22	Paper products	0.3108	0.2588	0.7241	-0.2512	0.2916	0.8554
23	Printing and related support activities	-0.0116	0.2273	0.7617	-0.1924	0.1982	0.5936
24	Petroleum and coal products	0.9946	0.7207	1.5646	-0.1531	0.3392	0.1734
25	Chemical products	0.5078	0.4868	1.7643	-0.3855	0.3952	1.1349
26	Plastics and rubber products	0.2402	0.2563	0.7200	-0.2327	0.2857	0.7253
27	Wholesale Trade	-0.2961	0.6012	1.7955	-0.6698	0.5916	1.7099
28	Retail Trade	-0.1954	0.3619	1.1450	-0.4142	0.3405	1.1177
29	Air transportation	-0.1100	0.5218	2.0591	-0.5785	0.6421	2.4610
30	Rail transportation	-0.0488	0.4972	1.5451	-0.5086	0.4470	1.2381
31	Water transportation	0.3397	0.4234	1.2545	-0.4518	0.4799	1.2509
32	Truck transportation	-0.0180	0.3051	1.1100	-0.3009	0.3586	1.3671

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	Industry	*yl*			*wp*		
		Mean	St. Dev.	$\Delta_{1947\text{-}2014}$	Mean	St. Dev.	$\Delta_{1947\text{-}2014}$
33	Transit and ground passenger transportation	0.3793	0.1143	-0.0263	-0.5259	0.5943	1.6457
34	Pipeline transportation	0.0284	0.8393	3.1355	-1.0115	0.7807	2.4567
35	Other transportation and support activities	0.2939	0.1471	0.1048	-0.3657	0.4927	1.1518
36	Warehousing and storage	-0.2582	0.4032	0.9122	-0.4948	0.4163	1.1717
37	Publishing industries (includes software)	-0.1842	0.5386	1.7979	-0.6508	0.4107	1.4802
38	Motion picture and sound recording industries	0.3557	0.4642	1.1118	-0.7111	0.5804	1.2094
39	Broadcasting and telecommunications	-0.2172	0.8457	2.7467	-1.0716	0.7215	2.0342
40	Information and data processing services	0.2183	0.3490	0.1749	-0.5657	0.2790	1.0064
41	Federal Reserve banks, credit intermediation and related activities	0.2594	0.3173	0.8215	-0.5284	0.3469	1.0518
42	Securities, commodity contracts and investments	-0.9545	0.7133	2.0283	-1.1368	0.7840	2.7885
43	Insurance carriers and related activities	-0.0175	0.3630	1.1887	-0.3904	0.2874	0.8775
44	Funds, trusts and other financial vehicles	-0.2324	0.8719	3.1394	-1.1419	0.9462	3.1925
45	Real estate	2.6793	0.1769	0.5842	-0.2696	0.3099	0.9026
46	Rental and leasing services and lessors of intangible assets	1.3242	0.4379	1.4853	-0.3124	0.3952	1.2110
47	Legal services	0.2455	0.2392	0.6805	-0.3826	0.5161	1.5036
48	Computer systems design and related services	-0.0405	0.2003	0.4528	-0.5534	0.5361	2.0384
49	Miscellaneous professional scientific and technical services	-0.2794	0.4042	0.9782	-0.8150	0.6741	2.0673
50	Management of companies and enterprises	0.0104	0.4215	1.1586	-0.7195	1.0330	2.9859
51	Administrative and support services	-0.3819	0.4084	1.6382	-0.7225	0.6094	2.2081
52	Waste management and remediation services	0.0249	0.3369	1.1014	-0.8317	0.7583	2.2174
53	Educational services	-0.0603	0.3351	0.9090	-0.2728	0.4643	1.2471
54	Ambulatory health care services	0.0186	0.2746	0.7841	-0.1261	0.3329	0.9205
55	Hospitals, nursing and residential care facilities	0.0849	0.2165	0.6475	-0.2723	0.4678	1.3848
56	Social assistance	-0.5447	0.6609	2.0039	-0.6690	0.6925	2.2934
57	Performing arts, spectator sports, museums and related activities	-0.2658	0.3900	1.1589	-1.0141	0.7580	2.4351
58	Amusement, gambling and recreation industries	0.4830	0.0985	-0.0360	-0.0533	0.1797	0.2571
59	Accommodation	0.2444	0.2600	0.7491	-0.1809	0.2845	0.6474
60	Food services and drinking places	0.1821	0.1228	0.2553	0.0203	0.1093	0.1573
61	Other services except government	0.3931	0.1061	-0.2643	0.2362	0.1920	-0.4381
62	Federal General government	0.1315	0.4187	0.7910	-0.8431	0.5872	1.4825
63	Federal Government enterprises	0.9090	0.2361	0.4074	-0.0496	0.3840	0.6824
64	S&L Government enterprises	1.2844	0.1588	-0.0651	0.0646	0.3743	0.6118
65	S&L General Government	0.3337	0.1057	0.2051	-0.3682	0.3143	0.6335

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Table 3.1.3: Summary statistics of regression variables: *kl* and *wr*

Industry		*kl*			*wr*		
		Mean	St. Dev.	$\Delta_{1947\text{-}2014}$	Mean	St. Dev.	$\Delta_{1947\text{-}2014}$
AG	Aggregate	-0.7918	0.3790	1.1828	-0.5337	0.4474	1.2623
1	Farms	-0.2952	0.5413	1.8009	-0.4758	0.4166	1.1482
2	Forestry, fishing and related activities	-0.5436	0.2850	0.6248	-0.4275	0.6131	1.7662
3	Oil and gas extraction	1.4689	0.3630	0.7307	0.1864	0.4308	-0.2937
4	Mining except oil and gas	0.4588	0.5329	1.8057	0.5793	0.5198	0.1516
5	Support activities for mining	-0.8836	0.6693	1.7971	-0.4515	0.6066	1.0961
6	Utilities	0.2435	0.4323	1.3451	-0.6755	0.5041	1.1025
7	Construction	-2.0984	0.3327	1.3284	0.1670	0.3826	0.3148
8	Wood products	-1.9969	0.4914	1.7835	-0.8293	0.5687	1.6703
9	Nonmetallic mineral products	-1.3342	0.5271	1.5556	-0.7766	0.7026	1.4836
10	Primary metals	-1.5014	0.5826	1.8407	-0.9595	0.7417	1.4791
11	Fabricated metal products	-1.5300	0.5383	1.5202	-0.4579	0.3982	1.1741
12	Machinery	-1.8334	0.8171	2.4369	-1.3506	1.0779	2.6018
13	Computer and electronic products	-1.8026	1.1045	3.6329	-0.7266	0.7353	1.6260
14	Electrical equipment appliances and components	-1.3361	0.7468	2.2281	-1.1039	1.0131	2.7059
15	Motor vehicles bodies and trailers and parts	-1.5309	0.7165	2.3504	-0.9643	0.7472	1.4919
16	Other transportation equipment	-1.2806	0.7295	1.6883	-0.6105	0.8002	0.8856
17	Furniture and related products	-2.9505	0.6088	1.7599	-1.1961	0.4300	1.4967
18	Miscellaneous manufacturing	-1.4329	0.7106	2.5978	-0.3338	0.4257	1.0588
19	Food and beverage and tobacco products	-0.2137	0.4818	1.2662	-0.0153	0.3789	0.9972
20	Textile mills and textile product mills	-1.9173	0.4533	1.5936	-0.6538	0.4805	1.9125
21	Apparel and leather and allied products	-3.0248	0.9339	2.7398	-1.7951	1.0180	1.9167
22	Paper products	-0.6705	0.4999	1.4741	-0.3786	0.5721	1.7348
23	Printing and related support activities	-1.9347	0.5029	1.6893	-0.2538	0.4100	0.8143
24	Petroleum and coal products	0.7852	0.7500	2.4667	0.1121	0.4873	0.5945
25	Chemical products	-0.2974	0.7833	2.5202	-0.6471	0.6208	1.5416
26	Plastics and rubber products	-0.9882	0.4322	1.6045	-0.4770	0.5168	1.6173
27	Wholesale Trade	-1.6897	0.9083	2.7894	-0.8879	0.9011	2.5580
28	Retail Trade	-2.1149	0.7110	2.1763	-0.6791	0.6346	2.0707
29	Air transportation	-1.4191	0.4783	1.4574	-0.8517	0.7750	2.3188
30	Rail transportation	-0.9577	0.5991	1.8093	-0.3442	0.5869	1.1009
31	Water transportation	0.5248	0.4133	0.4615	0.3736	0.5930	0.4551
32	Truck transportation	-1.5132	0.2308	0.8357	-0.3683	0.4349	1.6423

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	Industry	*kl*			*wr*		
		Mean	St. Dev.	$\Delta_{1947\text{-}2014}$	Mean	St. Dev.	$\Delta_{1947\text{-}2014}$
33	Transit and ground passenger transportation	-0.3718	0.2612	-0.7253	-0.5758	0.7600	1.8912
34	Pipeline transportation	-0.8750	0.8030	2.2987	-1.4384	0.7543	1.2580
35	Other transportation and support activities	-0.7210	0.2955	-0.9843	-0.4809	0.6122	0.8666
36	Warehousing and storage	-1.0081	0.1055	-0.0747	0.4393	0.6655	0.7106
37	Publishing industries (includes software)	-1.2942	0.7802	2.5949	-0.7333	0.4636	1.7140
38	Motion picture and sound recording industries	-0.3406	0.5774	2.0025	-0.9742	0.7639	2.1471
39	Broadcasting and telecommunications	-0.9370	1.0508	3.5764	-1.2180	0.8394	2.3425
40	Information and data processing services	-2.7346	1.4442	4.4953	-2.8153	1.8095	5.7475
41	Federal Reserve banks, credit intermediation and related activities	-1.4672	1.0375	2.6929	-1.6445	1.0952	3.1278
42	Securities, commodity contracts and investments	-5.0064	1.9642	5.0742	-3.2508	2.3006	7.6823
43	Insurance carriers and related activities	-2.2399	1.4004	3.9524	-1.3996	1.2326	3.0351
44	Funds, trusts and other financial vehicles	-0.3334	0.5471	1.5938	-0.6686	0.6185	1.6855
45	Real estate	2.6855	0.1704	0.3952	-0.2068	0.2790	0.7303
46	Rental and leasing services and lessors of intangible assets	-0.0477	0.9439	3.5835	-1.4661	0.9108	3.2327
47	Legal services	-1.8448	0.5252	1.8169	-1.5763	1.1944	3.5131
48	Computer systems design and related services	-3.9060	1.0563	2.6921	-3.1160	2.0623	6.5013
49	Miscellaneous professional scientific and technical services	-2.7675	0.8256	2.4427	-2.2855	1.5027	4.8794
50	Management of companies and enterprises	-3.1088	1.0845	3.2910	-2.7901	2.3395	6.7009
51	Administrative and support services	-3.1265	0.8708	2.5260	-2.0389	1.4878	4.1455
52	Waste management and remediation services	-0.7753	0.2524	0.0850	-0.9436	0.9702	1.9601
53	Educational services	-3.1130	0.6570	2.2848	-1.4632	1.2019	3.9293
54	Ambulatory health care services	-2.7345	0.9040	2.9118	-0.7132	1.2409	3.6000
55	Hospitals, nursing and residential care facilities	-2.3541	0.6721	2.3481	-1.2272	1.5278	4.5933
56	Social assistance	-3.5306	1.0278	2.4684	-1.4352	1.2403	3.8526
57	Performing arts, spectator sports, museums and related activities	-1.5511	0.1179	0.3153	-1.4168	1.0654	2.9881
58	Amusement, gambling and recreation industries	-1.1436	0.1674	0.2754	-0.7381	0.4724	1.0654
59	Accommodation	-0.8998	0.2922	1.0175	-0.2411	0.3970	0.7185
60	Food services and drinking places	-1.3395	0.1746	0.5959	0.4709	0.4157	0.0050
61	Other services except government	-1.2007	0.2047	0.3680	0.8640	0.8568	-2.1486
62	Federal General government	-0.8731	0.6627	1.3447	-1.3555	0.9246	2.3645
63	Federal Government enterprises	-0.2501	0.6403	2.0970	-0.7097	0.8324	2.4957
64	S&L Government enterprises	0.4886	0.1963	0.4450	-0.3473	0.6483	1.2828
65	S&L General Government	-0.6491	0.1294	0.1023	-0.6212	0.5044	0.8638

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Table 3.2.1: Endogeneity tests p-values based on 2SLS regressions – Durbin and Wu-Hausman

Industry	CES_1		CES_2		CES_3		VES_1		VES_2	
	Durbin	Wu-Hausman	Durbin	Wu-Hausman	Durbin	Wu-Hausman	Durbin	Wu-Hausman	Durbin	Wu-Hausman
AG	0.5243	0.5380	0.0958*	0.1040	0.0845*	0.0919*	0.0524*	0.0602*	0.4145	0.4438
1	0.0177**	0.0193**	0.3822	0.3973	0.0942*	0.1023	0.0000***	0.0000***	0.2468	0.2722
2	0.0112**	0.0121**	0.2858	0.3005	0.0007***	0.0006***	0.2682	0.2946	0.7002	0.7216
3	0.0001***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
4	0.0044***	0.0046***	0.3886	0.4037	0.0812*	0.0884*	0.0004***	0.0003***	0.0013***	0.0012***
5	0.0000***	0.0000***	0.0183**	0.0199**	0.0000***	0.0000***	0.0229**	0.0260**	0.0113**	0.0125**
6	0.0010***	0.0010***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
7	0.0038***	0.0039***	0.5454	0.5587	0.2188	0.2323	0.0253**	0.0289**	0.3728	0.4018
8	0.0369**	0.0404**	0.0001***	0.0001***	0.0006***	0.0005***	0.1343	0.1518	0.0006***	0.0004***
9	0.2698	0.2842	0.8497	0.8548	0.0005***	0.0004***	0.0000***	0.0000***	0.7248	0.7449
10	0.0393**	0.0393**	0.0138**	0.0149**	0.0050***	0.0052***	0.4888	0.5175	0.2552	0.2809
11	0.1813	0.1937	0.8546	0.8595	0.8544	0.8593	0.0582*	0.0668*	0.1789	0.2002
12	0.8280	0.8338	0.6866	0.6966	0.9950	0.9951	0.0031***	0.0031***	0.0066***	0.0071***
13	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
14	0.1089	0.1179	0.6951	0.7049	0.5724	0.5852	0.0065***	0.0070***	0.0315**	0.0360**
15	0.0101**	0.0108**	0.0188**	0.0205**	0.6583	0.6690	0.0032***	0.0032***	0.9995	0.9995
16	0.0062***	0.0065***	0.0363**	0.0397**	0.0005***	0.0004***	0.6112	0.6366	0.0552*	0.0634*
17	0.0000***	0.0000***	0.4293	0.4442	0.0001***	0.0000***	0.0007***	0.0006***	0.9762	0.9783
18	0.0000***	0.0000***	0.0724*	0.0790*	0.0001***	0.0000***	0.0081***	0.0088***	0.1827	0.2042
19	0.1507	0.1618	0.0160**	0.0174**	0.0024***	0.0023***	0.5431	0.5707	0.0377**	0.0433**
20	0.0398**	0.0436**	0.8107	0.8170	0.1571	0.1686	0.0216**	0.0246**	0.0974*	0.1111
21	0.0002***	0.0002***	0.0300**	0.0329**	0.0019***	0.0019***	0.0009***	0.0008***	0.0230**	0.0262**
22	0.0185**	0.0201**	0.1044	0.1131	0.0657*	0.0718*	0.0000***	0.0000***	0.0199**	0.0226**
23	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	1.0000	1.0000	0.0000***	0.0000***
24	0.1077	0.1167	0.2624	0.2768	0.0000***	0.0000***	0.3138	0.3416	0.0003***	0.0002***
25	0.5542	0.5673	0.0025***	0.0025***	0.0658*	0.0718*	0.0000***	0.0000***	0.0016***	0.0015***
26	0.0798*	0.0870*	0.0262**	0.0286**	0.0000***	0.0000***	0.0000***	0.0000***	0.0822*	0.0940*
27	0.4469	0.4616	0.3063	0.3212	0.0050***	0.0052***	0.0896*	0.1023	0.2605	0.2865
28	0.7379	0.7464	0.0450**	0.0492**	0.4033	0.4183	0.8066	0.8218	0.4700	0.4989
29	0.0001***	0.0001***	0.0000***	0.0000***	0.0829*	0.0902*	0.0171**	0.0193**	0.0000***	0.0000***
30	0.3509	0.3660	0.2373	0.2512	0.4858	0.5000	0.0504*	0.0579*	0.5176	0.5457
31	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
32	0.1503	0.1614	0.2835	0.2981	0.0168**	0.0182**	0.1637	0.1838	0.2680	0.2944
33	0.0003***	0.0003***	0.0023***	0.0023***	0.2285	0.2422	0.0000***	0.0000***	0.0000***	0.0000***
34	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
35	0.4139	0.4289	0.0000***	0.0000***	0.2433	0.2574	0.5364	0.5642	0.0002***	0.0001***
36	0.9646	0.9658	0.4220	0.4369	0.9576	0.9590	0.0849*	0.0971*	0.0167**	0.0189**

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Industry	CES_1		CES_2		CES_3		VES_1		VES_2	
	Durbin	Wu-Hausman	Durbin	Wu-Hausman	Durbin	Wu-Hausman	Durbin	Wu-Hausman	Durbin	Wu-Hausman
37	0.0880*	0.0957*	0.6641	0.6747	0.0000***	0.0000***	0.0151**	0.0169**	0.4531	0.4822
38	0.0004***	0.0003***	0.0643*	0.0702*	0.0064***	0.0067***	0.0115**	0.0127**	0.1796	0.2010
39	0.0000***	0.0000***	0.5297	0.5432	0.0090***	0.0095***	0.0000***	0.0000***	0.0021***	0.0020***
40	0.0688*	0.0751*	0.0008***	0.0007***	0.0006***	0.0005***	0.0215**	0.0244**	0.0663*	0.0761*
41	0.0000***	0.0000***	0.2174	0.2308	0.0000***	0.0000***	0.7839	0.8005	0.4877	0.5164
42	0.0000***	0.0000***	0.3680	0.3831	0.0000***	0.0000***	0.0000***	0.0000***	0.7050	0.7262
43	0.0004***	0.0003***	0.2338	0.2476	0.0006***	0.0005***	0.5735	0.6003	0.3487	0.3774
44	0.0001***	0.0001***	0.2122	0.2255	0.1531	0.1643	0.0002***	0.0001***	0.3896	0.4187
45	0.1396	0.1502	0.4970	0.5111	0.4537	0.4683	0.5974	0.6233	0.3729	0.4019
46	0.1028	0.1115	0.0833*	0.0906*	0.0139**	0.0150**	0.0257**	0.0293**	0.0969*	0.1104
47	0.0081***	0.0085***	0.3614	0.3766	0.8641	0.8687	0.0215**	0.0244**	0.2319	0.2565
48	0.0000***	0.0000***	0.1892	0.2018	0.0252**	0.0275**	0.1461	0.1647	0.0410**	0.0470**
49	0.0000***	0.0000***	0.4292	0.4440	0.0000***	0.0000***	0.0297**	0.0339**	0.0019***	0.0018***
50	0.2419	0.2559	0.5398	0.5532	0.6592	0.6699	0.1195	0.1355	0.2155	0.2392
51	0.0573*	0.0627*	0.1790	0.1912	0.6707	0.6811	0.0701*	0.0804*	0.4599	0.4889
52	0.5528	0.5659	0.1825	0.1949	0.3305	0.3455	0.7382	0.7576	0.2894	0.3165
53	0.0115**	0.0123**	0.0000***	0.0000***	0.0106**	0.0114**	0.0000***	0.0000***	0.0000***	0.0000***
54	0.5995	0.6116	0.0117**	0.0125**	0.0008***	0.0007***	0.0000***	0.0000***	0.0018***	0.0017***
55	0.0000***	0.0000***	0.0000***	0.0000***	0.1310	0.1412	0.0000***	0.0000***	0.0000***	0.0000***
56	0.0000***	0.0000***	0.0764*	0.0833*	0.0000***	0.0000***	0.0000***	0.0000***	0.0519*	0.0596*
57	0.0029***	0.0028***	0.3912	0.4063	0.0419**	0.0459**	0.0283**	0.0323**	0.1540	0.1733
58	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0007***	0.0006***	0.0000***	0.0000***
59	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0031***	0.0031***	0.0000***	0.0000***
60	0.0109**	0.0117**	0.7730	0.7805	0.0000***	0.0000***	0.8135	0.8282	0.7655	0.7832
61	0.0000***	0.0000***	0.0240**	0.0262**	0.0001***	0.0001***	0.6943	0.7160	0.0646*	0.0741*
62	0.0033***	0.0033***	0.0077***	0.0081***	0.0050***	0.0052***	0.2929	0.3201	0.1495	0.1684
63	0.0000***	0.0000***	0.0001***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0001***	0.0000***
64	0.0000***	0.0000***	0.0002***	0.0002***	0.7598	0.7677	0.0003***	0.0002***	0.0003***	0.0002***
65	0.1346	0.1450	0.0155**	0.0167**	0.3288	0.3438	0.0000***	0.0000***	0.0000***	0.0000***

Note: *, ** and *** denote rejection of the exogeneity null at, respectively, the 10%, 5% and 1% significance levels.

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Table 3.2.2: Endogeneity tests p-values based on 2SLS regressions – Wooldridge and robust regression

Industry	CES_1		CES_2		CES_3		VES_1		VES_2	
	Wooldridge	Robust regression	Wooldridge	Robust regression	Wooldridge	Robust regression	Wooldridge	Robust regression	Wooldridge	Robust regression
AG	0.5335	0.5514	0.0903*	0.0576*	0.0864*	0.0901*	0.0885*	0.0594*	0.2807	0.2777
1	0.0821*	0.0905*	0.3981	0.3972	0.1518	0.1311	0.0022***	0.0000***	0.2634	0.2953
2	0.0133**	0.0089***	0.2853	0.2827	0.0021***	0.0003***	0.3292	0.2816	0.7155	0.7741
3	0.0011***	0.0000***	0.0004***	0.0000***	0.0000***	0.0000***	0.0003***	0.0000***	0.0034***	0.0000***
4	0.0056***	0.0018***	0.2420	0.2886	0.0829*	0.0453**	0.0036***	0.0000***	0.0064***	0.0016***
5	0.0002***	0.0000***	0.0334**	0.0177**	0.0013***	0.0001***	0.0797*	0.0144**	0.0079***	0.0055***
6	0.0339**	0.1104	0.0006***	0.0000***	0.0003***	0.0000***	0.0013***	0.0001***	0.0031***	0.0000***
7	0.0084***	0.0026***	0.5444	0.5326	0.2942	0.2933	0.0804*	0.0492**	0.4914	0.4454
8	0.1110	0.0711*	0.0001***	0.0000***	0.0047***	0.0009***	0.2146	0.1813	0.0000***	0.0000***
9	0.1795	0.1645	0.8593	0.8662	0.0025***	0.0003***	0.0010***	0.0000***	0.7935	0.7915
10	0.0353**	0.0448**	0.0458**	0.0354**	0.0076***	0.0095***	0.5522	0.4768	0.0911*	0.1170
11	0.2724	0.2551	0.8664	0.8744	0.8628	0.8683	0.1684	0.0918*	0.2295	0.1886
12	0.8393	0.8455	0.7394	0.7398	0.9943	0.9945	0.0117**	0.0022***	0.0048***	0.0015***
13	0.0056***	0.0000***	0.1913	0.0000***	0.0000***	0.0000***	0.0035***	0.0000***	0.3158	0.0000***
14	0.0715*	0.0623*	0.7815	0.7802	0.4592	0.4520	0.0180**	0.0010***	0.0787*	0.0515*
15	0.0982*	0.0803*	0.0153**	0.0622*	0.6754	0.6883	0.0122**	0.0196**	0.9993	0.9994
16	0.0108**	0.0122**	0.1813	0.1763	0.0016***	0.0005***	0.5798	0.6231	0.0216**	0.0361**
17	0.0001***	0.0000***	0.4391	0.4507	0.0002***	0.0000***	0.0064***	0.0012***	0.9723	0.9739
18	0.0001***	0.0000***	0.0137**	0.0143**	0.0001***	0.0000***	0.0027***	0.0019***	0.0448**	0.0746*
19	0.0989*	0.1023	0.0647*	0.0459**	0.0004***	0.0003***	0.5096	0.5413	0.1285	0.1121
20	0.0770*	0.0866*	0.8279	0.8309	0.2096	0.2588	0.0896*	0.0445**	0.0828*	0.0219**
21	0.0206**	0.0002***	0.0730*	0.0221**	0.0307**	0.0019***	0.0131**	0.0006***	0.0517*	0.0158**
22	0.0154**	0.0271**	0.2129	0.1572	0.0570*	0.0378**	0.0002***	0.0000***	0.0649*	0.0319**
23	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0001***	0.0000***
24	0.1255	0.1206	0.1306	0.1716	0.0000***	0.0000***	0.3519	0.3437	0.0007***	0.0003***
25	0.5841	0.5929	0.0333**	0.0128**	0.0363**	0.0343**	0.0002***	0.0000***	0.0481**	0.0076***
26	0.2118	0.0954*	0.0305**	0.0152**	0.0038***	0.0000***	0.0025***	0.0000***	0.1365	0.0947*
27	0.4518	0.4853	0.2661	0.2506	0.0077***	0.0130**	0.0980*	0.0477**	0.2233	0.1957
28	0.7768	0.7867	0.0687*	0.0699*	0.5107	0.5194	0.7308	0.7609	0.3636	0.4559
29	0.0010***	0.0002***	0.0085***	0.0000***	0.0166**	0.0113**	0.0373**	0.0368**	0.0113**	0.0000***
30	0.3144	0.3459	0.3657	0.3338	0.5295	0.5321	0.0541*	0.0828*	0.6525	0.6390
31	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
32	0.2296	0.2126	0.5824	0.5382	0.0666*	0.0650*	0.1620	0.1964	0.3474	0.3959
33	0.0255**	0.0010***	0.0038***	0.0039***	0.1644	0.2027	0.0158**	0.0000***	0.0002***	0.0000***
34	0.0000***	0.0000***	0.0002***	0.0000***	0.0000***	0.0000***	0.0041***	0.0002***	0.0003***	0.0000***
35	0.3355	0.3511	0.0033***	0.0018***	0.1905	0.2295	0.5014	0.5007	0.0033***	0.0038***
36	0.9469	0.9487	0.5555	0.5571	0.9582	0.9600	0.0700*	0.0618*	0.0895*	0.0385**

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Industry	CES_1		CES_2		CES_3		VES_1		VES_2	
	Wooldridge	Robust regression	Wooldridge	Robust regression	Wooldridge	Robust regression	Wooldridge	Robust regression	Wooldridge	Robust regression
37	0.3879	0.2987	0.6187	0.6252	0.0082***	0.0000***	0.0349**	0.0725*	0.5999	0.5983
38	0.0081***	0.0002***	0.1265	0.1145	0.0078***	0.0064***	0.0296**	0.0104**	0.2961	0.2853
39	0.0023***	0.0000***	0.5743	0.5724	0.0275**	0.0291**	0.0039***	0.0000***	0.0024***	0.0022***
40	0.2688	0.2342	0.0005***	0.0127**	0.1061	0.0067***	0.0461**	0.3904	0.2208	0.0723*
41	0.0001***	0.0000***	0.1240	0.1789	0.0000***	0.0000***	0.8329	0.8409	0.3582	0.3775
42	0.0003***	0.0000***	0.3104	0.3246	0.0007***	0.0001***	0.0000***	0.0000***	0.6935	0.6988
43	0.0235**	0.0381**	0.2571	0.2415	0.0062***	0.0242**	0.4984	0.4821	0.4011	0.4008
44	0.1416	0.0354**	0.3266	0.2876	0.4062	0.4109	0.1830	0.0225**	0.4037	0.3624
45	0.1172	0.1614	0.4114	0.4445	0.3756	0.4095	0.5297	0.6046	0.2370	0.2905
46	0.0956*	0.0948*	0.1504	0.2062	0.0117**	0.0044***	0.0205**	0.0117**	0.2027	0.2228
47	0.0793*	0.0483**	0.4246	0.4465	0.8988	0.9025	0.0430**	0.0644*	0.2042	0.1423
48	0.0193**	0.0007***	0.0812*	0.0796*	0.0751*	0.0448**	0.3023	0.3750	0.0256**	0.0056***
49	0.0507*	0.0001***	0.3754	0.3690	0.0183**	0.0000***	0.0056***	0.1944	0.0035***	0.0124**
50	0.4873	0.4003	0.5734	0.5786	0.5677	0.5497	0.4727	0.1775	0.1550	0.1756
51	0.2234	0.0429**	0.0694*	0.0459**	0.7028	0.6768	0.0573*	0.0548*	0.4674	0.4732
52	0.3287	0.3481	0.1402	0.0950*	0.2656	0.2621	0.5573	0.5727	0.2417	0.1501
53	0.0000***	0.0000***	0.0001***	0.0000***	0.0101**	0.0064***	0.0000***	0.0000***	0.0004***	0.0000***
54	0.4308	0.3926	0.0368**	0.0160**	0.0000***	0.0016***	0.0001***	0.0000***	0.0406**	0.0025***
55	0.0006***	0.0000***	0.0353**	0.0001***	0.3618	0.3516	0.0026***	0.0000***	0.0014***	0.0000***
56	0.0010***	0.0000***	0.0722*	0.0766*	0.0033***	0.0000***	0.0003***	0.0000***	0.0223**	0.0585*
57	0.0088***	0.0010***	0.3655	0.3896	0.0269**	0.0031***	0.0432**	0.0204**	0.2628	0.2575
58	0.0007***	0.0007***	0.0006***	0.0033***	0.0002***	0.0000***	0.0045***	0.0005***	0.0016***	0.0054***
59	0.0001***	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***	0.0147**	0.0018***	0.0000***	0.0000***
60	0.0071***	0.0013***	0.7972	0.8031	0.0000***	0.0000***	0.7765	0.8107	0.7738	0.7741
61	0.0000***	0.0000***	0.0171**	0.0050***	0.0001***	0.0000***	0.7051	0.7142	0.0596*	0.0596*
62	0.0708*	0.0483**	0.1941	0.1401	0.1558	0.1020	0.3612	0.4244	0.2221	0.0350**
63	0.0000***	0.0000***	0.0092***	0.0025***	0.0000***	0.0000***	0.0006***	0.0001***	0.0174**	0.0066***
64	0.0006***	0.0000***	0.0002***	0.0012***	0.7502	0.7622	0.0022***	0.0001***	0.0008***	0.0007***
65	0.1625	0.1693	0.0340**	0.1891	0.3791	0.4446	0.0031***	0.0000***	0.0002***	0.0000***

Note: *, ** and *** denote rejection of the exogeneity null at, respectively, the 10%, 5% and 1% significance levels.

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Table 3.3.1: Durbin Watson statistics based on OLS single equation regressions

Industry	CES_1	CES_2	CES_3	VES_1	VES_2
AG	0.2092***	0.4841***	0.3750***	0.2450***	0.4868***
1	0.3154***	0.5681***	0.0783***	0.8685***	1.4483**
2	0.3172***	0.3677***	0.2842***	0.3441***	0.3641***
3	1.3800***	0.3827***	0.6755***	1.3148***	0.2742***
4	0.4424***	0.1778***	0.5472***	0.3654***	0.6729***
5	0.4886***	0.4634***	0.2615***	0.4425***	0.6413***
6	1.5990	0.9352***	0.8444***	1.7208	0.9298***
7	0.1706***	0.2544***	0.0962***	0.1401***	0.4853***
8	0.2580***	0.6305***	0.2414***	0.4171***	0.6526***
9	0.3752***	0.5485***	1.0591***	0.3176***	1.2399***
10	1.1058***	0.5817***	1.0462***	0.8749***	0.8485***
11	0.2561***	0.3690***	0.2295***	0.2120***	0.4410***
12	0.2055***	0.2556***	0.6403***	0.1904***	0.5867***
13	1.7954	1.7160	0.8048***	1.5786	1.7080
14	0.2486***	0.3712***	0.6769***	0.2505***	0.5110***
15	0.8901***	0.4221***	0.4844***	0.8404***	0.3472***
16	0.4657***	0.6548***	0.5933***	0.2527***	0.7435***
17	0.4580***	0.8520***	0.5779***	0.1698***	0.9316***
18	0.4323***	0.7142***	0.2798***	0.6082***	0.7087***
19	0.1239***	0.8374***	0.1761***	0.1065***	0.8629***
20	0.2508***	0.6452***	0.7867***	0.1808***	0.9099***
21	0.2268***	0.7295***	0.1952***	0.3230***	0.7303***
22	0.2373***	1.2384***	0.2735***	0.3443***	1.3653**
23	0.3488***	0.7611***	0.1333***	0.2616***	1.4476**
24	1.9152	0.3585***	0.6785***	1.9122	0.8512***
25	0.0596***	0.7091***	0.1727***	0.4837***	0.7617***
26	0.4154***	1.2255***	0.9943***	0.4412***	1.2718***
27	0.2417***	0.4452***	0.2772***	0.3399***	0.4717***
28	0.3076***	0.4167***	0.1292***	0.3511***	0.4416***
29	0.3164***	1.3867***	0.1807***	0.2565***	1.4097**
30	0.3767***	0.7978***	0.3317***	0.5765***	0.7969***
31	1.5513	1.0479***	1.0789***	1.0289***	0.8707***
32	0.1521***	0.9216***	0.2414***	0.1406***	0.9843***
33	0.6998***	0.1730***	0.1404***	0.9392***	0.5047***
34	1.2284***	0.7015***	0.0978***	1.4277**	0.7477***
35	0.2339***	0.5872***	0.2480***	0.2283***	0.5876***
36	0.3284***	0.0871***	0.3405***	0.3148***	0.1907***
37	0.2822***	0.8413***	0.2659***	0.2515***	1.1239***
38	0.5063***	0.7807***	0.2153***	0.4851***	0.7809***

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Industry	CES_1	CES_2	CES_3	VES_1	VES_2
39	0.4047***	0.2860***	0.1676***	0.6307***	0.4199***
40	0.1009***	0.2372***	0.2077***	0.5677***	0.2797***
41	0.5051***	0.4742***	0.4901***	0.5134***	0.6954***
42	0.6671***	0.8031***	0.5584***	0.3834***	0.9233***
43	0.2878***	0.6122***	0.2214***	0.8431***	0.6256***
44	0.5719***	0.2881***	0.0612***	0.6820***	0.7862***
45	0.0932***	0.0685***	0.0721***	0.1303***	0.2918***
46	0.1649***	0.2153***	0.2127***	0.2800***	0.2723***
47	0.1544***	0.1750***	0.0675***	0.1919***	0.3057***
48	0.3217***	0.1129***	0.1070***	0.0794***	0.1984***
49	0.4471***	0.6939***	0.4067***	0.2487***	0.6900***
50	0.1074***	0.4487***	0.2471***	0.1075***	0.6188***
51	0.0897***	0.1374***	0.0368***	0.1957***	0.2057***
52	0.1228***	0.1760***	0.0513***	0.1679***	0.1856***
53	0.0454***	1.7858	0.1268***	0.0490***	1.8146
54	0.0626***	0.9128***	0.2141***	0.6944***	1.1509***
55	0.4803***	0.6115***	0.1069***	0.4888***	1.0751***
56	0.2888***	0.8154***	0.1471***	0.2908***	1.1114***
57	0.2217***	0.1899***	0.1814***	0.2812***	0.1858***
58	0.5500***	0.5221***	0.3738***	0.4503***	0.5218***
59	0.4647***	0.7782***	0.3278***	0.2757***	0.7713***
60	0.3277***	0.5971***	0.4192***	0.2841***	0.5989***
61	0.1544***	0.3489***	0.1330***	0.2123***	0.3492***
62	0.4193***	0.400***	0.4013***	0.3241***	0.3847***
63	0.9107***	1.1617***	0.3624***	1.0036***	1.2352***
64	0.4265***	0.3317***	0.3860***	0.4241***	0.3256***
65	0.0780***	0.2468***	0.0876***	0.4581***	0.8121***

Note: ** and *** denote rejection of the no serial correlation null at, respectively, the 5% and 1% significance levels, based on the Durbin-Watson lower-bound values (Savin and White, 1977).

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Table 3.3.2: Durbin Watson statistics based on Prais-Winsten AR(1) regressions

Industry	CES_1	CES_2	CES_3	VES_1	VES_2
AG	1.8571	2.0508	1.6739	1.7299	2.0039
1	1.9733	2.2768	1.3645***	1.9826	2.0443
2	1.9186	2.0518	1.6340	1.8435	2.0650
3	2.0841	1.5559	1.3914**	1.9491	1.6811
4	1.8224	2.1723	1.9354	1.5092**	2.1888
5	2.2253	1.8898	1.6298	2.0861	1.9046
6	2.1524	1.9283	2.1456	2.1127	1.9253
7	0.8931***	2.1860	0.9184***	1.3775**	2.0929
8	1.8309	1.7359	1.7998	1.9430	1.8063
9	1.9988	1.7851	1.9747	1.4834**	1.8316
10	1.9138	2.3135	1.7940	2.0356	2.1034
11	1.5995	1.8463	1.8540	1.5420	1.8473
12	1.8070	1.7342	1.7446	1.0830***	1.7827
13	1.6109	1.5995	1.4783**	1.4647**	1.4876**
14	1.2369***	1.8507	1.5947	1.2509***	1.8579
15	2.2239	2.0365	1.8762	2.3371	1.9612
16	1.2164***	1.9173	1.2477***	1.8661	1.8946
17	1.9968	1.8400	1.9986	1.5777	1.8840
18	1.9244	1.8033	1.5572	1.9364	1.8758
19	1.5778	1.9519	0.9230***	1.7543	1.9666
20	2.3189	1.6385	2.0112	2.4243	1.6890
21	1.7558	2.1187	1.6123	1.9506	2.1319
22	1.6051	1.9503	1.9436	1.5564	1.9211
23	1.5552	1.8046	0.8663***	1.6337	1.9415
24	1.9947	2.2175	1.6499	1.9939	2.1326
25	1.3488***	2.1695	1.5838	1.4961**	2.2086
26	1.9067	2.0753	2.0382	1.3256***	2.0711
27	1.3037***	1.9186	1.2195***	1.4935**	1.9259
28	1.5617	1.9921	0.9752***	1.9826	1.9653
29	1.3777***	2.0622	0.9396***	1.5837	2.0621
30	1.9177	1.8906	2.0708	2.0149	1.8845
31	2.1936	2.0208	1.2820***	2.1484	1.9204
32	1.5306**	1.8160	1.3169***	1.6980	1.8135
33	1.9492	1.6004	1.1904***	2.0561	1.9110
34	2.3668	2.2530	1.4037**	2.1337	2.2645
35	2.0206	1.8056	1.4998**	2.0399	1.7750
36	2.0666	1.8534	1.7800	2.2928	1.8322
37	0.9549***	1.9402	0.7191***	1.7672	1.9106
38	2.2904	2.2387	1.4277**	2.3456	2.2415

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Industry	CES_1	CES_2	CES_3	VES_1	VES_2
39	1.7077	1.7416	1.3655***	1.8868	1.8352
40	1.2756***	2.1169	0.6186***	2.4746	2.2990
41	1.6654	1.6562	0.8150***	1.9933	1.5836
42	1.7942	1.6125	1.1242***	1.9172	1.6227
43	1.2743***	2.0274	0.8297***	1.7306	2.0252
44	1.8120	1.8989	0.9932***	2.0041	1.9198
45	1.0924***	0.9257***	0.8639***	1.4536**	2.0899
46	1.5846	1.7594	1.2715***	1.6887	1.8235
47	1.2061***	1.8449	1.4594**	1.2961***	1.7532
48	0.9499***	1.3148***	0.7732***	1.0704***	1.3375***
49	1.1079***	1.6662	1.4717**	1.3929**	1.7165
50	1.6300	1.8111	1.4390**	1.5636	1.8067
51	0.9152***	1.5561	0.7745***	1.3633**	1.6982
52	2.0925	1.4087**	1.1168***	1.9855	1.4154**
53	1.1038***	1.7622	1.3174***	1.4748**	1.6232
54	1.1806***	2.0064	1.3092***	1.7181	1.9758
55	1.9735	2.1974	1.3758***	2.0880	2.3871
56	1.6169	2.0576	0.8116***	1.8388	2.0113
57	1.6037	1.5635	1.4662**	1.6184	1.6046
58	1.7160	1.8120	1.0413***	2.0673	1.8820
59	1.3338***	1.5876	1.0576***	1.5652	1.5622
60	1.5538	1.8735	0.9445***	1.6437	1.8734
61	1.8154	1.8765	1.9268	1.8619	1.8786
62	1.1776***	1.2463***	1.2009***	1.4471**	1.3547***
63	2.2391	1.7187	1.2482***	2.2499	1.7223
64	1.2759***	1.1106***	1.5491	1.2180***	0.8713***
65	0.7983***	1.1255***	0.8499***	1.1503***	1.1977***

Note: ** and *** denote rejection of the no serial correlation null at, respectively, the 5% and 1% significance levels, based on the Durbin-Watson lower-bound values (Savin and White, 1977).

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Table 3.4.1: Breusch-Godfrey LM test p-values based on OLS residuals regressions (1 lag)

Industry	CES_1	CES_2	CES_3	VES_1	VES_2
AG	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
1	0.0000***	0.0000***	0.0000***	0.0000***	0.0282**
2	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
3	0.0115**	0.0000***	0.0000***	0.0046***	0.0000***
4	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
5	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
6	0.1017	0.0000***	0.0000***	0.2507	0.0000***
7	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
8	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
9	0.0000***	0.0000***	0.0001***	0.0000***	0.0022***
10	0.0002***	0.0000***	0.0001***	0.0000***	0.0000***
11	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
12	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
13	0.4598	0.2147	0.0000***	0.0708*	0.1844
14	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
15	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
16	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
17	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
18	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
19	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
20	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
21	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
22	0.0000***	0.0026***	0.0000***	0.0000***	0.0108**
23	0.0000***	0.0000***	0.0000***	0.0000***	0.0199**
24	0.7305	0.0000***	0.0000***	0.7238	0.0000***
25	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
26	0.0000***	0.0016***	0.0001***	0.0000***	0.0028***
27	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
28	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
29	0.0000***	0.0141**	0.0000***	0.0000***	0.0173**
30	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
31	0.0525*	0.0000***	0.0000***	0.0000***	0.0000***
32	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
33	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
34	0.0014***	0.0000***	0.0000***	0.0170**	0.0000***
35	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
36	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
37	0.0000***	0.0000***	0.0000***	0.0000***	0.0003***
38	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***

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Industry	CES_1	CES_2	CES_3	VES_1	VES_2
39	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
40	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
41	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
42	0.0000***	0.0003***	0.0000***	0.0000***	0.0008***
43	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
44	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
45	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
46	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
47	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
48	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
49	0.0000***	0.0007***	0.0000***	0.0000***	0.0004***
50	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
51	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
52	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
53	0.0000***	0.3908	0.0000***	0.0000***	0.4573
54	0.0000***	0.0000***	0.0000***	0.0000***	0.0006***
55	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
56	0.0000***	0.0002***	0.0000***	0.0000***	0.0040***
57	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
58	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
59	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
60	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
61	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
62	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
63	0.0000***	0.0006***	0.0000***	0.0001***	0.0013***
64	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
65	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***

Note: *, ** and *** denote rejection of the no serial correlation null at, respectively, the 10%, 5% and 1% significance levels.

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Table 3.4.2: Breusch-Godfrey LM test p-values based on OLS residuals regressions (5 lags)

Industry	CES_1	CES_2	CES_3	VES_1	VES_2
AG	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
1	0.0000***	0.0000***	0.0000***	0.0001***	0.2438
2	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
3	0.0216**	0.0000***	0.0000***	0.0100***	0.0000***
4	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
5	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
6	0.0097***	0.0000***	0.0000***	0.0159**	0.0000***
7	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
8	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
9	0.0000***	0.0000***	0.0077***	0.0000***	0.0287**
10	0.0038***	0.0000***	0.0003***	0.0002***	0.0003***
11	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
12	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
13	0.0039***	0.0855*	0.0000***	0.0007***	0.0597*
14	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
15	0.0001***	0.0000***	0.0000***	0.0000***	0.0000***
16	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
17	0.0000***	0.0004***	0.0000***	0.0000***	0.0034***
18	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
19	0.0000***	0.0001***	0.0000***	0.0000***	0.0001***
20	0.0000***	0.0000***	0.0001***	0.0000***	0.0003***
21	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
22	0.0000***	0.0067***	0.0000***	0.0000***	0.0374**
23	0.0000***	0.0000***	0.0000***	0.0000***	0.2941
24	0.9787	0.0000***	0.0000***	0.9788	0.0000***
25	0.0000***	0.0001***	0.0000***	0.0000***	0.0001***
26	0.0000***	0.0517*	0.0049***	0.0000***	0.0746*
27	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
28	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
29	0.0000***	0.0296**	0.0000***	0.0000***	0.0281**
30	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
31	0.0307**	0.0005***	0.0000***	0.0001***	0.0001***
32	0.0000***	0.0005***	0.0000***	0.0000***	0.0012***
33	0.0000***	0.0000***	0.0000***	0.0003***	0.0000***
34	0.0033***	0.0000***	0.0000***	0.0676*	0.0000***
35	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
36	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
37	0.0000***	0.0000***	0.0000***	0.0000***	0.0006***
38	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***

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Industry	CES_1	CES_2	CES_3	VES_1	VES_2
39	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
40	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
41	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
42	0.0000***	0.0019***	0.0000***	0.0000***	0.0045***
43	0.0000***	0.0000***	0.0000***	0.0002***	0.0000***
44	0.0000***	0.0000***	0.0000***	0.0000***	0.0001***
45	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
46	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
47	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
48	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
49	0.0000***	0.0124**	0.0000***	0.0000***	0.0074***
50	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
51	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
52	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
53	0.0000***	0.2362	0.0000***	0.0000***	0.2423
54	0.0000***	0.0002***	0.0000***	0.0000***	0.0031***
55	0.0000***	0.0000***	0.0000***	0.0000***	0.0001***
56	0.0000***	0.0007***	0.0000***	0.0000***	0.0151**
57	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
58	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
59	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
60	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
61	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
62	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
63	0.0000***	0.0013***	0.0000***	0.0011***	0.0022***
64	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
65	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***

Note: *, ** and *** denote rejection of the no serial correlation null at, respectively, the 10%, 5% and 1% significance levels.

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Table 3.5.1: ADF unit root tests (variables in levels)

Industry	*yk*	*rp*	*yl*	*wp*	*kl*	*wr*
AG	0.1313 (1)	0.3096 (0)	0.8454 (1)	0.9837 (0)	0.5829 (1)	0.9486 (0)
1	0.1185 (1)	0.0028 (0)***	0.7619 (1)	0.3809 (0)	0.8258 (0)	0.1665 (0)
2	0.8423 (0)	0.6752 (0)	0.5052 (0)	0.5395 (0)	0.7568 (1)	0.7133 (0)
3	0.9941 (0)	0.9826 (0)	0.7091 (1)	0.0145 (0)**	0.4236 (3)	0.9223 (2)
4	0.5610 (0)	0.5815 (0)	0.3769 (0)	0.9760 (1)	0.6933 (0)	0.9132 (0)
5	0.8236 (0)	0.1057 (0)	0.1580 (0)	0.1754 (0)	0.9250 (0)	0.0797 (0)*
6	0.0442 (0)**	0.4708 (5)	0.1737 (0)	0.0737 (3)*	0.5328 (1)	0.2531 (10)
7	0.6834 (1)	0.5995 (1)	0.1150 (0)	0.2213 (0)	0.5215 (1)	0.7802 (1)
8	0.0575 (1)*	0.0005 (1)***	0.8077 (0)	0.6771 (0)	0.4244 (1)	0.0024 (1)***
9	0.1995 (1)	0.4827 (0)	0.3378 (0)	0.9944 (0)	0.7731 (2)	0.7443 (0)
10	0.3588 (0)	0.3196 (0)	0.0880 (0)*	0.0175 (0)**	0.4135 (0)	0.2480 (0)
11	0.2510 (0)	0.1722 (0)	0.9471 (0)	0.9473 (0)	0.8198 (0)	0.1708 (1)
12	0.3753 (1)	0.7552 (0)	0.7109 (1)	0.8962 (1)	0.2471 (1)	0.9356 (0)
13	0.5936 (0)	0.1376 (0)	0.4722 (0)	0.0706 (0)*	0.1161 (8)	0.0000 (0)***
14	0.5106 (0)	0.4882 (0)	0.1865 (0)	0.3192 (0)	0.5071 (0)	0.6497 (0)
15	0.0142 (0)**	0.1650 (0)	0.0149 (0)**	0.0346 (0)**	0.1242 (1)	0.4790 (0)
16	0.2868 (0)	0.2466 (0)	0.0296 (0)**	0.8078 (0)	0.2140 (1)	0.5628 (0)
17	0.2205 (1)	0.0215 (0)**	0.8475 (0)	0.5431 (0)	0.2001 (1)	0.0087 (0)***
18	0.1676 (0)	0.3846 (2)	0.2979 (0)	0.1011 (0)	0.1000 (1)*	0.4511 (2)
19	0.3385 (0)	0.1179 (0)	0.5960 (0)	0.9499 (0)	0.8749 (1)	0.5914 (0)
20	0.6190 (0)	0.0582 (0)*	0.7355 (0)	0.7085 (1)	0.0529 (0)*	0.0209 (0)**
21	0.1610 (3)	0.4486 (0)	0.6317 (0)	0.9852 (1)	0.4532 (1)	0.8815 (0)
22	0.0204 (0)**	0.0039 (0)***	0.9633 (2)	0.9086 (0)	0.8266 (0)	0.2443 (0)
23	0.4791 (0)	0.0000 (0)***	0.6051 (1)	0.2498 (0)	0.4313 (1)	0.0000 (0)***
24	0.3475 (0)	0.2183 (0)	0.2907 (0)	0.1482 (0)	0.9377 (0)	0.3618 (1)
25	0.0593 (0)*	0.0194 (0)**	0.0035 (0)***	0.9810 (0)	0.3912 (0)	0.8628 (0)
26	0.2231 (0)	0.0319 (0)**	0.6861 (0)	0.9880 (0)	0.2156 (0)	0.6797 (1)
27	0.8287 (0)	0.8299 (0)	0.8282 (0)	0.9993 (0)	0.9996 (0)	0.9904 (0)
28	0.1851 (1)	0.0570 (0)*	0.6991 (0)	0.4632 (0)	0.8048 (1)	0.0675 (0)*
29	0.0912 (1)*	0.0139 (0)**	0.0372 (0)**	0.0496 (0)**	0.2032 (1)	0.0129 (0)**
30	0.2089 (0)	0.0861 (0)*	0.2154 (0)	0.2179 (0)	0.6933 (0)	0.1717 (0)
31	0.8752 (0)	0.6484 (1)	0.3587 (0)	0.1244 (1)	0.9941 (1)	0.3752 (1)
32	0.4996 (1)	0.5876 (0)	0.1447 (0)	0.0678 (0)*	0.5397 (1)	0.2728 (0)
33	0.0697 (0)*	0.0186 (0)**	0.3684 (2)	0.3322 (2)	0.4185 (1)	0.3981 (2)
34	0.0931 (1)*	0.0051 (2)***	0.4253 (3)	0.0003 (0)***	0.8373 (1)	0.0000 (0)***
35	0.5377 (0)	0.3156 (0)	0.8361 (0)	0.2996 (1)	0.3985 (1)	0.2077 (1)
36	0.5256 (0)	0.6194 (0)	0.3996 (0)	0.8413 (0)	0.7164 (0)	0.7183 (0)
37	0.0703 (0)*	0.0004 (0)***	0.5244 (0)	0.9804 (0)	0.1176 (1)	0.0047 (0)***
38	0.1419 (0)	0.0891 (0)*	0.0823 (0)*	0.1143 (0)	0.2786 (3)	0.8957 (3)

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Industry	*yk*	*rp*	*yl*	*wp*	*kl*	*wr*
39	0.5991 (0)	0.0191 (0)**	0.3531 (0)	0.0015 (0)***	0.4346 (1)	0.0004 (0)***
40	0.5603 (1)	0.0261 (1)**	0.7829 (1)	0.5576 (0)	0.9472 (1)	0.7855 (3)
41	0.2207 (0)	0.1415 (0)	0.2902 (0)	0.1593 (0)	0.4406 (1)	0.1861 (0)
42	0.6519 (0)	0.0980 (0)*	0.5053 (0)	0.3796 (0)	0.2612 (2)	0.2079 (0)
43	0.9994 (0)	0.4740 (0)	0.0468 (0)**	0.4270 (2)	0.9913 (1)	0.5211 (0)
44	0.5836 (0)	0.0809 (0)*	0.7586 (0)	0.5252 (0)	0.8903 (1)	0.0530 (0)*
45	0.6933 (0)	0.9042 (0)	0.5652 (1)	0.9528 (0)	0.4502 (1)	0.9853 (0)
46	0.3876 (2)	0.4474 (2)	0.3826 (3)	0.2963 (5)	0.1597 (2)	0.1979 (2)
47	0.8385 (1)	0.6385 (0)	0.6024 (0)	0.9958 (0)	0.8099 (1)	0.8846 (0)
48	0.5478 (1)	0.3162 (0)	0.6050 (2)	0.6407 (1)	0.5179 (1)	0.3881 (0)
49	0.9407 (1)	0.8806 (0)	0.0287 (0)**	0.9650 (1)	0.9431 (1)	0.7840 (0)
50	0.5761 (1)	0.5478 (1)	0.9472 (1)	0.9979 (0)	0.3445 (1)	0.9948 (1)
51	0.1413 (1)	0.2687 (2)	0.0783 (0)*	0.2849 (0)	0.5655 (1)	0.1977 (3)
52	0.2555 (0)	0.2755 (2)	0.5883 (0)	0.9975 (0)	0.0382 (5)**	0.5943 (2)
53	0.9551 (1)	0.0000 (0)***	0.9569 (0)	0.9717 (3)	0.4065 (1)	0.1635 (2)
54	0.9738 (2)	0.3257 (0)	0.8696 (0)	0.8486 (0)	0.9862 (0)	0.5633 (0)
55	0.7772 (0)	0.7462 (1)	0.7858 (0)	0.9538 (1)	0.7647 (0)	0.9292 (1)
56	0.1505 (1)	0.3662 (1)	0.9195 (1)	0.7850 (0)	0.5795 (2)	0.5138 (1)
57	0.5770 (0)	0.4868 (0)	0.8596 (0)	0.0642 (2)*	0.1526 (0)	0.5096 (0)
58	0.0024 (8)***	0.3604 (0)	0.4350 (0)	0.1243 (1)	0.3983 (2)	0.0496 (0)**
59	0.4641 (1)	0.0168 (0)**	0.5718 (1)	0.5996 (2)	0.7077 (1)	0.5448 (2)
60	0.0000 (0)***	0.0336 (0)**	0.9074 (0)	0.8759 (0)	0.0045 (0)***	0.1125 (0)
61	0.7635 (0)	0.3900 (2)	0.6147 (0)	0.4094 (0)	0.6377 (0)	0.4816 (2)
62	0.0003 (1)***	0.0989 (0)*	0.0012 (1)***	0.0337 (0)**	0.0006 (1)***	0.0442 (0)**
63	0.9196 (0)	0.0379 (0)**	0.8187 (0)	0.4363 (0)	0.1690 (1)	0.0007 (0)***
64	0.2703 (1)	0.7066 (0)	0.2594 (1)	0.4793 (0)	0.0091 (2)***	0.2987 (0)
65	0.9098 (1)	0.0777 (0)*	0.0280 (1)**	0.0878 (0)*	0.3862 (1)	0.0699 (0)*

Notes: We report MacKinnon (1996) one-sided p-values, where *, ** and *** denote the rejection of the unit root null hypothesis at, respectively, the 10%, 5% and 1% significance levels. Tests include an intercept and a trend. Lag length selection was based on the Schwarz Information Criterion, with an upper bound of 9 lags (figures enclosed in parentheses are the lag length).

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Table 3.5.2: ADF unit root tests (variables in first differences)

Industry	*yk*	*rp*	*yl*	*wp*	*kl*	*wr*
AG	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (1)***	0.0000 (0)***
1	0.0000 (1)***	0.0001 (0)***	0.0000 (1)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
2	0.0000 (0)***	0.0000 (1)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
3	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (1)***	0.0000 (0)***	0.0000 (1)***
4	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0001 (0)***	0.0000 (0)***	0.0000 (0)***
5	0.0000 (1)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
6	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (2)***	0.0000 (0)***	0.0807 (8)*
7	0.0040 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0044 (0)***	0.0000 (0)***
8	0.0000 (0)***	0.0000 (1)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (1)***
9	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (1)***	0.0000 (0)***
10	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (3)***	0.0000 (0)***	0.0000 (1)***
11	0.0000 (1)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (1)***	0.0000 (0)***
12	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0046 (0)***	0.0000 (0)***	0.0000 (0)***
13	0.0000 (0)***	0.0001 (0)***	0.0000 (0)***	0.0001 (0)***	0.0000 (0)***	0.0000 (1)***
14	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (1)***	0.0000 (0)***
15	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
16	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0011 (0)***	0.0000 (0)***
17	0.0000 (1)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
18	0.0000 (0)***	0.0000 (1)***	0.0000 (0)***	0.0000 (1)***	0.0000 (0)***	0.0000 (1)***
19	0.0000 (1)***	0.0000 (1)***	0.0000 (1)***	0.0000 (0)***	0.0060 (0)***	0.0000 (0)***
20	0.0000 (0)***	0.0000 (2)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (2)***
21	0.0123 (1)**	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0001 (0)***	0.0000 (0)***
22	0.0000 (1)***	0.0000 (1)***	0.0000 (1)***	0.0000 (1)***	0.0000 (0)***	0.0000 (0)***
23	0.0000 (0)***	0.0000 (4)***	0.0000 (0)***	0.0000 (0)***	0.0072 (0)***	0.0000 (4)***
24	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
25	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
26	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
27	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0001 (0)***	0.0000 (0)***
28	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0027 (0)***	0.0000 (1)***
29	0.0007 (0)***	0.0000 (0)***	0.0000 (1)***	0.0000 (1)***	0.0040 (0)***	0.0000 (1)***
30	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (3)***	0.0000 (0)***	0.0000 (3)***
31	0.0000 (0)***	0.0001 (0)***	0.0000 (0)***	0.0001 (0)***	0.0000 (0)***	0.0001 (0)***
32	0.0001 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0010 (0)***	0.0000 (0)***
33	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0001 (1)***	0.0000 (0)***	0.0000 (1)***
34	0.0000 (0)***	0.0000 (1)***	0.0000 (0)***	0.0000 (1)***	0.0000 (0)***	0.0000 (1)***
35	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
36	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
37	0.0000 (0)***	0.0000 (3)***	0.0000 (3)***	0.0000 (0)***	0.0303 (0)**	0.0000 (3)***
38	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0253 (1)**	0.0009 (2)***

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Industry	*yk*	*rp*	*yl*	*wp*	*kl*	*wr*
39	0.0000 (0)***	0.0000 (0)***	0.0095 (1)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
40	0.0000 (0)***	0.0000 (2)***	0.0000 (1)***	0.0000 (1)***	0.0043 (0)***	0.0000 (2)***
41	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0230 (0)**	0.0000 (0)***
42	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0041 (0)***	0.0000 (0)***
43	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (1)***	0.0172 (0)**	0.0000 (0)***
44	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0022 (0)***	0.0000 (0)***
45	0.0000 (0)***	0.0000 (0)***	0.0037 (0)***	0.0000 (0)***	0.0065 (0)***	0.0000 (0)***
46	0.2647 (1)	0.1981 (1)	0.0705 (1)*	0.0665 (1)*	0.2539 (0)	0.2434 (1)
47	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
48	0.0144 (0)**	0.0000 (0)***	0.0016 (0)***	0.0000 (0)***	0.0423 (0)**	0.0000 (0)***
49	0.0002 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
50	0.0000 (1)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
51	0.0007 (0)***	0.0291 (1)**	0.0000 (0)***	0.0000 (0)***	0.0196 (0)**	0.0252 (1)**
52	0.0000 (0)***	0.0521 (1)*	0.0000 (0)***	0.0000 (0)***	0.0220 (0)**	0.1556 (1)
53	0.0003 (0)***	0.0000 (1)***	0.0000 (0)***	0.0000 (1)***	0.0000 (0)***	0.0000 (1)***
54	0.0369 (1)**	0.0000 (3)***	0.0000 (0)***	0.0000 (0)***	0.0023 (1)***	0.0000 (0)***
55	0.0000 (0)***	0.0001 (0)***	0.0000 (0)***	0.0001 (0)***	0.0000 (0)***	0.0001 (0)***
56	0.0735 (2)*	0.0000 (0)***	0.0000 (0)***	0.0005 (1)***	0.0041 (0)***	0.0000 (0)***
57	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0129 (1)**	0.0000 (0)***	0.0055 (1)***
58	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0016 (0)***	0.0000 (0)***
59	0.0002 (0)***	0.0000 (1)***	0.0000 (0)***	0.0000 (1)***	0.0015 (0)***	0.0000 (1)***
60	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***
61	0.0000 (0)***	0.0000 (1)***	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0000 (1)***
62	0.0012 (0)***	0.0000 (0)***	0.0002 (0)***	0.0000 (0)***	0.0005 (0)***	0.0000 (0)***
63	0.0000 (0)***	0.0000 (0)***	0.0000 (0)***	0.0001 (0)***	0.0001 (0)***	0.0000 (0)***
64	0.0329 (0)**	0.0000 (0)***	0.0041 (0)***	0.0000 (0)***	0.0000 (1)***	0.0001 (0)***
65	0.0004 (0)***	0.0000 (0)***	0.0008 (0)***	0.0000 (0)***	0.0013 (0)***	0.0000 (0)***

Notes: We report MacKinnon (1996) one-sided p-values, where *, ** and *** denote the rejection of the unit root null hypothesis at, respectively, the 10%, 5% and 1% significance levels. Tests include an intercept and a trend. Lag length selection was based on the Schwarz Information Criterion, with an upper bound of 9 lags (figures enclosed in parentheses are the lag length).

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Table 3.6.1: PP unit root tests (variables in levels)

Industry	*yk*	*rp*	*yl*	*wp*	*kl*	*wr*
AG	0.1836 (2)	0.2930 (2)	0.9492 (0)	0.9784 (3)	0.7911 (2)	0.9574 (3)
1	0.0248 (3)**	0.0036 (3)***	0.2948 (2)	0.4293 (6)	0.8259 (2)	0.2121 (4)
2	0.7964 (4)	0.7847 (3)	0.4309 (3)	0.4435 (2)	0.7571 (1)	0.7192 (5)
3	0.9863 (1)	0.9867 (3)	0.6043 (4)	0.0128 (4)**	0.7985 (4)	0.0820 (4)*
4	0.5610 (0)	0.6119 (6)	0.3860 (3)	0.9930 (2)	0.6626 (2)	0.9387 (7)
5	0.9029 (2)	0.1145 (1)	0.1618 (2)	0.1341 (4)	0.9052 (3)	0.0606 (3)*
6	0.0441 (4)**	0.0200 (4)**	0.1768 (4)	0.0101 (3)**	0.4886 (1)	0.0001 (4)***
7	0.9038 (3)	0.2057 (1)	0.1409 (2)	0.2198 (2)	0.5683 (4)	0.4014 (3)
8	0.0874 (1)*	0.1353 (9)	0.8242 (2)	0.7573 (6)	0.4772 (5)	0.2030 (11)
9	0.3665 (1)	0.3469 (2)	0.3008 (1)	0.9851 (4)	0.7500 (5)	0.6579 (3)
10	0.3681 (2)	0.3820 (1)	0.1285 (1)	0.0349 (3)**	0.4808 (5)	0.3713 (2)
11	0.2062 (2)	0.1722 (0)	0.9547 (1)	0.9473 (0)	0.8681 (5)	0.3433 (1)
12	0.5662 (2)	0.6528 (1)	0.8458 (1)	0.9728 (4)	0.4868 (3)	0.8696 (2)
13	0.5574 (1)	0.2345 (5)	0.4662 (1)	0.1308 (2)	0.3825 (2)	0.0000 (5)***
14	0.5396 (3)	0.5021 (2)	0.2409 (5)	0.2829 (3)	0.4360 (3)	0.5194 (3)
15	0.0117 (3)**	0.1764 (4)	0.0184 (3)**	0.0346 (0)**	0.1938 (4)	0.5659 (4)
16	0.2014 (2)	0.2466 (0)	0.0272 (2)**	0.8396 (2)	0.3947 (2)	0.4803 (1)
17	0.1854 (3)	0.0230 (4)**	0.8805 (2)	0.5136 (3)	0.1957 (1)	0.0091 (4)***
18	0.1623 (3)	0.0004 (4)***	0.2979 (0)	0.1511 (3)	0.0871 (3)*	0.0005 (4)***
19	0.3385 (0)	0.1607 (3)	0.7580 (2)	0.9702 (5)	0.9139 (5)	0.7079 (8)
20	0.6354 (1)	0.0470 (3)**	0.7961 (3)	0.6731 (3)	0.0461 (3)**	0.0225 (6)**
21	0.2863 (4)	0.3572 (1)	0.6897 (2)	0.9991 (1)	0.2923 (5)	0.7531 (1)
22	0.0308 (3)**	0.0039 (0)***	0.3183 (2)	0.9787 (17)	0.7688 (2)	0.3231 (5)
23	0.5408 (6)	0.0000 (0)***	0.6822 (2)	0.3513 (3)	0.7188 (4)	0.0000 (1)***
24	0.3834 (1)	0.2866 (2)	0.3301 (2)	0.1958 (2)	0.9207 (2)	0.1575 (2)
25	0.0581 (2)*	0.0215 (2)**	0.0034 (1)***	0.9913 (8)	0.3903 (3)	0.8958 (1)
26	0.2164 (4)	0.0319 (0)**	0.8470 (4)	0.9876 (4)	0.2228 (4)	0.5090 (5)
27	0.8095 (2)	0.8655 (2)	0.7541 (3)	0.9982 (2)	0.9953 (4)	0.9937 (3)
28	0.4664 (1)	0.0766 (2)*	0.5852 (3)	0.5920 (2)	0.7849 (5)	0.1054 (2)
29	0.2151 (3)	0.0123 (2)**	0.0387 (4)**	0.0552 (3)*	0.4922 (4)	0.0170 (3)**
30	0.2341 (3)	0.0791 (2)*	0.2154 (0)	0.2623 (11)	0.7432 (2)	0.2578 (6)
31	0.8704 (1)	0.1056 (3)	0.4092 (2)	0.0000 (4)***	0.9877 (4)	0.0009 (4)***
32	0.8110 (3)	0.5416 (2)	0.1448 (1)	0.0340 (2)**	0.6019 (4)	0.2916 (5)
33	0.0691 (2)*	0.0167 (4)**	0.5258 (5)	0.0000 (4)***	0.5018 (4)	0.0000 (4)***
34	0.0318 (5)**	0.0083 (5)***	0.0663 (5)*	0.0001 (5)***	0.4969 (3)	0.0000 (2)***
35	0.5109 (3)	0.3156 (0)	0.8987 (4)	0.2208 (6)	0.3785 (4)	0.2671 (4)
36	0.5605 (1)	0.6563 (4)	0.4092 (1)	0.9071 (2)	0.6484 (3)	0.7610 (4)
37	0.0439 (2)**	0.0004 (3)***	0.6066 (2)	0.9509 (3)	0.5515 (4)	0.0043 (2)***
38	0.1323 (4)	0.0932 (5)*	0.0689 (4)*	0.1085 (5)	0.4647 (5)	0.0486 (6)**

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Industry	*yk*	*rp*	*yl*	*wp*	*kl*	*wr*
39	0.4273 (3)	0.0219 (1)**	0.1822 (4)	0.0021 (1)***	0.7609 (0)	0.0005 (3)***
40	0.7164 (4)	0.2469 (7)	0.9399 (5)	0.4746 (1)	0.9734 (5)	0.6010 (6)
41	0.2284 (3)	0.1415 (0)	0.2522 (2)	0.1647 (1)	0.3394 (5)	0.1884 (5)
42	0.6002 (1)	0.1000 (1)*	0.5546 (6)	0.3371 (1)	0.6750 (5)	0.1791 (2)
43	0.9987 (2)	0.4679 (2)	0.0558 (2)*	0.2178 (6)	0.9928 (5)	0.5218 (3)
44	0.5263 (3)	0.0726 (2)*	0.7784 (3)	0.5291 (2)	0.9357 (4)	0.0602 (7)*
45	0.7203 (1)	0.9275 (1)	0.6509 (5)	0.9528 (0)	0.5500 (5)	0.9744 (2)
46	0.8462 (5)	0.8501 (5)	0.7108 (5)	0.8414 (5)	0.5443 (6)	0.5992 (5)
47	0.9554 (0)	0.6365 (4)	0.6014 (2)	0.9951 (2)	0.7089 (5)	0.8846 (0)
48	0.5755 (5)	0.3161 (3)	0.8197 (5)	0.5456 (2)	0.7282 (5)	0.3549 (1)
49	0.9588 (4)	0.8892 (1)	0.0076 (4)***	0.9718 (3)	0.6933 (3)	0.7104 (3)
50	0.6108 (4)	0.3737 (2)	0.9638 (1)	0.9973 (1)	0.6288 (1)	0.9790 (1)
51	0.2603 (4)	0.3145 (4)	0.1014 (2)	0.3546 (2)	0.7840 (5)	0.5206 (5)
52	0.2762 (2)	0.4990 (4)	0.4030 (3)	0.9959 (2)	0.7834 (5)	0.8801 (4)
53	0.9304 (5)	0.0000 (1)***	0.9457 (4)	0.5468 (4)	0.5838 (4)	0.0000 (4)***
54	0.9674 (5)	0.4435 (1)	0.8748 (2)	0.8509 (2)	0.9822 (4)	0.5633 (0)
55	0.7773 (2)	0.0463 (5)**	0.7902 (4)	0.9359 (1)	0.6832 (4)	0.5546 (5)
56	0.0721 (4)*	0.0603 (2)*	0.9309 (3)	0.7427 (2)	0.4931 (5)	0.0206 (2)**
57	0.5168 (4)	0.5602 (1)	0.7019 (3)	0.3296 (3)	0.1526 (0)	0.4317 (2)
58	0.7281 (5)	0.3326 (4)	0.4008 (1)	0.0241 (2)**	0.5740 (5)	0.0457 (3)**
59	0.6055 (2)	0.0170 (4)**	0.5803 (3)	0.0185 (4)**	0.7758 (4)	0.0032 (4)***
60	0.0002 (3)***	0.0426 (8)**	0.8123 (3)	0.8296 (3)	0.0400 (5)**	0.1398 (12)
61	0.7672 (1)	0.0003 (5)***	0.5968 (1)	0.4799 (1)	0.6368 (2)	0.0007 (5)***
62	0.0221 (1)**	0.0989 (0)*	0.0017 (3)***	0.0203 (3)**	0.0035 (2)***	0.0302 (2)**
63	0.9125 (1)	0.0341 (2)**	0.8697 (6)	0.6551 (4)	0.3072 (3)	0.0006 (3)***
64	0.4478 (5)	0.5753 (4)	0.6018 (4)	0.5934 (5)	0.0004 (4)***	0.4343 (4)
65	0.5709 (4)	0.0706 (3)*	0.0307 (3)**	0.0802 (1)*	0.0787 (4)*	0.0545 (2)*

Notes: We report MacKinnon (1996) one-sided p-values, where *, ** and *** denote the rejection of the unit root null hypothesis at, respectively, the 10%, 5% and 1% significance levels. Tests include an intercept and a trend. Bandwidth selection was made according to the Newey-West (1994) method, using Bartlett kernel (figures enclosed in parentheses represent the Newey-West bandwidth).

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Table 3.6.2: PP unit root tests (variables in first differences)

Industry	*yk*	*rp*	*yl*	*wp*	*kl*	*wr*
AG	0.0000 (7)***	0.0000 (2)***	0.0000 (4)***	0.0000 (1)***	0.0000 (14)***	0.0000 (1)***
1	0.0001 (4)***	0.0001 (7)***	0.0001 (19)***	0.0000 (20)***	0.0000 (2)***	0.0000 (13)***
2	0.0000 (4)***	0.0000 (7)***	0.0000 (3)***	0.0000 (0)***	0.0001 (6)***	0.0000 (10)***
3	0.0000 (4)***	0.0000 (3)***	0.0000 (2)***	0.0001 (3)***	0.0000 (2)***	0.0001 (1)***
4	0.0000 (2)***	0.0000 (8)***	0.0000 (8)***	0.0001 (4)***	0.0000 (1)***	0.0001 (9)***
5	0.0000 (7)***	0.0000 (5)***	0.0000 (5)***	0.0000 (3)***	0.0000 (1)***	0.0000 (0)***
6	0.0000 (3)***	0.0000 (3)***	0.0000 (4)***	0.0001 (6)***	0.0000 (1)***	0.0001 (4)***
7	0.0043 (3)***	0.0001 (4)***	0.0000 (2)***	0.0000 (0)***	0.0060 (7)***	0.0001 (6)***
8	0.0000 (7)***	0.0000 (47)***	0.0000 (0)***	0.0000 (13)***	0.0000 (9)***	0.0001 (65)***
9	0.0000 (7)***	0.0000 (7)***	0.0000 (5)***	0.0000 (4)***	0.0000 (16)***	0.0000 (8)***
10	0.0000 (6)***	0.0000 (9)***	0.0000 (4)***	0.0001 (16)***	0.0000 (19)***	0.0001 (26)***
11	0.0000 (8)***	0.0000 (7)***	0.0000 (3)***	0.0000 (6)***	0.0000 (12)***	0.0000 (7)***
12	0.0000 (7)***	0.0000 (4)***	0.0000 (4)***	0.0045 (3)***	0.0000 (11)***	0.0000 (1)***
13	0.0000 (3)***	0.0001 (4)***	0.0000 (3)***	0.0001 (1)***	0.0000 (6)***	0.0001 (2)***
14	0.0000 (5)***	0.0000 (0)***	0.0000 (2)***	0.0000 (3)***	0.0000 (10)***	0.0000 (2)***
15	0.0000 (14)***	0.0000 (19)***	0.0000 (21)***	0.0001 (23)***	0.0000 (9)***	0.0000 (13)***
16	0.0000 (7)***	0.0000 (10)***	0.0000 (12)***	0.0000 (0)***	0.0050 (17)***	0.0000 (9)***
17	0.0000 (7)***	0.0001 (33)***	0.0000 (5)***	0.0000 (4)***	0.0000 (4)***	0.0001 (34)***
18	0.0000 (0)***	0.0001 (24)***	0.0000 (4)***	0.0000 (8)***	0.0000 (1)***	0.0001 (40)***
19	0.0000 (3)***	0.0000 (27)***	0.0000 (23)***	0.0000 (10)***	0.0048 (4)***	0.0001 (31)***
20	0.0000 (3)***	0.0000 (14)***	0.0000 (7)***	0.0001 (10)***	0.0000 (2)***	0.0000 (19)***
21	0.0000 (4)***	0.0000 (1)***	0.0000 (0)***	0.0001 (5)***	0.0000 (4)***	0.0000 (2)***
22	0.0000 (19)***	0.0001 (38)***	0.0001 (58)***	0.0001 (65)***	0.0000 (0)***	0.0001 (28)***
23	0.0000 (17)***	0.0001 (19)***	0.0000 (4)***	0.0000 (14)***	0.0072 (0)***	0.0001 (18)***
24	0.0000 (1)***	0.0000 (1)***	0.0000 (1)***	0.0000 (8)***	0.0000 (4)***	0.0001 (11)***
25	0.0000 (6)***	0.0000 (9)***	0.0000 (16)***	0.0000 (13)***	0.0000 (4)***	0.0000 (6)***
26	0.0000 (19)***	0.0001 (15)***	0.0000 (6)***	0.0000 (9)***	0.0000 (7)***	0.0000 (13)***
27	0.0000 (1)***	0.0000 (4)***	0.0000 (2)***	0.0000 (1)***	0.0001 (4)***	0.0000 (3)***
28	0.0000 (1)***	0.0000 (7)***	0.0000 (2)***	0.0000 (4)***	0.0031 (2)***	0.0001 (12)***
29	0.0011 (4)***	0.0000 (2)***	0.0000 (10)***	0.0000 (7)***	0.0047 (4)***	0.0001 (7)***
30	0.0000 (12)***	0.0000 (14)***	0.0001 (15)***	0.0001 (30)***	0.0000 (6)***	0.0001 (46)***
31	0.0000 (1)***	0.0001 (4)***	0.0000 (0)***	0.0001 (20)***	0.0000 (4)***	0.0001 (13)***
32	0.0001 (1)***	0.0000 (6)***	0.0000 (2)***	0.0000 (2)***	0.0011 (1)***	0.0000 (11)***
33	0.0000 (6)***	0.0001 (7)***	0.0000 (4)***	0.0001 (24)***	0.0000 (3)***	0.0001 (18)***
34	0.0000 (4)***	0.0001 (3)***	0.0000 (4)***	0.0001 (5)***	0.0000 (0)***	0.0001 (2)***
35	0.0000 (6)***	0.0000 (1)***	0.0000 (5)***	0.0001 (65)***	0.0000 (3)***	0.0000 (10)***
36	0.0000 (2)***	0.0000 (5)***	0.0000 (2)***	0.0000 (2)***	0.0000 (2)***	0.0000 (5)***
37	0.0000 (3)***	0.0001 (14)***	0.0000 (11)***	0.0000 (1)***	0.0216 (1)**	0.0000 (7)***
38	0.0000 (3)***	0.0000 (4)***	0.0000 (2)***	0.0000 (2)***	0.0000 (4)***	0.0001 (4)***

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Industry	*yk*	*rp*	*yl*	*wp*	*kl*	*wr*
39	0.0000 (0)***	0.0000 (6)***	0.0000 (4)***	0.0001 (16)***	0.0000 (6)***	0.0001 (21)***
40	0.0000 (12)***	0.0000 (48)***	0.0000 (10)***	0.0000 (7)***	0.0039 (3)***	0.0000 (15)***
41	0.0000 (4)***	0.0000 (0)***	0.0000 (1)***	0.0000 (5)***	0.0328 (2)**	0.0000 (5)***
42	0.0000 (5)***	0.0000 (8)***	0.0000 (17)***	0.0000 (8)***	0.0034 (3)***	0.0000 (2)***
43	0.0000 (2)***	0.0000 (9)***	0.0000 (9)***	0.0000 (37)***	0.0234 (2)**	0.0000 (10)***
44	0.0000 (2)***	0.0000 (12)***	0.0000 (1)***	0.0000 (1)***	0.0022 (1)***	0.0001 (65)***
45	0.0000 (2)***	0.0000 (1)***	0.0035 (3)***	0.0000 (2)***	0.0062 (1)***	0.0000 (3)***
46	0.0049 (3)***	0.0005 (3)***	0.0000 (5)***	0.0000 (4)***	0.2799 (4)	0.0002 (4)***
47	0.0001 (6)***	0.0000 (5)***	0.0000 (2)***	0.0000 (2)***	0.0000 (3)***	0.0000 (3)***
48	0.0105 (4)**	0.0000 (7)***	0.0023 (1)***	0.0000 (0)***	0.0292 (4)**	0.0000 (6)***
49	0.0003 (1)***	0.0000 (0)***	0.0000 (1)***	0.0000 (1)***	0.0000 (4)***	0.0000 (2)***
50	0.0000 (8)***	0.0000 (2)***	0.0000 (4)***	0.0000 (1)***	0.0000 (4)***	0.0000 (1)***
51	0.0004 (4)***	0.0000 (4)***	0.0000 (2)***	0.0000 (0)***	0.0181 (3)**	0.0000 (4)***
52	0.0000 (2)***	0.0000 (3)***	0.0000 (2)***	0.0000 (3)***	0.0251 (3)**	0.0000 (3)***
53	0.0001 (5)***	0.0001 (24)***	0.0000 (4)***	0.0001 (11)***	0.0000 (4)***	0.0001 (33)***
54	0.0000 (5)***	0.0001 (6)***	0.0000 (2)***	0.0000 (2)***	0.0000 (4)***	0.0000 (6)***
55	0.0000 (3)***	0.0001 (4)***	0.0000 (4)***	0.0001 (3)***	0.0000 (4)***	0.0001 (3)***
56	0.0000 (4)***	0.0001 (7)***	0.0000 (3)***	0.0000 (2)***	0.0025 (4)***	0.0001 (10)***
57	0.0000 (4)***	0.0000 (1)***	0.0000 (2)***	0.0000 (2)***	0.0000 (2)***	0.0000 (2)***
58	0.0000 (4)***	0.0000 (3)***	0.0000 (0)***	0.0001 (9)***	0.0014 (3)***	0.0000 (2)***
59	0.0003 (3)***	0.0001 (4)***	0.0000 (2)***	0.0001 (7)***	0.0017 (1)***	0.0001 (8)***
60	0.0000 (4)***	0.0001 (42)***	0.0000 (3)***	0.0000 (3)***	0.0000 (0)***	0.0001 (36)***
61	0.0000 (1)***	0.0001 (2)***	0.0000 (2)***	0.0000 (8)***	0.0000 (3)***	0.0001 (3)***
62	0.0024 (5)***	0.0000 (5)***	0.0003 (2)***	0.0000 (5)***	0.0007 (3)***	0.0000 (5)***
63	0.0000 (4)***	0.0001 (20)***	0.0000 (25)***	0.0001 (0)***	0.0001 (1)***	0.0001 (17)***
64	0.0345 (2)**	0.0000 (3)***	0.0036 (3)***	0.0000 (3)***	0.0000 (13)***	0.0001 (1)***
65	0.0005 (3)***	0.0000 (11)***	0.0021 (5)***	0.0000 (11)***	0.0037 (10)***	0.0000 (11)***

Notes: We report MacKinnon (1996) one-sided p-values, where *, ** and *** denote the rejection of the unit root null hypothesis at, respectively, the 10%, 5% and 1% significance levels. Tests include an intercept and a trend. Bandwidth selection was made according to the Newey-West (1994) method, using Bartlett kernel (figures enclosed in parentheses represent the Newey-West bandwidth).

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Table 3.7.1: Lag length selection (*yk rp*) and (*yl wp*)

Industry	*yk rp*				*yl wp*			
	0 lags	**1 lag**	**2 lags**	**3 lags**	**0 lags**	**1 lag**	**2 lags**	**3 lags**
AG	-6.9721	-9.2899*	-9.1634	-8.9299	-6.9816	-10.0416*	-9.8729	-9.6472
1	-2.2604	-3.7855*	-3.6419	-3.4374	-1.5202	-3.0880*	-2.9949	-2.8815
2	-2.0183	-4.9909*	-4.7843	-4.6095	-2.5967	-5.0433*	-4.9158	-4.7493
3	-2.4956	-4.5507*	-4.5423	-4.4896	0.1754	-1.9423*	-1.9136	-1.7527
4	-1.2502	-4.4291*	-4.2041	-4.0701	-1.0365	-5.2799	-5.2831*	-5.1090
5	0.7883	-1.2220*	-1.0302	-0.9502	-1.2076	-2.9030*	-2.6564	-2.4237
6	-5.2671	-6.8233*	-6.8099	-6.6922	-2.9719	-4.6993*	-4.5654	-4.3915
7	0.1641	-3.3661	-3.7381*	-3.4916	-4.7173	-9.1912*	-8.9849	-8.8973
8	-1.6401	-3.6049	-3.6178*	-3.3841	-4.1459	-6.6123*	-6.5005	-6.3282
9	-2.1574	-4.3429*	-4.2894	-4.0538	-4.1215	-7.5451*	-7.3294	-7.1756
10	-1.0984	-2.2139*	-1.9886	-1.8324	-3.4557	-4.4376*	-4.2389	-4.1808
11	-2.9341	-5.1831*	-5.0741	-4.8562	-5.6748	-8.7220*	-8.5624	-8.3547
12	-1.7273	-4.8848*	-4.7456	-4.6111	-3.4959	-7.6675	-7.7942*	-7.5461
13	1.6111	-1.8499*	-1.7144	-1.4883	0.6393	-2.7628*	-2.5582	-2.3800
14	-2.7399	-5.1004*	-5.0774	-4.9690	-3.8487	-6.3555*	-6.1233	-5.9207
15	-0.6351	-1.8719*	-1.7292	-1.5388	-2.4951	-3.9813*	-3.9225	-3.7286
16	-1.3621	-3.3546	-3.4479*	-3.2166	-4.0802	-6.1284*	-5.8843	-5.6421
17	-1.7900	-3.4445*	-3.3272	-3.1041	-5.9453	-8.6201*	-8.4397	-8.2291
18	-1.7927	-3.1531*	-2.9350	-2.8763	-4.8567	-5.8525*	-5.6809	-5.5353
19	-3.0694	-6.0982*	-5.8722	-5.7621	-3.9256	-6.6927*	-6.5693	-6.4281
20	-1.9348	-3.9573*	-3.8055	-3.7357	-4.8794	-7.0004*	-6.9146	-6.7860
21	-1.2022	-4.0752*	-3.8506	-3.7039	-4.9597	-6.7046*	-6.5945	-6.3432
22	-4.0112	-5.6764*	-5.4991	-5.3527	-4.5936	-6.6115*	-6.3724	-6.3709
23	-2.0416	-3.2695*	-3.1101	-2.9919	-4.6271	-6.6922*	-6.5302	-6.4689
24	-0.7752	-1.9440*	-1.7289	-1.4946	0.7122	-0.9643*	-0.8209	-0.6282
25	-3.5567	-7.2282*	-7.1244	-6.9461	-3.4258	-6.5935*	-6.4009	-6.1784
26	-3.0942	-4.6397	-4.6626*	-4.4504	-4.2922	-6.9928*	-6.8811	-6.6944
27	-3.7291	-6.8351*	-6.8176	-6.6410	-5.5041	-8.6931*	-8.4730	-8.2375
28	-3.2130	-4.8349*	-4.6594	-4.4674	-6.0109	-8.0718*	-7.8455	-7.7342
29	-0.2910	-2.1983	-2.3152*	-2.0847	-2.4399	-3.7518*	-3.6982	-3.5111
30	-1.2053	-2.8075*	-2.5886	-2.3995	-2.7878	-3.8823*	-3.7051	-3.5483
31	-0.4083	-1.8987*	-1.6968	-1.5303	-0.7906	-1.6832*	-1.5157	-1.3485
32	-1.3577	-4.7252*	-4.6665	-4.5802	-5.3784	-7.4652*	-7.3752	-7.4412
33	-3.0022	-4.0302*	-3.9251	-3.8944	-0.9565	-2.7281*	-2.5148	-2.5302
34	-0.3030	-1.7239*	-1.6771	-1.4852	-0.1145	-0.8047*	-0.6901	-0.5171
35	-1.6214	-3.9453*	-3.7623	-3.6201	-1.5966	-3.3710*	-3.1974	-3.0091
36	-0.2406	-3.1855*	-2.9558	-2.8406	-3.2678	-7.1920*	-7.0250	-6.8533
37	-3.9621	-5.4226	-5.6316*	-5.5387	-4.4482	-7.1462*	-6.9566	-6.8274

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Industry	*yk rp*				*yl wp*			
	0 lags	**1 lag**	**2 lags**	**3 lags**	**0 lags**	**1 lag**	**2 lags**	**3 lags**
38	-2.8325	-4.6744*	-4.6037	-4.5337	-2.0898	-3.1630*	-3.0860	-2.9275
39	-4.0395	-5.8711*	-5.6406	-5.5111	-4.0458	-5.4200*	-5.1921	-5.1605
40	0.9044	-3.6425*	-3.5647	-3.4876	-1.5264	-4.8491	-4.8061	-4.8585*
41	-4.0360	-6.7571*	-6.6237	-6.4975	-4.9421	-6.6337*	-6.4251	-6.2307
42	2.0990	-0.1138*	0.1014	0.3397	-1.8776	-3.5640*	-3.3894	-3.1702
43	-0.4747	-3.5224*	-3.3583	-3.2021	-5.6250	-6.9558*	-6.8318	-6.7273
44	1.2295	-0.3468*	-0.2180	0.0362	1.2455	-1.1644*	-0.9344	-0.7057
45	-10.2638	-14.1912	-14.2088*	-14.0280	-2.3175	-7.6105*	-7.5500	-7.3063
46	-4.0165	-9.0772	-9.2732*	-9.1730	-1.8536	-7.0021*	-6.8794	-6.7646
47	-1.0277	-6.1526*	-6.1285	-5.8761	-2.3737	-7.7360*	-7.5058	-7.3561
48	2.1422	-1.5320	-1.7567*	-1.6259	-0.0462	-4.7436	-4.8740*	-4.7171
49	-1.8355	-6.2529*	-6.1866	-6.0004	-5.4156	-8.5485*	-8.3535	-8.1348
50	-0.1017	-3.5385	-3.5579*	-3.4601	-1.7102	-6.2204	-6.2640*	-6.0982
51	0.5533	-5.5503*	-5.4423	-5.4716	-3.3638	-8.5114*	-8.3722	-8.2583
52	-1.2516	-5.4553*	-5.3005	-5.3378	-1.9744	-6.2748*	-6.1692	-6.0427
53	1.1217	-2.1611	-2.3236*	-2.1748	-1.6951	-4.9548*	-4.7986	-4.6317
54	0.5646	-3.2227*	-3.1860	-3.1991	-3.7358	-7.1463*	-6.9544	-6.8005
55	-1.8038	-4.3496*	-4.3361	-4.1139	-3.1008	-7.1167	-7.2849*	-7.0367
56	0.3183	-2.4838*	-2.3188	-2.0874	-3.6587	-6.1630*	-6.0543	-5.9144
57	0.0250	-3.3757*	-3.1740	-3.0456	-1.0849	-4.0577*	-3.8920	-3.8217
58	-1.5863	-4.2396*	-4.0527	-3.8693	-3.2960	-4.7270*	-4.5378	-4.3886
59	-1.4475	-3.6932	-3.6977*	-3.5147	-3.5590	-5.3057*	-5.1417	-5.0708
60	-2.6721	-4.9290*	-4.8348	-4.6725	-6.1226	-8.8545*	-8.6445	-8.5745
61	0.7275	-1.5927*	-1.3404	-1.2585	-5.5658	-7.7741*	-7.5741	-7.4710
62	-6.3859	-7.7225	-7.8613*	-7.6814	-3.8557	-5.0246	-5.0104	-5.0768*
63	-3.1518	-4.6768*	-4.5499	-4.4272	-2.3651	-3.5271*	-3.5106	-3.4563
64	-2.6106	-5.6892	-6.1067*	-5.9025	-0.9995	-3.7216	-4.1117*	-3.9870
65	-4.3231	-8.3801*	-8.3017	-8.0761	-5.2874	-7.0958	-7.1431*	-7.0245

Note: Schwarz information criterion values; * denotes lag order selected by the criterion.

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Table 3.7.2: Lag length selection (*kl wr*)

Industry	*kl wr*			
	0 lags	**1 lag**	**2 lags**	**3 lags**
AG	-5.3978	-8.1555*	-8.1255	-7.9231
1	0.1313	-4.0395*	-3.8496	-3.6183
2	-0.1379	-3.8801	-4.0144*	-3.7718
3	0.4602	-1.5770*	-1.5659	-1.5283
4	-0.8398	-3.5436*	-3.4493	-3.3165
5	2.0427	-0.9869*	-0.8544	-0.8715
6	-3.8892	-6.0360*	-6.0246	-5.8517
7	0.5169	-3.2525	-3.5441*	-3.3492
8	-0.1761	-2.9926*	-2.9396	-2.7094
9	-2.0710	-3.9293*	-3.8905	-3.6978
10	-0.9154	-2.0665*	-1.8623	-1.7892
11	-1.9248	-4.6092*	-4.4690	-4.2631
12	-2.0610	-4.3411*	-4.2826	-4.0854
13	0.6113	-0.8622*	-0.8014	-0.6217
14	-2.0258	-3.6381*	-3.5142	-3.2908
15	-0.4798	-2.2622*	-2.2464	-2.1229
16	-0.3810	-2.6458	-2.8800*	-2.6760
17	-1.9795	-3.1149*	-3.0555	-2.8507
18	-1.4385	-3.0674*	-3.0278	-2.9351
19	-1.9181	-6.6365*	-6.4896	-6.3687
20	-3.2886	-4.3913*	-4.1706	-4.1480
21	-0.6795	-3.3690*	-3.3468	-3.1845
22	-2.7782	-4.9948*	-4.7741	-4.6190
23	-0.9602	-3.2831	-3.4376*	-3.1966
24	-0.8260	-3.3110*	-3.1528	-2.9928
25	-2.7647	-6.3587	-6.4896*	-6.3052
26	-2.3166	-4.0824*	-3.9138	-3.7534
27	-2.1251	-6.1834*	-6.1433	-5.9272
28	-2.3201	-4.9573	-4.9960*	-4.8564
29	-0.1455	-2.3033	-2.5443*	-2.3245
30	-0.4688	-2.4269*	-2.2502	-2.0812
31	1.6444	-1.4486*	-1.3702	-1.2039
32	-1.0847	-4.6435	-4.6549*	-4.5887
33	-0.1087	-2.0177	-2.1245*	-2.0880
34	0.7818	-1.9168*	-1.8049	-1.6063
35	-0.8807	-2.9993*	-2.8523	-2.6240
36	-0.4014	-3.3972*	-3.2290	-3.0509
37	-2.4043	-4.6574	-5.0494*	-4.8261

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Industry	*kl wr*			
	0 lags	**1 lag**	**2 lags**	**3 lags**
38	-1.7682	-4.2199*	-4.1413	-4.1394
39	-2.4186	-4.4339*	-4.2386	-4.0684
40	2.3134	-3.0363*	-3.0269	-2.8245
41	-2.0574	-5.9417	-6.2023*	-5.9689
42	2.6158	-0.7726	-0.9872*	-0.8079
43	0.1499	-3.6598	-3.7275*	-3.5063
44	2.3714	-1.4164	-1.4719*	-1.2540
45	-2.1649	-7.2768	-7.3396*	-7.0891
46	-0.9581	-5.3314	-6.1726*	-6.1456
47	-1.1664	-5.3131*	-5.2432	-5.0958
48	3.1480	-0.9815	-1.2917*	-1.1308
49	-1.2831	-5.7531	-5.8643*	-5.6777
50	-1.0529	-3.7174	-3.7423*	-3.5215
51	0.5094	-5.3223*	-5.1425	-5.0685
52	0.5354	-5.6162	-5.6671*	-5.6452
53	0.2256	-1.7917*	-1.7372	-1.7717
54	1.7839	-2.5751*	-2.4547	-2.3568
55	-0.0636	-3.4363	-3.7082*	-3.5204
56	0.4946	-2.6846	-3.1702*	-3.0096
57	0.3399	-2.6888*	-2.4703	-2.4001
58	-0.6599	-3.2948	-3.3134*	-3.1925
59	-0.3298	-3.3036	-3.3257*	-3.1641
60	-1.5048	-5.0809*	-5.0344	-4.9454
61	0.8699	-1.6778*	-1.4614	-1.3930
62	-2.2592	-3.4317	-3.4858*	-3.4664
63	-2.9303	-4.5673*	-4.4939	-4.3746
64	-2.9990	-4.2395	-4.3484*	-4.1502
65	-2.2858	-5.3493	-5.3746*	-5.1658

Note: Schwarz information criterion values; * denotes lag order selected by the criterion.

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Table 3.7.3: Lag length selection (*yk rp kl*) and (*yl wp kl*)

Industry	*yk rp kl*				*yl wp kl*			
	0 lags	**1 lag**	**2 lags**	**3 lags**	**0 lags**	**1 lag**	**2 lags**	**3 lags**
AG	-10.3695	-14.4034	-14.4488*	-14.0510	-10.9218	-14.9034	-14.9574*	-14.5700
1	-3.3590	-7.5451*	-7.1151	-6.6778	-2.9096	-7.0189*	-6.6160	-6.2136
2	-2.8311	-7.6669*	-7.5967	-7.1200	-3.2202	-8.1841*	-8.0365	-7.5809
3	-3.1512	-7.0950*	-6.8986	-6.6069	-0.4112	-4.4805*	-4.2670	-3.9700
4	-3.9219	-7.7912*	-7.4654	-7.1028	-3.0053	-8.2597*	-8.0302	-7.6365
5	0.1392	-3.6995*	-3.3606	-3.1456	-0.4250	-4.4855*	-4.0740	-3.9581
6	-8.0859	-11.8290*	-11.5986	-11.2481	-6.0201	-9.7427*	-9.4941	-9.1357
7	-1.6385	-7.7598	-8.1969*	-7.9307	-5.7194	-12.1613	-12.4235*	-12.1798
8	-3.1740	-6.9884*	-6.7450	-6.4019	-5.4367	-9.3018*	-9.0772	-8.7407
9	-5.0594	-9.0757*	-8.8532	-8.5490	-6.2407	-10.3923*	-10.1437	-9.8476
10	-4.6412	-5.8551*	-5.4876	-5.1295	-5.5648	-6.8507*	-6.4236	-6.1751
11	-5.1692	-9.2937*	-9.1652	-8.6691	-7.4288	-11.5312*	-11.4046	-10.9153
12	-4.1949	-8.7069	-8.7600*	-8.3212	-5.4215	-10.1873	-10.3235*	-9.8985
13	0.5409	-4.4831*	-4.2578	-3.8151	-0.2695	-5.3684*	-5.0658	-4.5585
14	-4.9933	-8.2953*	-8.0817	-7.6510	-5.9683	-9.2382*	-9.0698	-8.6477
15	-2.5784	-4.6977*	-4.4488	-4.1273	-3.8456	-6.2088*	-6.0719	-5.7374
16	-3.4274	-6.7397*	-6.6861	-6.1772	-5.0149	-8.2536*	-8.1570	-7.6636
17	-4.4909	-7.8483*	-7.6866	-7.2311	-7.9846	-11.5314*	-11.4010	-10.9219
18	-4.4319	-6.5881*	-6.2615	-5.9732	-6.6470	-9.0692*	-8.7787	-8.4658
19	-4.8685	-11.1700*	-10.7071	-10.4372	-5.4419	-11.8499*	-11.4717	-11.1346
20	-5.1597	-7.8468*	-7.5938	-7.3448	-7.7063	-10.2785*	-10.0517	-9.8873
21	-4.0816	-7.9582*	-7.6800	-7.2129	-5.9006	-9.9407*	-9.6858	-9.1984
22	-6.6559	-9.9612*	-9.7130	-9.3843	-7.1372	-10.3508*	-10.1135	-9.7842
23	-3.9676	-7.4457	-7.4656*	-7.1364	-7.2741	-10.8238*	-10.8126	-10.4630
24	-2.3689	-5.6999*	-5.2411	-4.7899	-1.4311	-4.8656*	-4.4174	-3.9568
25	-7.1521	-11.4925	-11.6072*	-11.2470	-6.2486	-10.8984	-11.0206*	-10.6397
26	-5.0038	-8.6744*	-8.3889	-7.9939	-6.0624	-9.6974*	-9.4076	-8.9988
27	-6.3498	-11.3043*	-11.0585	-10.5824	-7.9191	-12.9095*	-12.6754	-12.2123
28	-5.9865	-9.8245*	-9.4862	-9.1705	-8.8383	-12.8205*	-12.4523	-12.1476
29	-1.9572	-5.2820	-5.6269*	-5.1381	-3.3231	-6.3261	-6.7159*	-6.2337
30	-3.7516	-6.0786*	-5.6096	-5.2057	-4.5447	-6.7240*	-6.2854	-5.9087
31	-1.2285	-5.0437*	-4.6342	-4.2105	-0.6969	-4.5562*	-4.1877	-3.8054
32	-4.1372	-8.6842*	-8.6777	-8.3472	-6.3046	-10.5561	-10.6800*	-10.4840
33	-4.8832	-7.6541*	-7.5134	-7.2912	-3.7922	-6.4253*	-6.3070	-6.0332
34	-1.4270	-4.8166*	-4.6053	-4.0853	-0.6949	-4.0946*	-3.8938	-3.3877
35	-3.6880	-7.6012*	-7.2976	-6.9552	-3.9425	-6.9805*	-6.7023	-6.2616
36	-2.5057	-6.8278*	-6.5507	-6.1356	-5.5917	-10.3352*	-9.9141	-9.5199
37	-5.6209	-9.7147	-10.0271*	-9.6065	-6.6122	-10.7851	-11.1648*	-10.7495

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Industry	*yk rp kl*				*yl wp kl*			
	0 lags	**1 lag**	**2 lags**	**3 lags**	**0 lags**	**1 lag**	**2 lags**	**3 lags**
38	-4.8220	-8.1435*	-7.8687	-7.6297	-3.6313	-6.7193*	-6.4205	-6.1231
39	-6.7776	-9.8413*	-9.3773	-9.2354	-6.2736	-9.4046*	-8.9492	-8.8164
40	-0.3796	-6.4332	-6.6388*	-6.2361	-1.1498	-7.2346	-7.4122*	-7.1636
41	-6.3750	-10.7906*	-10.7805	-10.2903	-6.0981	-10.4747*	-10.4726	-9.9746
42	2.9189	-1.5646*	-1.3108	-0.8815	-0.2578	-4.6269*	-4.4821	-4.0308
43	-3.7948	-7.5902*	-7.4601	-6.9835	-6.1733	-10.6093*	-10.4859	-10.1185
44	1.7751	-2.7075*	-2.6504	-2.1743	1.0212	-3.6077*	-3.4299	-2.9223
45	-12.2591	-18.2552*	-18.1596	-17.6702	-6.6345	-12.9772*	-12.7117	-12.2080
46	-4.3808	-12.5327	-13.0241*	-12.7412	-1.4753	-9.6802	-10.1697*	-9.9054
47	-2.8388	-9.9143*	-9.6559	-9.2161	-3.9128	-11.4394*	-11.2445	-10.8497
48	1.7651	-5.4442*	-5.3085	-4.9522	0.8309	-7.4839*	-7.3616	-7.0257
49	-4.7767	-10.8653*	-10.5875	-10.2152	-6.0268	-12.5986*	-12.5360	-12.0872
50	-2.5530	-7.3630*	-7.2193	-6.8979	-4.1945	-9.9092*	-9.6676	-9.1781
51	-1.6541	-9.6124*	-9.2999	-9.1036	-4.1918	-12.3321*	-12.0314	-11.6403
52	-2.7904	-9.7410*	-9.5424	-9.5612	-2.4643	-10.4244*	-10.1511	-10.0347
53	-0.7725	-6.0105*	-5.9622	-5.7514	-3.1638	-8.3863*	-8.3350	-8.0867
54	-0.9715	-6.9421*	-6.6645	-6.5247	-5.0718	-11.1863*	-11.1132	-10.7950
55	-3.1827	-8.6939*	-8.6082	-8.1309	-5.8856	-11.2289*	-11.1627	-10.6483
56	-0.0961	-5.6243*	-5.5443	-5.1459	-3.9976	-9.4752*	-9.3697	-9.0855
57	-2.6347	-7.2646*	-6.7909	-6.4905	-3.1043	-8.0020*	-7.5259	-7.2462
58	-3.9575	-8.5352*	-8.0721	-7.7226	-4.0141	-8.4208*	-8.0302	-7.7064
59	-3.3335	-7.9113*	-7.6614	-7.4203	-4.4942	-8.9373*	-8.6722	-8.3899
60	-4.9332	-9.5612*	-9.2954	-9.0547	-8.7409	-13.5200*	-13.2425	-13.1394
61	-2.2862	-6.1601*	-5.7149	-5.4621	-6.2166	-10.7940*	-10.3873	-10.1290
62	-9.7230	-12.4928*	-12.3093	-12.0659	-8.4591	-11.0912*	-10.9277	-10.9158
63	-6.4724	-8.8994*	-8.6793	-8.3019	-5.2816	-7.6995*	-7.5562	-7.3593
64	-6.1731	-9.7050	-10.1705*	-9.6725	-4.4864	-7.9997	-8.5392*	-8.1297
65	-8.7724	-13.8536*	-13.7952	-13.4693	-8.5915	-13.3376*	-13.2423	-12.8703

Note: Schwarz information criterion values; * denotes lag order selected by the criterion.

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Table 3.8.1: Cointegration tests (*yk rp*)

Industry	*Trace test*		*Max eigenvalue test*	
	CVs=0	**CVs≤1**	**CVs=0**	**CVs≤1**
AG	13.8586	3.9722	9.8864	3.9722
1	20.5367	4.7801	15.7566	4.7801
2	12.4062	2.9464	9.4598	2.9464
3	22.6091	3.1239	19.4852**	3.1239
4	15.2181	3.6450	11.5731	3.6450
5	28.0170**	8.6264	19.3906**	8.6264
6	41.8380***	18.1759***	23.6621**	18.1759***
7	20.8212	2.6358	18.1854*	2.6358
8	20.1255	3.9123	16.2133	3.9123
9	12.1489	4.6989	7.4500	4.6989
10	24.8466*	4.3442	20.5024**	4.3442
11	17.4116	6.3052	11.1064	6.3052
12	8.6607	2.7972	5.8635	2.7972
13	39.8474***	16.2006**	23.6469**	16.2006**
14	25.6481*	9.4169	16.2311	9.4169
15	25.3460*	4.6506	20.6954**	4.6506
16	24.7130*	5.1550	19.5581**	5.1550
17	30.7120**	11.6084*	19.1036*	11.6084*
18	30.1573**	7.9819	22.1754**	7.9819
19	36.1337***	7.8591	28.2746***	7.8591
20	23.3557*	5.1077	18.2480*	5.1077
21	23.8140*	5.8968	17.9172*	5.8968
22	26.7893**	8.2235	18.5658*	8.2235
23	42.1971***	7.3738	34.8233***	7.3738
24	42.4269***	6.6444	35.7825***	6.6444
25	23.7003*	4.7923	18.9080*	4.7923
26	10.7749	5.1011	5.6738	5.1011
27	20.6956	3.6824	17.0133	3.6824
28	20.2305	6.9072	13.3233	6.9072
29	22.8120	4.1311	18.6809*	4.1311
30	16.6380	6.7856	9.8524	6.7856
31	23.1050	2.3880	20.7170**	2.3880
32	18.5860	4.9053	13.6807	4.9053
33	24.6025*	11.5722*	13.0302	11.5722*

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Industry	*Trace test*		*Max eigenvalue test*	
	CVs=0	**CVs≤1**	**CVs=0**	**CVs≤1**
34	42.2016***	18.7318***	23.4698**	18.7318***
35	14.8155	2.9054	11.9100	2.9054
36	12.8447	5.1552	7.6895	5.1552
37	33.2802***	14.0990**	19.1812*	14.0990**
38	15.8055	6.4763	9.3292	6.4763
39	19.5184	4.3796	15.1388	4.3796
40	44.2789***	5.4788	38.8001***	5.4788
41	25.7495*	6.3017	19.4477**	6.3017
42	32.8173***	5.7441	27.0732***	5.7441
43	19.9581	2.7204	17.2377*	2.7204
44	28.5488**	3.9847	24.5641***	3.9847
45	11.8809	3.5239	8.3570	3.5239
46	18.9184	5.1742	13.7442	5.1742
47	23.9650*	7.8763	16.0886	7.8763
48	15.0686	4.9972	10.0713	4.9972
49	20.6780	2.9251	17.7529*	2.9251
50	16.6021	4.3911	12.2110	4.3911
51	47.2071***	12.2504*	34.9567***	12.2504*
52	17.9661	2.4637	15.5024	2.4637
53	21.2861	3.4028	17.8832*	3.4028
54	14.2037	2.6618	11.5419	2.6618
55	13.8579	2.0018	11.8561	2.0018
56	27.0163**	9.4286	17.5877*	9.4286
57	13.3541	2.9094	10.4446	2.9094
58	19.5172	2.2459	17.2713*	2.2459
59	13.3358	5.1071	8.2287	5.1071
60	23.0592	7.0607	15.9985	7.0607
61	29.5674**	9.7049	19.8625**	9.7049
62	36.5898***	11.5231*	25.0667***	11.5231*
63	32.2809***	5.3632	26.9177***	5.3632
64	10.2347	3.9827	6.2521	3.9827
65	18.6064	7.7089	10.8975	7.7089

Notes: *, ** and *** denote rejection of the null hypotheses of 0 or at most 1 cointegrating vectors (CVs) at the 10%, 5% and 1% significance levels, respectively; lags selected according to the Schwarz Information Criterion; trends and intercepts are included in the tests.

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Table 3.8.2: Cointegration tests (*yl wp*)

Industry	*Trace test*		*Max eigenvalue test*	
	CVs=0	**CVs≤1**	**CVs=0**	**CVs≤1**
AG	12.6292	4.7054	7.9238	4.7054
1	14.7918	5.3806	9.4111	5.3806
2	14.7282	5.0083	9.7198	5.0083
3	12.9517	3.0228	9.9289	3.0228
4	14.4720	4.7771	9.6949	4.7771
5	20.3800	7.8186	12.5615	7.8186
6	38.3304***	15.3702**	22.9602**	15.3702**
7	18.9756	3.6520	15.3236	3.6520
8	32.4284***	7.1509	25.2775***	7.1509
9	21.0134	7.6399	13.3734	7.6399
10	21.5491	5.3900	16.1591	5.3900
11	15.7483	4.5369	11.2114	4.5369
12	8.4191	3.2138	5.2053	3.2138
13	42.7245***	19.0126***	23.7120**	19.0126***
14	27.8410**	7.1001	20.7409**	7.1001
15	24.5425*	4.8871	19.6554**	4.8871
16	14.1234	3.8520	10.2714	3.8520
17	30.1977**	5.5753	24.6224***	5.5753
18	19.4724	7.3130	12.1594	7.3130
19	31.5975***	12.5095*	19.0879*	12.5095*
20	34.5136***	9.4836	25.0300***	9.4836
21	13.7662	5.0372	8.7291	5.0372
22	25.2874*	5.6761	19.6113**	5.6761
23	15.8512	4.1363	11.7149	4.1363
24	22.0993	8.2175	13.8818	8.2175
25	29.5023**	7.2815	22.2207**	7.2815
26	23.9754*	10.4964	13.4790	10.4964
27	15.9569	3.5003	12.4566	3.5003
28	14.1489	4.5852	9.5637	4.5852
29	40.4876***	14.6562**	25.8313***	14.6562**
30	25.5809*	7.3573	18.2236*	7.3573
31	26.7439**	5.6671	21.0768**	5.6671
32	48.6419***	16.1207**	32.5212***	16.1207**
33	27.6681**	3.5912	24.0769***	3.5912

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Industry	*Trace test*		*Max eigenvalue test*	
	CVs=0	**CVs≤1**	**CVs=0**	**CVs≤1**
34	30.9597**	11.7386*	19.2211*	11.7386*
35	30.0845**	5.5700	24.5144***	5.5700
36	21.7109	8.0211	13.6897	8.0211
37	16.7296	2.5709	14.1587	2.5709
38	13.1244	5.4870	7.6374	5.4870
39	22.6321	7.6281	15.0040	7.6281
40	17.6631	5.6728	11.9902	5.6728
41	22.1603	7.1565	15.0038	7.1565
42	102.3770***	5.3167	97.0604***	5.3167
43	25.0916*	8.9942	16.0974	8.9942
44	9.8682	3.1502	6.7180	3.1502
45	20.2807	5.9188	14.3619	5.9188
46	37.3624***	14.8242**	22.5383**	14.8242**
47	26.1213**	7.4766	18.6447*	7.4766
48	12.5150	3.7050	8.8100	3.7050
49	20.5484	6.2192	14.3292	6.2192
50	24.5051*	6.9451	17.5600*	6.9451
51	23.3428*	8.0655	15.2773	8.0655
52	20.3299	1.7398	18.5901*	1.7398
53	51.8892***	9.8369	42.0523***	9.8369
54	31.3754***	10.9046*	20.4708**	10.9046*
55	20.6655	4.6924	15.9731	4.6924
56	20.9329	5.5052	15.4277	5.5052
57	12.2447	3.2194	9.0252	3.2194
58	25.4667*	4.6061	20.8606**	4.6061
59	20.7418	4.1598	16.5820	4.1598
60	17.9403	6.0790	11.8613	6.0790
61	12.8774	6.0010	6.8764	6.0010
62	63.8131***	20.0888***	43.7244***	20.0888***
63	35.0857***	4.9857	30.1000***	4.9857
64	16.7777	6.0901	10.6876	6.0901
65	24.8167*	11.0904*	13.7263	11.0904*

Notes: *, ** and *** denote rejection of the null hypotheses of 0 or at most 1 cointegrating vectors (CVs) at the 10%, 5% and 1% significance levels, respectively; lags selected according to the Schwarz Information Criterion; trends and intercepts are included in the tests.

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Table 3.8.3: Cointegration tests (*kl wr*)

Industry	*Trace test*		*Max eigenvalue test*	
	CVs=0	**CVs≤1**	**CVs=0**	**CVs≤1**
AG	10.9748	3.3090	7.6658	3.3090
1	29.3704**	8.6250	20.7454**	8.6250
2	12.6288	4.0481	8.5807	4.0481
3	17.9943	3.5728	14.4215	3.5728
4	15.9286	6.2276	9.7010	6.2276
5	43.5176***	11.1155*	32.4020***	11.1155*
6	27.8668**	3.9313	23.9355**	3.9313
7	15.3977	6.5357	8.8620	6.5357
8	28.2393**	5.2499	22.9893**	5.2499
9	21.8806	4.6868	17.1938	4.6868
10	28.2987**	5.1832	23.1156**	5.1832
11	14.5486	3.1760	11.3725	3.1760
12	16.7365	2.6233	14.1132	2.6233
13	24.2185*	6.0090	18.2096*	6.0090
14	20.4237	3.6975	16.7263	3.6975
15	14.1851	3.2257	10.9594	3.2257
16	23.9550*	3.7456	20.2094**	3.7456
17	27.8294**	9.4512	18.3782*	9.4512
18	32.4111***	10.4307	21.9804**	10.4307
19	28.5402**	2.9931	25.5470***	2.9931
20	30.5262**	10.0838	20.4424**	10.0838
21	20.3408	5.3493	14.9915	5.3493
22	15.0774	3.7973	11.2801	3.7973
23	22.4830	5.5331	16.9499	5.5331
24	21.4981	4.3689	17.1292	4.3689
25	30.4105**	4.4578	25.9527***	4.4578
26	19.1816	6.2636	12.9179	6.2636
27	16.3952	3.3844	13.0109	3.3844
28	12.4450	4.8898	7.5552	4.8898
29	9.7226	4.0522	5.6703	4.0522
30	13.6956	3.3776	10.3181	3.3776
31	24.9748*	2.9194	22.0553**	2.9194
32	11.6611	2.4154	9.2457	2.4154
33	12.6244	5.1097	7.5147	5.1097

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Industry	*Trace test*		*Max eigenvalue test*	
	CVs=0	**CVs≤1**	**CVs=0**	**CVs≤1**
34	34.3009***	3.6297	30.6713***	3.6297
35	14.8730	6.0308	8.8422	6.0308
36	19.6113	6.5469	13.0644	6.5469
37	24.8109*	9.2762	15.5347	9.2762
38	15.7134	3.9795	11.7339	3.9795
39	25.8093*	5.6203	20.1890**	5.6203
40	27.2617**	5.0789	22.1828**	5.0789
41	24.0217*	4.9746	19.0471*	4.9746
42	24.0573*	7.1637	16.8936	7.1637
43	19.0702	2.2149	16.8554	2.2149
44	14.7403	2.6790	12.0613	2.6790
45	11.8722	4.5147	7.3575	4.5147
46	24.3948*	8.1394	16.2554	8.1394
47	21.2736	5.2011	16.0726	5.2011
48	13.7719	5.7427	8.0292	5.7427
49	22.2453	3.4410	18.8043*	3.4410
50	15.5603	4.2391	11.3212	4.2391
51	39.8994***	14.6300**	25.2694***	14.6300**
52	19.5837	6.3544	13.2293	6.3544
53	34.8453***	6.1912	28.6541***	6.1912
54	30.3132**	4.5501	25.7631***	4.5501
55	13.2290	5.6112	7.6178	5.6112
56	12.3829	5.3274	7.0555	5.3274
57	22.6018	4.2174	18.3843*	4.2174
58	26.0894**	6.0061	20.0833**	6.0061
59	17.0672	4.9545	12.1127	4.9545
60	24.5513*	9.1236	15.4277	9.1236
61	36.3152***	14.4049**	21.9103**	14.4049**
62	46.7660***	10.9401*	35.8259***	10.9401*
63	26.1342**	8.5386	17.5956*	8.5386
64	27.0125**	4.8917	22.1208**	4.8917
65	17.8116	7.6308	10.1808	7.6308

Notes: *, ** and *** denote rejection of the null hypotheses of 0 or at most 1 cointegrating vectors (CVs) at the 10%, 5% and 1% significance levels, respectively; lags selected according to the Schwarz Information Criterion; trends and intercepts are included in the tests.

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Table 3.8.4: Cointegration tests (*yk rp kl*)

Industry	*Trace test*			*Max eigenvalue test*		
	CVs=0	**CVs≤1**	**CVs≤2**	**CVs=0**	**CVs≤1**	**CVs≤2**
AG	32.2505	12.1334	2.5901	20.1171	9.5433	2.5901
1	45.5340**	23.3850*	6.9167	22.1490	16.4683	6.9167
2	29.7836	14.4111	5.7299	15.3725	8.6812	5.7299
3	37.2894	12.9621	2.0611	24.3273*	10.9010	2.0611
4	30.5691	13.8576	2.9734	16.7114	10.8842	2.9734
5	54.8374***	21.8555	4.2201	32.9819***	17.6354*	4.2201
6	63.0653***	33.0560***	14.1746**	30.0094**	18.8813*	14.1746**
7	59.0812***	18.9857	6.6435	40.0956***	12.3421	6.6435
8	42.6057*	14.4463	7.0184	28.1595**	7.4278	7.0184
9	39.6596	16.3336	6.3833	23.3260	9.9503	6.3833
10	43.9208**	18.2236	4.4053	0.3225*	0.1889	0.0646
11	31.4256	14.8786	4.5583	16.5470	10.3202	4.5583
12	27.9138	11.1819	3.8144	16.7320	7.3674	3.8144
13	52.2893***	24.3660*	6.5343	27.9232**	17.8318*	6.5343
14	48.0534**	23.7282*	5.3952	24.3251*	18.3330*	5.3952
15	36.5364	15.9642	5.2048	20.5723	10.7594	5.2048
16	32.1163	11.7065	4.1869	20.4098	7.5195	4.1869
17	0.3126**	0.1554	0.1138	24.7429*	11.1472	7.9749
18	41.7620*	17.9276	7.1808	23.8344*	10.7469	7.1808
19	51.7012***	18.8247	5.2980	32.8765***	13.5267	5.2980
20	48.5115**	25.4130*	4.7743	23.0985	20.6387**	4.7743
21	38.2694	17.7663	5.5308	20.5031	12.2355	5.5308
22	42.8951*	19.9432	6.0572	22.9520	13.8860	6.0572
23	51.3003***	14.4970	6.0439	36.8033***	8.4531	6.0439
24	55.3238***	17.3123	6.1693	38.0115***	11.1430	6.1693
25	60.4899***	21.6785	5.2355	38.8114***	16.4430	5.2355
26	34.6892	17.3720	4.9006	17.3172	12.4713	4.9006
27	36.2187	17.9366	2.9865	18.2821	14.9501	2.9865
28	41.2782*	17.2023	5.4809	24.0759*	11.7214	5.4809
29	43.9916**	17.1186	5.5126	26.8730**	11.6060	5.5126
30	26.0239	10.8237	3.4086	15.2002	7.4151	3.4086
31	50.4404***	21.2244	3.4710	29.2160**	17.7535*	3.4710
32	49.8918***	21.8295	4.6122	28.0624**	17.2173	4.6122
33	38.1683	17.9006	4.2736	20.2677	13.6270	4.2736
34	54.2275***	23.4425*	5.8562	30.7850**	17.5863*	5.8562
35	26.2192	10.9047	3.6522	15.3146	7.2524	3.6522

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Industry	*Trace test*			*Max eigenvalue test*		
	CVs=0	**CVs≤1**	**CVs≤2**	**CVs=0**	**CVs≤1**	**CVs≤2**
36	37.7522	17.9100	5.1959	19.8422	12.7141	5.1959
37	40.3454*	17.6559	2.9379	22.6895	14.7180	2.9379
38	23.6686	11.0638	3.2069	12.6048	7.8569	3.2069
39	34.2567	11.2035	4.1318	23.0532	7.0716	4.1318
40	40.2318*	16.8882	4.8026	23.3436	12.0856	4.8026
41	42.5835*	16.2404	5.5898	26.3431**	10.6506	5.5898
42	54.9419***	17.0881	7.9003	37.8539***	9.1878	7.9003
43	39.5795	16.3996	1.9787	23.1798	14.4209	1.9787
44	37.1426	7.3561	2.9838	29.7865**	4.3724	2.9838
45	24.0892	12.2888	4.0614	11.8004	8.2273	4.0614
46	51.5709***	26.6121**	11.3091*	24.9588*	15.3030	11.3091*
47	42.4293*	22.1609	6.5953	20.2684	15.5656	6.5953
48	41.3951*	17.2889	4.2340	24.1062*	13.0549	4.2340
49	48.7199**	19.8325	3.9163	28.8873**	15.9163	3.9163
50	36.2262	14.3253	4.8274	21.9010	9.4979	4.8274
51	74.3559***	37.6409***	14.2817**	36.7150***	23.3592**	14.2817**
52	34.4093	15.1009	6.0253	19.3084	9.0756	6.0253
53	57.7402***	18.4091	7.5599	39.3311***	10.8492	7.5599
54	46.4014**	20.9846	1.6747	25.4169*	19.3099*	1.6747
55	41.7620*	16.2045	6.9189	25.5574*	9.2856	6.9189
56	32.4798	13.2930	4.7366	19.1868	8.5564	4.7366
57	36.2481	15.8415	3.3879	20.4066	12.4536	3.3879
58	51.1136***	17.3549	5.4882	33.7587***	11.8667	5.4882
59	30.8921	13.0581	4.8983	17.8341	8.1598	4.8983
60	37.5939	14.5366	5.5997	23.0573	8.9368	5.5997
61	52.9472***	25.9129**	6.7898	27.0343**	19.1231*	6.7898
62	46.6922**	18.9535	7.0095	27.7387**	11.9440	7.0095
63	47.1017**	19.2582	5.2387	27.8435**	14.0195	5.2387
64	37.2660	11.2035	3.8759	26.0624**	7.3276	3.8759
65	46.9025**	17.1961	6.1552	29.7064**	11.0409	6.1552

Notes: *, ** and *** denote rejection of the null hypotheses of 0 or at most 1 cointegrating vectors (CVs) at the 10%, 5% and 1% significance levels, respectively; lags selected according to the Schwarz Information Criterion; trends and intercepts are included in the tests.

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Table 3.8.5: Cointegration tests (*yl wp kl*)

Industry	*Trace test*			*Max eigenvalue test*		
	CVs=0	**CVs≤1**	**CVs≤2**	**CVs=0**	**CVs≤1**	**CVs≤2**
AG	32.7365	12.3263	2.5854	20.4103	9.7408	2.5854
1	48.3438**	26.7056**	7.9653	21.6382	18.7403*	7.9653
2	30.4378	14.8051	5.9402	15.6328	8.8649	5.9402
3	34.6522	12.5536	2.0420	22.0986	10.5116	2.0420
4	33.3290	17.3173	6.6502	16.0117	10.6671	6.6502
5	45.2410**	16.7005	3.9404	28.5406**	12.7601	3.9404
6	64.3853***	34.6233***	15.1487**	29.7620**	19.4746**	15.1487**
7	52.2444***	19.6704	4.3372	32.5740***	15.3332	4.3372
8	43.4792**	14.0903	6.7251	29.3889**	7.3652	6.7251
9	42.9206**	17.0730	6.3584	25.8476**	10.7146	6.3584
10	42.8081*	19.0421	4.4061	23.7661*	14.6359	4.4061
11	31.9539	14.3459	4.3553	17.6080	9.9906	4.3553
12	27.3833	11.4394	4.4347	15.9440	7.0046	4.4347
13	59.7856***	31.9325***	6.0769	27.8531**	25.8555***	6.0769
14	53.3141***	26.9041**	5.2727	26.4100**	21.6314**	5.2727
15	39.4478	15.7998	4.8513	23.6479*	10.9485	4.8513
16	32.0698	12.3366	4.1689	19.7332	8.1677	4.1689
17	46.5204**	18.4276	8.0005	28.0928**	10.4271	8.0005
18	35.8120	15.9139	6.1829	19.8981	9.7310	6.1829
19	53.6901***	22.8139	5.7776	30.8762***	17.0363	5.7776
20	52.2317***	24.5788*	4.9578	27.6529**	19.6210**	4.9578
21	31.9826	14.2888	5.5025	17.6937	8.7864	5.5025
22	44.2137**	19.7267	6.0975	24.4870*	13.6292	6.0975
23	44.7392**	12.1815	4.7821	32.5577***	7.3994	4.7821
24	40.7852*	18.5760	6.0545	22.2092	12.5215	6.0545
25	54.6899***	21.8016	5.9333	32.8883***	15.8684	5.9333
26	34.3560	17.1873	4.4954	17.1687	12.6920	4.4954
27	36.1351	18.4442	3.1896	17.6909	15.2546	3.1896
28	41.7103*	15.6332	5.6334	26.0770**	9.9998	5.6334
29	43.2702**	17.6849	6.4491	25.5853*	11.2358	6.4491
30	30.7870	12.5485	3.1998	18.2385	9.3487	3.1998
31	49.5391***	21.8476	3.4989	27.6915**	18.3487*	3.4989
32	54.3433***	23.4830*	5.7084	30.8603***	17.7746*	5.7084
33	48.8986**	17.9513	4.0977	30.9473***	13.8536	4.0977
34	53.6579***	23.0899	5.6723	30.5680**	17.4177*	5.6723
35	42.5465*	15.6270	3.6903	26.9195**	11.9367	3.6903

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Industry	*Trace test*			*Max eigenvalue test*		
	CVs=0	**CVs≤1**	**CVs≤2**	**CVs=0**	**CVs≤1**	**CVs≤2**
36	39.6702	21.8410	9.4340	17.8292	12.4070	9.4340
37	38.0240	15.7156	2.9389	22.3084	12.7767	2.9389
38	26.1700	11.3106	3.6770	14.8594	7.6336	3.6770
39	33.6376	11.7188	4.1159	21.9188	7.6028	4.1159
40	43.9127**	13.7662	3.5451	30.1465**	10.2210	3.5451
41	43.4238**	16.7697	5.6641	26.6541**	11.1056	5.6641
42	119.5036***	19.7618	7.7037	99.7418***	12.0581	7.7037
43	41.3422*	16.2835	2.0284	25.0587*	14.2551	2.0284
44	31.0311	8.0475	3.2432	22.9836	4.8043	3.2432
45	28.5970	14.2224	4.6497	14.3747	9.5727	4.6497
46	53.1997***	25.9434**	10.9735*	27.2562**	14.9700	10.9735*
47	45.3575**	20.3057	3.9215	25.0518*	16.3843	3.9215
48	39.1816	16.3177	5.8272	22.8640	10.4905	5.8272
49	35.6450	10.5875	3.0435	25.0576*	7.5440	3.0435
50	52.3757***	22.4408	8.1737	29.9350**	14.2671	8.1737
51	61.8211***	32.9463***	7.4293	28.8748**	25.5170***	7.4293
52	38.4657	18.3070	6.9878	20.1586	11.3193	6.9878
53	64.3397***	17.9508	7.4163	46.3890***	10.5345	7.4163
54	55.2229***	24.9650*	2.0067	30.2578**	22.9583**	2.0067
55	44.8983**	14.7776	5.6915	30.1206**	9.0861	5.6915
56	39.5981	15.6017	4.8306	23.9963*	10.7712	4.8306
57	33.9470	14.8293	3.6797	19.1177	11.1496	3.6797
58	56.5837***	25.0503*	7.1851	31.5334***	17.8652*	7.1851
59	33.4986	12.7193	4.5579	20.7793	8.1614	4.5579
60	39.3610	14.9769	5.3873	24.3841*	9.5896	5.3873
61	40.1540*	14.2323	6.8027	25.9218**	7.4295	6.8027
62	51.1748***	17.7793	6.4643	33.3955***	11.3150	6.4643
63	49.3806***	17.7272	5.8489	31.6534***	11.8784	5.8489
64	41.0839*	14.5300	6.3245	26.5539**	8.2056	6.3245
65	53.1759***	22.0810	6.2401	31.0949***	15.8409	6.2401

Notes: *, ** and *** denote rejection of the null hypotheses of 0 or at most 1 cointegrating vectors (CVs) at the 10%, 5% and 1% significance levels, respectively; lags selected according to the Schwarz Information Criterion; trends and intercepts are included in the tests.

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Table 3.9: Estimates of aggregate elasticity of substitution and technological change – CES production function, single equation

Equation		Method			
		OLS	**OLS differenced**	**2SLS**	**GIV**
CES_1	σ_1	0.4123*** (0.0793)	0.4644*** (0.0552)	0.3636*** (0.0973)	0.4549*** (0.0556)
	ζ_K	-0.0029	-0.0027[a]	-0.0032	-0.0046
	R^2	0.8656	0.5208	0.8693	0.6289
CES_2	σ_2	0.6524*** (0.0303)	0.5060*** (0.0650)	0.6668*** (0.0316)	0.5635*** (0.0529)
	ζ_L	0.0125	0.0139	0.0123	0.0131
	R^2	0.9957	0.4824	0.9954	0.9670
CES_3	σ_3	0.3362*** (0.0355)	0.2184*** (0.0477)	0.3659*** (0.0388)	0.2502*** (0.0452)
	$\zeta_L - \zeta_K$	0.0175	0.0173	0.0174	0.0180
	R^2	0.9932	0.2442	0.9929	0.9430

Notes: Figures enclosed in parentheses are the estimated standard errors; ***significant at the 1% level; [a] the estimated regression coefficient is not significant at the 10% level; the remaining technological progress regressions coefficients are all statistically significant at the 1% level.

Table 3.10: Estimates of aggregate elasticity of substitution and technological change – CES production function, normalized system

	Method	
	NLSUR	**GMM**
σ	0.5923*** (0.0019)	0.6223*** (0.0289)
ζ_K	-0.0008*** (0.0004)	-0.0005*** (0.0006)
ζ_L	0.0128*** (0.0003)	0.0129*** (0.0004)
ξ	1.0028*** (0.0049)	1.0013*** (0.0032)

Notes: Figures enclosed in parentheses are the estimated standard errors; ***significant at the 1% level.

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Table 3.11.1: Estimates of industry elasticities of substitution from OLS regressions – CES production function, single equation

Industry	CES_1	CES_2	CES_3
1	0.4359*** (0.0746)	0.3407*** (0.0780)	0.2005*** (0.0755)
2	0.6980*** (0.0476)	0.7567*** (0.0515)	0.6179*** (0.0514)
3	0.8524*** (0.0305)	0.3331*** (0.0674)	0.2631*** (0.0451)
4	0.6374*** (0.0200)	0.2034** (0.0940)	0.2517*** (0.0167)
5	0.7293*** (0.0759)	0.5316*** (0.0587)	0.4737*** (0.0793)
6	0.8295*** (0.0256)	0.6490*** (0.0766)	0.1909*** (0.0362)
7	-0.2275*** (0.0842)	0.7780*** (0.0304)	-0.0726*** (0.0595)
8	0.4116*** (0.0454)	0.9290*** (0.0578)	0.4627*** (0.0614)
9	0.5307*** (0.0226)	0.5141*** (0.0676)	0.3640*** (0.0166)
10	0.4208*** (0.0216)	-0.0312 (0.0786)	0.2245*** (0.0163)
11	0.3442*** (0.0574)	0.7451*** (0.0554)	0.3119*** (0.0569)
12	0.6033*** (0.0373)	0.7254*** (0.0543)	0.3467*** (0.0261)
13	0.6840*** (0.0457)	0.9378*** (0.0605)	0.0827** (0.0339)
14	0.5393*** (0.0355)	0.7532*** (0.0723)	0.2870*** (0.0312)
15	0.4610*** (0.0306)	0.6823*** (0.1009)	0.2041*** (0.0301)
16	0.5547*** (0.0307)	0.6243*** (0.0993)	0.4073*** (0.0384)
17	0.3547*** (0.0433)	0.8806*** (0.0489)	0.2024*** (0.0354)
18	0.2439*** (0.0518)	0.5308*** (0.0679)	0.1510*** (0.0449)
19	0.6204*** (0.0653)	0.6070*** (0.0499)	0.3164*** (0.0549)
20	0.4492*** (0.0567)	0.8277*** (0.0370)	0.1720*** (0.0249)
21	0.4377*** (0.0673)	0.4246*** (0.0395)	0.2647*** (0.0526)
22	0.3715*** (0.0587)	0.4464*** (0.0473)	0.2111*** (0.0374)
23	-0.0395 (0.0370)	0.7636*** (0.0637)	-0.0464 (0.0440)
24	0.7787*** (0.0211)	0.6403*** (0.1106)	0.1949*** (0.0190)
25	0.7631*** (0.0724)	0.2561*** (0.0490)	-0.0583 (0.0485)
26	0.5571*** (0.0478)	0.7314*** (0.0352)	0.4362*** (0.0344)
27	0.4184*** (0.0295)	0.5890*** (0.0469)	0.4100*** (0.0330)
28	0.0988*** (0.0340)	0.6721*** (0.0714)	0.0455 (0.0371)
29	0.5855*** (0.1055)	0.6646*** (0.0320)	0.1090** (0.0511)
30	0.1231** (0.0505)	0.2607*** (0.0327)	0.0902*** (0.0240)
31	0.6256*** (0.0524)	0.3278*** (0.0505)	0.3629*** (0.0494)
32	0.4993*** (0.0713)	0.6720*** (0.0226)	0.3359*** (0.0400)
33	0.1311*** (0.0334)	0.0348 (0.0446)	-0.0051 (0.0286)
34	0.7440*** (0.0527)	0.3501*** (0.0760)	0.0682 (0.0586)

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Industry	CES_1	CES_2	CES_3
35	0.1779***	0.3101***	0.0603***
	(0.0528)	(0.0421)	(0.0219)
36	0.2411***	0.7581***	0.1109***
	(0.0151)	(0.1254)	(0.0134)
37	0.4802***	1.1091***	0.3059***
	(0.0520)	(0.0869)	(0.0913)
38	0.8691***	0.5556***	0.2159***
	(0.0399)	(0.0624)	(0.0558)
39	0.4672***	0.1751*	0.0084
	(0.0722)	(0.0888)	(0.0669)
40	0.8038***	1.9505***	1.2468***
	(0.0799)	(0.1281)	(0.1383)
41	1.0094***	0.9384***	1.0017***
	(0.0395)	(0.1029)	(0.0707)
42	0.8343***	0.8843***	0.6463***
	(0.0758)	(0.0326)	(0.0699)
43	0.4286***	0.1266	0.2832***
	(0.0425)	(0.1777)	(0.0509)
44	0.8858***	0.6413***	0.0861
	(0.1268)	(0.0428)	(0.1016)
45	0.8611***	-0.3000	-0.3229*
	(0.0465)	(0.1955)	(0.1833)
46	0.9968***	1.1605***	1.1168***
	(0.0104)	(0.0524)	(0.0555)
47	0.8156***	0.7159***	0.1359
	(0.0546)	(0.0437)	(0.1022)
48	0.5941***	0.3743***	0.3342***
	(0.0635)	(0.0455)	(0.0692)
49	0.7453***	0.4521***	0.6465***
	(0.0371)	(0.0539)	(0.0591)
50	0.3145***	0.4514***	0.0720***
	(0.0679)	(0.0168)	(0.0210)
51	0.7904***	0.5790***	0.3181**
	(0.0871)	(0.0403)	(0.1418)
52	0.5837***	0.2556***	0.3080***
	(0.0392)	(0.0637)	(0.0459)
53	0.0455	0.6642***	-0.0177
	(0.0850)	(0.0345)	(0.0267)
54	0.0283	0.7427***	0.2248***
	(0.0280)	(0.0179)	(0.0268)
55	-0.1238***	0.5569***	0.1107***
	(0.0314)	(0.0215)	(0.0282)
56	0.5349***	0.9307***	0.2698***
	(0.1012)	(0.0243)	(0.0950)
57	0.1836***	-0.0181	0.0543***
	(0.0347)	(0.0385)	(0.0182)
58	0.6214***	0.2956***	0.3036***
	(0.0446)	(0.0768)	(0.0568)
59	0.4193***	0.4517***	0.2576***
	(0.0669)	(0.0575)	(0.0574)
60	0.2270***	0.7620***	0.3039***
	(0.0300)	(0.0315)	(0.0297)
61	0.1191**	0.4468***	0.1049**
	(0.0510)	(0.0662)	(0.0459)
62	0.5173***	0.3999***	0.4321***
	(0.0947)	(0.0999)	(0.1011)
63	1.0654***	0.4319***	-0.1056***
	(0.0860)	(0.0392)	(0.0378)
64	0.8362***	0.3474***	-0.0072
	(0.0622)	(0.0483)	(0.0220)
65	0.1970**	0.1115***	0.0893
	(0.0811)	(0.0375)	(0.0576)

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.11.2: Estimates of industry elasticities of substitution from 2SLS regressions – CES production function, single equation

Industry	CES_1	CES_2	CES_3
1	0.1616 (0.1422)	0.2808*** (0.0951)	0.2583*** (0.0941)
2	0.7506*** (0.0527)	0.7777*** (0.0573)	0.6790*** (0.0557)
3	0.9065*** (0.0339)	0.7007*** (0.1238)	0.5180*** (0.0770)
4	0.6549*** (0.0216)	0.1728* (0.0935)	0.2608*** (0.0178)
5	0.9956*** (0.1059)	0.5986*** (0.0705)	0.7377*** (0.1112)
6	0.8870*** (0.0327)	1.0759*** (0.1223)	0.4810*** (0.0817)
7	-0.4355*** (0.1154)	0.7660*** (0.0319)	-0.1432** (0.0693)
8	0.4958*** (0.0689)	1.0445*** (0.0666)	0.6495*** (0.0931)
9	0.5445*** (0.0261)	0.5013*** (0.0679)	0.3933*** (0.0188)
10	0.4518*** (0.0266)	-0.2818** (0.1368)	0.2575*** (0.0207)
11	0.2911*** (0.0718)	0.7532*** (0.0578)	0.3233*** (0.0658)
12	0.6070*** (0.0410)	0.7201*** (0.0546)	0.3468*** (0.0281)
13	0.8577*** (0.0576)	1.1858*** (0.0788)	0.4912*** (0.1216)
14	0.5615*** (0.0406)	0.7475*** (0.0812)	0.2983*** (0.0366)
15	0.4019*** (0.0390)	0.4095*** (0.1558)	0.1923*** (0.0348)
16	0.6002*** (0.0384)	0.5081*** (0.1093)	0.4763*** (0.0457)
17	0.5719*** (0.0677)	0.9286*** (0.0531)	0.3910*** (0.0610)
18	0.6690*** (0.1486)	0.6451*** (0.0964)	0.4447*** (0.1131)
19	0.6901*** (0.0829)	0.5814*** (0.0530)	0.4185*** (0.0614)
20	0.5792*** (0.0755)	0.8593*** (0.0384)	0.2044*** (0.0350)
21	0.6329*** (0.0927)	0.4697*** (0.0454)	0.3982*** (0.0695)
22	0.1741 (0.1163)	0.4895*** (0.0501)	0.2777*** (0.0470)
23	-0.9821** (0.4600)	0.9874*** (0.0833)	-1.3527* (0.7420)
24	0.8005*** (0.0246)	0.7531*** (0.1464)	0.2835*** (0.0281)
25	0.7510*** (0.0973)	0.1860*** (0.0483)	-0.1025** (0.0503)
26	0.6476*** (0.0729)	0.7057*** (0.0365)	0.5109*** (0.0411)
27	0.4271*** (0.0324)	0.5756*** (0.0467)	0.4423*** (0.0343)
28	0.1220** (0.0478)	0.7855*** (0.0832)	0.0845 (0.0525)
29	1.0340*** (0.1860)	0.7440*** (0.0422)	0.2190** (0.0890)
30	0.0816 (0.0692)	0.2912*** (0.0419)	0.1049*** (0.0312)
31	0.8398*** (0.0711)	0.8647*** (0.1648)	0.7367*** (0.0931)
32	0.5658*** (0.0762)	0.6802*** (0.0263)	0.3884*** (0.0450)
33	0.2553*** (0.0538)	0.5911** (0.3425)	0.0896 (0.0947)
34	1.0015*** (0.0849)	1.0861*** (0.2701)	1.5743 (1.1775)

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Industry	CES_1	CES_2	CES_3
35	0.1451**	0.4608***	0.0812***
	(0.0653)	(0.0607)	(0.0292)
36	0.2400***	0.7071***	0.1162***
	(0.0163)	(0.1292)	(0.0138)
37	0.6754***	1.1169***	0.9223***
	(0.1375)	(0.0887)	(0.2154)
38	0.9626***	0.6406***	0.3749***
	(0.0536)	(0.0840)	(0.0862)
39	0.8269***	0.2483	-0.3311*
	(0.1307)	(0.1822)	(0.1711)
40	0.8934***	2.1972***	1.4488***
	(0.0986)	(0.1483)	(0.1547)
41	1.0950***	1.0219***	1.1377***
	(0.0478)	(0.1277)	(0.0816)
42	1.1409***	0.9222***	0.9019***
	(0.1016)	(0.0304)	(0.0809)
43	0.5386***	-0.0485	0.4040***
	(0.0549)	(0.2211)	(0.0642)
44	1.3501***	0.6742***	0.2391
	(0.1888)	(0.0501)	(0.1508)
45	0.8149***	-0.3662*	-0.4066**
	(0.0527)	(0.1980)	(0.1845)
46	1.0002***	1.1598***	1.1407***
	(0.0100)	(0.0513)	(0.0554)
47	0.8709***	0.6916***	0.1247
	(0.0588)	(0.0441)	(0.1160)
48	0.7407***	0.3954***	0.4306***
	(0.0768)	(0.0481)	(0.0808)
49	0.8011***	0.4914***	0.7474***
	(0.0393)	(0.0386)	(0.0610)
50	0.3466***	0.4512***	0.0762***
	(0.0813)	(0.0169)	(0.0223)
51	0.8175***	0.5465***	0.3118**
	(0.0941)	(0.0419)	(0.1525)
52	0.5721***	0.2130***	0.3135***
	(0.0404)	(0.0643)	(0.0463)
53	0.5896***	0.7765***	-0.3206
	(0.0547)	(0.0409)	(0.2070)
54	0.0103	0.7515***	0.2585***
	(0.0330)	(0.0185)	(0.0299)
55	-0.2758***	0.5712***	0.1350***
	(0.0477)	(0.0220)	(0.0333)
56	0.9632***	0.9754***	0.7625***
	(0.1461)	(0.0217)	(0.1607)
57	0.2373***	-0.0377	0.0696***
	(0.0391)	(0.0435)	(0.0194)
58	0.7618***	0.6795***	0.5878***
	(0.0542)	(0.1329)	(0.0905)
59	0.8159***	0.7991***	0.6904***
	(0.1208)	(0.0997)	(0.1255)
60	0.2352***	0.7705***	0.3569***
	(0.0357)	(0.0327)	(0.0358)
61	0.5231***	0.5436***	0.4017***
	(0.1473)	(0.0802)	(0.1115)
62	0.6898***	0.5869***	0.6280***
	(0.1280)	(0.1456)	(0.1467)
63	1.5935***	0.5514***	-0.4547***
	(0.1538)	(0.0519)	(0.1158)
64	0.9499***	0.4668***	-0.0063
	(0.0707)	(0.0594)	(0.0253)
65	0.2462**	0.1874***	0.1078
	(0.1061)	(0.0524)	(0.0770)

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.11.3: Estimates of AR(1) coefficients, GIV method (second-stage) – CES production function, single equation

Industry	CES_1	CES_2	CES_3
AG	0.8790*** (0.0558)	0.7574*** (0.0813)	0.8022*** (0.0728)
1	0.7050*** (0.0831)	0.7144*** (0.0893)	0.9402*** (0.0393)
2	0.8121*** (0.0696)	0.8108*** (0.0717)	0.8205*** (0.0671)
3	0.2911** (0.1177)	0.5590*** (0.1030)	0.4232*** (0.1114)
4	0.7850*** (0.0836)	0.8764*** (0.0501)	0.7275*** (0.0871)
5	0.6178*** (0.0962)	0.7091*** (0.0815)	0.7314*** (0.0832)
6	0.1657 (0.1196)	0.1607 (0.1172)	0.1484 (0.1168)
7	0.8463*** (0.0681)	0.8566*** (0.0594)	0.9031*** (0.0414)
8	0.8098*** (0.0697)	0.6497*** (0.0957)	0.7681*** (0.0792)
9	0.8122*** (0.0741)	0.7130*** (0.0840)	0.4450*** (0.1105)
10	0.4238*** (0.1116)	0.6215*** (0.0972)	0.4240*** (0.1110)
11	0.8566*** (0.0628)	0.8229*** (0.0731)	0.9011*** (0.0596)
12	0.9154*** (0.0561)	0.8736*** (0.0611)	0.6799*** (0.0903)
13	-0.1021 (0.1221)	-0.0591 (0.1223)	-0.0995 (0.1225)
14	0.8284*** (0.0597)	0.8140*** (0.0720)	0.6667*** (0.0950)
15	0.5006*** (0.1074)	0.7079*** (0.0865)	0.7285*** (0.0800)
16	0.7314*** (0.0832)	0.6378*** (0.0925)	0.6649*** (0.0921)
17	0.4462*** (0.0909)	0.5389*** (0.0992)	0.4266*** (0.0963)
18	0.3757*** (0.1098)	0.6061*** (0.0986)	0.5022*** (0.0996)
19	0.8670*** (0.0469)	0.5792*** (0.1037)	0.8390*** (0.0590)
20	0.7825*** (0.0671)	0.6178*** (0.0865)	0.5897*** (0.0991)
21	0.8353*** (0.0894)	0.6482*** (0.1110)	0.8487*** (0.0763)
22	0.7336*** (0.0801)	0.3648*** (0.1121)	0.7958*** (0.0666)
23	0.0352 (0.1234)	0.4978*** (0.1080)	0.1132 (0.1227)
24	0.0103 (0.1226)	0.7849*** (0.0716)	0.4698*** (0.1086)
25	0.9736*** (0.0299)	0.5643*** (0.0904)	0.8567*** (0.0511)
26	0.7665*** (0.0854)	0.3828*** (0.1130)	0.4246*** (0.1091)
27	0.8775*** (0.0590)	0.7443*** (0.0761)	0.8430*** (0.0647)
28	0.8348*** (0.0671)	0.7372*** (0.0771)	0.9431*** (0.0494)
29	0.6595*** (0.0928)	0.2470** (0.1194)	0.8571*** (0.0643)
30	0.8017*** (0.0731)	0.5955*** (0.1018)	0.8427*** (0.0711)
31	0.0029 (0.1224)	-0.0142 (0.1229)	-0.0368 (0.1227)
32	0.8789*** (0.0493)	0.5392*** (0.1060)	0.8561*** (0.0627)
33	0.4939*** (0.1055)	0.3520*** (0.1144)	0.8112*** (0.0711)

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Industry	CES_1	CES_2	CES_3
34	0.1588 (0.1217)	0.2522** (0.1199)	0.1591 (0.1213)
35	0.8974*** (0.0612)	0.5866*** (0.0996)	0.8599*** (0.0621)
36	0.8363*** (0.0677)	0.9015*** (0.0351)	0.8056*** (0.0682)
37	0.7079*** (0.0887)	0.5755*** (0.1014)	0.5431*** (0.1037)
38	0.6813*** (0.0925)	0.5865*** (0.1001)	0.7755*** (0.0738)
39	0.5706*** (0.0995)	0.8362*** (0.0668)	0.7403*** (0.0820)
40	0.9438*** (0.0474)	0.8071*** (0.0672)	0.8771*** (0.0631)
41	0.7007*** (0.0908)	0.7594*** (0.0825)	0.7145*** (0.0888)
42	0.4423*** (0.1029)	0.4134*** (0.0833)	0.4810*** (0.0934)
43	0.7833*** (0.0793)	0.6767*** (0.0898)	0.8214*** (0.0719)
44	0.5863*** (0.0998)	0.8520*** (0.0657)	0.9406*** (0.0432)
45	0.9294*** (0.0407)	0.9440*** (0.0320)	0.9296*** (0.0325)
46	0.8707*** (0.0477)	0.8639*** (0.0546)	0.8567*** (0.0550)
47	0.9438*** (0.0542)	0.8937*** (0.0503)	0.9626*** (0.0317)
48	0.7614*** (0.0787)	0.9603*** (0.0430)	0.8990*** (0.0478)
49	0.7530*** (0.0824)	0.3976*** (0.0678)	0.7078*** (0.0778)
50	0.9413*** (0.0422)	0.7744*** (0.0777)	0.8563*** (0.0602)
51	0.9773*** (0.0392)	0.9148*** (0.0460)	0.9793*** (0.0237)
52	0.9285*** (0.0429)	0.8843*** (0.0512)	0.9651*** (0.0278)
53	0.5407*** (0.1030)	-0.0489 (0.1229)	0.3908*** (0.1118)
54	0.9904*** (0.0338)	0.5413*** (0.1038)	0.8758*** (0.0632)
55	0.5259*** (0.1030)	0.6751*** (0.0897)	0.9181*** (0.0431)
56	0.5940*** (0.0882)	0.4203*** (0.0836)	0.6271*** (0.0804)
57	0.8235*** (0.0626)	0.9174*** (0.0548)	0.8367*** (0.0523)
58	0.5913*** (0.0952)	0.5184*** (0.1023)	0.5619*** (0.0973)
59	0.4735*** (0.1080)	0.3182*** (0.1165)	0.4410*** (0.1099)
60	0.7392*** (0.0653)	0.6965*** (0.0892)	0.7207*** (0.0862)
61	0.5047*** (0.1038)	0.8062*** (0.0756)	0.5890*** (0.0966)
62	0.6891*** (0.0809)	0.6476*** (0.0773)	0.6603*** (0.0788)
63	0.2751** (0.1184)	0.3281*** (0.1154)	0.3759*** (0.1148)
64	0.7734*** (0.0894)	0.7858*** (0.0836)	0.6573*** (0.0631)
65	0.9581*** (0.0403)	0.7529*** (0.0679)	0.8947*** (0.0368)

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.11.4: Estimates of industry elasticities of substitution from GIV regressions – CES production function, single equation

Industry	CES_1	CES_2	CES_3
1	0.5440***	0.4240***	-0.0065
	(0.0493)	(0.0944)	(0.0221)
2	0.4851***	0.6526***	0.2656***
	(0.0480)	(0.0650)	(0.0462)
3	0.8284***	0.1340***	0.1382***
	(0.0386)	(0.0488)	(0.0431)
4	0.5127***	0.4451***	0.1963***
	(0.0291)	(0.1058)	(0.0277)
5	0.4702***	0.3383***	0.1831***
	(0.0648)	(0.0569)	(0.0444)
6	0.8217***	0.5295***	0.1669***
	(0.0330)	(0.0705)	(0.0366)
7	0.0659*	0.6697***	0.0300
	(0.0383)	(0.0773)	(0.0312)
8	0.3101***	0.6757***	0.2316***
	(0.0269)	(0.0776)	(0.0320)
9	0.4926***	0.4769***	0.3337***
	(0.0248)	(0.1297)	(0.0227)
10	0.3911***	0.0993	0.1950***
	(0.0273)	(0.0682)	(0.0196)
11	0.4296***	0.7651***	0.2859***
	(0.0431)	(0.0915)	(0.0499)
12	0.5863***	0.7371***	0.3607***
	(0.0379)	(0.1000)	(0.0398)
13	0.6984***	0.9553***	0.1064***
	(0.0433)	(0.0613)	(0.0353)
14	0.4458***	0.7004***	0.2785***
	(0.0283)	(0.1013)	(0.0411)
15	0.5287***	0.8953***	0.2256***
	(0.0345)	(0.0834)	(0.0327)
16	0.4296***	0.8124***	0.2334***
	(0.0325)	(0.1350)	(0.0479)
17	0.2788***	0.8879***	0.1616***
	(0.0310)	(0.0844)	(0.0305)
18	0.1642***	0.4237***	0.0803***
	(0.0386)	(0.0709)	(0.0262)
19	0.4951***	0.7345***	0.0561
	(0.0269)	(0.0880)	(0.0339)
20	0.3543***	0.8617***	0.1355***
	(0.0399)	(0.0582)	(0.0321)
21	0.1578***	0.2986***	0.0943***
	(0.0290)	(0.0515)	(0.0248)
22	0.4761***	0.4660***	0.1412***
	(0.0296)	(0.0662)	(0.0295)
23	-0.0343	0.5272***	-0.0346
	(0.0360)	(0.0707)	(0.0401)
24	0.7806***	0.5014***	0.1253***
	(0.0220)	(0.0897)	(0.0196)
25	0.6550***	0.3087***	0.0975**
	(0.0221)	(0.0762)	(0.0389)
26	0.4689***	0.7321***	0.3239***
	(0.0385)	(0.0517)	(0.0421)
27	0.3663***	0.6926***	0.2132***
	(0.0336)	(0.0731)	(0.0431)
28	0.0923***	0.5094***	0.0080
	(0.0262)	(0.0785)	(0.0182)
29	0.2770***	0.5934***	0.0341
	(0.0646)	(0.0415)	(0.0244)
30	0.1677***	0.2271***	0.0657***
	(0.0419)	(0.0405)	(0.0205)
31	0.6272***	0.3329***	0.3781***
	(0.0528)	(0.0511)	(0.0498)
32	0.3440***	0.6535***	0.1461***
	(0.0522)	(0.0430)	(0.0420)
33	0.0538*	0.0140	-0.0196*
	(0.0304)	(0.0320)	(0.0102)
34	0.6403***	0.2203***	0.0299
	(0.0585)	(0.0670)	(0.0495)

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Industry	CES_1	CES_2	CES_3
35	0.2365***	0.1637***	0.0285*
	(0.0404)	(0.0411)	(0.0153)
36	0.2408***	0.9443***	0.1258***
	(0.0227)	(0.0755)	(0.0205)
37	0.4172***	1.0253***	0.1054*
	(0.0283)	(0.1464)	(0.0585)
38	0.6864***	0.4295***	0.0703**
	(0.0386)	(0.0743)	(0.0284)
39	0.2721***	0.0759	0.0377
	(0.0531)	(0.0485)	(0.0306)
40	0.5497***	1.3719***	0.2444***
	(0.0277)	(0.0829)	(0.0799)
41	0.7336***	0.7746***	0.3685***
	(0.0477)	(0.1077)	(0.0860)
42	0.6166***	0.8941***	0.4302***
	(0.0699)	(0.0337)	(0.0633)
43	0.2560***	0.3520*	0.0623**
	(0.0303)	(0.2055)	(0.0297)
44	0.4936***	0.5582***	-0.0711***
	(0.1168)	(0.0406)	(0.0255)
45	0.9624***	0.0224	-0.0366
	(0.0253)	(0.1582)	(0.1520)
46	0.9581***	0.7786***	0.7224***
	(0.0162)	(0.0950)	(0.0687)
47	0.4061***	0.7742***	0.1472***
	(0.0374)	(0.1015)	(0.0508)
48	0.1963***	0.1654***	0.0975***
	(0.0433)	(0.0493)	(0.0271)
49	0.4584***	0.5142***	0.2958***
	(0.0516)	(0.0466)	(0.0637)
50	0.1592***	0.4710***	0.0616***
	(0.0343)	(0.0403)	(0.0221)
51	0.2553***	0.8065***	0.1324**
	(0.0445)	(0.0756)	(0.0538)
52	0.4886***	0.4941***	0.1528***
	(0.0452)	(0.0832)	(0.0346)
53	0.0063	0.6684***	-0.0090
	(0.0365)	(0.0339)	(0.0175)
54	0.0439***	0.7187***	0.0418**
	(0.0114)	(0.0327)	(0.0165)
55	-0.0176	0.4218***	0.0493***
	(0.0255)	(0.0374)	(0.0137)
56	0.2175***	0.9675***	0.1080**
	(0.0556)	(0.0293)	(0.0471)
57	0.0199	0.0430	-0.0081
	(0.0230)	(0.0336)	(0.0122)
58	0.4241***	0.1047	0.1180***
	(0.0444)	(0.0647)	(0.0415)
59	0.2127***	0.3244***	0.1169***
	(0.0526)	(0.0561)	(0.0416)
60	0.0895***	0.7525***	0.0765***
	(0.0205)	(0.0570)	(0.0221)
61	0.0541*	0.2388***	0.0373*
	(0.0290)	(0.0610)	(0.0220)
62	0.1888***	0.1126*	0.1194*
	(0.0712)	(0.0634)	(0.0663)
63	0.9014***	0.3734***	-0.0430
	(0.0872)	(0.0457)	(0.0283)
64	0.3999***	0.1126***	0.0065
	(0.0655)	(0.0393)	(0.0159)
65	0.0252	0.0236	0.0102
	(0.0205)	(0.0199)	(0.0169)

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.11.5: Estimates of industry elasticities of substitution from OLS regressions of differenced variables – CES production function, single equation

Industry	CES_1	CES_2	CES_3
1	0.5658*** (0.0427)	0.4476*** (0.0970)	0.0104*** (0.0249)
2	0.4534*** (0.0473)	0.6433*** (0.0660)	0.2173*** (0.0433)
3	0.5382*** (0.0771)	0.0509*** (0.0317)	-0.0306*** (0.0286)
4	0.4870*** (0.0290)	0.5058*** (0.1159)	0.1682*** (0.0328)
5	0.3524*** (0.0533)	0.3193*** (0.0580)	0.1410*** (0.0340)
6	0.6207*** (0.0580)	0.0870*** (0.0412)	0.0189*** (0.0233)
7	0.0804*** (0.0317)	0.7479*** (0.0731)	0.0437*** (0.0297)
8	0.3139*** (0.0258)	0.4723*** (0.0808)	0.2226*** (0.0268)
9	0.4897*** (0.0250)	0.5054*** (0.2083)	0.2387*** (0.0329)
10	0.3333*** (0.0349)	0.1369*** (0.0637)	0.1425*** (0.0230)
11	0.4319*** (0.0419)	0.7380*** (0.0998)	0.2821*** (0.0486)
12	0.5894*** (0.0377)	0.7809*** (0.1135)	0.3765*** (0.0501)
13	-0.0348*** (0.0273)	0.0083*** (0.0380)	-0.0750*** (0.0141)
14	0.4472*** (0.0289)	0.7293*** (0.1015)	0.2608*** (0.0456)
15	0.5914*** (0.0361)	0.9476*** (0.0754)	0.2327*** (0.0344)
16	0.4122*** (0.0323)	1.0733*** (0.1574)	0.1342*** (0.0489)
17	0.1808*** (0.0264)	0.6253*** (0.1276)	0.0818*** (0.0266)
18	0.0906*** (0.0259)	0.3690*** (0.0709)	0.0522*** (0.0190)
19	0.4943*** (0.0278)	0.9596*** (0.1482)	0.0069*** (0.0262)
20	0.3269*** (0.0371)	0.7809*** (0.0793)	0.1196*** (0.0319)
21	0.1555*** (0.0294)	0.2476*** (0.0635)	0.0840*** (0.0255)
22	0.4814*** (0.0263)	0.3785*** (0.1459)	0.1201*** (0.0278)
23	0.0307*** (0.0137)	0.2334*** (0.0590)	0.0121*** (0.0098)
24	0.6067*** (0.0468)	0.4827*** (0.0885)	0.0444*** (0.0124)
25	0.6702*** (0.0243)	0.8685*** (0.1271)	0.1256*** (0.0397)
26	0.4601*** (0.0360)	0.8546*** (0.1442)	0.1304*** (0.0504)
27	0.3646*** (0.0332)	0.8064*** (0.0997)	0.1330*** (0.0414)
28	0.0854*** (0.0251)	0.4292*** (0.0784)	0.0078*** (0.0174)
29	0.2352*** (0.0523)	0.3363*** (0.0560)	0.0343*** (0.0228)
30	0.1698*** (0.0408)	0.2003*** (0.0433)	0.0629*** (0.0198)
31	0.1032*** (0.0514)	0.0750*** (0.0320)	-0.0286*** (0.0140)
32	0.3177*** (0.0528)	0.6119*** (0.0588)	0.1277*** (0.0385)
33	0.0113*** (0.0283)	-0.0062*** (0.0142)	-0.0191*** (0.0091)
34	0.2602*** (0.0446)	0.0737*** (0.0481)	0.0003*** (0.0114)

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Industry	CES_1	CES_2	CES_3
35	0.2412*** (0.0395)	0.0744*** (0.0354)	0.0274*** (0.0149)
36	0.2423*** (0.0230)	0.9519*** (0.0805)	0.1170*** (0.0220)
37	0.4111*** (0.0239)	0.8224*** (0.2752)	0.0208*** (0.0331)
38	0.6592*** (0.0357)	0.3841*** (0.0783)	0.0575*** (0.0252)
39	0.1891*** (0.0397)	0.0798*** (0.0468)	0.0417*** (0.0252)
40	0.5563*** (0.0283)	1.2770*** (0.0730)	0.2031*** (0.0670)
41	0.6431*** (0.0393)	0.7524*** (0.1057)	0.1266*** (0.0584)
42	0.3258*** (0.0538)	0.7974*** (0.0540)	0.0702*** (0.0377)
43	0.2122*** (0.0237)	0.4662*** (0.2119)	0.0224*** (0.0216)
44	0.2958*** (0.1019)	0.5489*** (0.0399)	-0.0708*** (0.0245)
45	0.9701*** (0.0240)	0.0817*** (0.1560)	0.0703*** (0.1518)
46	0.9381*** (0.0186)	0.6988*** (0.1088)	0.6443*** (0.0721)
47	0.4172*** (0.0367)	0.8930*** (0.0966)	0.1513*** (0.0500)
48	0.1279*** (0.0311)	0.1598*** (0.0470)	0.0894*** (0.0255)
49	0.2400*** (0.0425)	0.5499*** (0.1400)	0.0397*** (0.0567)
50	0.1668*** (0.0347)	0.5051*** (0.0679)	0.0518*** (0.0227)
51	0.3047*** (0.0532)	0.8150*** (0.0626)	0.1326*** (0.0579)
52	0.5220*** (0.0464)	0.5829*** (0.0836)	0.1496*** (0.0353)
53	-0.0035*** (0.0115)	0.0669*** (0.0267)	-0.0014*** (0.0073)
54	0.0489*** (0.0121)	0.5223*** (0.0768)	0.0421*** (0.0159)
55	0.0580*** (0.0153)	0.1983*** (0.0457)	0.0505*** (0.0136)
56	0.0942*** (0.0370)	0.7981*** (0.0667)	0.0036*** (0.0249)
57	0.0009*** (0.0213)	0.0461*** (0.0330)	-0.0116*** (0.0128)
58	0.2509*** (0.0334)	-0.0224*** (0.0512)	0.0074*** (0.0237)
59	0.0687*** (0.0289)	0.0790*** (0.0354)	0.0121*** (0.0151)
60	0.1170*** (0.0237)	0.6986*** (0.0757)	0.0657*** (0.0208)
61	0.0199*** (0.0142)	0.2175*** (0.0596)	0.0162*** (0.0121)
62	0.1659*** (0.0723)	0.1000*** (0.0671)	0.1055*** (0.0692)
63	0.4647*** (0.0610)	0.1550*** (0.0530)	0.0072*** (0.0159)
64	0.3063*** (0.0614)	0.0765*** (0.0345)	0.0047*** (0.0184)
65	0.0368*** (0.0261)	0.0191*** (0.0205)	0.0190*** (0.0203)

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.12: Simple and value-added weighted averages of industry-level estimates in CES production function single equation estimates

Equation		Method			
		OLS	**OLS differenced**	**2SLS**	**GIV**
CES_1	σ_1, SA	0.5052	0.3201	0.5964	0.3901
	σ_1, WA	0.4461	0.3422	0.4876	0.3723
	ζ_K, SA	-0.0103	-0.0102	0.0150	-0.0142
	ζ_K, WA	-0.0113	-0.0097	-0.0024	-0.0123
CES_2	σ_2, SA	0.5602	0.4602	0.6359	0.5196
	σ_2, WA	0.4212	0.3934	0.4660	0.4040
	ζ_L, SA	0.0147	0.0149	0.0154	0.0141
	ζ_L, WA	0.0110	0.0132	0.0142	0.0096
CES_3	σ_3, SA	0.2534	0.0884	0.3474	0.1363
	σ_3, WA	0.1635	0.0746	0.2094	0.0943
	$\zeta_L - \zeta_K$, SA	0.0570	0.0268	0.0283	0.0285
	$\zeta_L - \zeta_K$, WA	0.0634	0.0231	0.0237	0.0240

Note: SA and WA denote single average and weighted average, respectively.

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Table 3.13: Estimates of industry elasticities of substitution and technological change – CES production function, normalized system

Industry	NLSUR				GMM			
	σ	ζ_K	ζ_L	ξ	σ	ζ_K	ζ_L	ξ
1	0.3663***	0.0063***	0.0351***	1.0108***	0.2112***	0.0070***	0.0357***	1.0210***
	(0.0113)	(0.0007)	(0.0008)	(0.0103)	(0.0576)	(0.0007)	(0.0010)	(0.0074)
2	0.6610***	0.0053***	-0.0243***	1.0335***	0.7113***	0.0122***	-0.0290***	1.0539***
	(0.0116)	(0.0014)	(0.0013)	(0.0140)	(0.0297)	(0.0035)	(0.0033)	(0.0142)
3	0.5011***	-0.0136***	0.0137***	1.0285***	0.8808***	-0.0268***	0.0419***	1.0294***
	(0.0050)	(0.0011)	(0.0017)	(0.0233)	(0.0288)	(0.0044)	(0.0149)	(0.0182)
4	0.4702***	-0.0097***	0.0336***	1.0454***	0.5872***	-0.0153***	0.0334***	1.0627***
	(0.0081)	(0.0010)	(0.0016)	(0.0203)	(0.0258)	(0.0013)	(0.0016)	(0.0142)
5	0.6054***	-0.0127***	0.0207***	1.0389***	0.9795***	-0.1867	0.1366*	1.1071***
	(0.0161)	(0.0029)	(0.0016)	(0.0194)	(0.0148)	(0.1206)	(0.0797)	(0.0614)
6	0.7358***	-0.0103***	0.0037*	1.0232***	0.9951***	0.1527***	-0.4002***	1.0770***
	(0.0030)	(0.0007)	(0.0021)	(0.0130)	(0.0020)	(0.0443)	(0.1098)	(0.0163)
7	0.1599***	-0.0096***	0.0069***	1.0129***	0.2449***	-0.0096***	0.0049***	1.0290***
	(0.0099)	(0.0012)	(0.0008)	(0.0152)	(0.0751)	(0.0026)	(0.0007)	(0.0088)
8	0.5006***	-0.0108***	0.0137***	1.0064***	0.7244***	-0.0091***	0.0112***	0.9896***
	(0.0053)	(0.0007)	(0.0007)	(0.0079)	(0.0493)	(0.0021)	(0.0007)	(0.0091)
9	0.5101***	-0.0113***	0.0091***	1.0258***	0.5332***	-0.0100***	0.0085***	1.0173***
	(0.0044)	(0.0007)	(0.0006)	(0.0103)	(0.0143)	(0.0008)	(0.0006)	(0.0076)
10	0.3467***	-0.0198***	0.0109***	1.0197***	0.4365***	-0.0199***	0.0088***	1.0133***
	(0.0073)	(0.0007)	(0.0007)	(0.0120)	(0.0262)	(0.0006)	(0.0006)	(0.0080)
11	0.4126***	-0.0163***	0.0147***	1.0011***	0.4908***	-0.0211***	0.0171***	1.0170***
	(0.0093)	(0.0006)	(0.0004)	(0.0067)	(0.0528)	(0.0018)	(0.0007)	(0.0043)
12	0.6674***	-0.0074***	0.0080***	1.0124***	0.8127***	0.0137**	-0.0045	1.0076***
	(0.0050)	(0.0010)	(0.0010)	(0.0156)	(0.0279)	(0.0068)	(0.0043)	(0.0132)
13	0.5882***	-0.0184***	0.0840***	1.1110***	0.7820***	-0.0369**	0.0958***	1.0155***
	(0.0129)	(0.0033)	(0.0031)	(0.0566)	(0.0377)	(0.0149)	(0.0064)	(0.0474)
14	0.5503***	-0.0117***	0.0106***	1.0089***	0.5502***	-0.0107***	0.0144***	0.9829***
	(0.0059)	(0.0008)	(0.0009)	(0.0142)	(0.0502)	(0.0014)	(0.0013)	(0.0076)
15	0.4624***	-0.0215***	0.0217***	1.0203***	0.4079***	-0.0181***	0.0193***	1.0215***
	(0.0070)	(0.0010)	(0.0010)	(0.0166)	(0.0244)	(0.0010)	(0.0009)	(0.0113)
16	0.5530***	-0.0219***	0.0171***	1.0164***	0.6447***	-0.0219***	0.0152***	1.0268***
	(0.0069)	(0.0009)	(0.0007)	(0.0119)	(0.0328)	(0.0011)	(0.0007)	(0.0095)
17	0.3963***	-0.0243***	0.0156***	1.0036***	0.7117***	-0.0499***	0.0213***	1.0406***
	(0.0055)	(0.0007)	(0.0005)	(0.0101)	(0.0523)	(0.0081)	(0.0015)	(0.0064)
18	0.2401***	-0.0105***	0.0288***	1.0056***	0.5927***	-0.0256***	0.0347***	1.0331***
	(0.0120)	(0.0006)	(0.0004)	(0.0079)	(0.0629)	(0.0051)	(0.0017)	(0.0082)
19	0.6311***	-0.0135***	0.0266***	1.0054***	0.6335***	-0.0158***	0.0269***	1.0345***
	(0.0067)	(0.0009)	(0.0008)	(0.0111)	(0.0476)	(0.0020)	(0.0015)	(0.0080)
20	0.5454***	-0.0015	0.0236***	1.0193***	0.7839***	-0.0094***	0.0268***	1.0299***
	(0.0035)	(0.0013)	(0.0007)	(0.0139)	(0.0418)	(0.0037)	(0.0012)	(0.0106)
21	0.4143***	-0.0245***	0.0186***	1.0020***	0.7190***	-0.0222***	0.0176***	1.0223***
	(0.0103)	(0.0009)	(0.0004)	(0.0070)	(0.0779)	(0.0043)	(0.0013)	(0.0059)
22	0.3974***	-0.0117***	0.0119***	1.0050***	0.3905***	-0.0128***	0.0130***	1.0097***
	(0.0041)	(0.0005)	(0.0004)	(0.0073)	(0.0441)	(0.0005)	(0.0004)	(0.0049)
23	0.0821***	-0.0151***	0.0109***	1.0073***	0.0432***	-0.0156***	0.0117***	1.0037***
	(0.0106)	(0.0005)	(0.0005)	(0.0081)	(0.0124)	(0.0006)	(0.0002)	(0.0051)
24	0.5273***	-0.0143***	0.0616***	1.0316***	0.7223***	-0.0306***	0.0884***	1.1385***
	(0.0098)	(0.0016)	(0.0027)	(0.0320)	(0.0303)	(0.0041)	(0.0089)	(0.0351)
25	0.4342***	-0.0155***	0.0281***	1.0155***	0.2279***	-0.0186***	0.0259***	1.0284***
	(0.0098)	(0.0008)	(0.0008)	(0.0102)	(0.0444)	(0.0008)	(0.0006)	(0.0063)
26	0.6284***	-0.0068***	0.0101***	1.0198***	0.6900***	-0.0034***	0.0094***	1.0196***
	(0.0035)	(0.0010)	(0.0006)	(0.0108)	(0.0343)	(0.0012)	(0.0008)	(0.0081)
27	0.4510***	-0.0164***	0.0309***	1.0027***	0.4754***	-0.0168***	0.0313***	1.0001***
	(0.0038)	(0.0003)	(0.0003)	(0.0047)	(0.0276)	(0.0005)	(0.0003)	(0.0039)
28	0.1661***	-0.0179***	0.0176***	1.0024***	0.2913***	-0.0199***	0.0186***	0.9960***
	(0.0071)	(0.0003)	(0.0003)	(0.0058)	(0.0499)	(0.0007)	(0.0003)	(0.0044)
29	0.7201***	0.0300***	0.0091***	1.0351***	0.9764***	0.2555***	-0.1237***	1.1927***
	(0.0125)	(0.0035)	(0.0018)	(0.0206)	(0.0063)	(0.0432)	(0.0245)	(0.0287)
30	0.1586***	-0.0058***	0.0257***	1.0068***	0.2057***	-0.0080***	0.0271***	1.0025***
	(0.0090)	(0.0006)	(0.0004)	(0.0084)	(0.0337)	(0.0007)	(0.0004)	(0.0059)
31	0.4633***	0.0044***	0.0202***	1.0171***	0.8306***	-0.0011	0.0275***	1.0229***
	(0.0128)	(0.0013)	(0.0012)	(0.0167)	(0.0422)	(0.0042)	(0.0049)	(0.0161)
32	0.5498***	0.0078***	0.0116***	1.0123***	0.6121***	0.0095***	0.0114***	1.0321***
	(0.0064)	(0.0016)	(0.0005)	(0.0091)	(0.0425)	(0.0021)	(0.0006)	(0.0062)
33	0.1054***	0.0148***	-0.0002	1.0096***	0.1979***	0.0171***	-0.0037***	1.0287***
	(0.0094)	(0.0004)	(0.0006)	(0.0078)	(0.0437)	(0.0013)	(0.0014)	(0.0073)

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Industry	NLSUR				GMM			
	σ	ζ_K	ζ_L	ξ	σ	ζ_K	ζ_L	ξ
34	0.5710***	-0.0059**	0.0516***	1.0394***	0.9807***	-0.1829***	0.3557***	1.2724***
	(0.0133)	(0.0023)	(0.0028)	(0.0302)	(0.0068)	(0.0356)	(0.0616)	(0.0355)
35	0.1541***	0.0208***	0.0004	1.0142***	0.5061***	0.0422***	-0.0172***	1.1031***
	(0.0194)	(0.0009)	(0.0008)	(0.0112)	(0.0366)	(0.0031)	(0.0024)	(0.0129)
36	0.2178***	0.0185***	0.0179***	1.0230***	0.2417***	0.0174***	0.0200***	1.0122***
	(0.0072)	(0.0006)	(0.0008)	(0.0119)	(0.0127)	(0.0005)	(0.0005)	(0.0087)
37	0.5358***	-0.0241***	0.0328***	1.0195***	0.6190***	-0.0300***	0.0351***	1.0227***
	(0.0086)	(0.0007)	(0.0007)	(0.0096)	(0.0878)	(0.0066)	(0.0038)	(0.0129)
38	0.7136***	0.0013	0.0091***	1.0400***	0.9223***	0.0367**	-0.0525*	1.0231***
	(0.0051)	(0.0013)	(0.0017)	(0.0189)	(0.0302)	(0.0175)	(0.0313)	(0.0270)
39	0.3322***	-0.0127***	0.0452***	1.0043***	0.7286***	-0.0251***	0.0635***	1.0332***
	(0.0100)	(0.0005)	(0.0005)	(0.0079)	(0.0641)	(0.0043)	(0.0059)	(0.0076)
40	1.2902***	-0.1158***	0.0557***	0.9148***	1.7264***	-0.0893***	0.0259***	0.9729***
	(0.0285)	(0.0035)	(0.0038)	(0.0226)	(0.1140)	(0.0024)	(0.0026)	(0.0114)
41	0.9813***	0.0805***	-0.1228***	1.0640***	1.0954***	-0.0566***	0.0380***	1.0042***
	(0.0029)	(0.0156)	(0.0186)	(0.0130)	(0.0346)	(0.0073)	(0.0085)	(0.0096)
42	0.7705***	-0.0169**	0.0217***	1.0049***	0.9076***	0.0208	0.0139***	1.0759***
	(0.0140)	(0.0081)	(0.0024)	(0.0433)	(0.0154)	(0.0224)	(0.0040)	(0.0391)
43	0.4136***	-0.0548***	0.0196***	1.0145***	0.5935***	-0.0633***	0.0234***	1.0225***
	(0.0139)	(0.0009)	(0.0006)	(0.0094)	(0.0749)	(0.0039)	(0.0018)	(0.0086)
44	0.6728***	0.0206***	0.0392***	1.0552***	0.8094***	0.0197***	0.0366***	1.1084***
	(0.0165)	(0.0050)	(0.0032)	(0.0334)	(0.0525)	(0.0030)	(0.0038)	(0.0296)
45	0.2183***	0.0026***	0.0015***	1.0013***	0.3056***	0.0028***	-0.0005	0.9988***
	(0.0243)	(0.0002)	(0.0011)	(0.0035)	(0.1015)	(0.0002)	(0.0024)	(0.0022)
46	1.0651***	-0.0233***	0.0007	0.9900***	1.0223***	-0.0314***	0.0256	0.9982***
	(0.0012)	(0.0031)	(0.0092)	(0.0324)	(0.0071)	(0.0039)	(0.0158)	(0.0313)
47	0.7989***	0.0599***	-0.0521***	1.2485***	0.7793***	0.0562***	-0.0483***	1.2526***
	(0.0089)	(0.0034)	(0.0026)	(0.0138)	(0.0099)	(0.0034)	(0.0027)	(0.0216)
48	0.4423***	-0.0263***	-0.0151***	1.1119***	0.6048***	-0.0003	-0.0240***	1.1987***
	(0.0240)	(0.0034)	(0.0021)	(0.0249)	(0.0337)	(0.0069)	(0.0038)	(0.0354)
49	0.6472***	0.0194***	-0.0041**	1.1079***	0.7149***	0.0312***	-0.0115***	1.1269***
	(0.0161)	(0.0024)	(0.0016)	(0.0092)	(0.0115)	(0.0024)	(0.0013)	(0.0060)
50	0.4683***	-0.0028	-0.0069***	1.1780***	0.4901***	-0.0009	-0.0091***	1.1909***
	(0.0146)	(0.0019)	(0.0016)	(0.0157)	(0.0125)	(0.0015)	(0.0011)	(0.0129)
51	0.7778***	0.0702***	-0.0167***	1.1867***	0.7256***	0.0427***	-0.0051*	1.1500***
	(0.0102)	(0.0051)	(0.0020)	(0.0152)	(0.0240)	(0.0076)	(0.0026)	(0.0170)
52	0.4699***	0.0231***	-0.0043**	1.0696***	0.5044***	0.0245***	-0.0062**	1.1084***
	(0.0207)	(0.0015)	(0.0020)	(0.0159)	(0.0338)	(0.0032)	(0.0030)	(0.0144)
53	0.2294***	-0.0183***	0.0107***	1.0111***	0.9482***	0.2880***	-0.0574***	1.2437***
	(0.0100)	(0.0018)	(0.0011)	(0.0208)	(0.0094)	(0.0327)	(0.0071)	(0.0127)
54	0.1554***	-0.0332***	0.0106***	1.0270***	0.0388***	-0.0322***	0.0088***	1.0336***
	(0.0126)	(0.0008)	(0.0010)	(0.0150)	(0.0105)	(0.0006)	(0.0011)	(0.0102)
55	0.1756***	-0.0210***	0.0044***	1.0238***	0.3983***	-0.0052**	-0.0025***	1.0549***
	(0.0237)	(0.0013)	(0.0008)	(0.0118)	(0.0341)	(0.0025)	(0.0010)	(0.0094)
56	0.6782***	-0.0007	0.0281***	1.0247***	0.9906***	0.9300***	-0.0950***	1.2803***
	(0.0065)	(0.0041)	(0.0014)	(0.0256)	(0.0025)	(0.1298)	(0.0167)	(0.0172)
57	0.0940***	0.0177***	0.0176***	1.0119***	0.1386***	0.0210***	0.0155***	1.0349***
	(0.0095)	(0.0008)	(0.0007)	(0.0133)	(0.0250)	(0.0010)	(0.0008)	(0.0076)
58	0.5245***	0.0119***	-0.0105***	1.0267***	0.8225***	0.0560***	-0.0402***	1.0898***
	(0.0202)	(0.0015)	(0.0012)	(0.0123)	(0.0302)	(0.0099)	(0.0066)	(0.0219)
59	0.4163***	0.0013***	0.0117***	1.0076***	0.8173***	-0.0006	0.0132***	1.0030***
	(0.0074)	(0.0008)	(0.0005)	(0.0094)	(0.0631)	(0.0031)	(0.0017)	(0.0084)
60	0.2651***	-0.0051***	0.0048***	1.0080***	0.3713***	-0.0094***	0.0068***	1.0076***
	(0.0096)	(0.0006)	(0.0004)	(0.0072)	(0.0398)	(0.0016)	(0.0004)	(0.0055)
61	0.1411***	-0.0089***	-0.0040***	1.0054***	0.3620***	-0.0228***	-0.0020***	1.0278***
	(0.0099)	(0.0007)	(0.0004)	(0.0069)	(0.0450)	(0.0035)	(0.0006)	(0.0059)
62	0.4519***	-0.0087***	0.0147***	1.0083***	0.4036***	-0.0095***	0.0158***	1.0091***
	(0.0214)	(0.0004)	(0.0006)	(0.0019)	(0.0814)	(0.0011)	(0.0017)	(0.0019)
63	0.5969***	-0.0143***	0.0016	1.0023***	0.9380***	0.0387**	-0.0850***	1.0830***
	(0.0089)	(0.0012)	(0.0010)	(0.0132)	(0.0190)	(0.0159)	(0.0251)	(0.0174)
64	0.4227***	-0.0086***	-0.0134***	1.0291***	0.6104***	-0.0014	-0.0264***	1.0520***
	(0.0104)	(0.0010)	(0.0012)	(0.0177)	(0.0491)	(0.0025)	(0.0051)	(0.0144)
65	0.2000***	0.0029***	0.0031***	1.0074***	0.2417***	0.0049***	0.0017*	1.0121***
	(0.0174)	(0.0004)	(0.0003)	(0.0022)	(0.0460)	(0.0009)	(0.0009)	(0.0023)

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.14: Simple and value-added weighted averages of industry-level estimates in CES production function normalized system estimates

	Method	
	NLSUR	**GMM**
σ, SA	0.4753	0.6224
σ, WA	0.3821	0.4763
ζ_K, SA	-0.0055	0.0139
ζ_K, WA	-0.0048	0.0024
ζ_L, SA	0.0120	0.0075
ζ_L, WA	0.0071	-0.0016

Note: SA and WA denote single average and weighted average, respectively.

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Table 3.15.1: Estimates of industry rates of factor augmentation from OLS regressions – CES production function, single equation

Industry	Regression coefficients			Parameters		
	ξ_2^K	ξ_2^L	ξ_2^{LK}	ζ_K	ζ_L	$\zeta_L - \zeta_K$
1	0.0020* (0.0012)	0.0241*** (0.0000)	0.0226*** (0.0016)	0.0036	0.0365	0.0283
2	0.0035*** (0.0012)	-0.0085*** (0.0000)	-0.0098*** (0.0016)	0.0115	-0.0350	-0.0256
3	-0.0035*** (0.0005)	0.0048*** (0.0000)	0.0143*** (0.0010)	-0.0237	0.0071	0.0194
4	-0.0069*** (0.0004)	0.0200*** (0.0000)	0.0244*** (0.0004)	-0.0189	0.0251	0.0326
5	-0.0070*** (0.0014)	0.0105*** (0.0000)	0.0190*** (0.0024)	-0.0258	0.0225	0.0361
6	-0.0015*** (0.0004)	0.0026** (0.0000)	0.0171*** (0.0009)	-0.0086	0.0074	0.0211
7	-0.0065*** (0.0013)	0.0030*** (0.0000)	0.0139*** (0.0012)	-0.0053	0.0135	0.0130
8	-0.0053*** (0.0008)	0.0006 (0.0000)	0.0113*** (0.0018)	-0.0090	0.0084	0.0210
9	-0.0052*** (0.0005)	0.0046*** (0.0000)	0.0146*** (0.0006)	-0.0112	0.0094	0.0230
10	-0.0113*** (0.0006)	0.0095*** (0.0000)	0.0225*** (0.0006)	-0.0195	0.0092	0.0290
11	-0.0111*** (0.0006)	0.0053*** (0.0000)	0.0213*** (0.0011)	-0.0169	0.0206	0.0309
12	-0.0048*** (0.0012)	0.0018 (0.0000)	0.0227*** (0.0014)	-0.0121	0.0064	0.0348
13	-0.0097*** (0.0022)	0.0107** (0.0000)	0.0531*** (0.0013)	-0.0307	0.1714	0.0579
14	-0.0056*** (0.0010)	0.0003 (0.0000)	0.0232*** (0.0016)	-0.0122	0.0012	0.0326
15	-0.0107*** (0.0008)	0.0069*** (0.0000)	0.0292*** (0.0011)	-0.0199	0.0218	0.0367
16	-0.0089*** (0.0008)	0.0059*** (0.0000)	0.0211*** (0.0016)	-0.0200	0.0156	0.0356
17	-0.0147*** (0.0006)	0.0036*** (0.0000)	0.0271*** (0.0008)	-0.0228	0.0298	0.0339
18	-0.0094*** (0.0007)	0.0156*** (0.0000)	0.0331*** (0.0010)	-0.0125	0.0333	0.0390
19	-0.0044*** (0.0005)	0.0098*** (0.0000)	0.0187*** (0.0011)	-0.0115	0.0250	0.0273
20	-0.0002 (0.0007)	0.0043*** (0.0000)	0.0191*** (0.0006)	-0.0004	0.0250	0.0231
21	-0.0145*** (0.0022)	0.0108*** (0.0000)	0.0336*** (0.0027)	-0.0259	0.0188	0.0457
22	-0.0074*** (0.0009)	0.0066*** (0.0000)	0.0193*** (0.0011)	-0.0118	0.0119	0.0245
23	-0.0145*** (0.0005)	0.0039*** (0.0000)	0.0255*** (0.0009)	-0.0140	0.0165	0.0244
24	-0.0091*** (0.0005)	0.0271*** (0.0000)	0.0368*** (0.0005)	-0.0409	0.0754	0.0457
25	-0.0063*** (0.0010)	0.0197*** (0.0000)	0.0411*** (0.0015)	-0.0264	0.0264	0.0389
26	-0.0035*** (0.0006)	0.0025*** (0.0000)	0.0109*** (0.0009)	-0.0078	0.0094	0.0193
27	-0.0094*** (0.0005)	0.0128*** (0.0000)	0.0276*** (0.0015)	-0.0161	0.0312	0.0468
28	-0.0165*** (0.0006)	0.0067*** (0.0000)	0.0344*** (0.0012)	-0.0183	0.0205	0.0361
29	0.0048*** (0.0014)	0.0050*** (0.0000)	0.0192*** (0.0020)	0.0115	0.0148	0.0215
30	-0.0052*** (0.0007)	0.0197*** (0.0000)	0.0282*** (0.0007)	-0.0060	0.0266	0.0310
31	0.0008 (0.0009)	0.0137*** (0.0000)	0.0104*** (0.0015)	0.0022	0.0203	0.0163
32	0.0048*** (0.0008)	0.0035*** (0.0000)	0.0039*** (0.0009)	0.0096	0.0106	0.0059
33	0.0137*** (0.0004)	0.0003 (0.0000)	-0.0118*** (0.0011)	0.0158	0.0003	-0.0117

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Industry	Regression coefficients			Parameters		
	ξ_2^K	ξ_2^L	ξ_2^{LK}	ζ_K	ζ_L	$\zeta_L - \zeta_K$
34	-0.0020* (0.0010)	0.0283*** (0.0000)	0.0371*** (0.0022)	-0.0077	0.0435	0.0398
35	0.0178*** (0.0006)	-0.0030*** (0.0000)	-0.0156*** (0.0007)	0.0217	-0.0043	-0.0166
36	0.0139*** (0.0005)	0.0038 (0.0000)	0.0009*** (0.0004)	0.0183	0.0156	0.0010
37	-0.0115*** (0.0004)	0.0041** (0.0000)	0.0322*** (0.0021)	-0.0221	-0.0376	0.0464
38	0.0017*** (0.0006)	0.0069*** (0.0000)	0.0207*** (0.0022)	0.0131	0.0156	0.0264
39	-0.0078*** (0.0006)	0.0363*** (0.0000)	0.0526*** (0.0028)	-0.0147	0.0440	0.0530
40	-0.0045 (0.0064)	-0.0244*** (0.0000)	-0.0462*** (0.0127)	-0.0228	0.0257	0.1872
41	0.0019 (0.0015)	-0.0007 (0.0000)	-0.0034 (0.0039)	-0.1967	-0.0117	1.9479
42	0.0002 (0.0062)	0.0007 (0.0000)	0.0230*** (0.0081)	0.0014	0.0059	0.0650
43	-0.0329*** (0.0021)	0.0162*** (0.0000)	0.0534*** (0.0032)	-0.0575	0.0185	0.0745
44	0.0030 (0.0030)	0.0141*** (0.0000)	0.0185*** (0.0032)	0.0260	0.0393	0.0203
45	0.0009*** (0.0001)	0.0075** (0.0000)	0.0048* (0.0026)	0.0062	0.0058	0.0036
46	-0.0003 (0.0003)	-0.0021* (0.0000)	-0.0044* (0.0026)	-0.0923	0.0129	0.0376
47	0.0121*** (0.0021)	-0.0089*** (0.0000)	0.0173*** (0.0062)	0.0656	-0.0312	0.0200
48	-0.0019 (0.0054)	-0.0077*** (0.0000)	0.0156** (0.0072)	-0.0046	-0.0123	0.0234
49	0.0104*** (0.0016)	0.0049*** (0.0000)	-0.0079* (0.0045)	0.0408	0.0090	-0.0224
50	-0.0143*** (0.0047)	-0.0027*** (0.0000)	0.0463*** (0.0025)	-0.0209	-0.0049	0.0499
51	0.0137*** (0.0042)	0.0027** (0.0000)	0.0178* (0.0107)	0.0654	0.0064	0.0262
52	0.0129*** (0.0007)	0.0066*** (0.0000)	-0.0064*** (0.0022)	0.0310	0.0088	-0.0092
53	-0.0179*** (0.0035)	0.0011 (0.0000)	0.0337*** (0.0016)	-0.0188	0.0032	0.0331
54	-0.0326*** (0.0013)	0.0018*** (0.0000)	0.0332*** (0.0017)	-0.0335	0.0069	0.0428
55	-0.0322*** (0.0017)	-0.0031*** (0.0000)	0.0253*** (0.0022)	-0.0286	-0.0070	0.0285
56	-0.0041 (0.0032)	0.0008 (0.0000)	0.0340*** (0.0060)	-0.0087	0.0115	0.0466
57	0.0184*** (0.0008)	0.0197*** (0.0000)	-0.0007 (0.0010)	0.0226	0.0194	-0.0007
58	0.0071*** (0.0008)	-0.0039*** (0.0000)	-0.0072*** (0.0014)	0.0188	-0.0055	-0.0103
59	0.0001 (0.0007)	0.0067*** (0.0000)	0.0090*** (0.0012)	0.0002	0.0122	0.0121
60	-0.0037*** (0.0006)	0.0030*** (0.0000)	0.0087*** (0.0006)	-0.0048	0.0126	0.0125
61	-0.0111*** (0.0018)	-0.0007 (0.0000)	0.0070*** (0.0020)	-0.0125	-0.0012	0.0078
62	-0.0033** (0.0016)	0.0088*** (0.0000)	0.0126*** (0.0047)	-0.0069	0.0147	0.0222
63	0.0048** (0.0022)	0.0035*** (0.0000)	0.0365*** (0.0016)	-0.0738	0.0061	0.0330
64	0.0026** (0.0012)	-0.0064*** (0.0000)	0.0098*** (0.0007)	0.0161	-0.0098	0.0097
65	0.0025*** (0.0008)	0.0033*** (0.0000)	0.0021 (0.0015)	0.0031	0.0037	0.0023

Notes: $\xi_2^K = (1-\sigma)\zeta_K$; $\xi_2^L = (1-\sigma)\zeta_L$; $\xi_2^{LK} = (1-\sigma)(\zeta_L - \zeta_K)$. Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.15.2: Estimates of industry rates of factor augmentation from 2SLS regressions – CES production function, single equation

Industry	Regression coefficients			Parameters		
	ξ_2^K	ξ_2^L	ξ_2^{LK}	ζ_K	ζ_L	$\zeta_L - \zeta_K$
1	0.0060*** (0.0021)	0.0255*** (0.0026)	0.0215*** (0.0017)	0.0072	0.0355	0.0289
2	0.0048*** (0.0013)	-0.0087*** (0.0005)	-0.0116*** (0.0017)	0.0193	-0.0389	-0.0362
3	-0.0029*** (0.0005)	0.0067*** (0.0015)	0.0129*** (0.0012)	-0.0309	0.0225	0.0267
4	-0.0069*** (0.0004)	0.0208*** (0.0014)	0.0243*** (0.0004)	-0.0200	0.0251	0.0329
5	-0.0061*** (0.0016)	0.0091*** (0.0013)	0.0137*** (0.0029)	-1.3912	0.0227	0.0524
6	-0.0007 (0.0005)	-0.0029* (0.0016)	0.0100*** (0.0020)	-0.0064	0.0386	0.0192
7	-0.0055*** (0.0014)	0.0030*** (0.0003)	0.0134*** (0.0011)	-0.0038	0.0127	0.0117
8	-0.0042*** (0.0009)	-0.0008 (0.0009)	0.0067*** (0.0024)	-0.0083	0.0190	0.0192
9	-0.0051*** (0.0006)	0.0046*** (0.0010)	0.0137*** (0.0007)	-0.0111	0.0093	0.0226
10	-0.0107*** (0.0007)	0.0116*** (0.0012)	0.0215*** (0.0007)	-0.0195	0.0090	0.0290
11	-0.0115*** (0.0006)	0.0052*** (0.0007)	0.0212*** (0.0013)	-0.0162	0.0211	0.0313
12	-0.0047*** (0.0013)	0.0018 (0.0013)	0.0227*** (0.0015)	-0.0119	0.0064	0.0348
13	-0.0159*** (0.0027)	-0.0056 (0.0054)	0.0419*** (0.0037)	-0.1120	0.0300	0.0825
14	-0.0048*** (0.0011)	0.0005 (0.0020)	0.0227*** (0.0019)	-0.0111	0.0020	0.0323
15	-0.0116*** (0.0009)	0.0111*** (0.0026)	0.0293*** (0.0012)	-0.0194	0.0188	0.0363
16	-0.0081*** (0.0010)	0.0075*** (0.0017)	0.0187*** (0.0018)	-0.0203	0.0152	0.0357
17	-0.0144*** (0.0007)	0.0031*** (0.0007)	0.0245*** (0.0011)	-0.0337	0.0430	0.0402
18	-0.0120*** (0.0013)	0.0130*** (0.0022)	0.0280*** (0.0020)	-0.0364	0.0365	0.0504
19	-0.0047*** (0.0005)	0.0103*** (0.0009)	0.0174*** (0.0011)	-0.0151	0.0246	0.0300
20	-0.0009 (0.0007)	0.0037*** (0.0009)	0.0184*** (0.0008)	-0.0020	0.0265	0.0232
21	-0.0092*** (0.0029)	0.0100*** (0.0009)	0.0275*** (0.0035)	-0.0249	0.0188	0.0457
22	-0.0102*** (0.0016)	0.0061*** (0.0007)	0.0177*** (0.0013)	-0.0123	0.0120	0.0245
23	-0.0199*** (0.0030)	0.0020** (0.0008)	0.0440*** (0.0108)	-0.0100	0.1575	0.0187
24	-0.0092*** (0.0005)	0.0268*** (0.0021)	0.0366*** (0.0005)	-0.0463	0.1084	0.0511
25	-0.0066*** (0.0013)	0.0207*** (0.0009)	0.0427*** (0.0016)	-0.0264	0.0254	0.0387
26	-0.0025*** (0.0009)	0.0028*** (0.0005)	0.0090*** (0.0010)	-0.0071	0.0095	0.0184
27	-0.0092*** (0.0005)	0.0133*** (0.0014)	0.0263*** (0.0015)	-0.0161	0.0314	0.0471
28	-0.0163*** (0.0007)	0.0049*** (0.0014)	0.0334*** (0.0016)	-0.0185	0.0229	0.0364
29	0.0071*** (0.0019)	0.0026** (0.0013)	0.0153*** (0.0032)	-0.2085	0.0103	0.0196
30	-0.0053*** (0.0007)	0.0191*** (0.0009)	0.0280*** (0.0008)	-0.0057	0.0269	0.0313
31	-0.0008*** (0.0011)	0.0035 (0.0034)	0.0060*** (0.0022)	-0.0051	0.0257	0.0228
32	0.0043*** (0.0008)	0.0034*** (0.0004)	0.0033*** (0.0009)	0.0099	0.0105	0.0054
33	0.0144*** (0.0005)	-0.0137 (0.0087)	-0.0147*** (0.0029)	0.0193	-0.0334	-0.0162

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Industry	Regression coefficients			Parameters		
	ξ_2^K	ξ_2^L	ξ_2^{LK}	ζ_K	ζ_L	$\zeta_L - \zeta_K$
34	-0.0032*** (0.0012)	0.0015 (0.0098)	-0.0107 (0.0380)	2.2172	-0.0170	0.0186
35	0.0177*** (0.0007)	-0.0060*** (0.0014)	-0.0162*** (0.0008)	0.0207	-0.0111	-0.0176
36	0.0139*** (0.0006)	0.0052* (0.0027)	0.0011** (0.0004)	0.0183	0.0177	0.0012
37	-0.0111*** (0.0005)	0.0040** (0.0018)	0.0186*** (0.0049)	-0.0342	-0.0343	0.2394
38	0.0027*** (0.0006)	0.0047* (0.0024)	0.0146*** (0.0032)	0.0710	0.0129	0.0233
39	-0.0057*** (0.0009)	0.0337*** (0.0066)	0.0668*** (0.0072)	-0.0330	0.0449	0.0502
40	0.0023 (0.0079)	-0.0269*** (0.0020)	-0.0640*** (0.0142)	0.0214	0.0225	0.1426
41	0.0051*** (0.0018)	-0.0021 (0.0022)	-0.0108** (0.0046)	-0.0534	0.0966	0.0785
42	0.0227*** (0.0082)	0.0001 (0.0011)	-0.0034 (0.0092)	-0.1609	0.0016	-0.0348
43	-0.0280*** (0.0026)	0.0188*** (0.0032)	0.0464*** (0.0040)	-0.0607	0.0179	0.0778
44	-0.0056 (0.0041)	0.0128*** (0.0023)	0.0154*** (0.0040)	0.0160	0.0393	0.0203
45	0.0010*** (0.0001)	0.0081*** (0.0031)	0.0054** (0.0026)	0.0052	0.0060	0.0039
46	-0.0001 (0.0003)	-0.0023** (0.0010)	-0.0058** (0.0025)	0.5434	0.0144	0.0411
47	0.0142*** (0.0023)	-0.0085*** (0.0011)	0.0178** (0.0070)	0.1097	-0.0275	0.0203
48	0.0094 (0.0065)	-0.0080*** (0.0012)	0.0069 (0.0083)	0.0362	-0.0132	0.0122
49	0.0127*** (0.0017)	0.0040*** (0.0013)	-0.0151*** (0.0046)	0.0638	0.0078	-0.0596
50	-0.0124** (0.0057)	-0.0027*** (0.0009)	0.0461*** (0.0026)	-0.0189	-0.0048	0.0499
51	0.0147*** (0.0046)	0.0035*** (0.0013)	0.0188 (0.0115)	0.0804	0.0077	0.0273
52	0.0125*** (0.0007)	0.0079*** (0.0024)	-0.0064*** (0.0023)	0.0293	0.0100	-0.0093
53	0.0012*** (0.0000)	-0.0010 (0.0009)	0.0499*** (0.0113)	0.0029	-0.0046	0.0378
54	-0.0329*** (0.0014)	0.0017*** (0.0003)	0.0313*** (0.0018)	-0.0333	0.0067	0.0422
55	-0.0405*** (0.0026)	-0.0035*** (0.0005)	0.0233*** (0.0025)	-0.0317	-0.0081	0.0270
56	0.0067 (0.0044)	-0.0004 (0.0007)	0.0054 (0.0098)	0.1818	-0.0153	0.0226
57	0.0190*** (0.0008)	0.0203*** (0.0016)	-0.0017* (0.0010)	0.0249	0.0196	-0.0018
58	0.0091*** (0.0009)	-0.0065*** (0.0010)	-0.0129*** (0.0020)	0.0383	-0.0202	-0.0312
59	0.0003 (0.0009)	0.0022 (0.0014)	0.0033* (0.0020)	0.0015	0.0110	0.0107
60	-0.0035*** (0.0006)	0.0030*** (0.0002)	0.0091*** (0.0007)	-0.0045	0.0131	0.0141
61	-0.0208*** (0.0041)	0.0002 (0.0008)	0.0166*** (0.0041)	-0.0436	0.0004	0.0277
62	-0.0006 (0.0022)	0.0038 (0.0043)	0.0043 (0.0069)	-0.0019	0.0093	0.0115
63	0.0181*** (0.0039)	0.0017* (0.0009)	0.0509*** (0.0047)	-0.0305	0.0038	0.0350
64	0.0045*** (0.0014)	-0.0076*** (0.0010)	0.0101*** (0.0008)	0.0899	-0.0143	0.0100
65	0.0027*** (0.0010)	0.0024*** (0.0008)	0.0021 (0.0019)	0.0036	0.0029	0.0023

Notes: $\xi_2^K = (1-\sigma)\zeta_K$; $\xi_2^L = (1-\sigma)\zeta_L$; $\xi_2^{LK} = (1-\sigma)(\zeta_L - \zeta_K)$. Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.15.3: Estimates of industry rates of factor augmentation from GIV regressions – CES production function, single equation

Industry	Regression coefficients			Parameters		
	ξ_2^{GK}	ξ_2^{GL}	ξ_2^{GLK}	ζ_K	ζ_L	$\zeta_L - \zeta_K$
1	0.0003 (0.0004)	0.0060*** (0.0009)	0.0004** (0.0002)	0.0019	0.0362	0.0074
2	0.0001 (0.0003)	-0.0016*** (0.0003)	-0.0008** (0.0004)	0.0007	-0.0248	-0.0062
3	-0.0026*** (0.0005)	0.0015** (0.0007)	0.0083*** (0.0007)	-0.0217	0.0039	0.0168
4	-0.0013*** (0.0003)	0.0028*** (0.0004)	0.0067*** (0.0003)	-0.0120	0.0402	0.0305
5	-0.0023** (0.0009)	0.0032*** (0.0005)	0.0048*** (0.0008)	-0.0111	0.0166	0.0219
6	-0.0013*** (0.0004)	0.0030*** (0.0009)	0.0150*** (0.0008)	-0.0086	0.0075	0.0211
7	-0.0017*** (0.0004)	0.0003*** (0.0001)	0.0011*** (0.0003)	-0.0116	0.0070	0.0118
8	-0.0009*** (0.0003)	0.0013*** (0.0004)	0.0033*** (0.0004)	-0.0072	0.0116	0.0188
9	-0.0013*** (0.0002)	0.0013** (0.0005)	0.0086*** (0.0005)	-0.0132	0.0090	0.0233
10	-0.0068*** (0.0005)	0.0032*** (0.0004)	0.0133*** (0.0005)	-0.0194	0.0093	0.0286
11	-0.0016*** (0.0002)	0.0009*** (0.0002)	0.0020*** (0.0003)	-0.0191	0.0209	0.0285
12	-0.0006** (0.0002)	0.0002 (0.0003)	0.0070*** (0.0007)	-0.0178	0.0062	0.0344
13	-0.0109*** (0.0023)	0.0101** (0.0045)	0.0577*** (0.0014)	-0.0327	0.2144	0.0587
14	-0.0011*** (0.0002)	0.0005 (0.0005)	0.0078*** (0.0007)	-0.0113	0.0083	0.0323
15	-0.0048*** (0.0006)	0.0012** (0.0006)	0.0074*** (0.0005)	-0.0204	0.0380	0.0352
16	-0.0033*** (0.0004)	0.0010 (0.0008)	0.0093*** (0.0008)	-0.0215	0.0154	0.0362
17	-0.0089*** (0.0004)	0.0017*** (0.0005)	0.0162*** (0.0004)	-0.0224	0.0320	0.0337
18	-0.0052*** (0.0005)	0.0070*** (0.0007)	0.0165*** (0.0004)	-0.0099	0.0307	0.0360
19	-0.0010*** (0.0002)	0.0034*** (0.0006)	0.0036*** (0.0002)	-0.0146	0.0303	0.0239
20	-0.0004 (0.0003)	0.0015*** (0.0005)	0.0081*** (0.0003)	-0.0026	0.0285	0.0228
21	-0.0046*** (0.0003)	0.0047*** (0.0004)	0.0069*** (0.0003)	-0.0329	0.0189	0.0507
22	-0.0019*** (0.0002)	0.0041*** (0.0006)	0.0044*** (0.0002)	-0.0133	0.0121	0.0249
23	-0.0141*** (0.0005)	0.0030*** (0.0004)	0.0225*** (0.0008)	-0.0141	0.0126	0.0245
24	-0.0090*** (0.0005)	0.0067*** (0.0009)	0.0195*** (0.0003)	-0.0415	0.0626	0.0420
25	-0.0006*** (0.0001)	0.0079*** (0.0006)	0.0056*** (0.0002)	-0.0678	0.0263	0.0430
26	-0.0011*** (0.0003)	0.0015*** (0.0004)	0.0075*** (0.0006)	-0.0091	0.0091	0.0192
27	-0.0012*** (0.0001)	0.0026*** (0.0006)	0.0055*** (0.0003)	-0.0153	0.0333	0.0445
28	-0.0027*** (0.0002)	0.0025*** (0.0004)	0.0018*** (0.0002)	-0.0182	0.0198	0.0327
29	0.0003 (0.0006)	0.0051*** (0.0010)	0.0026*** (0.0004)	0.0012	0.0166	0.0192
30	-0.0012*** (0.0004)	0.0081*** (0.0004)	0.0043*** (0.0003)	-0.0071	0.0260	0.0295
31	0.0007 (0.0009)	0.0138*** (0.0013)	0.0107*** (0.0015)	0.0018	0.0204	0.0165
32	-0.0001 (0.0003)	0.0017*** (0.0003)	0.0010*** (0.0003)	-0.0009	0.0106	0.0080
33	0.0069*** (0.0003)	0.0005 (0.0007)	-0.0024*** (0.0003)	0.0145	0.0009	-0.0125

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Industry	Regression coefficients			Parameters		
	ξ_2^{GK}	ξ_2^{GL}	ξ_2^{GLK}	ζ_K	ζ_L	$\zeta_L - \zeta_K$
34	-0.0017* (0.0009)	0.0240*** (0.0020)	0.0328*** (0.0017)	-0.0058	0.0411	0.0402
35	0.0015*** (0.0003)	-0.0003 (0.0005)	-0.0023*** (0.0002)	0.0190	-0.0007	-0.0169
36	0.0023*** (0.0003)	0.0005** (0.0002)	0.0003 (0.0003)	0.0182	0.0842	0.0017
37	-0.0033*** (0.0002)	0.0025* (0.0013)	0.0169*** (0.0007)	-0.0196	-0.2316	0.0413
38	0.0002 (0.0003)	0.0045*** (0.0010)	0.0055*** (0.0003)	0.0018	0.0191	0.0263
39	-0.0037*** (0.0003)	0.0067*** (0.0004)	0.0134*** (0.0004)	-0.0118	0.0442	0.0536
40	-0.0024*** (0.0003)	-0.0026*** (0.0004)	0.0077*** (0.0012)	-0.0930	0.0369	0.0827
41	-0.0026*** (0.0006)	0.0005 (0.0005)	0.0092*** (0.0014)	-0.0330	0.0089	0.0512
42	-0.0104*** (0.0033)	0.0009 (0.0008)	0.0258*** (0.0039)	-0.0486	0.0148	0.0873
43	-0.0085*** (0.0004)	0.0043*** (0.0010)	0.0116*** (0.0004)	-0.0529	0.0206	0.0692
44	0.0042*** (0.0016)	0.0029*** (0.0006)	0.0022*** (0.0005)	0.0202	0.0446	0.0343
45	0.0000** (0.0000)	0.0000 (0.0003)	-0.0002 (0.0003)	0.0156	0.0000	-0.0034
46	-0.0001 (0.0001)	0.0001 (0.0003)	0.0014*** (0.0005)	-0.0193	0.0045	0.0346
47	-0.0007*** (0.0002)	-0.0011*** (0.0002)	0.0006** (0.0003)	-0.0221	-0.0450	0.0175
48	-0.0088*** (0.0011)	0.0000 (0.0003)	0.0048*** (0.0006)	-0.0457	0.0007	0.0532
49	-0.0006 (0.0006)	0.0021** (0.0009)	0.0059*** (0.0014)	-0.0043	0.0071	0.0287
50	-0.0021*** (0.0003)	-0.0007* (0.0004)	0.0069*** (0.0004)	-0.0420	-0.0062	0.0510
51	-0.0016*** (0.0003)	-0.0001 (0.0002)	0.0016*** (0.0003)	-0.0936	-0.0079	0.0916
52	0.0003 (0.0002)	-0.0004 (0.0004)	0.0003 (0.0002)	0.0088	-0.0064	0.0114
53	-0.0094*** (0.0010)	0.0009 (0.0008)	0.0201*** (0.0007)	-0.0207	0.0027	0.0327
54	0.0003* (0.0002)	0.0009*** (0.0002)	0.0039*** (0.0003)	0.0361	0.0070	0.0329
55	-0.0127*** (0.0007)	-0.0003 (0.0003)	0.0021*** (0.0002)	-0.0263	-0.0017	0.0272
56	-0.0065*** (0.0009)	0.0001 (0.0006)	0.0170*** (0.0012)	-0.0204	0.0037	0.0510
57	0.0035*** (0.0003)	0.0012*** (0.0003)	-0.0003 (0.0002)	0.0201	0.0155	-0.0018
58	0.0021*** (0.0004)	-0.0014*** (0.0004)	-0.0019*** (0.0006)	0.0088	-0.0033	-0.0049
59	0.0003 (0.0005)	0.0056*** (0.0006)	0.0058*** (0.0006)	0.0008	0.0122	0.0117
60	0.0001 (0.0002)	0.0009*** (0.0001)	0.0009*** (0.0002)	0.0005	0.0122	0.0036
61	-0.0038*** (0.0007)	-0.0006*** (0.0002)	0.0009 (0.0006)	-0.0080	-0.0038	0.0024
62	-0.0030*** (0.0004)	0.0066*** (0.0007)	0.0099*** (0.0011)	-0.0118	0.0210	0.0332
63	0.0003 (0.0017)	0.0029*** (0.0006)	0.0214*** (0.0008)	0.0044	0.0070	0.0329
64	-0.0015*** (0.0004)	-0.0007** (0.0003)	0.0036*** (0.0002)	-0.0109	-0.0036	0.0104
65	-0.0004*** (0.0001)	0.0013*** (0.0001)	0.0011*** (0.0001)	-0.0105	0.0055	0.0102

Notes: $\xi_2^{GK} = (1-\hat{\rho})(1-\sigma)\zeta_K$; $\xi_2^{L} = (1-\hat{\rho})(1-\sigma)\zeta_L$; $\xi_2^{LK} = (1-\hat{\rho})(1-\sigma)(\zeta_L - \zeta_K)$. Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.15.4: Estimates of industry rates of factor augmentation from OLS regressions of differenced variables – CES production function, single equation

Industry	Regression coefficients			Parameters		
	ξ_0^{DK}	ξ_0^{DL}	ξ_0^{DLK}	ζ_K	ζ_L	$\zeta_L - \zeta_K$
1	-0.0005 (0.0069)	0.0197* (0.0118)	0.0267*** (0.0050)	-0.0011	0.0357	0.027
2	-0.0027 (0.0051)	-0.0063 (0.0058)	0.0036 (0.0064)	-0.0049	-0.0177	0.0046
3	-0.0022 (0.0078)	0.0099 (0.0089)	0.0108 (0.0096)	-0.0048	0.0104	0.0105
4	-0.0101** (0.0047)	0.0158** (0.0077)	0.0266*** (0.0060)	-0.0196	0.0319	0.0319
5	-0.0053 (0.0146)	0.0164* (0.0096)	0.0245* (0.0129)	-0.0081	0.0242	0.0285
6	-0.0028 (0.0046)	0.0135** (0.0060)	0.0198*** (0.0044)	-0.0074	0.0148	0.0201
7	-0.0108* (0.0063)	0.0038 (0.0024)	0.0196*** (0.0063)	-0.0118	0.0152	0.0205
8	-0.0098* (0.0053)	0.0070 (0.0046)	0.0211*** (0.0065)	-0.0143	0.0133	0.0271
9	-0.0062 (0.0043)	0.0060 (0.0061)	0.0179*** (0.0057)	-0.0121	0.0122	0.0236
10	-0.0132 (0.0090)	0.0082 (0.0069)	0.0243*** (0.0076)	-0.0199	0.0095	0.0284
11	-0.0082* (0.0047)	0.0040 (0.0030)	0.0177*** (0.0059)	-0.0144	0.0151	0.0247
12	-0.0071 (0.0046)	0.0029 (0.0044)	0.0217*** (0.0066)	-0.0173	0.0134	0.0349
13	0.0097 (0.0107)	0.0624*** (0.0105)	0.0560*** (0.0089)	0.0094	0.063	0.0521
14	-0.0097** (0.0039)	0.0010 (0.0061)	0.0227*** (0.0073)	-0.0175	0.0036	0.0307
15	-0.0096 (0.0102)	0.0062 (0.0085)	0.0299*** (0.0088)	-0.0234	0.1192	0.039
16	-0.0076 (0.0064)	0.0033 (0.0073)	0.0234** (0.0094)	-0.0129	-0.0446	0.0271
17	-0.0110* (0.0064)	0.0055 (0.0041)	0.0244*** (0.0067)	-0.0134	0.0148	0.0266
18	-0.0129** (0.0065)	0.0186*** (0.0053)	0.0379*** (0.0057)	-0.0142	0.0294	0.04
19	-0.0020 (0.0032)	0.0026 (0.0066)	0.0188*** (0.0029)	-0.004	0.0649	0.0189
20	0.0007 (0.0059)	0.0040 (0.0045)	0.0204*** (0.0053)	0.0011	0.0183	0.0231
21	-0.0203*** (0.0051)	0.0150*** (0.0038)	0.0385*** (0.0056)	-0.024	0.0199	0.042
22	-0.0049 (0.0033)	0.0060 (0.0065)	0.0189*** (0.0040)	-0.0094	0.0096	0.0215
23	-0.0137*** (0.0047)	0.0093** (0.0037)	0.0251*** (0.0038)	-0.0142	0.0121	0.0254
24	-0.0097 (0.0124)	0.0221 (0.0190)	0.0364*** (0.0042)	-0.0245	0.0427	0.0381
25	-0.0072*** (0.0022)	0.0116* (0.0062)	0.0347*** (0.0036)	-0.0219	0.0884	0.0397
26	-0.0071 (0.0049)	0.0015 (0.0061)	0.0208*** (0.0070)	-0.0131	0.0103	0.0239
27	-0.0102*** (0.0026)	0.0062 (0.0038)	0.0366*** (0.0038)	-0.0161	0.0321	0.0422
28	-0.0142*** (0.0039)	0.0099*** (0.0032)	0.0322*** (0.0031)	-0.0155	0.0174	0.0325
29	0.0085 (0.0110)	0.0184** (0.0090)	0.0206*** (0.0071)	0.0111	0.0277	0.0213
30	-0.0043 (0.0082)	0.0194*** (0.0065)	0.0260*** (0.0063)	-0.0052	0.0242	0.0277
31	0.0106 (0.0129)	0.0173 (0.0109)	0.0071 (0.0077)	0.0118	0.0187	0.0069
32	0.0054 (0.0058)	0.0041 (0.0038)	0.0093* (0.0053)	0.0079	0.0105	0.0107
33	0.0105* (0.0055)	-0.0002 (0.0054)	-0.0103** (0.0051)	0.0106	-0.0002	-0.0101

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Industry	Regression coefficients			Parameters		
	ξ_0^{DK}	ξ_0^{DL}	ξ_0^{DLK}	ζ_K	ζ_L	$\zeta_L - \zeta_K$
34	0.0078 (0.0130)	0.0441*** (0.0160)	0.0343*** (0.0064)	0.0106	0.0476	0.0343
35	0.0152** (0.0061)	0.0003 (0.0072)	-0.0150*** (0.0047)	0.0201	0.0003	-0.0155
36	0.0131** (0.0055)	-0.0030 (0.0041)	-0.0024 (0.0051)	0.0172	-0.063	-0.0027
37	-0.0105*** (0.0033)	0.0087 (0.0093)	0.0382*** (0.0047)	-0.0178	0.0488	0.039
38	-0.0041 (0.0048)	0.0097 (0.0104)	0.0280*** (0.0046)	-0.0119	0.0157	0.0298
39	-0.0115*** (0.0039)	0.0386*** (0.0050)	0.0519*** (0.0049)	-0.0142	0.0419	0.0542
40	-0.0251*** (0.0065)	-0.0166** (0.0066)	0.0497*** (0.0126)	-0.0566	0.0598	0.0623
41	-0.0080** (0.0032)	0.0004 (0.0053)	0.0343*** (0.0053)	-0.0224	0.0018	0.0393
42	-0.0217 (0.0227)	-0.0029 (0.0121)	0.0677*** (0.0173)	-0.0321	-0.0144	0.0728
43	-0.0344*** (0.0053)	0.0116 (0.0073)	0.0580*** (0.0051)	-0.0437	0.0218	0.0593
44	0.0164 (0.0235)	0.0207* (0.0117)	0.0256*** (0.0089)	0.0233	0.0459	0.0239
45	0.0003 (0.0004)	0.0076 (0.0055)	0.0051 (0.0055)	0.0109	0.0083	0.0055
46	-0.0030** (0.0013)	0.0095* (0.0054)	0.0224*** (0.0067)	-0.0487	0.0317	0.063
47	-0.0044 (0.0036)	-0.0099** (0.0046)	0.0192*** (0.0056)	-0.0076	-0.0924	0.0226
48	-0.0249** (0.0098)	0.0019 (0.0053)	0.0315*** (0.0102)	-0.0286	0.0023	0.0346
49	-0.0118*** (0.0040)	-0.0024 (0.0064)	0.0336*** (0.0069)	-0.0155	-0.0053	0.035
50	-0.0226*** (0.0064)	-0.0052 (0.0055)	0.0439*** (0.0052)	-0.0271	-0.0105	0.0463
51	-0.0044 (0.0060)	-0.0024 (0.0033)	0.0295*** (0.0072)	-0.0064	-0.013	0.034
52	0.0132*** (0.0044)	-0.0029 (0.0056)	-0.0031 (0.0041)	0.0275	-0.0068	-0.0037
53	-0.0207*** (0.0059)	0.0123*** (0.0046)	0.0342*** (0.0049)	-0.0206	0.0132	0.0341
54	-0.0298*** (0.0039)	0.0045 (0.0040)	0.0412*** (0.0057)	-0.0313	0.0095	0.043
55	-0.0226*** (0.0036)	0.0056* (0.0032)	0.0316*** (0.0040)	-0.024	0.0069	0.0333
56	-0.0047 (0.0093)	0.0026 (0.0055)	0.0366*** (0.0069)	-0.0052	0.0128	0.0368
57	0.0126** (0.0050)	0.0156*** (0.0052)	0.0052 (0.0048)	0.0126	0.0164	0.0052
58	-0.0016 (0.0051)	-0.0005 (0.0058)	0.0040 (0.0056)	-0.0022	-0.0004	0.004
59	-0.0039 (0.0055)	0.0104** (0.0042)	0.0151*** (0.0045)	-0.0042	0.0113	0.0152
60	-0.0053 (0.0042)	0.0022 (0.0024)	0.0089** (0.0039)	-0.0061	0.0072	0.0095
61	-0.0099 (0.0069)	-0.0025 (0.0028)	0.0060 (0.0062)	-0.0101	-0.0032	0.0061
62	-0.0061* (0.0034)	0.0096 (0.0070)	0.0163 (0.0102)	-0.0073	0.0107	0.0183
63	-0.0126* (0.0067)	0.0045 (0.0080)	0.0310*** (0.0035)	-0.0236	0.0053	0.0313
64	-0.0045 (0.0047)	-0.0017 (0.0058)	0.0066 (0.0040)	-0.0066	-0.0018	0.0066
65	0.0017 (0.0019)	0.0029 (0.0020)	0.0013 (0.0033)	0.0017	0.0029	0.0013

Notes: $\xi_0^{DK} = (1-\sigma)\zeta_K$; $\xi_0^{DL} = (1-\sigma)\zeta_L$; $\xi_0^{DLK} = (1-\sigma)(\zeta_L - \zeta_K)$. Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.16: Estimates of parameters ψ, υ and technological change at the aggregate-level – VES production function, single equation

Equation			Method			
			OLS	**OLS differenced**	**2SLS**	**GIV**
VES1	Regression coefficient	ξ_1^{VK}	0.4646*** (0.0914)	0.3575*** (0.0540)	0.4818*** (0.1155)	0.3563*** (0.0578)
		ξ_2^{VK}	-0.0035** (0.0017)	0.0050** (0.0022)	-0.0052*** (0.0017)	0.0004* (0.0002)
		ξ_3^{VK}	0.1111 (0.0969)	-0.3856*** (0.0857)	0.1987* (0.1052)	-0.3180*** (0.0877)
		R^2	0.8683	0.6360	0.8700	0.7181
	Parameters	ψ	-1.1524	-1.7973	-1.0755	-1.8068
		υ	1.2075	0.3998	1.3834	0.5060
		ζ (Hicks-neut.)	-0.0066	0.0077	-0.0099	0.0046
		ζ_L (Harrod-neut.)	0.0317	0.0129	0.0259	0.0094
		ζ_K (Solow-neut.)	-0.0054	0.0193	-0.0072	0.0091
VES2	Regression coefficient	ξ_1^{VL}	0.5807*** (0.0413)	0.4558*** (0.0676)	0.5892*** (0.0473)	0.4927*** (0.0593)
		ξ_2^{VL}	0.0023** (0.0010)	0.0045** (0.0022)	0.0021* (0.0011)	0.0008** (0.0003)
		ξ_3^{VL}	0.1709** (0.0697)	0.1732** (0.0815)	0.1718** (0.0821)	0.1886** (0.0802)
		R^2	0.9961	0.5165	0.9958	0.9701
	Parameters	ψ	-0.7221	-1.1939	-0.6972	-1.0296
		υ	0.4077	0.3182	0.4183	0.3718
		ζ (Hicks-neut.)	0.0054	0.0083	0.0051	0.0064
		ζ_L (Harrod-neut.)	0.0091	0.0122	0.0088	0.0102
		ζ_K (Solow-neut.)	0.0133	0.0262	0.0122	0.0173

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.17: Estimates and implied parameters at the aggregate-level – VES production functions, normalized system

Equation		Method	
		NLSUR	**GMM**
VES_L	ψ (CES implied)	-0.6885	-0.6069
	υ	0.9263*** (0.0748)	1.2183*** (0.1437)
	ζ_K	-0.0002 (0.0008)	-0.0015*** (0.0006)
	ζ_L	0.0123*** (0.0006)	0.0136*** (0.0004)
	ξ	1.0036*** (0.0049)	1.0002*** (0.0032)
	Implied β_{12}	0.4706	0.3579
	Implied σ_0	0.6256	0.5429
VES_K	ψ (CES implied)	-0.6885	-0.6069
	υ	0.1179* (0.0689)	-0.2136* (0.1137)
	ζ_K	0.0006 (0.0011)	-0.0017*** (0.0005)
	ζ_L	0.0118*** (0.0009)	0.0137*** (0.0004)
	ξ	1.0038*** (0.0048)	1.0006*** (0.0032)
	Implied β_{12}	0.6394	0.4648
	Implied σ_0	0.6656	0.5251

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

Table 3.18: Chi-square test statistics and p-values for the Cobb-Douglas hypothesis at the aggregate level in normalized VES production function estimations

Equation		Method	
		NLSUR	**GMM**
VES_L	χ^2	43.01***	29.62***
	p-value	0.0000	0.0000
VES_K	χ^2	21.31***	32.61***
	p-value	0.0000	0.0000

Note: *, ** and *** denote rejection of the Cobb-Douglas hypothesis null ($\upsilon = \pi_0$) at, respectively, the 10%, 5% and 1% significance levels.

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Table 3.19.1: Estimates of parameters ψ and υ from OLS regressions at the industry-level – VES production function, single equation

Industry	VES$_1$				VES$_2$			
	Regression coefficients		Parameters		Regression coefficients		Parameters	
	ξ_1^{VK}	ξ_3^{VK}	ψ	υ	ξ_1^{VL}	ξ_3^{VL}	ψ	υ
1	0.3060*** (0.0535)	-0.3917*** (0.0457)	-2.2675	0.4356	0.2121*** (0.0517)	0.4820*** (0.0496)	-3.7158	0.6117
2	0.5098*** (0.0541)	-0.2394*** (0.0460)	-0.9616	0.5117	0.6265*** (0.0748)	0.1280** (0.0548)	-0.5962	0.3426
3	0.8353*** (0.0349)	-0.0456 (0.0450)	-0.1971	0.7230	0.2755*** (0.0719)	0.2458** (0.1225)	-2.6300	0.3393
4	0.5891*** (0.0483)	-0.1544 (0.1407)	-0.6976	0.6242	0.3977*** (0.0610)	-0.8898*** (0.0862)	-1.5143	-1.4774
5	0.3141*** (0.0626)	-0.5849*** (0.0576)	-2.1834	0.1472	0.4795*** (0.0529)	0.1562*** (0.0349)	-1.0857	0.3000
6	0.8338*** (0.0256)	0.0843 (0.0639)	-0.1994	1.5073	0.6471*** (0.0888)	0.0102 (0.2256)	-0.5455	0.0289
7	-0.1241** (0.0527)	-0.8423*** (0.0810)	9.0564	0.2507	0.7818*** (0.0227)	0.1365*** (0.0188)	-0.2792	0.6253
8	0.2494*** (0.0290)	-0.4067*** (0.0342)	-3.0099	0.4582	0.7744*** (0.0971)	0.1055* (0.0539)	-0.2914	0.4677
9	0.5027*** (0.0592)	-0.0668 (0.1303)	-0.9894	0.8656	0.7513*** (0.0499)	-0.3789*** (0.0392)	-0.3311	-1.5236
10	0.1708*** (0.0364)	-0.8781*** (0.1154)	-4.8537	-0.0590	0.2200*** (0.0664)	-0.4680*** (0.0617)	-3.5454	-0.6000
11	0.1763*** (0.0447)	-0.5269*** (0.0628)	-4.6711	0.3603	0.6640*** (0.0636)	0.1069** (0.0453)	-0.5060	0.3180
12	0.5902*** (0.0682)	-0.0346 (0.1503)	-0.6944	0.9156	0.7929*** (0.0432)	-0.3350*** (0.0501)	-0.2611	-1.6177
13	0.6645*** (0.0466)	-0.3229* (0.1931)	-0.5049	0.0375	0.9378*** (0.0610)	0.0112 (0.1764)	-0.0663	0.1797
14	0.5402*** (0.0435)	0.0035 (0.0955)	-0.8513	1.0076	0.8989*** (0.0830)	-0.3219*** (0.1050)	-0.1124	-3.1849
15	0.3860*** (0.0347)	-0.3697*** (0.1008)	-1.5909	0.3978	0.7635*** (0.1017)	-0.2768** (0.1069)	-0.3098	-1.1701
16	0.3327*** (0.0293)	-0.5200*** (0.0518)	-2.0054	0.2207	0.7627*** (0.1084)	-0.1342*** (0.0506)	-0.3112	-0.5654
17	0.1767*** (0.0397)	-0.8443*** (0.1124)	-4.6599	-0.0255	0.8752*** (0.0467)	-0.1113*** (0.0405)	-0.1426	-0.8917
18	0.1185*** (0.0348)	-0.7301*** (0.0726)	-7.4395	0.1718	0.5085*** (0.0709)	0.0621 (0.0573)	-0.9666	0.1263
19	0.4619*** (0.0709)	-0.3720*** (0.0927)	-1.1651	0.3088	0.5835*** (0.0516)	0.0934 (0.0599)	-0.7138	0.2242
20	0.3825*** (0.0777)	-0.3393 (0.2713)	-1.6146	0.4506	0.8322*** (0.0325)	-0.3114*** (0.0690)	-0.2016	-1.8562
21	-0.0225 (0.0437)	-1.0380*** (0.0683)	45.4024	-0.0151	0.4244*** (0.0398)	-0.0047 (0.0296)	-1.3563	-0.0082
22	0.2414*** (0.0663)	-0.3728*** (0.1088)	-3.1422	0.5085	0.4053*** (0.0509)	0.1489* (0.0763)	-1.4674	0.2503
23	0.0105 (0.0330)	-0.3977*** (0.0787)	-94.4845	0.5981	0.6018*** (0.0442)	0.3979*** (0.0412)	-0.6616	0.9993
24	0.7721*** (0.0251)	-0.0487 (0.0974)	-0.2952	0.7864	0.9502*** (0.0903)	-1.6927*** (0.2218)	-0.0524	-34.0188
25	0.4640*** (0.0499)	-0.9778*** (0.0869)	-1.1550	-0.8244	0.2204*** (0.0623)	-0.1214 (0.1312)	-3.5371	-0.1558
26	0.5678*** (0.0645)	0.0209 (0.0839)	-0.7612	1.0483	0.7637*** (0.0467)	-0.0571 (0.0544)	-0.3094	-0.2415
27	0.2380*** (0.0339)	-0.3462*** (0.0490)	-3.2016	0.5457	0.4951*** (0.0865)	0.0833 (0.0647)	-1.0198	0.1651
28	0.0964*** (0.0271)	-0.4801*** (0.0770)	-9.3696	0.4686	0.5379*** (0.0738)	0.2704*** (0.0708)	-0.8592	0.5850
29	0.4252*** (0.1014)	-0.6891*** (0.1634)	-1.3516	-0.1989	0.6646*** (0.0320)	0.0560 (0.0615)	-0.5046	0.1670
30	-0.0329 (0.0430)	-0.8616*** (0.1170)	31.3979	0.1658	0.2586*** (0.0343)	0.0163 (0.0777)	-2.8665	0.0219
31	0.3319*** (0.0615)	-0.4297*** (0.0669)	-2.0126	0.3569	0.2431*** (0.0513)	0.1948*** (0.0517)	-3.1140	0.2573
32	0.0770 (0.1169)	-0.7694*** (0.1790)	-11.9806	0.1664	0.6814*** (0.0228)	-0.0465* (0.0259)	-0.4675	-0.1458
33	0.1846*** (0.0305)	-0.3034*** (0.0608)	-4.4168	0.6279	-0.0316 (0.0260)	0.8454*** (0.0723)	32.6549	0.8195

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Industry	VES$_1$				VES$_2$			
	Regression coefficients		Parameters		Regression coefficients		Parameters	
	ξ_1^{VK}	ξ_3^{VK}	ψ	υ	ξ_1^{VL}	ξ_3^{VL}	ψ	υ
34	0.5672*** (0.0451)	-0.6170*** (0.0814)	-0.7632	-0.4254	0.3766*** (0.0844)	0.0923 (0.1254)	-1.6552	0.1481
35	0.1746*** (0.0536)	-0.0722 (0.1566)	-4.7258	0.9125	0.2516*** (0.0420)	0.5208*** (0.1457)	-2.9747	0.6959
36	0.2358*** (0.0201)	-0.0498 (0.1244)	-3.2412	0.9349	1.0914*** (0.1309)	-0.6389*** (0.1379)	0.0837	6.9915
37	0.4787*** (0.0450)	-0.2403*** (0.0503)	-1.0888	0.5390	0.8128*** (0.0933)	0.3712*** (0.0718)	-0.2303	1.9830
38	0.7796*** (0.0461)	-0.2831*** (0.0861)	-0.2828	-0.2843	0.5547*** (0.0635)	-0.0117 (0.1107)	-0.8028	-0.0263
39	0.3980*** (0.0527)	-0.4852*** (0.0619)	-1.5123	0.1939	0.2429*** (0.0720)	0.4773*** (0.0783)	-3.1167	0.6304
40	0.4566*** (0.0195)	-0.3973*** (0.0108)	-1.1902	0.2689	1.0644*** (0.1195)	0.2904*** (0.0289)	0.0605	-4.5130
41	0.6123*** (0.0400)	-0.3412*** (0.0286)	-0.6332	0.1200	0.6412*** (0.0930)	0.1925*** (0.0298)	-0.5596	0.5365
42	0.5207*** (0.0986)	-0.4043*** (0.0931)	-0.9205	0.1564	0.8562*** (0.0314)	0.0748*** (0.0222)	-0.1680	0.5202
43	0.2078*** (0.0160)	-0.7285*** (0.0295)	-3.8133	0.0805	0.0535 (0.1921)	0.0504 (0.0505)	-17.6949	0.0533
44	0.8072*** (0.1041)	-0.4939*** (0.0846)	-0.2388	-1.5623	0.6368*** (0.0235)	0.4073*** (0.0331)	-0.5704	1.1214
45	0.9013*** (0.0251)	-0.0539*** (0.0042)	-0.1095	0.4536	0.0125 (0.0322)	0.9666*** (0.0196)	-79.0064	0.9788
46	0.9537*** (0.0083)	-0.0696*** (0.0076)	-0.0486	-0.5031	1.0693*** (0.0484)	0.1647*** (0.0330)	0.0648	-2.3777
47	0.6522*** (0.0451)	-0.6093*** (0.0795)	-0.5333	-0.7518	0.8282*** (0.0369)	0.3763*** (0.0540)	-0.2074	2.1907
48	0.1386** (0.0645)	-0.7582*** (0.0818)	-6.2125	0.1198	0.4169*** (0.0388)	0.1809*** (0.0335)	-1.3988	0.3103
49	0.3030*** (0.0694)	-0.6458*** (0.0926)	-2.2998	0.0734	0.5237*** (0.0547)	0.0986*** (0.0299)	-0.9096	0.2070
50	0.3147*** (0.0807)	0.0013 (0.3054)	-2.1781	1.0019	0.4499*** (0.0149)	0.3159*** (0.0739)	-1.2226	0.5743
51	0.3314*** (0.0357)	-0.9184*** (0.0407)	-2.0178	-0.3735	0.7753*** (0.0383)	0.1951*** (0.0248)	-0.2899	0.8681
52	0.3631*** (0.0513)	-0.4412*** (0.0793)	-1.7542	0.3073	0.2425*** (0.0638)	0.0917 (0.0612)	-3.1244	0.1211
53	0.0385 (0.0711)	-1.2330*** (0.2294)	-24.9694	-0.2824	0.6680*** (0.0352)	0.0572 (0.0907)	-0.4970	0.1722
54	-0.1358*** (0.0211)	-0.5730*** (0.0487)	8.3653	0.4955	0.6306*** (0.0259)	0.1340*** (0.0252)	-0.5858	0.3629
55	-0.1229*** (0.0317)	0.0267 (0.0749)	9.1365	1.0238	0.4216*** (0.0214)	0.3954*** (0.0455)	-1.3720	0.6837
56	0.3938*** (0.0779)	-0.6771*** (0.0930)	-1.5393	-0.1170	0.9171*** (0.0204)	0.1030*** (0.0188)	-0.0904	1.2431
57	0.1187*** (0.0244)	-0.8501*** (0.0951)	-7.4224	0.0354	-0.0234 (0.0421)	0.0371 (0.1150)	43.7639	0.0362
58	0.3587*** (0.0354)	-0.6303*** (0.0570)	-1.7875	0.0171	0.2961*** (0.0777)	0.0043 (0.0618)	-2.3771	0.0061
59	0.1543*** (0.0503)	-0.6633*** (0.0674)	-5.4823	0.2158	0.4096*** (0.0557)	0.1435*** (0.0462)	-1.4411	0.2431
60	0.0661** (0.0320)	-0.4650*** (0.0654)	-14.1386	0.5021	0.7727*** (0.0531)	-0.0096 (0.0385)	-0.2942	-0.0424
61	0.0116 (0.0152)	-0.9525*** (0.0355)	-85.5688	0.0364	0.4482*** (0.0687)	-0.0024 (0.0275)	-1.2310	-0.0043
62	0.0545 (0.0372)	-0.3254*** (0.0141)	-17.3599	0.6559	0.0469*** (0.0167)	0.6493*** (0.0125)	-20.3445	0.6812
63	0.8191*** (0.0763)	-0.9697*** (0.1459)	-0.2209	-4.3600	0.4574*** (0.0474)	0.1581 (0.1644)	-1.1864	0.2913
64	0.7953*** (0.0648)	-0.3913* (0.2088)	-0.2573	-0.9122	0.3566*** (0.0498)	0.2142 (0.2764)	-1.8044	0.3330
65	-0.1138*** (0.0269)	-0.7244*** (0.0279)	9.7884	0.3496	0.1252*** (0.0167)	0.3360*** (0.0206)	-6.9862	0.3841

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.19.2: Estimates of parameters ψ and υ from 2SLS regressions at the industry-level – VES production function, single equation

Industry	VES$_1$				VES$_2$			
	Regression coefficients		Parameters		Regression coefficients		Parameters	
	ξ_1^{VK}	ξ_3^{VK}	ψ	υ	ξ_1^{VL}	ξ_3^{VL}	ψ	υ
1	-0.0790 (0.1228)	-0.4771*** (0.0658)	13.6605	0.5578	0.1642*** (0.0619)	0.5029*** (0.0513)	-5.0919	0.6016
2	0.5425*** (0.0655)	-0.2268*** (0.0522)	-0.8434	0.5043	0.6547*** (0.0879)	0.1053* (0.0600)	-0.5273	0.3050
3	0.9274*** (0.0410)	0.0458 (0.0518)	-0.0782	1.6316	0.8201*** (0.1817)	-0.2571 (0.2214)	-0.2193	-1.4292
4	0.8221*** (0.0936)	0.4978* (0.2695)	-0.2163	3.7988	0.3870*** (0.0626)	-0.9750*** (0.0920)	-1.5841	-1.5905
5	0.4638*** (0.1049)	-0.4968*** (0.0791)	-1.1560	0.0734	0.5376*** (0.0643)	0.1484*** (0.0359)	-0.8602	0.3208
6	0.8786*** (0.0322)	0.1864** (0.0739)	-0.1382	2.5346	1.4655*** (0.2480)	-1.4072** (0.5533)	0.3176	3.0230
7	-0.2248*** (0.0694)	-0.8442*** (0.0848)	5.4475	0.3108	0.7847*** (0.0241)	0.1406*** (0.0195)	-0.2744	0.6531
8	0.2999*** (0.0420)	-0.3798*** (0.0367)	-2.3344	0.4575	0.8899*** (0.1208)	0.0975 (0.0655)	-0.1237	0.8857
9	0.9878*** (0.1759)	0.9511*** (0.3625)	-0.0123	78.9873	0.7567*** (0.0520)	-0.3867*** (0.0432)	-0.3216	-1.5893
10	0.2569*** (0.0888)	-0.6237** (0.2794)	-2.8932	0.1607	0.3226** (0.1360)	-0.5810*** (0.0966)	-2.1001	-0.8577
11	0.1249** (0.0553)	-0.4965*** (0.0689)	-7.0093	0.4326	0.6271*** (0.0701)	0.1553*** (0.0528)	-0.5947	0.4164
12	0.7796*** (0.0954)	0.4496** (0.2207)	-0.2827	3.0400	0.8054*** (0.0447)	-0.4234*** (0.0585)	-0.2416	-2.1760
13	0.8838*** (0.0668)	0.3381 (0.2769)	-0.1315	3.9086	1.1755*** (0.0810)	-0.4437* (0.2310)	0.1493	2.5288
14	0.6226*** (0.0561)	0.2186* (0.1302)	-0.6060	1.5793	0.9755*** (0.0975)	-0.5202*** (0.1360)	-0.0251	-21.2571
15	0.3697*** (0.0431)	-0.1900 (0.1319)	-1.7052	0.6985	0.7469*** (0.1776)	-0.3047* (0.1745)	-0.3388	-1.2041
16	0.3074*** (0.0460)	-0.5314*** (0.0740)	-2.2532	0.2328	0.6874*** (0.1281)	-0.1419** (0.0587)	-0.4547	-0.4540
17	0.4496*** (0.0923)	-0.3356 (0.2059)	-1.2243	0.3902	0.9260*** (0.0488)	-0.1310*** (0.0458)	-0.0799	-1.7704
18	0.3519*** (0.1123)	-0.5825*** (0.1339)	-1.8414	0.1011	0.6360*** (0.1000)	0.0232 (0.0685)	-0.5724	0.0637
19	0.3814*** (0.1084)	-0.4122*** (0.1085)	-1.6221	0.3336	0.5503*** (0.0556)	0.1029* (0.0610)	-0.8171	0.2288
20	0.7033*** (0.1488)	0.5562 (0.5309)	-0.4219	2.8748	0.8500*** (0.0354)	-0.4113*** (0.0944)	-0.1764	-2.7426
21	-0.2126** (0.0849)	-1.2534*** (0.1105)	5.7027	-0.0336	0.4700*** (0.0453)	-0.0089 (0.0319)	-1.1279	-0.0167
22	-0.3715 (0.2366)	-0.7728*** (0.2434)	3.6920	0.4365	0.4267*** (0.0564)	0.2109** (0.0864)	-1.3438	0.3679
23	0.1328* (0.0752)	-0.5630*** (0.0212)	-6.5297	0.3508	0.7307*** (0.0567)	0.3870*** (0.0461)	-0.3686	1.4370
24	0.7969*** (0.0300)	-0.0206 (0.1047)	-0.2548	0.8984	1.2956*** (0.1394)	-2.0940*** (0.2765)	0.2282	7.0827
25	0.2496*** (0.0768)	-1.2186*** (0.1079)	-3.0069	-0.6239	0.1065 (0.0671)	-0.2604* (0.1489)	-8.3918	-0.2914
26	1.1271*** (0.2091)	0.6269*** (0.2166)	0.1128	-3.9307	0.7526*** (0.0513)	-0.0846 (0.0658)	-0.3287	-0.3419
27	0.1850*** (0.0430)	-0.3946*** (0.0575)	-4.4067	0.5159	0.4284*** (0.0932)	0.1246* (0.0691)	-1.3344	0.2180
28	0.1205*** (0.0377)	-0.4654*** (0.0776)	-7.3019	0.4708	0.6295*** (0.0921)	0.2251*** (0.0770)	-0.5886	0.6074
29	0.7304*** (0.1825)	-0.5709*** (0.2047)	-0.3691	-1.1177	0.7454*** (0.0421)	0.0559 (0.0690)	-0.3416	0.2194
30	-0.1310** (0.0614)	-0.9542*** (0.1411)	8.6338	0.1563	0.2857*** (0.0438)	0.0261 (0.0898)	-2.5007	0.0365
31	0.8901*** (0.1833)	0.0571 (0.1695)	-0.1235	1.5192	1.2781*** (0.4976)	-0.3328 (0.2768)	0.2176	1.1967
32	-0.1791 (0.1696)	-1.1584*** (0.2456)	6.5832	0.0175	0.6905*** (0.0262)	-0.0574** (0.0266)	-0.4483	-0.1854
33	0.3274*** (0.0526)	-0.3352*** (0.0785)	-2.0540	0.5016	-0.5745** (0.2790)	1.2819*** (0.2838)	2.7406	0.8142

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Industry	VES$_1$				VES$_2$			
	Regression coefficients		Parameters		Regression coefficients		Parameters	
	ξ_1^{VK}	ξ_3^{VK}	ψ	υ	ξ_1^{VL}	ξ_3^{VL}	ψ	υ
34	0.7676*** (0.0753)	-0.4489*** (0.1053)	-0.3028	-0.9317	1.6056*** (0.4760)	0.9496** (0.3975)	0.3772	-1.5679
35	0.1543** (0.0650)	-0.0089 (0.1712)	-5.4826	0.9895	0.3999*** (0.0626)	0.4140** (0.1825)	-1.5008	0.6899
36	0.2541*** (0.0233)	0.1062 (0.1473)	-2.9348	1.1424	1.2305*** (0.1424)	-0.8778*** (0.1543)	0.1873	3.8075
37	0.6869*** (0.1240)	-0.2132*** (0.0600)	-0.4558	0.3191	0.7639*** (0.0999)	0.3994*** (0.0780)	-0.3091	1.6915
38	0.8666*** (0.0685)	-0.2131** (0.1061)	-0.1540	-0.5973	0.6412*** (0.0857)	0.0428 (0.1206)	-0.5597	0.1193
39	0.6407*** (0.0850)	-0.5241*** (0.0730)	-0.5608	-0.4585	0.6841*** (0.1918)	0.6603*** (0.1245)	-0.4617	2.0905
40	0.4231*** (0.0237)	-0.4059*** (0.0113)	-1.3637	0.2964	0.8953*** (0.1796)	0.3243*** (0.0389)	-0.1169	3.0989
41	0.5958*** (0.0596)	-0.3505*** (0.0385)	-0.6784	0.1327	0.5791*** (0.1220)	0.2083*** (0.0333)	-0.7268	0.4949
42	1.4823*** (0.3191)	0.3129 (0.2478)	0.3254	0.3513	0.8992*** (0.0304)	0.0483** (0.0194)	-0.1120	0.4796
43	0.2095*** (0.0219)	-0.7346*** (0.0333)	-3.7741	0.0707	-0.1755 (0.2438)	0.0643 (0.0520)	6.6973	0.0547
44	1.1876*** (0.1551)	-0.4217*** (0.0938)	0.1579	3.2482	0.6568*** (0.0273)	0.4074*** (0.0331)	-0.5226	1.1869
45	0.8921*** (0.0287)	-0.0545*** (0.0044)	-0.1210	0.4952	0.0137 (0.0329)	0.9777*** (0.0200)	-72.0850	0.9912
46	0.9594*** (0.0083)	-0.0657*** (0.0076)	-0.0423	-0.6208	1.0782*** (0.0472)	0.1583*** (0.0326)	0.0725	-2.0259
47	0.6707*** (0.0492)	-0.6298*** (0.0828)	-0.4911	-0.9122	0.8345*** (0.0398)	0.3992*** (0.0579)	-0.1983	2.4122
48	0.2529*** (0.0898)	-0.6437*** (0.0988)	-2.9536	0.1383	0.4431*** (0.0407)	0.1941*** (0.0337)	-1.2569	0.3486
49	0.1059 (0.1348)	-0.9361*** (0.1784)	-8.4435	-0.0470	0.5301*** (0.0398)	0.0540** (0.0216)	-0.8865	0.1149
50	0.4229*** (0.1028)	0.4633 (0.3676)	-1.3647	1.8027	0.4462*** (0.0150)	0.3810*** (0.0832)	-1.2413	0.6879
51	0.3282*** (0.0371)	-0.9148*** (0.0396)	-2.0465	-0.3619	0.7592*** (0.0393)	0.1996*** (0.0244)	-0.3172	0.8287
52	0.3294*** (0.0525)	-0.4561*** (0.0778)	-2.0357	0.3199	0.1899*** (0.0634)	0.1292** (0.0594)	-4.2671	0.1595
53	8.3489 (17.4440)	-0.4128 (3.9991)	0.8802	1.0562	0.7825*** (0.0418)	0.0931 (0.1031)	-0.2779	0.4279
54	-0.2431*** (0.0316)	-0.7335*** (0.0653)	5.1130	0.4100	0.6548*** (0.0263)	0.1170*** (0.0257)	-0.5273	0.3389
55	-0.2748*** (0.0480)	0.0701 (0.0901)	4.6387	1.0550	0.4346*** (0.0221)	0.3917*** (0.0479)	-1.3011	0.6927
56	0.7619*** (0.1223)	-0.4893*** (0.1107)	-0.3125	-1.0547	0.9578*** (0.0195)	0.0725*** (0.0174)	-0.0440	1.7175
57	0.1484*** (0.0292)	-0.8483*** (0.1108)	-5.7380	0.0039	-0.0323 (0.0487)	-0.0321 (0.1317)	31.9321	-0.0311
58	0.4866*** (0.0530)	-0.4879*** (0.0760)	-1.0550	0.0496	0.6846*** (0.1329)	-0.0109 (0.0724)	-0.4606	-0.0346
59	0.4457*** (0.1237)	-0.4280*** (0.1156)	-1.2435	0.2278	0.7648*** (0.1034)	0.0563 (0.0631)	-0.3076	0.2395
60	0.0410 (0.0445)	-0.4221*** (0.0785)	-23.3921	0.5598	0.7664*** (0.0649)	0.0048 (0.0505)	-0.3048	0.0204
61	0.0397 (0.0400)	-0.9355*** (0.0468)	-24.1804	0.0259	0.5518*** (0.0826)	-0.0117 (0.0296)	-0.8121	-0.0262
62	0.1121** (0.0540)	-0.3259*** (0.0191)	-7.9202	0.6329	0.0873*** (0.0276)	0.6254*** (0.0169)	-10.4612	0.6852
63	1.3231*** (0.1660)	-0.6066** (0.2491)	0.2442	2.8771	0.6533*** (0.0749)	0.5771** (0.2437)	-0.5306	1.6647
64	0.9219*** (0.0752)	-0.3098 (0.3196)	-0.0847	-2.9689	0.4703*** (0.0611)	0.0710 (0.4217)	-1.1264	0.1341
65	-0.2214*** (0.0411)	-0.7948*** (0.0354)	5.5163	0.3493	0.2120*** (0.0272)	0.3362*** (0.0276)	-3.7179	0.4266

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.19.3: Estimates of AR(1) coefficients, GIV method (second-stage) – VES production function, single equation

Industry	VES_1	VES_2
AG	0.8498***	0.7555***
	(0.0622)	(0.0814)
1	0.2717***	0.2455***
	(0.1204)	(0.1200)
2	0.8224***	0.8179***
	(0.0700)	(0.0716)
3	0.2781**	0.4854***
	(0.1182)	(0.1076)
4	0.6275***	0.6350***
	(0.0995)	(0.0940)
5	0.7032***	0.6369***
	(0.0861)	(0.0911)
6	0.0911	-0.0240
	(0.1213)	(0.1220)
7	0.8427***	0.7576***
	(0.0595)	(0.0810)
8	0.7670***	0.6402***
	(0.0818)	(0.0954)
9	0.4356***	0.3637***
	(0.1112)	(0.1127)
10	0.5118***	0.5327***
	(0.1073)	(0.1052)
11	0.8581***	0.7694***
	(0.0632)	(0.0803)
12	0.7941***	0.6609***
	(0.0770)	(0.0919)
13	-0.1445	-0.1348
	(0.1216)	(0.1214)
14	0.7746***	0.7038***
	(0.0728)	(0.0877)
15	0.4987***	0.8148***
	(0.1070)	(0.0695)
16	0.8420***	0.6135***
	(0.0610)	(0.0975)
17	0.5156***	0.4704***
	(0.0856)	(0.1004)
18	0.4191***	0.6083***
	(0.1120)	(0.0987)
19	0.9077***	0.5675***
	(0.0446)	(0.1044)
20	0.7082***	0.4950***
	(0.0802)	(0.1038)
21	0.6727***	0.6476***
	(0.0910)	(0.1110)
22	0.3733***	0.3051**
	(0.1148)	(0.1160)
23	0.7593***	0.1714
	(0.0793)	(0.1221)
24	0.0109	0.4500***
	(0.1226)	(0.1097)
25	0.5710***	0.5266***
	(0.0985)	(0.0966)
26	0.3668***	0.3486***
	(0.1130)	(0.1137)
27	0.7917***	0.7183***
	(0.0732)	(0.0785)
28	0.7983***	0.7556***
	(0.0699)	(0.0792)
29	0.7264***	0.2347***
	(0.0813)	(0.1200)
30	0.6550***	0.5969***
	(0.0959)	(0.1015)
31	-0.0061	-0.0441
	(0.1224)	(0.1228)
32	0.8106***	0.5054***
	(0.0581)	(0.1079)
33	0.3062**	0.1058
	(0.1198)	(0.1246)

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Industry	VES_1	VES_2
34	0.0542 (0.1234)	0.0943 (0.1231)
35	0.9003*** (0.0609)	0.5912*** (0.0991)
36	0.8224*** (0.0702)	0.7939*** (0.0587)
37	0.6599*** (0.0956)	0.4364*** (0.1109)
38	0.7179*** (0.0897)	0.5868*** (0.1001)
39	0.4410*** (0.1057)	0.5045*** (0.1083)
40	0.6754*** (0.0909)	0.8357*** (0.0683)
41	0.7440*** (0.0829)	0.6419*** (0.0940)
42	0.3494*** (0.1071)	0.3770*** (0.0883)
43	0.5716*** (0.1009)	0.6684*** (0.0919)
44	0.5304*** (0.1044)	0.5972*** (0.0984)
45	0.9290*** (0.0447)	0.8760*** (0.0690)
46	0.8398*** (0.0629)	0.8458*** (0.0615)
47	0.9544*** (0.0607)	0.8758*** (0.0701)
48	0.9136*** (0.0482)	0.9182*** (0.0577)
49	0.7394*** (0.0691)	0.3843*** (0.0684)
50	0.9038*** (0.0501)	0.6868*** (0.0931)
51	0.8956*** (0.0541)	0.8793*** (0.0555)
52	0.8937*** (0.0518)	0.8621*** (0.0520)
53	0.0266 (0.1233)	-0.0675 (0.1228)
54	0.4284*** (0.1119)	0.4125*** (0.1120)
55	0.5196*** (0.1040)	0.4419*** (0.1101)
56	0.6006*** (0.0935)	0.3150*** (0.0959)
57	0.8509*** (0.0688)	0.9156*** (0.0552)
58	0.6469*** (0.0928)	0.5160*** (0.1024)
59	0.5916*** (0.0987)	0.3138*** (0.1168)
60	0.7468*** (0.0593)	0.6955*** (0.0889)
61	0.8541*** (0.0647)	0.8054*** (0.0760)
62	0.7948*** (0.0701)	0.7069*** (0.0822)
63	0.2405** (0.1197)	0.2300* (0.1198)
64	0.7753*** (0.0891)	0.7879*** (0.0837)
65	0.6057*** (0.0971)	0.3733*** (0.1143)

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.19.4: Estimates of parameters ψ and υ from GIV regressions at the industry-level – VES production function, single equation

Industry	VES$_1$				VES$_2$			
	Regression coefficients		Parameters		Regression coefficients		Parameters	
	ξ_1^{VK}	ξ_3^{VK}	ψ	υ	ξ_1^{VL}	ξ_3^{VL}	ψ	υ
1	0.3968*** (0.0535)	-0.3800*** (0.0550)	-1.5200	0.3699	0.2557*** (0.0611)	0.4960*** (0.0648)	-2.9106	0.6664
2	0.4523*** (0.0498)	-0.1404* (0.0788)	-1.2111	0.7436	0.5654*** (0.0789)	0.1913* (0.1027)	-0.7686	0.4402
3	0.7909*** (0.0428)	-0.1045* (0.0557)	-0.2643	0.5002	0.1449*** (0.0506)	0.3181*** (0.1144)	-5.9014	0.3720
4	0.4736*** (0.0353)	-0.3516*** (0.0997)	-1.1117	0.3322	0.4015*** (0.0899)	-0.4969*** (0.1296)	-1.4904	-0.8303
5	0.1720*** (0.0481)	-0.7844*** (0.0834)	-4.8137	0.0527	0.3532*** (0.0577)	0.0440 (0.0556)	-1.8315	0.0681
6	0.8332*** (0.0310)	0.0705 (0.0689)	-0.2002	1.4225	0.6157*** (0.0836)	0.0787 (0.2101)	-0.6243	0.2047
7	0.0398** (0.0174)	-0.9714*** (0.0610)	-24.1234	-0.0116	0.7184*** (0.0598)	0.0759** (0.0372)	-0.3919	0.2697
8	0.2052*** (0.0259)	-0.4463*** (0.0638)	-3.8740	0.4386	0.6399*** (0.1109)	0.0415 (0.0752)	-0.5627	0.1153
9	0.3868*** (0.0433)	-0.3447*** (0.1001)	-1.5855	0.4379	0.7073*** (0.0682)	-0.3478*** (0.0509)	-0.4139	-1.1880
10	0.1428*** (0.0340)	-0.9464*** (0.1100)	-6.0014	-0.1041	0.1930*** (0.0619)	-0.3944*** (0.0726)	-4.1807	-0.4887
11	0.2494*** (0.0289)	-0.6324*** (0.0542)	-3.0092	0.1574	0.7681*** (0.0943)	0.0019 (0.0514)	-0.3020	0.0083
12	0.3913*** (0.0405)	-0.5014*** (0.0733)	-1.5559	0.1763	0.7558*** (0.0700)	-0.1544*** (0.0572)	-0.3231	-0.6322
13	0.6932*** (0.0439)	-0.2077 (0.1778)	-0.4426	0.3231	0.9798*** (0.0589)	-0.0689 (0.1633)	-0.0206	-3.4062
14	0.3969*** (0.0276)	-0.2391*** (0.0521)	-1.5194	0.6035	0.6935*** (0.1360)	0.0048 (0.1183)	-0.4419	0.0155
15	0.4062*** (0.0408)	-0.5560*** (0.1247)	-1.4619	0.0638	0.8493*** (0.0760)	-0.3299*** (0.0911)	-0.1774	-2.1893
16	0.3443*** (0.0179)	-0.5521*** (0.0429)	-1.9042	0.1580	0.8286*** (0.1475)	-0.0420 (0.0777)	-0.2069	-0.2450
17	0.1620*** (0.0227)	-0.7215*** (0.0813)	-5.1726	0.1390	0.9349*** (0.0747)	-0.1320** (0.0529)	-0.0697	-2.0266
18	0.0826*** (0.0297)	-0.6906*** (0.0976)	-11.1128	0.2472	0.4000*** (0.0748)	0.0958 (0.0977)	-1.5002	0.1597
19	0.4935*** (0.0251)	-0.2841** (0.1093)	-1.0264	0.4391	0.6962*** (0.0948)	0.0944 (0.1125)	-0.4364	0.3107
20	0.2786*** (0.0394)	-0.7016*** (0.1347)	-2.5896	0.0274	0.8612*** (0.0487)	-0.1627** (0.0796)	-0.1612	-1.1717
21	0.0621** (0.0271)	-0.7766*** (0.0769)	-15.1044	0.1719	0.2879*** (0.0532)	0.0493 (0.0591)	-2.4734	0.0692
22	0.3656*** (0.0508)	-0.2652** (0.1039)	-1.7352	0.5820	0.4408*** (0.0692)	0.0795 (0.0992)	-1.2687	0.1422
23	0.0240* (0.0130)	-0.5533*** (0.1052)	-40.5906	0.4331	0.5591*** (0.0493)	0.4064*** (0.0473)	-0.7887	0.9216
24	0.7735*** (0.0258)	-0.0527 (0.0990)	-0.2929	0.7672	0.7400*** (0.0946)	-1.3314*** (0.2966)	-0.3513	-5.1213
25	0.5725*** (0.0440)	-0.6055*** (0.0961)	-0.7468	-0.4163	0.3323*** (0.0763)	0.2372 (0.1579)	-2.0095	0.3552
26	0.4762*** (0.0535)	-0.1271 (0.0866)	-1.0998	0.7574	0.7502*** (0.0604)	-0.0400*** (0.0711)	-0.3330	-0.1603
27	0.3074*** (0.0309)	-0.3135*** (0.0612)	-2.2534	0.5474	0.6492*** (0.1015)	0.0370 (0.0846)	-0.5402	0.1055
28	0.0853*** (0.0219)	-0.6307*** (0.1119)	-10.7240	0.3105	0.4589*** (0.0783)	0.2272** (0.0984)	-1.1793	0.4199
29	0.1780*** (0.0497)	-0.8921*** (0.1476)	-4.6189	-0.0853	0.5981*** (0.0414)	0.0293 (0.0739)	-0.6720	0.0728
30	0.0667 (0.0406)	-0.7116*** (0.1341)	-13.9965	0.2375	0.2214*** (0.0422)	0.0531 (0.1037)	-3.5167	0.0682
31	0.3371*** (0.0621)	-0.4257*** (0.0673)	-1.9664	0.3579	0.2550*** (0.0527)	0.1890*** (0.0517)	-2.9219	0.2537
32	0.2271*** (0.0471)	-0.6887*** (0.1044)	-3.4032	0.1090	0.6611*** (0.0413)	-0.0343 (0.0416)	-0.5126	-0.1012
33	0.1258*** (0.0305)	-0.2761*** (0.0719)	-6.9510	0.6842	-0.0176 (0.0240)	0.8515*** (0.0725)	57.9801	0.8368

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Industry	VES_1				VES_2			
	Regression coefficients		Parameters		Regression coefficients		Parameters	
	ξ_1^{VK}	ξ_3^{VK}	ψ	υ	ξ_1^{VL}	ξ_3^{VL}	ψ	υ
34	0.5320*** (0.0472)	-0.6152*** (0.0837)	-0.8798	-0.3145	0.3153*** (0.0773)	0.1521 (0.1249)	-2.1719	0.2222
35	0.2143*** (0.0405)	-0.3506** (0.1606)	-3.6655	0.5537	0.1309*** (0.0399)	0.5317*** (0.1727)	-6.6404	0.6118
36	0.1874*** (0.0246)	-0.4560*** (0.1180)	-4.3369	0.4388	0.9416*** (0.0807)	-0.1732** (0.0786)	-0.0620	-2.9679
37	0.4135*** (0.0239)	-0.3535*** (0.0590)	-1.4184	0.3973	0.8047*** (0.1325)	0.3610*** (0.1022)	-0.2428	1.8483
38	0.6667*** (0.0389)	-0.1338 (0.1115)	-0.4999	0.5985	0.4234*** (0.0752)	0.1228 (0.1833)	-1.3618	0.2130
39	0.2748*** (0.0456)	-0.4777*** (0.0693)	-2.6397	0.3413	0.0894* (0.0533)	0.4661*** (0.0853)	-10.1795	0.5119
40	0.5094*** (0.0201)	-0.3866*** (0.0193)	-0.9631	0.2119	1.2429*** (0.0774)	0.1923*** (0.0507)	0.1954	-0.7915
41	0.6194*** (0.0355)	-0.3430*** (0.0452)	-0.6145	0.0989	0.6866*** (0.1012)	0.2450*** (0.0609)	-0.4564	0.7818
42	0.4384*** (0.0800)	-0.4358*** (0.0917)	-1.2809	0.2240	0.8825*** (0.0339)	0.0381 (0.0266)	-0.1331	0.3242
43	0.2040*** (0.0182)	-0.7360*** (0.0456)	-3.9018	0.0753	0.3313 (0.2144)	0.0242 (0.0865)	-2.0186	0.0362
44	0.5304*** (0.1028)	-0.5928*** (0.1232)	-0.8855	-0.2623	0.6072*** (0.0316)	0.4289*** (0.0605)	-0.6468	1.0919
45	0.9508*** (0.0167)	-0.0531*** (0.0058)	-0.0518	-0.0791	0.0712 (0.0517)	0.9401*** (0.0397)	-13.0361	1.0123
46	0.9077*** (0.0173)	-0.0874*** (0.0176)	-0.1017	0.0532	0.7454*** (0.0933)	0.1536** (0.0653)	-0.3415	0.6034
47	0.3689*** (0.0303)	-0.3860*** (0.0669)	-1.7108	0.3885	0.7174*** (0.0939)	0.2126** (0.0908)	-0.3939	0.7525
48	0.0331* (0.0198)	-0.7809*** (0.0675)	-29.1753	0.1923	0.1445*** (0.0524)	0.1182* (0.0624)	-5.9197	0.1382
49	0.2895*** (0.0419)	-0.5926*** (0.0703)	-2.4544	0.1659	0.5550*** (0.0465)	0.0745*** (0.0275)	-0.8018	0.1674
50	0.1298*** (0.0332)	-0.5372*** (0.1485)	-6.7013	0.3826	0.4523*** (0.0326)	0.1382 (0.1090)	-1.2112	0.2523
51	0.1868*** (0.0308)	-0.6559*** (0.0600)	-4.3524	0.1935	0.7040*** (0.0676)	0.1882*** (0.0445)	-0.4204	0.6357
52	0.4310*** (0.0487)	-0.2806** (0.1154)	-1.3204	0.5068	0.4594*** (0.0862)	0.0631 (0.1239)	-1.1766	0.1167
53	0.0375 (0.0682)	-1.2730*** (0.2268)	-25.6459	-0.3227	0.6757*** (0.0343)	0.0534 (0.0869)	-0.4800	0.1646
54	-0.0658*** (0.0209)	-0.4743*** (0.0571)	16.1877	0.5550	0.6044*** (0.0382)	0.1577*** (0.0374)	-0.6546	0.3987
55	-0.0242 (0.0261)	-0.0953 (0.0924)	42.3486	0.9069	0.3847*** (0.0306)	0.3985*** (0.0653)	-1.5994	0.6477
56	0.1822*** (0.0476)	-0.5209*** (0.1068)	-4.4890	0.3631	0.9480*** (0.0255)	0.0671*** (0.0241)	-0.0548	1.2916
57	0.0269 (0.0207)	-0.4911*** (0.1336)	-36.2367	0.4953	0.0427 (0.0294)	0.5784*** (0.1266)	-22.3972	0.6043
58	0.2558*** (0.0298)	-0.7058*** (0.0691)	-2.9093	0.0516	0.1065 (0.0656)	0.0089 (0.0800)	-8.3932	0.0100
59	0.0702** (0.0307)	-0.7134*** (0.0747)	-13.2367	0.2327	0.2890*** (0.0540)	0.1733*** (0.0549)	-2.4604	0.2437
60	0.0727*** (0.0200)	-0.3064*** (0.1000)	-12.7605	0.6696	0.6870*** (0.0773)	0.1045 (0.0836)	-0.4557	0.3340
61	0.0030 (0.0067)	-1.0068*** (0.0632)	-332.3556	-0.0099	0.2476*** (0.0620)	-0.0432 (0.0528)	-3.0385	-0.0574
62	0.0299 (0.0258)	-0.3285*** (0.0158)	-32.4320	0.6614	0.0202* (0.0118)	0.6564*** (0.0156)	-48.5059	0.6699
63	0.7273*** (0.0770)	-1.0260*** (0.1680)	-0.3749	-2.7623	0.4043*** (0.0503)	0.0487 (0.1901)	-1.4732	0.0817
64	0.3942*** (0.0658)	-0.1475 (0.1879)	-1.5366	0.7565	0.1069*** (0.0363)	0.7462*** (0.2143)	-8.3523	0.8356
65	-0.0283 (0.0221)	-0.6696*** (0.0420)	36.3396	0.3488	0.0828*** (0.0169)	0.3282*** (0.0299)	-11.0719	0.3578

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.19.5: Estimates of parameters ψ and υ from OLS regressions of differenced variables at the industry-level – VES production function, single equation

Industry	VES$_1$				VES$_2$			
	Regression coefficients		Parameters		Regression coefficients		Parameters	
	ξ_1^{VK}	ξ_3^{VK}	ψ	υ	ξ_1^{VL}	ξ_3^{VL}	ψ	υ
1	0.5620*** (0.0411)	-0.4162** (0.1667)	-0.7793	0.0498	0.4422*** (0.0960)	0.4520 (0.2860)	-1.2616	0.8102
2	0.4397*** (0.0487)	-0.0992 (0.0859)	-1.2744	0.8230	0.5475*** (0.0788)	0.2443** (0.1163)	-0.8265	0.5399
3	0.4557*** (0.0638)	-0.4914*** (0.0825)	-1.1943	0.0972	0.0798*** (0.0290)	0.4482*** (0.1050)	-11.5348	0.4870
4	0.4304*** (0.0291)	-0.3500*** (0.0825)	-1.3233	0.3856	0.5458*** (0.1239)	-0.1327 (0.1442)	-0.8323	-0.2921
5	0.1630*** (0.0461)	-0.8251*** (0.1081)	-5.1361	0.0143	0.3309*** (0.0585)	-0.1039 (0.0824)	-2.0218	-0.1553
6	0.5208*** (0.0558)	-0.5528*** (0.1243)	-0.9200	-0.1536	0.0873** (0.0417)	0.0130 (0.1697)	-10.4503	0.0143
7	0.0460** (0.0180)	-0.8317*** (0.0694)	-20.7624	0.1282	0.7318*** (0.0743)	0.0517 (0.0462)	-0.3666	0.1928
8	0.1912*** (0.0265)	-0.5070*** (0.0733)	-4.2294	0.3732	0.5793*** (0.1014)	-0.1295* (0.0760)	-0.7264	-0.3079
9	0.3265*** (0.0175)	-0.6576*** (0.0483)	-2.0630	0.0236	0.4789** (0.1958)	-0.2664*** (0.0855)	-1.0879	-0.5112
10	0.1308*** (0.0326)	-0.9638*** (0.1079)	-6.6459	-0.1088	0.1861*** (0.0591)	-0.3203*** (0.0827)	-4.3747	-0.3935
11	0.2448*** (0.0275)	-0.6607*** (0.0534)	-3.0846	0.1252	0.7540*** (0.1046)	-0.0279 (0.0517)	-0.3262	-0.1135
12	0.3789*** (0.0313)	-0.5555*** (0.0546)	-1.6389	0.1056	0.7997*** (0.1150)	-0.0572 (0.0569)	-0.2505	-0.2857
13	0.0383 (0.0270)	-0.6361*** (0.1225)	-25.1121	0.3386	0.1212*** (0.0371)	0.6588*** (0.1167)	-7.2532	0.7496
14	0.3956*** (0.0266)	-0.2542*** (0.0501)	-1.5275	0.5794	0.6544*** (0.1395)	0.0908 (0.1155)	-0.5282	0.2626
15	0.4360*** (0.0425)	-0.6830*** (0.1304)	-1.2938	-0.2109	0.8733*** (0.0734)	-0.2997*** (0.0888)	-0.1450	-2.3658
16	0.3505*** (0.0172)	-0.5768*** (0.0426)	-1.8531	0.1120	1.0463*** (0.1613)	0.0719 (0.0894)	0.0442	-1.5542
17	0.1123*** (0.0138)	-0.8352*** (0.0581)	-7.9068	0.0591	0.6477*** (0.1301)	-0.0619 (0.0673)	-0.5438	-0.1757
18	0.0555** (0.0231)	-0.5992*** (0.1178)	-17.0203	0.3656	0.3337*** (0.0745)	0.1557 (0.1085)	-1.9968	0.2337
19	0.4969*** (0.0263)	-0.3734*** (0.1296)	-1.0124	0.2579	0.9179*** (0.1491)	0.4127 (0.2674)	-0.0894	5.0263
20	0.2436*** (0.0322)	-0.6896*** (0.1097)	-3.1053	0.0884	0.7878*** (0.0794)	-0.0971 (0.0866)	-0.2694	-0.4574
21	0.0898*** (0.0219)	-0.6610*** (0.0787)	-10.1368	0.2738	0.2098*** (0.0666)	0.1363* (0.0817)	-3.7653	0.1725
22	0.4252*** (0.0253)	-0.4372*** (0.0895)	-1.3517	0.2394	0.4179*** (0.1486)	-0.2251 (0.1789)	-1.3927	-0.3867
23	0.0219* (0.0114)	-0.6907*** (0.1248)	-44.5915	0.2938	0.2148*** (0.0593)	0.1949 (0.1179)	-3.6559	0.2482
24	0.6213*** (0.0491)	0.3450 (0.3517)	-0.6096	1.9109	0.5201*** (0.0909)	-0.8158 (0.5294)	-0.9226	-1.7001
25	0.6597*** (0.0243)	-0.1487** (0.0727)	-0.5160	0.5632	0.8568*** (0.1333)	0.0643 (0.2044)	-0.1672	0.4490
26	0.3963*** (0.0227)	-0.5639*** (0.0534)	-1.5235	0.0660	0.8336*** (0.1452)	0.1121 (0.1012)	-0.1996	0.6739
27	0.3279*** (0.0286)	-0.4038*** (0.0746)	-2.0497	0.3992	0.7724*** (0.1108)	0.0753 (0.1059)	-0.2946	0.3308
28	0.0799*** (0.0208)	-0.7211*** (0.1299)	-11.5149	0.2163	0.4203*** (0.0772)	0.2134* (0.1193)	-1.3793	0.3681
29	0.1940*** (0.0475)	-0.7381*** (0.1721)	-4.1550	0.0842	0.3351*** (0.0566)	0.0374 (0.1528)	-1.9846	0.0562
30	0.0913** (0.0385)	-0.7010*** (0.1427)	-9.9529	0.2286	0.1970*** (0.0447)	0.0404 (0.1216)	-4.0758	0.0503
31	0.1275*** (0.0428)	-0.9286*** (0.1673)	-6.8401	-0.0644	0.0920*** (0.0334)	0.2796 (0.1774)	-9.8684	0.3079
32	0.2339*** (0.0483)	-0.5793*** (0.1174)	-3.2749	0.2438	0.6040*** (0.0604)	0.0521 (0.0820)	-0.6555	0.1315
33	0.0497* (0.0253)	-0.5833*** (0.1158)	-19.1091	0.3862	0.0057 (0.0129)	0.4964*** (0.1162)	-174.0700	0.4993

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Industry	VES$_1$				VES$_2$			
	Regression coefficients		Parameters		Regression coefficients		Parameters	
	ξ_1^{VK}	ξ_3^{VK}	ψ	υ	ξ_1^{VL}	ξ_3^{VL}	ψ	υ
34	0.2578*** (0.0441)	-0.3954 (0.2509)	-2.8792	0.4672	0.0758 (0.0472)	0.5662* (0.3044)	-12.1959	0.6126
35	0.2187*** (0.0396)	-0.3522** (0.1573)	-3.5715	0.5491	0.0631* (0.0350)	0.3768** (0.1827)	-14.8401	0.4022
36	0.1882*** (0.0237)	-0.4990*** (0.1135)	-4.3122	0.3853	0.9632*** (0.0811)	-0.0830 (0.0770)	-0.0382	-2.2555
37	0.4019*** (0.0157)	-0.5477*** (0.0584)	-1.4882	0.0843	0.7831*** (0.2723)	0.3134* (0.1846)	-0.2770	1.4451
38	0.6567*** (0.0363)	-0.0618 (0.1269)	-0.5228	0.8200	0.3627*** (0.0802)	0.3241 (0.2776)	-1.7573	0.5085
39	0.1652*** (0.0364)	-0.3584*** (0.0903)	-5.0517	0.5706	0.0338 (0.0402)	0.5548*** (0.1043)	-28.5681	0.5742
40	0.5263*** (0.0196)	-0.3830*** (0.0443)	-0.9002	0.1916	1.2404*** (0.0731)	0.1437** (0.0668)	0.1938	-0.5980
41	0.6189*** (0.0344)	-0.3249*** (0.0676)	-0.6158	0.1474	0.7007*** (0.1036)	0.3251** (0.1283)	-0.4272	1.0859
42	0.2897*** (0.0484)	-0.6319*** (0.1454)	-2.4518	0.1104	0.7929*** (0.0547)	0.0546 (0.0872)	-0.2611	0.2636
43	0.2004*** (0.0191)	-0.6338*** (0.1037)	-3.9897	0.2073	0.4136* (0.2173)	0.1829 (0.1701)	-1.4178	0.3119
44	0.3800*** (0.0899)	-1.3069*** (0.2727)	-1.6313	-1.1081	0.5848*** (0.0382)	0.5119*** (0.1454)	-0.7101	1.2328
45	0.9496*** (0.0166)	-0.0500*** (0.0058)	-0.0531	0.0088	0.0860 (0.0530)	0.9032*** (0.0404)	-10.6310	0.9882
46	0.8666*** (0.0191)	-0.1114*** (0.0184)	-0.1540	0.1654	0.5763*** (0.1111)	0.2214*** (0.0754)	-0.7353	0.5226
47	0.3928*** (0.0328)	-0.3289*** (0.0734)	-1.5458	0.4583	0.8197*** (0.1072)	0.1601 (0.1056)	-0.2200	0.8879
48	0.0306 (0.0188)	-0.8200*** (0.0664)	-31.7312	0.1542	0.1420*** (0.0479)	0.0927 (0.0594)	-6.0443	0.1080
49	0.2319*** (0.0364)	-0.3446*** (0.0698)	-3.3115	0.5513	0.4444*** (0.1043)	0.5896*** (0.0793)	-1.2503	1.0612
50	0.1354*** (0.0316)	-0.6265*** (0.1442)	-6.3840	0.2754	0.5004*** (0.0702)	0.0360 (0.1221)	-0.9982	0.0721
51	0.2244*** (0.0352)	-0.7030*** (0.0729)	-3.4563	0.0936	0.7994*** (0.0600)	0.1277*** (0.0468)	-0.2510	0.6367
52	0.4603*** (0.0494)	-0.3634*** (0.1300)	-1.1724	0.3266	0.5894*** (0.0853)	-0.0629 (0.1371)	-0.6967	-0.1531
53	-0.0009 (0.0092)	-0.7469*** (0.1206)	1087.3661	0.2538	0.0645** (0.0261)	0.2400** (0.1152)	-14.4923	0.2566
54	0.0367*** (0.0108)	-0.3457*** (0.0725)	-26.2526	0.6412	0.2542*** (0.0946)	0.4119*** (0.0998)	-2.9343	0.5523
55	0.0293** (0.0139)	-0.4944*** (0.0927)	-33.0865	0.4906	0.1266*** (0.0473)	0.3190*** (0.0936)	-6.9001	0.3652
56	0.0960*** (0.0326)	-0.6576*** (0.1486)	-9.4193	0.2726	0.7798*** (0.0641)	0.2346*** (0.0874)	-0.2824	1.0655
57	0.0158 (0.0195)	-0.4722*** (0.1177)	-62.4127	0.5202	0.0433 (0.0286)	0.5424*** (0.1141)	-22.0773	0.5669
58	0.2191*** (0.0252)	-0.6243*** (0.0856)	-3.5644	0.2006	-0.0071 (0.0508)	0.2444* (0.1260)	142.1233	0.2427
59	0.0481** (0.0220)	-0.8132*** (0.1151)	-19.7924	0.1457	0.0774** (0.0352)	0.1444 (0.1141)	-11.9159	0.1566
60	0.0738*** (0.0195)	-0.6693*** (0.1009)	-12.5563	0.2774	0.7022*** (0.0807)	-0.0105 (0.0753)	-0.4240	-0.0352
61	0.0035 (0.0063)	-0.9879*** (0.0600)	-283.6003	0.0086	0.2256*** (0.0612)	-0.0353 (0.0551)	-3.4328	-0.0456
62	0.0281 (0.0250)	-0.3186*** (0.0140)	-34.6297	0.6722	0.0174 (0.0109)	0.6743*** (0.0137)	-56.6342	0.6862
63	0.4437*** (0.0599)	-0.5188** (0.2284)	-1.2537	0.0675	0.1562*** (0.0532)	0.2439 (0.2888)	-5.4006	0.2891
64	0.2950*** (0.0608)	-0.2464* (0.1435)	-2.3904	0.6505	0.0775** (0.0307)	0.6814*** (0.1591)	-11.9043	0.7386
65	0.0143 (0.0145)	-0.4739*** (0.0388)	-68.7122	0.5192	0.0049 (0.0107)	0.5195*** (0.0389)	-201.7452	0.5221

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.20: Simple and value-added weighted averages of industry-level estimates in VES production function single equation estimates

Equation		Method			
		OLS	**OLS differenced**	**2SLS**	**GIV**
VES_1	ψ, SA	-3.8753	3.5533	-1.3114	-9.4160
	ψ, WA	-3.6107	-13.5959	-1.5486	-10.2576
	υ, SA	0.1918	0.2688	1.6980	0.2629
	υ, WA	0.3282	0.2923	0.9496	0.2788
	ζ, SA	0.0139	0.0096	-0.0278	0.0088
	ζ, WA	0.0072	0.0060	-0.0097	0.0048
	ζ_K, SA	-0.0059	0.0912	0.0765	0.0323
	ζ_K, WA	0.0064	0.1931	0.0073	0.0135
	ζ_L, SA	0.2361	0.0122	0.0602	0.0047
	ζ_L, WA	0.2750	0.0073	0.0457	-0.0014
VES_2	ψ, SA	-1.6901	-8.0680	-1.4260	-2.1117
	ψ, WA	-11.8143	-27.7823	-9.6399	-6.6745
	υ, SA	-0.3881	0.2457	0.1080	-0.0083
	υ, WA	0.0087	0.4633	0.3790	0.2815
	ζ, SA	0.0473	0.0071	0.0041	0.0240
	ζ, WA	0.0231	0.0035	0.0017	0.0094
	ζ_K, SA	-0.0190	0.0123	-0.0059	0.0587
	ζ_K, WA	0.0044	0.0233	0.0099	0.0617
	ζ_L, SA	-0.2313	0.0256	0.0135	0.0001
	ζ_L, WA	-0.0543	0.0475	0.0332	-0.0276

Note: SA and WA denote single average and weighted average, respectively. Technological progress estimates are based on the respective neutrality assumption.

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Table 3.21.1: Estimates of parameters ψ and υ and technological change rates at the industry-level – VES_L production function, normalized system

Industry	NLSUR					GMM				
	ψ (CES impl.)	υ	ζ_K	ζ_L	ξ	ψ (CES impl.)	υ	ζ_K	ζ_L	ξ
1	-1.7300	0.3073*** (0.0238)	0.0159*** (0.0009)	0.0247*** (0.0011)	0.9901*** (0.0107)	-3.7352	0.4222*** (0.0269)	0.0145*** (0.0014)	0.0262*** (0.0017)	0.9927*** (0.0071)
2	-0.5129	0.8090*** (0.0312)	0.0175*** (0.0032)	-0.0347*** (0.0027)	1.0523*** (0.0156)	-0.4058	0.8212*** (0.0371)	0.0235*** (0.0038)	-0.0392*** (0.0034)	1.0743*** (0.0141)
3	-0.9954	0.9554*** (0.0293)	-0.0148*** (0.0013)	0.0138*** (0.0028)	1.0187*** (0.0245)	-0.1354	1.6214*** (0.2536)	-0.0184*** (0.0015)	0.0135*** (0.0046)	1.0236*** (0.0165)
4	-1.1268	1.4629*** (0.0511)	-0.0086*** (0.0014)	0.0268*** (0.0013)	1.0106*** (0.0256)	-0.7029	2.2873*** (0.1728)	-0.0072*** (0.0008)	0.0259*** (0.0008)	1.0416*** (0.0146)
5	-0.6517	0.3925*** (0.0079)	0.1966** (0.0882)	-0.1217** (0.0592)	0.9602*** (0.0219)	-0.0209	-7.1769*** (2.2036)	0.0085* (0.0045)	0.0067** (0.0031)	1.0005*** (0.0214)
6	-0.3590	0.7174*** (0.0075)	0.0583 (0.0666)	-0.1633 (0.1636)	1.0233*** (0.0142)	-0.0050	-5.4762 (13.7824)	-0.0217 (0.0195)	0.0294 (0.0477)	1.0271*** (0.0149)
7	-5.2526	-0.1299*** (0.0356)	-0.0005 (0.0018)	0.0057*** (0.0008)	0.9792*** (0.0133)	-3.0841	-0.5160*** (0.0871)	-0.0052*** (0.0016)	0.0042*** (0.0005)	1.0466*** (0.0066)
8	-0.9974	0.2502*** (0.0082)	0.1884*** (0.0696)	-0.0491** (0.0211)	1.0336*** (0.0094)	-0.3804	0.2386*** (0.0025)	0.1025 (0.0629)	-0.0241 (0.0198)	1.0174*** (0.0093)
9	-0.9603	1.3296*** (0.0428)	-0.0126*** (0.0007)	0.0101*** (0.0006)	1.0122*** (0.0118)	-0.8755	1.2134*** (0.0955)	-0.0113*** (0.0007)	0.0092*** (0.0005)	1.0159*** (0.0072)
10	-1.8847	1.1070*** (0.0513)	-0.0199*** (0.0007)	0.0099*** (0.0008)	1.0063*** (0.0126)	-1.2911	1.5690*** (0.1575)	-0.0197*** (0.0005)	0.0090*** (0.0004)	1.0183*** (0.0077)
11	-1.4238	0.0739 (0.0476)	0.0071 (0.0044)	0.0065*** (0.0016)	0.9879*** (0.0077)	-1.0377	0.0214 (0.0837)	0.0069 (0.0073)	0.0066*** (0.0025)	1.0013*** (0.0052)
12	-0.4983	1.0988*** (0.0952)	-0.0097*** (0.0021)	0.0097*** (0.0014)	1.0126*** (0.0161)	-0.2305	0.6276*** (0.0300)	0.0768*** (0.0127)	-0.0426*** (0.0076)	1.0917*** (0.0206)
13	-0.7001	0.9950*** (0.2391)	-0.0149 (0.0113)	0.0853*** (0.0048)	1.0589*** (0.0578)	-0.2787	3.9955*** (0.9467)	0.0119*** (0.0042)	0.0844*** (0.0020)	0.9593*** (0.0348)
14	-0.8171	0.8904*** (0.0789)	-0.0095*** (0.0022)	0.0088*** (0.0020)	1.0075*** (0.0143)	-0.8175	1.4489*** (0.1514)	-0.0133*** (0.0008)	0.0167*** (0.0007)	0.9801*** (0.0076)
15	-1.1625	0.9990*** (0.1035)	-0.0214*** (0.0013)	0.0216*** (0.0014)	1.0077*** (0.0166)	-1.4518	0.9184*** (0.1174)	-0.0184*** (0.0008)	0.0193*** (0.0010)	1.0179*** (0.0109)
16	-0.8082	0.7163*** (0.0772)	-0.0232*** (0.0016)	0.0181*** (0.0013)	1.0085*** (0.0112)	-0.5512	0.9293*** (0.0881)	-0.0217*** (0.0010)	0.0149*** (0.0007)	1.0204*** (0.0091)
17	-1.5236	-0.0537 (0.1177)	0.0089 (0.0140)	0.0092*** (0.0027)	0.9934*** (0.0110)	-0.4051	-0.7594 (0.4924)	0.0114 (0.0144)	0.0099*** (0.0027)	1.0194*** (0.0076)
18	-3.1651	0.4258*** (0.0227)	-0.0288*** (0.0029)	0.0353*** (0.0010)	1.0204*** (0.0089)	-0.6871	0.7038*** (0.0963)	-0.0385*** (0.0073)	0.0389*** (0.0024)	1.0471*** (0.0110)
19	-0.5845	0.2324*** (0.0724)	0.0177*** (0.0060)	0.0007 (0.0051)	0.9826*** (0.0125)	-0.5784	0.2243*** (0.0682)	0.0150** (0.0063)	0.0020 (0.0052)	1.0116*** (0.0081)
20	-0.8335	2.0833*** (0.2335)	0.0003 (0.0009)	0.0234*** (0.0007)	1.0071*** (0.0143)	-0.2757	6.0419*** (1.1105)	0.0004 (0.0007)	0.0239*** (0.0006)	1.0241*** (0.0103)
21	-1.4138	0.1677* (0.0959)	-0.0432* (0.0257)	0.0243*** (0.0077)	1.0060*** (0.0088)	-0.3908	0.0408 (0.2489)	-0.0354*** (0.0128)	0.0217*** (0.0039)	1.0233*** (0.0058)
22	-1.5166	0.8599*** (0.0664)	-0.0113*** (0.0007)	0.0118*** (0.0005)	1.0016*** (0.0074)	-1.5607	0.4285*** (0.0009)	0.1301** (0.0534)	-0.0924** (0.0401)	1.0197*** (0.0050)
23	-11.1874	0.2153*** (0.0376)	-0.0270*** (0.0075)	0.0129*** (0.0014)	1.0021*** (0.0086)	-22.1483	0.6152*** (0.0582)	-0.0187*** (0.0008)	0.0124*** (0.0002)	1.0051*** (0.0049)
24	-0.8963	1.2015*** (0.0415)	-0.0125*** (0.0021)	0.0469*** (0.0029)	1.0159*** (0.0396)	-0.3845	1.4685*** (0.1617)	-0.0144*** (0.0026)	0.0576*** (0.0060)	1.0973*** (0.0279)
25	-1.3030	0.1733*** (0.0673)	-0.0113*** (0.0009)	0.0201*** (0.0011)	1.0035*** (0.0118)	-3.3872	0.3347*** (0.1264)	-0.0155*** (0.0008)	0.0220*** (0.0012)	1.0224*** (0.0062)
26	-0.5913	1.0333*** (0.0912)	-0.0067*** (0.0011)	0.0101*** (0.0007)	1.0139*** (0.0114)	-0.4492	1.4001*** (0.1420)	-0.0053*** (0.0008)	0.0103*** (0.0006)	1.0174*** (0.0078)
27	-1.2172	0.8044*** (0.0415)	-0.0180*** (0.0006)	0.0320*** (0.0004)	1.0062*** (0.0048)	-1.1037	0.6839*** (0.0634)	-0.0181*** (0.0008)	0.0320*** (0.0005)	0.9994*** (0.0038)
28	-5.0213	0.4451*** (0.1138)	-0.0385*** (0.0101)	0.0234*** (0.0025)	1.0109*** (0.0070)	-2.4331	0.2620*** (0.0207)	-0.0780*** (0.0162)	0.0327*** (0.0038)	1.0213*** (0.0079)
29	-0.3888	-0.3865 (0.3226)	-0.0170** (0.0076)	0.0356*** (0.0047)	0.9714*** (0.0238)	-0.0242	0.9533*** (0.1592)	0.2645*** (0.0452)	-0.1289*** (0.0255)	1.1918*** (0.0289)
30	-5.3045	0.6737*** (0.0553)	-0.0089*** (0.0011)	0.0270*** (0.0006)	1.0067*** (0.0084)	-3.8603	0.2088 (0.1462)	-0.0009 (0.0046)	0.0230*** (0.0026)	0.9953*** (0.0065)
31	-1.1583	0.6858*** (0.0555)	-0.0013 (0.0035)	0.0279*** (0.0039)	1.0070*** (0.0176)	-0.2039	1.2977*** (0.1812)	0.0018 (0.0025)	0.0242*** (0.0029)	1.0214*** (0.0159)
32	-0.8189	0.2450*** (0.0007)	0.5742*** (0.1588)	-0.1679*** (0.0515)	1.0542*** (0.0121)	-0.6337	0.2447*** (0.0002)	0.9318*** (0.2097)	-0.2826*** (0.0682)	1.0677*** (0.0101)
33	-8.4916	0.4816*** (0.0086)	0.0072*** (0.0006)	0.0098*** (0.0007)	1.0007*** (0.0083)	-4.0525	0.2623*** (0.0342)	0.0077*** (0.0005)	0.0074*** (0.0007)	0.9900*** (0.0056)

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Industry	NLSUR					GMM				
	ψ (CES impl.)	υ	ζ_K	ζ_L	ξ	ψ (CES impl.)	υ	ζ_K	ζ_L	ξ
34	-0.7512	0.2759*** (0.0987)	0.0036 (0.0022)	0.0354*** (0.0029)	1.0119*** (0.0321)	-0.0197	-17.020*** (2.7644)	0.0001 (0.0018)	0.0349*** (0.0021)	1.0370*** (0.0269)
35	-5.4892	0.7330*** (0.0338)	0.0265*** (0.0013)	-0.0037*** (0.0009)	1.0359*** (0.0115)	-0.9760	0.8348*** (0.0352)	0.0531*** (0.0027)	-0.0247*** (0.0018)	1.1349*** (0.0111)
36	-3.5913	0.8944*** (0.0742)	0.0189*** (0.0006)	0.0184*** (0.0009)	1.0137*** (0.0117)	-3.1372	1.2050*** (0.1026)	0.0177*** (0.0005)	0.0197*** (0.0005)	1.0141*** (0.0083)
37	-0.8664	0.6876*** (0.0869)	-0.0347*** (0.0056)	0.0381*** (0.0031)	1.0199*** (0.0103)	-0.6155	0.9581*** (0.1085)	-0.0304*** (0.0033)	0.0353*** (0.0017)	1.0236*** (0.0084)
38	-0.4014	0.8403*** (0.0798)	0.0077 (0.0060)	-0.0036 (0.0114)	1.0405*** (0.0212)	-0.0842	0.8243*** (0.0579)	0.0710*** (0.0229)	-0.1140*** (0.0407)	1.0572*** (0.0282)
39	-2.0099	0.4261*** (0.0484)	-0.0046** (0.0018)	0.0355*** (0.0024)	0.9899*** (0.0073)	-0.3725	-0.8420*** (0.1770)	-0.0063*** (0.0007)	0.0383*** (0.0008)	1.0013*** (0.0056)
40	0.2249	1.6355*** (0.0360)	-0.0796*** (0.0014)	0.0202*** (0.0011)	0.9605*** (0.0120)	0.4208	1.2140*** (0.0112)	-0.0811*** (0.0008)	0.0187*** (0.0005)	0.9668*** (0.0084)
41	-0.0191	1.1666*** (0.1530)	0.0570*** (0.0193)	-0.0949*** (0.0230)	1.0500*** (0.0139)	0.0871	1.7971*** (0.2325)	-0.0434*** (0.0017)	0.0224*** (0.0020)	1.0085*** (0.0092)
42	-0.2979	0.5130** (0.2156)	0.0349 (0.0589)	0.0120 (0.0113)	0.9923*** (0.0503)	-0.1018	1.3713** (0.5513)	0.0000 (0.0307)	0.0171*** (0.0057)	1.0579*** (0.0396)
43	-1.4175	0.4336*** (0.0493)	-0.0771*** (0.0098)	0.0285*** (0.0043)	1.0119*** (0.0096)	-0.6848	0.5435*** (0.0792)	-0.0801*** (0.0102)	0.0304*** (0.0044)	1.0256*** (0.0093)
44	-0.4864	0.0302 (0.0772)	0.0180*** (0.0016)	0.0399*** (0.0033)	1.0071*** (0.0306)	-0.2355	-0.4229*** (0.1263)	0.0183*** (0.0011)	0.0399*** (0.0016)	1.0823*** (0.0280)
45	-3.5809	0.9431*** (0.0001)	0.0010*** (0.0002)	0.0287*** (0.0007)	0.9972*** (0.0032)	-2.2719	0.9621*** (0.0017)	0.0029*** (0.0002)	-0.0212*** (0.0038)	0.9826*** (0.0018)
46	0.0611	1.8029*** (0.0802)	-0.0280*** (0.0017)	0.0131*** (0.0016)	1.0032*** (0.0287)	0.0218	2.4418*** (0.1778)	-0.0288*** (0.0014)	0.0157*** (0.0022)	0.9948*** (0.0310)
47	-0.2517	0.9721*** (0.0203)	0.0639*** (0.0030)	-0.0552*** (0.0022)	1.2614*** (0.0136)	-0.2831	1.0006*** (0.0246)	0.0556*** (0.0031)	-0.0479*** (0.0023)	1.2463*** (0.0209)
48	-1.2610	0.0798 (0.1172)	-0.0663*** (0.0091)	0.0116** (0.0055)	1.0319*** (0.0303)	-0.6535	-0.2032 (0.1599)	-0.0749*** (0.0083)	0.0143*** (0.0048)	0.9749*** (0.0267)
49	-0.5452	0.9530*** (0.0368)	0.0223*** (0.0026)	-0.0058*** (0.0016)	1.1142*** (0.0094)	-0.3989	0.9910*** (0.0287)	0.0315*** (0.0022)	-0.0115*** (0.0011)	1.1255*** (0.0058)
50	-1.1352	1.0103*** (0.0166)	-0.0037** (0.0016)	-0.0063*** (0.0012)	1.1709*** (0.0160)	-1.0403	0.9816*** (0.0164)	0.0003 (0.0014)	-0.0099*** (0.0009)	1.1948*** (0.0138)
51	-0.2856	0.8705*** (0.0357)	0.0893*** (0.0054)	-0.0243*** (0.0022)	1.2461*** (0.0167)	-0.3781	-1.3831*** (0.1572)	-0.0440*** (0.0021)	0.0257*** (0.0013)	1.0156*** (0.0142)
52	-1.1282	0.9759*** (0.0423)	0.0237*** (0.0018)	-0.0044** (0.0022)	1.0741*** (0.0183)	-0.9824	0.9477*** (0.0411)	0.0265*** (0.0025)	-0.0086*** (0.0024)	1.1132*** (0.0112)
53	-3.3593	-0.2845** (0.1165)	-0.0291*** (0.0027)	0.0153*** (0.0015)	0.9813*** (0.0244)	-0.0546	0.9164*** (0.1436)	0.3079*** (0.0360)	-0.0620*** (0.0077)	1.2472*** (0.0131)
54	-5.4333	0.5271*** (0.0500)	-0.0313*** (0.0016)	0.0101*** (0.0010)	1.0123*** (0.0156)	-24.7681	0.8774*** (0.0510)	-0.0278*** (0.0008)	0.0024*** (0.0005)	1.0658*** (0.0104)
55	-4.6950	0.5408*** (0.0125)	-0.0011 (0.0014)	-0.0028*** (0.0006)	1.0753*** (0.0087)	-1.5109	0.6594*** (0.0156)	0.0184*** (0.0018)	-0.0102*** (0.0007)	1.1114*** (0.0072)
56	-0.4746	0.1303*** (0.0061)	0.8838*** (0.1611)	-0.0815*** (0.0198)	1.1888*** (0.0230)	-0.0095	0.8180*** (0.1990)	1.0466*** (0.1557)	-0.1100*** (0.0201)	1.2803*** (0.0172)
57	-9.6429	0.6362*** (0.0393)	0.0246*** (0.0014)	0.0134*** (0.0008)	1.0020*** (0.0120)	-6.2156	0.4704*** (0.0108)	0.0819*** (0.0219)	-0.0350 (0.0219)	1.0306*** (0.0061)
58	-0.9064	-0.1846** (0.0881)	-0.0126*** (0.0018)	0.0071*** (0.0014)	1.0001*** (0.0109)	-0.2159	0.9362*** (0.1167)	0.0610*** (0.0113)	-0.0432*** (0.0073)	1.0964*** (0.0221)
59	-1.4023	0.2290*** (0.0868)	0.0042 (0.0052)	0.0101*** (0.0028)	1.0036*** (0.0099)	-0.2235	0.0463 (0.3708)	0.0122 (0.0150)	0.0067 (0.0079)	0.9995*** (0.0083)
60	-2.7723	0.4501*** (0.0415)	-0.0153*** (0.0024)	0.0076*** (0.0006)	1.0084*** (0.0079)	-1.6935	0.6161*** (0.1074)	-0.0165*** (0.0040)	0.0081*** (0.0007)	1.0091*** (0.0055)
61	-6.0888	-0.0254 (0.0437)	0.0073** (0.0035)	-0.0073*** (0.0007)	0.9956*** (0.0070)	-1.7622	-0.3290*** (0.1071)	0.0188*** (0.0045)	-0.0090*** (0.0010)	0.9982*** (0.0065)
62	-1.2127	0.7337*** (0.0261)	-0.0021 (0.0018)	0.0046* (0.0027)	1.0131*** (0.0025)	-1.4775	0.7570*** (0.0295)	-0.0047*** (0.0013)	0.0087*** (0.0019)	1.0132*** (0.0019)
63	-0.6754	-0.2160 (0.1501)	-0.0239*** (0.0009)	0.0149*** (0.0013)	0.9813*** (0.0150)	-0.0661	-16.200*** (1.7823)	-0.0225*** (0.0009)	0.0128*** (0.0009)	1.0438*** (0.0101)
64	-1.3659	1.0583*** (0.0856)	-0.0083*** (0.0013)	-0.0112*** (0.0023)	1.0205*** (0.0193)	-0.6382	1.1027*** (0.1938)	-0.0044 (0.0038)	-0.0189** (0.0081)	1.0326*** (0.0184)
65	-3.9996	0.4313*** (0.0473)	-0.0039 (0.0038)	0.0095** (0.0039)	0.9970*** (0.0042)	-3.1370	0.3027*** (0.0439)	-0.0030*** (0.0010)	0.0091*** (0.0011)	0.9998*** (0.0021)

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.21.2: Estimates of parameters ψ and υ and technological change rates at the industry-level – VES_K production function, normalized system

Industry	NLSUR					GMM				
	ψ (CES impl.)	υ	ζ_K	ζ_L	ξ	ψ (CES impl.)	υ	ζ_K	ζ_L	ξ
1	-1.7300	0.6354*** (0.0673)	0.0163** (0.0067)	0.0241*** (0.0077)	1.0025*** (0.0112)	-3.7352	0.5914*** (0.0553)	0.0135** (0.0062)	0.0278*** (0.0072)	1.0018*** (0.0069)
2	-0.5129	0.0623* (0.0711)	0.0075** (0.0037)	-0.0265*** (0.0034)	1.0338*** (0.0150)	-0.4058	-0.0467 (0.0782)	0.0102*** (0.0032)	-0.0269*** (0.0030)	1.0502*** (0.0133)
3	-0.9954	0.3843*** (0.1293)	-0.0168*** (0.0021)	0.0204*** (0.0065)	1.0197*** (0.0247)	-0.1354	-2.2929** (1.0258)	-0.0178*** (0.0015)	0.0121*** (0.0043)	1.0232*** (0.0163)
4	-1.1268	-0.2459*** (0.0501)	-0.0100*** (0.0014)	0.0268*** (0.0014)	1.0021*** (0.0252)	-0.7029	-1.0349*** (0.2068)	-0.0074*** (0.0009)	0.0266*** (0.0008)	1.0482*** (0.0140)
5	-0.6517	0.4473*** (0.0442)	0.0425 (0.0314)	-0.0131 (0.0198)	0.9775*** (0.0236)	-0.0209	6.0275*** (1.1412)	0.0075** (0.0038)	0.0075*** (0.0026)	1.0001*** (0.0214)
6	-0.3590	-0.7171* (0.4101)	-0.0112*** (0.0008)	0.0060*** (0.0016)	1.0164*** (0.0139)	-0.0050	-94.933*** (36.2206)	-0.0116*** (0.0009)	0.0046*** (0.0015)	1.0304*** (0.0139)
7	-5.2526	0.1156*** (0.0010)	-0.0051*** (0.0011)	0.0073*** (0.0007)	0.9991*** (0.0143)	-3.0841	0.2194*** (0.0460)	-0.0071*** (0.0018)	0.0036*** (0.0006)	1.0164*** (0.0090)
8	-0.9974	0.2409*** (0.0012)	-1.0727*** (0.2927)	0.3418*** (0.0917)	1.0813*** (0.0177)	-0.3804	0.3761*** (0.0904)	-0.0118*** (0.0036)	0.0122*** (0.0013)	0.9878*** (0.0089)
9	-0.9603	-0.1603*** (0.0175)	-0.0123*** (0.0007)	0.0099*** (0.0006)	1.0118*** (0.0118)	-0.8755	-0.0761* (0.0438)	-0.0108*** (0.0007)	0.0089*** (0.0005)	1.0166*** (0.0073)
10	-1.8847	-0.0438* (0.0251)	-0.0199*** (0.0007)	0.0100*** (0.0008)	1.0061*** (0.0125)	-1.2911	-0.2635*** (0.0897)	-0.0197*** (0.0005)	0.0090*** (0.0004)	1.0160*** (0.0079)
11	-1.4238	0.2145*** (0.0219)	-0.0348*** (0.0079)	0.0214*** (0.0028)	1.0089*** (0.0067)	-1.0377	0.2210*** (0.0148)	-0.0531*** (0.0099)	0.0282*** (0.0036)	1.0224*** (0.0048)
12	-0.4983	-0.1411** (0.0667)	-0.0115*** (0.0017)	0.0110*** (0.0012)	1.0137*** (0.0162)	-0.2305	0.2494*** (0.0254)	0.0730*** (0.0139)	-0.0425*** (0.0090)	1.0791*** (0.0173)
13	-0.7001	-0.0918 (0.0627)	-0.0073 (0.0055)	0.0818*** (0.0036)	1.0527*** (0.0567)	-0.2787	-0.8665*** (0.2368)	0.0057* (0.0032)	0.0831*** (0.0028)	0.9492*** (0.0323)
14	-0.8171	0.0566 (0.0787)	-0.0106*** (0.0020)	0.0098*** (0.0018)	1.0070*** (0.0144)	-0.8175	-0.4005*** (0.1127)	-0.0136*** (0.0008)	0.0168*** (0.0006)	0.9813*** (0.0075)
15	-1.1625	0.3561*** (0.0086)	-0.0893*** (0.0225)	0.0623*** (0.0131)	1.0519*** (0.0180)	-1.4518	0.1506* (0.0803)	-0.0193*** (0.0016)	0.0200*** (0.0013)	1.0165*** (0.0108)
16	-0.8082	0.1687*** (0.0409)	-0.0243*** (0.0019)	0.0189*** (0.0014)	1.0096*** (0.0112)	-0.5512	0.0569 (0.0484)	-0.0213*** (0.0012)	0.0146*** (0.0008)	1.0232*** (0.0092)
17	-1.5236	0.2163*** (0.0167)	-0.0020 (0.0032)	0.0114*** (0.0008)	0.9938*** (0.0106)	-0.4051	0.0391 (0.0285)	-0.0635*** (0.0112)	0.0239*** (0.0021)	1.0463*** (0.0068)
18	-3.1651	0.1918*** (0.0280)	-0.0168*** (0.0030)	0.0312*** (0.0012)	1.0061*** (0.0083)	-0.6871	0.0086 (0.0762)	-0.0260*** (0.0056)	0.0348*** (0.0020)	1.0322*** (0.0083)
19	-0.5845	0.7410*** (0.1150)	0.0071 (0.0045)	0.0106*** (0.0037)	0.9991*** (0.0121)	-0.5784	0.6929*** (0.0980)	0.0090 (0.0064)	0.0061 (0.0055)	1.0164*** (0.0073)
20	-0.8335	-0.2745*** (0.0633)	-0.0001 (0.0009)	0.0234*** (0.0007)	1.0079*** (0.0143)	-0.2757	-1.5477*** (0.2778)	0.0003 (0.0007)	0.0239*** (0.0006)	1.0251*** (0.0102)
21	-1.4138	0.1693*** (0.0223)	-0.0145*** (0.0054)	0.0158*** (0.0016)	1.0103*** (0.0083)	-0.3908	0.3620*** (0.0705)	-0.0313*** (0.0035)	0.0206*** (0.0012)	1.0228*** (0.0058)
22	-1.5166	0.4261*** (0.0014)	0.0698*** (0.0148)	-0.0511*** (0.0111)	1.0178*** (0.0068)	-1.5607	0.2268*** (0.0835)	-0.0120*** (0.0010)	0.0128*** (0.0008)	1.0107*** (0.0046)
23	-11.1874	0.1635*** (0.0003)	-0.0349*** (0.0062)	0.0145*** (0.0013)	1.0017*** (0.0081)	-22.1483	0.7613*** (0.1305)	-0.0157*** (0.0004)	0.0119*** (0.0002)	1.0076*** (0.0060)
24	-0.8963	-1.3534*** (0.1869)	-0.0093*** (0.0021)	0.0401*** (0.0023)	0.9725*** (0.0397)	-0.3845	-2.9162*** (0.6807)	-0.0068*** (0.0016)	0.0459*** (0.0025)	1.0337*** (0.0286)
25	-1.3030	0.5762*** (0.0025)	-0.0968*** (0.0077)	0.1458*** (0.0112)	1.0805*** (0.0110)	-3.3872	0.7160*** (0.1390)	-0.0131*** (0.0039)	0.0192*** (0.0054)	1.0245*** (0.0061)
26	-0.5913	-0.0276 (0.0567)	-0.0068*** (0.0010)	0.0101*** (0.0007)	1.0141*** (0.0114)	-0.4492	-0.1896* (0.1082)	-0.0057*** (0.0007)	0.0103*** (0.0006)	1.0167*** (0.0079)
27	-1.2172	0.1085*** (0.0221)	-0.0182*** (0.0007)	0.0321*** (0.0005)	1.0067*** (0.0048)	-1.1037	0.1748*** (0.0291)	-0.0191*** (0.0012)	0.0323*** (0.0006)	0.9991*** (0.0038)
28	-5.0213	0.3514*** (0.0523)	-0.0121*** (0.0022)	0.0169*** (0.0006)	1.0031*** (0.0064)	-2.4331	0.5337*** (0.0785)	-0.0155*** (0.0008)	0.0176*** (0.0003)	1.0015*** (0.0047)
29	-0.3888	0.8578*** (0.2029)	-0.0106** (0.0054)	0.0299*** (0.0036)	0.9941*** (0.0228)	-0.0242	0.1103* (0.0661)	0.3090*** (0.0491)	-0.1550*** (0.0283)	1.1977*** (0.0287)
30	-5.3045	0.3191*** (0.0258)	-0.0152*** (0.0038)	0.0309*** (0.0024)	1.0036*** (0.0090)	-3.8603	0.3557*** (0.0026)	-0.0510*** (0.0174)	0.0529*** (0.0097)	1.0147*** (0.0059)
31	-1.1583	0.3896*** (0.0724)	0.0010 (0.0039)	0.0251*** (0.0046)	1.0050*** (0.0175)	-0.2039	-0.3519* (0.2106)	0.0016 (0.0024)	0.0244*** (0.0028)	1.0214*** (0.0159)
32	-0.8189	0.2440*** (0.0004)	0.2263*** (0.0327)	-0.0603*** (0.0105)	1.0326*** (0.0101)	-0.6337	0.3040*** (0.0462)	-0.0064 (0.0107)	0.0168*** (0.0035)	1.0352*** (0.0065)
33	-8.4916	0.6153*** (0.0159)	0.0105*** (0.0008)	0.0043*** (0.0008)	1.0019*** (0.0087)	-4.0525	0.7912*** (0.0762)	0.0092*** (0.0011)	0.0042*** (0.0013)	1.0036*** (0.0057)

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Industry	NLSUR					GMM				
	ψ (CES impl.)	υ	ζ_K	ζ_L	ξ	ψ (CES impl.)	υ	ζ_K	ζ_L	ξ
34	-0.7512	1.5274*** (0.1705)	0.0036* (0.0019)	0.0353*** (0.0023)	1.0063*** (0.0320)	-0.0197	-0.1394 (0.2502)	-0.1664*** (0.0298)	0.3269*** (0.0520)	1.2746*** (0.0352)
35	-5.4892	0.5421*** (0.0300)	0.0128*** (0.0015)	0.0055*** (0.0012)	1.0099*** (0.0139)	-0.9760	1.1037*** (0.1694)	0.0081*** (0.0024)	0.0088*** (0.0019)	1.0036*** (0.0126)
36	-3.5913	0.0073 (0.0159)	0.0187*** (0.0006)	0.0186*** (0.0009)	1.0161*** (0.0118)	-3.1372	-0.0507** (0.0205)	0.0177*** (0.0005)	0.0199*** (0.0005)	1.0099*** (0.0084)
37	-0.8664	0.1227*** (0.0256)	-0.0310*** (0.0022)	0.0369*** (0.0016)	1.0275*** (0.0112)	-0.6155	0.0192 (0.0503)	-0.0306*** (0.0029)	0.0355*** (0.0017)	1.0243*** (0.0091)
38	-0.4014	0.4438*** (0.1271)	0.0176 (0.0142)	-0.0214 (0.0264)	1.0511*** (0.0251)	-0.0842	0.3056** (0.1378)	0.0651*** (0.0251)	-0.1045** (0.0458)	1.0490*** (0.0297)
39	-2.0099	0.5004*** (0.0180)	-0.0286*** (0.0030)	0.0688*** (0.0042)	1.0180*** (0.0076)	-0.3725	0.2836*** (0.0717)	-0.0384*** (0.0057)	0.0814*** (0.0081)	1.0444*** (0.0070)
40	0.2249	-0.7996*** (0.0480)	-0.0851*** (0.0011)	0.0229*** (0.0012)	0.9332*** (0.0112)	0.4208	-0.2551*** (0.0319)	-0.0816*** (0.0008)	0.0192*** (0.0007)	0.9584*** (0.0089)
41	-0.0191	-0.1909 (0.1818)	0.0576*** (0.0193)	-0.0954*** (0.0231)	1.0499*** (0.0138)	0.0871	-1.1772*** (0.2484)	-0.0429*** (0.0013)	0.0218*** (0.0015)	1.0093*** (0.0092)
42	-0.2979	0.2065*** (0.0372)	-0.1626*** (0.0540)	0.0484*** (0.0094)	0.9471*** (0.0372)	-0.1018	-0.1381 (0.0920)	-0.0004 (0.0208)	0.0193*** (0.0037)	1.0849*** (0.0360)
43	-1.4175	0.4513*** (0.0274)	-0.0430*** (0.0024)	0.0134*** (0.0008)	0.9837*** (0.0076)	-0.6848	0.5192*** (0.0562)	-0.0402*** (0.0037)	0.0122*** (0.0016)	0.9981*** (0.0082)
44	-0.4864	2.1206*** (0.0396)	0.0187*** (0.0018)	0.0401*** (0.0027)	1.0100*** (0.0342)	-0.2355	2.3067*** (0.1852)	0.0183*** (0.0011)	0.0386*** (0.0015)	1.0905*** (0.0275)
45	-3.5809	1.2824*** (0.0137)	0.0017*** (0.0002)	0.0113*** (0.0005)	0.9979*** (0.0031)	-2.2719	0.8934*** (0.0156)	0.0072*** (0.0012)	-0.0821*** (0.0216)	1.0074*** (0.0024)
46	0.0611	-3.2541*** (0.2972)	-0.0270*** (0.0017)	0.0121*** (0.0016)	0.9966*** (0.0283)	0.0218	-5.0559*** (0.6660)	-0.0292*** (0.0015)	0.0138*** (0.0021)	0.9919*** (0.0306)
47	-0.2517	0.0731*** (0.0164)	0.0708*** (0.0027)	-0.0612*** (0.0022)	1.2860*** (0.0128)	-0.2831	0.1048*** (0.0189)	0.0756*** (0.0037)	-0.0656*** (0.0034)	1.3429*** (0.0176)
48	-1.2610	0.3913*** (0.0263)	-0.0941*** (0.0109)	0.0186*** (0.0052)	1.0452*** (0.0257)	-0.6535	0.0660*** (0.0129)	0.0155*** (0.0037)	-0.0332*** (0.0025)	1.2764*** (0.0329)
49	-0.5452	0.0592*** (0.0129)	0.0250*** (0.0014)	-0.0086*** (0.0012)	1.1228*** (0.0088)	-0.3989	0.0333*** (0.0108)	0.0349*** (0.0017)	-0.0137*** (0.0010)	1.1309*** (0.0061)
50	-1.1352	0.1038*** (0.0163)	0.0035*** (0.0012)	-0.0145*** (0.0014)	1.2155*** (0.0130)	-1.0403	0.1142*** (0.0119)	0.0084*** (0.0012)	-0.0194*** (0.0012)	1.2487*** (0.0118)
51	-0.2856	0.0914*** (0.0126)	0.1025*** (0.0052)	-0.0289*** (0.0021)	1.2795*** (0.0155)	-0.3781	0.0907*** (0.0269)	0.0306*** (0.0117)	-0.0072* (0.0040)	1.1602*** (0.0115)
52	-1.1282	0.3233*** (0.0159)	0.0465*** (0.0020)	-0.0274*** (0.0022)	1.1840*** (0.0188)	-0.9824	0.2543*** (0.0159)	0.0443*** (0.0021)	-0.0266*** (0.0023)	1.1691*** (0.0151)
53	-3.3593	0.2336*** (0.0139)	-0.0299*** (0.0026)	0.0136*** (0.0013)	1.0146*** (0.0248)	-0.0546	0.0523*** (0.0178)	0.3585*** (0.0307)	-0.0742*** (0.0071)	1.2619*** (0.0145)
54	-5.4333	0.0980*** (0.0095)	-0.0299*** (0.0016)	0.0091*** (0.0009)	1.0102*** (0.0156)	-24.7681	0.2469*** (0.0348)	0.2192*** (0.0425)	-0.0840*** (0.0114)	1.1369*** (0.0134)
55	-4.6950	0.1267*** (0.0208)	-0.0139*** (0.0012)	0.0009 (0.0009)	1.0495*** (0.0109)	-1.5109	0.1201*** (0.0098)	0.0269*** (0.0027)	-0.0161*** (0.0011)	1.1686*** (0.0061)
56	-0.4746	0.2489*** (0.0308)	-0.0286*** (0.0033)	0.0318*** (0.0014)	0.9965*** (0.0257)	-0.0095	2.9873** (1.5194)	-0.0672*** (0.0161)	0.0191*** (0.0020)	1.3145*** (0.0207)
57	-9.6429	0.4418*** (0.0762)	0.0216*** (0.0065)	0.0160** (0.0063)	0.9911*** (0.0135)	-6.2156	0.0790 (0.1004)	0.0211*** (0.0012)	0.0152*** (0.0010)	1.0347*** (0.0073)
58	-0.9064	0.1778*** (0.0255)	0.0243*** (0.0030)	-0.0191*** (0.0022)	1.0522*** (0.0141)	-0.2159	0.0301 (0.0517)	0.0599*** (0.0083)	-0.0428*** (0.0056)	1.0966*** (0.0213)
59	-1.4023	0.4175*** (0.0454)	0.0026 (0.0034)	0.0110*** (0.0018)	1.0036*** (0.0099)	-0.2235	0.5631*** (0.2002)	0.0059 (0.0062)	0.0099*** (0.0032)	1.0015*** (0.0083)
60	-2.7723	0.0525*** (0.0106)	-0.0067*** (0.0009)	0.0058*** (0.0005)	1.0097*** (0.0077)	-1.6935	-0.0016 (0.0254)	-0.0097*** (0.0016)	0.0068*** (0.0004)	1.0070*** (0.0053)
61	-6.0888	0.1434*** (0.0112)	-0.0027 (0.0205)	-0.0063* (0.0033)	0.9952*** (0.0070)	-1.7622	0.0209 (0.0209)	-0.0254*** (0.0030)	-0.0014** (0.0006)	1.0324*** (0.0055)
62	-1.2127	0.9861*** (0.0515)	-0.0169*** (0.0008)	0.0275*** (0.0012)	0.9963*** (0.0023)	-1.4775	0.9350*** (0.1149)	-0.0175*** (0.0017)	0.0284*** (0.0025)	0.9976*** (0.0020)
63	-0.6754	0.5531*** (0.0195)	0.0349*** (0.0112)	-0.0818*** (0.0194)	1.0419*** (0.0144)	-0.0661	0.2204* (0.1259)	0.0599*** (0.0192)	-0.1185*** (0.0305)	1.0922*** (0.0179)
64	-1.3659	1.8891*** (0.3016)	-0.0145*** (0.0011)	0.0018 (0.0016)	1.0062*** (0.0191)	-0.6382	0.2992*** (0.1031)	0.0065 (0.0045)	-0.0436*** (0.0102)	1.0740*** (0.0202)
65	-3.9996	0.3833*** (0.0144)	0.0117*** (0.0008)	-0.0058*** (0.0010)	1.0151*** (0.0023)	-3.1370	0.3656*** (0.0199)	0.0142*** (0.0029)	-0.0083*** (0.0026)	1.0281*** (0.0030)

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.21.3: Implied parameters from VES production function estimations, normalized system

Industry	VES_L				VES_K			
	NLSUR		GMM		NLSUR		GMM	
	β_{12}	σ_0	β_{12}	σ_0	β_{12}	σ_0	β_{12}	σ_0
1	1.7682	9.4301	1.2867	99.1507	1.2527	1.4153	1.1179	1.4952
2	0.5839	0.7534	0.5752	0.7884	0.5627	0.6919	0.5041	0.6916
3	0.8117	0.5562	0.4783	0.6622	0.3647	0.6657	0.0682	0.6512
4	0.3196	0.3219	0.2044	0.2939	0.4274	0.3677	0.2617	0.3069
5	1.0147	1.0063	-0.0555	1.3574	1.0887	1.0872	-0.1197	1.4197
6	0.9949	0.9954	-0.1303	1.1202	0.1667	0.5815	0.0030	0.6006
7	-0.8033	-2.6716	-0.2023	-0.8801	1.0127	2.2898	1.1473	-0.4172
8	0.9586	0.9866	1.0051	1.0006	1.0015	1.0046	1.2184	1.2757
9	0.2754	0.4065	0.3018	0.4608	0.5462	0.4200	0.5889	0.4860
10	0.3362	0.3119	0.2372	0.2889	0.6015	0.3219	0.4969	0.3120
11	3.4933	1.5468	12.0775	1.4949	0.9446	0.8063	0.9523	0.8701
12	0.3497	0.6336	0.6123	0.9165	0.5396	0.5948	0.8203	0.9251
13	0.2755	0.5899	0.0686	0.4117	0.6648	0.5169	0.3889	0.4630
14	0.4984	0.6038	0.3063	0.4037	0.5896	0.5838	0.3972	0.3914
15	0.3665	0.4628	0.3986	0.4415	0.9845	0.9693	0.7462	0.5391
16	0.4761	0.6848	0.3669	0.6702	0.7928	0.7100	0.6988	0.6853
17	-2.8525	1.5939	-0.2019	1.7752	1.0804	2.6764	0.8811	0.7682
18	0.6102	0.5849	0.3691	0.7081	0.9158	0.5468	0.7466	0.6008
19	1.9422	1.3041	2.0124	1.3146	2.1189	1.6006	1.7868	1.4487
20	0.1068	0.3339	0.0368	0.3264	0.6101	0.3494	0.3052	0.3131
21	1.3681	1.1277	5.6205	1.1058	0.9276	0.7297	1.2077	1.2915
22	0.4978	0.4662	0.9989	0.9987	0.9965	0.9929	0.7397	0.5768
23	0.7601	0.5914	0.2660	0.0772	0.9998	0.9906	3.5039	-0.0125
24	0.5327	0.4170	0.4358	0.5305	0.1529	0.2637	0.0919	0.3188
25	3.3707	-3.4701	1.7458	-0.9672	0.9809	0.9823	1.4639	4.2302
26	0.3636	0.6162	0.2683	0.5757	0.6076	0.6117	0.5248	0.5967
27	0.3864	0.5343	0.4545	0.6260	0.7730	0.5579	0.8352	0.6744
28	0.4392	0.3909	0.7461	0.8325	1.2404	-0.3328	1.7252	-0.3116
29	-0.9496	1.8614	0.3850	0.9781	4.4524	2.0829	0.7115	0.9834
30	0.5298	0.2768	1.7093	9.0190	0.9444	0.6401	0.9980	0.9865
31	0.7811	0.7275	0.4128	0.7492	0.7607	0.7599	0.3434	0.7474
32	0.9978	0.9994	0.9993	0.9999	0.9993	0.9983	1.0854	1.1822
33	1.1120	69.9609	2.0412	-0.7231	1.2076	-3.7578	2.2242	-1.0697
34	2.2895	3.6424	-0.0371	17.1695	-0.6984	-15.3103	0.3233	0.9766
35	0.6076	0.2600	0.5334	0.5933	1.2114	-5.1753	-5.3504	-2.2582

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Industry	VES_L				VES_K			
	NLSUR		GMM		NLSUR		GMM	
	β_{12}	σ_0	β_{12}	σ_0	β_{12}	σ_0	β_{12}	σ_0
36	0.2301	0.2431	0.1708	0.2021	0.8001	0.2241	0.7559	0.2037
37	0.5337	0.6950	0.3830	0.6350	0.7216	0.6342	0.6454	0.6316
38	0.7748	0.8213	0.7899	0.9599	0.6274	0.8867	0.5025	0.9572
39	1.3340	2.9634	-0.6750	-4.6076	0.8640	0.8063	0.6025	0.8427
40	0.3170	2.0910	0.4270	2.5491	0.2676	2.3362	0.3837	2.6868
41	0.4664	0.9746	0.3027	1.3147	0.3829	0.9749	0.2094	1.3804
42	0.3123	0.8888	0.1168	0.8720	1.0583	1.0942	0.7379	0.8407
43	0.7085	0.7945	0.5651	0.8106	1.2627	2.9861	1.4411	1.8970
44	19.3286	2.8137	-1.3784	2.3150	-0.3722	-3.5334	-0.3192	3.2956
45	1.0022	1.1529	0.9824	0.5879	-0.1942	-3.6008	0.5146	0.8894
46	0.4461	1.4531	0.3294	1.2231	0.0460	1.4459	0.0323	1.1889
47	0.4522	0.8070	0.4394	0.7792	0.6046	0.8265	0.6259	0.8226
48	4.3127	2.0322	-1.6929	2.1982	1.0777	1.2098	0.7024	0.6544
49	0.4128	0.6654	0.3970	0.7179	0.6448	0.6835	0.6275	0.7326
50	0.4321	0.4638	0.4447	0.4984	0.6288	0.5361	0.6362	0.5656
51	0.3139	0.8099	-0.1976	7.2413	0.7998	0.8402	0.7992	0.7983
52	0.5473	0.4831	0.5636	0.5341	0.6884	0.6918	0.6247	0.6602
53	-0.6396	-1.0925	0.1986	0.9533	1.0673	21.1134	0.8632	0.9626
54	0.2511	0.2880	0.1508	0.0449	0.9619	0.4150	1.1521	-0.0489
55	0.5129	0.3688	0.4207	0.5560	0.8275	0.2817	0.8213	0.5386
56	0.8863	0.9921	0.1412	0.9925	1.1776	2.2123	-0.4451	1.3074
57	0.7509	0.2547	1.0157	1.0963	0.9357	0.5797	0.5671	0.1616
58	-2.1889	9.5299	0.4315	0.8384	0.7249	0.6633	0.6145	0.8335
59	1.4998	1.3235	7.4192	1.1125	1.1272	1.4337	1.5029	1.1669
60	0.3285	0.5042	0.2400	0.5180	0.8993	0.3586	0.8508	0.3687
61	-5.5466	-5.6395	-0.4278	27.3975	1.0031	1.1279	0.8776	0.3999
62	0.8384	0.7280	0.8125	0.6473	27.6676	3.7246	5.9223	4.3195
63	-2.8269	-2.3046	-0.0377	-0.5390	0.8713	0.9402	0.4995	0.9595
64	0.6499	0.3816	0.6237	0.5411	-0.3512	-0.7217	0.4455	0.7350
65	1.1425	1.9403	1.6280	-5.6896	0.8225	0.5295	0.7995	0.5525

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Table 3.22: Chi-square test statistics and p-values for the Cobb-Douglas hypothesis in normalized VES production function estimations

Industry	VES_L				VES_K			
	NLSUR		GMM		NLSUR		GMM	
	χ^2	p-value	χ^2	p-value	χ^2	p-value	χ^2	p-value
1	98.29***	0.0000	20.24***	0.0000	1.87	0.1710	0.76	0.3834
2	116.14***	0.0000	88.53***	0.0000	33.26***	0.0000	44.11***	0.0000
3	37.84***	0.0000	11.13***	0.0009	9.15***	0.0025	8.95***	0.0028
4	379.18***	0.0000	110.95***	0.0000	202.98***	0.0000	52.77***	0.0000
5	0.53	0.4670	11.82***	0.0006	1.23	0.2676	24.33***	0.0000
6	0.24	0.6224	0.20	0.6533	12.17***	0.0005	6.97***	0.0083
7	43.33***	0.0000	50.74***	0.0000	134.51***	0.0000	6.25**	0.0124
8	1.59	0.2076	0.24	0.6277	0.88	0.3492	2.27	0.1317
9	506.81***	0.0000	78.70***	0.0000	903.95***	0.0000	102.00***	0.0000
10	204.80***	0.0000	57.74***	0.0000	274.17***	0.0000	50.18***	0.0000
11	15.01***	0.0001	7.99***	0.0047	3.95**	0.0469	6.28**	0.0122
12	56.32***	0.0000	65.55***	0.0000	62.09***	0.0000	28.21***	0.0000
13	9.09***	0.0026	15.45***	0.0001	34.05***	0.0000	23.20***	0.0000
14	32.08***	0.0000	44.09***	0.0000	24.22***	0.0000	56.07***	0.0000
15	37.40***	0.0000	22.14***	0.0000	1.35	0.2456	7.20***	0.0073
16	23.63***	0.0000	44.63***	0.0000	17.70***	0.0000	34.40***	0.0000
17	3.10*	0.0785	3.44*	0.0638	14.29***	0.0002	16.03***	0.0001
18	53.45***	0.0000	21.27***	0.0000	5.93**	0.0149	10.87***	0.0010
19	9.15***	0.0025	11.08***	0.0009	6.35**	0.0117	6.08**	0.0136
20	63.54***	0.0000	27.46***	0.0000	61.56***	0.0000	40.61***	0.0000
21	0.41	0.5199	0.57	0.4485	7.28***	0.0070	3.54*	0.0601
22	42.24***	0.0000	0.25	0.6172	1.95	0.1621	5.81**	0.0159
23	1.88	0.1701	60.25***	0.0000	0.23	0.6321	20.96***	0.0000
24	182.88***	0.0000	26.24***	0.0000	113.78***	0.0000	27.30***	0.0000
25	37.32***	0.0000	3.90**	0.0484	10.20***	0.0014	0.90	0.3434
26	52.05***	0.0000	52.04***	0.0000	50.61***	0.0000	27.31***	0.0000
27	141.81***	0.0000	34.58***	0.0000	83.91***	0.0000	21.84***	0.0000
28	4.81**	0.0283	10.29***	0.0013	8.88***	0.0029	18.55***	0.0000
29	5.46**	0.0195	13.57***	0.0002	5.85**	0.0156	15.09***	0.0001
30	32.85***	0.0000	1.03	0.3111	2.15	0.1422	0.24	0.6222
31	7.32***	0.0068	17.68***	0.0000	4.07**	0.0436	17.77***	0.0000
32	0.52	0.4707	0.52	0.4714	1.36	0.2443	1.65	0.1984
33	39.30***	0.0000	63.76***	0.0000	25.20***	0.0000	11.27***	0.0008
34	13.00***	0.0003	40.78***	0.0000	27.60***	0.0000	9.50***	0.0021
35	72.39***	0.0000	122.67***	0.0000	10.41***	0.0013	15.10***	0.0001

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Industry	VES_L				VES_K			
	NLSUR		GMM		NLSUR		GMM	
	χ^2	p-value	χ^2	p-value	χ^2	p-value	χ^2	p-value
36	86.15***	0.0000	94.84***	0.0000	156.06***	0.0000	156.86***	0.0000
37	13.62***	0.0002	29.70***	0.0000	90.92***	0.0000	47.87***	0.0000
38	5.62**	0.0177	8.94***	0.0028	2.66	0.1028	6.28**	0.0122
39	8.64***	0.0033	63.50***	0.0000	14.18***	0.0002	15.77***	0.0001
40	961.20***	0.0000	3856.11***	0.0000	755.46***	0.0000	588.87***	0.0000
41	16.55***	0.0000	29.05***	0.0000	16.34***	0.0001	48.02***	0.0000
42	2.68	0.1017	4.83**	0.0280	1.55	0.2133	10.52***	0.0012
43	6.57**	0.0104	8.92***	0.0028	27.72***	0.0000	14.25***	0.0002
44	51.25***	0.0000	63.43***	0.0000	1506.42***	0.0000	86.68***	0.0000
45	362.16***	0.0000	95.23***	0.0000	609.37***	0.0000	11.00***	0.0009
46	155.16***	0.0000	84.80***	0.0000	186.47***	0.0000	77.42***	0.0000
47	685.64***	0.0000	518.27***	0.0000	498.06***	0.0000	312.59***	0.0000
48	5.08**	0.0242	11.71***	0.0006	3.24*	0.0717	461.64***	0.0000
49	231.76***	0.0000	434.15***	0.0000	675.84***	0.0000	1116.30***	0.0000
50	1191.75***	0.0000	1103.61***	0.0000	414.49***	0.0000	728.16***	0.0000
51	280.03***	0.0000	111.00***	0.0000	207.04***	0.0000	46.12***	0.0000
52	109.05***	0.0000	101.34***	0.0000	176.16***	0.0000	310.19***	0.0000
53	16.04***	0.0001	26.17***	0.0000	13.75***	0.0000	53.23***	0.0000
54	62.24***	0.0000	213.44***	0.0000	13.02***	0.0003	10.85***	0.0010
55	446.66***	0.0000	600.89***	0.0000	52.36***	0.0000	259.70***	0.0000
56	5.91**	0.0151	12.47***	0.0004	18.81***	0.0000	3.57*	0.0587
57	16.25***	0.0001	0.46	0.4962	0.22	0.6373	15.78***	0.0001
58	44.63***	0.0000	20.80***	0.0000	78.83***	0.0000	52.39***	0.0000
59	1.74	0.1874	0.64	0.4229	2.66	0.1028	1.20	0.2725
60	53.09***	0.0000	19.02***	0.0000	80.73***	0.0000	34.70***	0.0000
61	14.43***	0.0001	19.24***	0.0000	0.05	0.8154	32.94***	0.0000
62	20.72***	0.0000	23.16***	0.0000	51.85***	0.0000	7.75***	0.0054
63	30.33***	0.0000	88.96***	0.0000	8.72***	0.0032	9.61***	0.0019
64	18.75***	0.0000	4.59**	0.0322	15.87***	0.0001	14.21***	0.0002
65	1.69	0.1939	18.74***	0.0000	57.42***	0.0000	40.96***	0.0000

Note: *, ** and *** denote rejection of the Cobb-Douglas hypothesis null ($\upsilon = \pi_0$) at, respectively, the 10%, 5% and 1% significance levels.

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Table 3.23: Tests for the Cobb-Douglas and CES specifications using the normalized VES production function estimations

Industry	VES_L				VES_K			
	NLSUR		GMM		NLSUR		GMM	
	CD	CES	CD	CES	CD	CES	CD	CES
1					XXX		XXX	
2						XXX		XXX
3		XXX		X				X
4								
5	XXX				XXX			
6	XXX		XXX	XXX		XX		
7							X	
8	XXX		XXX		XXX		XXX	
9				X				XX
10		X				XX		
11					X		X	
12		XXX				X		
13		XXX				XXX		
14		XXX				XXX		
15		XXX		XXX	XXX			XX
16				XXX				XXX
17	XX		XX					XXX
18					X			XXX
19					X		X	
20								
21	XXX		XXX				XX	
22		X	XXX		XXX		X	
23	XXX				XXX			
24								
25			X				XXX	
26		XXX				XXX		XX
27								
28	X							
29	X			XXX	X			XX
30			XXX		XXX		XXX	
31				XXX	X			XX
32	XXX		XXX		XXX		XXX	
33								
34								XXX
35								

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Industry	VES_L				VES_K			
	NLSUR		GMM		NLSUR		GMM	
	CD	CES	CD	CES	CD	CES	CD	CES
36		XXX		X		XXX		X
37				XXX				XXX
38	X	X			XXX		X	X
39								
40								
41		XXX				XXX		
42	XXX	X	X	XXX	XXX			XXX
43	X							
44								
45								
46								
47		XXX		XXX				
48	X				XX			
49		XXX		XXX				
50		XXX		XXX				
51								
52		XXX		XXX				
53				XXX				
54				X				
55								
56	X			XXX			XX	X
57			XXX		XXX			XXX
58				XXX				XXX
59	XXX		XXX	X	XXX		XXX	
60								XXX
61					XXX			XXX
62								
63								XX
64		XXX	X	XXX				
65	XXX							

Note: CD and CES denote, respectively, the non-rejection of the Cobb-Douglas hypothesis ($\upsilon = \pi_0$) and of the CES hypothesis ($\upsilon = 1$ in the case of the VES_L function, or $\upsilon = 0$ in the case of the VES_K function) at the 1% (X), 5% (XX) or 10% (XXX) significance levels.

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Table 3.24.1: Estimates of industry rates of factor augmentation from OLS regressions – VES production function, single equation

Industry	VES$_1$				VES$_2$			
	Regression coefficient	Parameters (neutrality assumption)			Regression coefficient	Parameters (neutrality assumption)		
	ξ_2^{VK}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)	ξ_2^{VL}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)
1	0.0137*** (0.0016)	0.0197	0.0350	0.0453	0.0153*** (0.0017)	0.0195	0.0501	0.0318
2	0.0007 (0.0011)	0.0013	0.0027	0.0026	-0.0089*** (0.0005)	-0.0238	-0.0363	-0.0696
3	-0.0030*** (0.0007)	-0.0181	-0.0652	-0.0250	0.0006 (0.0024)	0.0008	0.0012	0.0023
4	-0.0026 (0.0039)	-0.0064	-0.0169	-0.0102	0.0409*** (0.0022)	0.0680	0.0274	-0.0460
5	0.0080*** (0.0017)	0.0116	0.0136	0.0790	0.0071*** (0.0013)	0.0135	0.0193	0.0451
6	-0.0032** (0.0014)	-0.0195	0.0384	-0.0129	0.0024 (0.0045)	0.0068	0.0070	0.2351
7	0.0047*** (0.0013)	0.0042	0.0056	0.0168	0.0011*** (0.0003)	0.0049	0.0131	0.0079
8	0.0020*** (0.0008)	0.0027	0.0049	0.0058	0.0002 (0.0008)	0.0010	0.0019	0.0021
9	-0.0040 (0.0025)	-0.0081	-0.0601	-0.0093	0.0112*** (0.0009)	0.0450	0.0178	-0.0295
10	0.0091*** (0.0027)	0.0109	0.0103	-0.1854	0.0209*** (0.0016)	0.0268	0.0167	-0.0446
11	0.0019*** (0.0016)	0.0023	0.0036	0.0065	0.0033*** (0.0033)	0.0099	0.0145	0.0310
12	-0.0038 (0.0046)	-0.0092	-0.1091	-0.0101	0.0139*** (0.0021)	0.0672	0.0257	-0.0416
13	0.0089 (0.0113)	0.0266	0.0276	0.7093	0.0100 (0.0106)	0.1615	0.1969	0.8984
14	-0.0057* (0.0031)	-0.0125	1.6367	-0.0124	0.0090*** (0.0033)	0.0889	0.0212	-0.0279
15	0.0013 (0.0033)	0.0021	0.0035	0.0053	0.0155*** (0.0037)	0.0655	0.0302	-0.0559
16	0.0051*** (0.0015)	0.0076	0.0098	0.0346	0.0085*** (0.0018)	0.0358	0.0229	-0.0634
17	0.0101*** (0.0033)	0.0123	0.0120	-0.4835	0.0070*** (0.0014)	0.0561	0.0297	-0.0629
18	0.0173*** (0.0027)	0.0197	0.0237	0.1145	0.0139*** (0.0022)	0.0283	0.0324	0.2244
19	0.0044* (0.0022)	0.0081	0.0117	0.0263	0.0080*** (0.0014)	0.0192	0.0248	0.0857
20	0.0076 (0.0063)	0.0123	0.0225	0.0274	0.0113*** (0.0017)	0.0672	0.0235	-0.0362
21	0.0201*** (0.0025)	0.0197	0.0194	-1.2995	0.0111*** (0.0016)	0.0192	0.0191	-2.3348
22	0.0002 (0.0024)	0.0002	0.0004	0.0004	0.0034* (0.0018)	0.0058	0.0077	0.0230
23	-0.0044** (0.0021)	-0.0044	-0.0110	-0.0074	-0.0046*** (0.0010)	-0.0115	-15.7127	-0.0115
24	-0.0072*** (0.0038)	-0.0316	-0.1477	-0.0401	0.0879*** (0.0081)	1.7656	0.0504	-0.0519
25	0.0288*** (0.0032)	0.0537	0.0295	-0.0652	0.0251*** (0.0060)	0.0322	0.0278	-0.2066
26	-0.0038** (0.0015)	-0.0087	0.1813	-0.0083	0.0033*** (0.0009)	0.0140	0.0113	-0.0581
27	0.0038** (0.0019)	0.0050	0.0111	0.0092	0.0118*** (0.0016)	0.0234	0.0280	0.1417
28	0.0007 (0.0028)	0.0008	0.0014	0.0016	-0.0007 (0.0022)	-0.0015	-0.0037	-0.0026
29	0.0197*** (0.0038)	0.0342	0.0285	-0.1719	0.0037** (0.0018)	0.0110	0.0132	0.0657
30	0.0207*** (0.0036)	0.0200	0.0240	0.1208	0.0192*** (0.0023)	0.0260	0.0265	1.1830
31	0.0092*** (0.0015)	0.0138	0.0215	0.0387	0.0124*** (0.0012)	0.0164	0.0221	0.0637
32	0.0121*** (0.0019)	0.0131	0.0157	0.0788	0.0038*** (0.0004)	0.0118	0.0103	-0.0807
33	0.0103*** (0.0008)	0.0126	0.0339	0.0201	0.0121*** (0.0013)	0.0118	0.0652	0.0144

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Industry	VES$_1$				VES$_2$			
	Regression coefficient	Parameters (neutrality assumption)			Regression coefficient	Parameters (neutrality assumption)		
	ξ_2^{VK}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)	ξ_2^{VL}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)
34	0.0231*** (0.0034)	0.0534	0.0375	-0.1256	0.0237*** (0.0069)	0.0380	0.0447	0.2568
35	0.0168*** (0.0023)	0.0203	0.2324	0.0223	0.0057** (0.0026)	0.0076	0.0249	0.0109
36	0.0140*** (0.0007)	0.0184	0.2819	0.0196	-0.0022 (0.0026)	0.0237	-0.0040	0.0034
37	-0.0021 (0.0020)	-0.0040	-0.0087	-0.0075	-0.0044* (0.0022)	-0.0234	0.0238	-0.0118
38	0.0090*** (0.0023)	0.0408	0.0318	-0.1436	0.0073* (0.0039)	0.0164	0.0159	-0.6226
39	0.0175*** (0.0033)	0.0291	0.0361	0.1499	0.0086 (0.0052)	0.0113	0.0306	0.0179
40	-0.0055*** (0.0014)	-0.0102	-0.0140	-0.0379	-0.0331*** (0.0014)	0.5137	0.0932	-0.1138
41	0.0045*** (0.0009)	0.0116	0.0132	0.0967	-0.0055*** (0.0016)	-0.0153	-0.0330	-0.0285
42	0.0143** (0.0064)	0.0298	0.0353	0.1903	-0.0055** (0.0022)	-0.0379	-0.0790	-0.0729
43	0.0083*** (0.0018)	0.0105	0.0114	0.1303	0.0137*** (0.0036)	0.0145	0.0153	0.2716
44	0.0145*** (0.0032)	0.0752	0.0293	-0.0481	0.0060*** (0.0013)	0.0164	-0.1352	0.0146
45	0.0008*** (0.0001)	0.0083	0.0152	0.0183	0.0023*** (0.0005)	0.0023	0.1096	0.0024
46	0.0016*** (0.0003)	0.0347	0.0231	-0.0690	-0.0079*** (0.0015)	0.1143	0.0339	-0.0481
47	0.0216*** (0.0020)	0.0622	0.0355	-0.0827	-0.0210*** (0.0020)	-0.1225	0.1029	-0.0559
48	-0.0013 (0.0035)	-0.0015	-0.0017	-0.0123	-0.0173*** (0.0021)	-0.0296	-0.0429	-0.0954
49	0.0183*** (0.0017)	0.0263	0.0284	0.3583	-0.0015 (0.0026)	-0.0031	-0.0039	-0.0149
50	-0.0144 (0.0146)	-0.0210	11.3207	-0.0209	-0.0199*** (0.0041)	-0.0362	-0.0850	-0.0630
51	0.0311*** (0.0016)	0.0466	0.0339	-0.1246	-0.0111*** (0.0020)	-0.0496	-0.3757	-0.0571
52	0.0145*** (0.0006)	0.0228	0.0329	0.0742	0.0064** (0.0024)	0.0084	0.0096	0.0696
53	0.0222*** (0.0080)	0.0231	0.0180	-0.0817	-0.0009 (0.0032)	-0.0026	-0.0032	-0.0153
54	-0.0134*** (0.0018)	-0.0118	-0.0233	-0.0238	-0.0028*** (0.0009)	-0.0077	-0.0120	-0.0211
55	-0.0330*** (0.0029)	-0.0294	1.2380	-0.0287	-0.0137*** (0.0013)	-0.0236	-0.0746	-0.0345
56	0.0261*** (0.0048)	0.0431	0.0386	-0.3686	-0.0039*** (0.0011)	-0.0476	0.1958	-0.0383
57	0.0194*** (0.0005)	0.0220	0.0228	0.6212	0.0199*** (0.0015)	0.0194	0.0201	0.5356
58	0.0029*** (0.0006)	0.0046	0.0046	0.2674	-0.0039*** (0.0007)	-0.0055	-0.0055	-0.8974
59	0.0082*** (0.0010)	0.0098	0.0124	0.0452	0.0054*** (0.0009)	0.0092	0.0122	0.0379
60	0.0009 (0.0008)	0.0010	0.0020	0.0020	0.0030*** (0.0002)	0.0133	0.0127	-0.3128
61	-0.0051*** (0.0006)	-0.0051	-0.0053	-0.1413	-0.0006 (0.0007)	-0.0011	-0.0011	0.2677
62	-0.0006 (0.0006)	-0.0006	-0.0017	-0.0009	-0.0020*** (0.0005)	-0.0021	-0.0066	-0.0031
63	0.0299*** (0.0041)	0.1651	0.0308	-0.0379	-0.0020 (0.0058)	-0.0037	-0.0052	-0.0128
64	0.0057*** (0.0020)	0.0277	0.0145	-0.0304	-0.0085*** (0.0029)	-0.0133	-0.0199	-0.0398
65	0.0028*** (0.0002)	0.0025	0.0039	0.0073	0.0017*** (0.0003)	0.0020	0.0032	0.0051

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.24.2: Estimates of industry rates of factor augmentation from 2SLS regressions – VES production function, single equation

Industry	VES_1				VES_2			
	Regression coefficient	Parameters (neutrality assumption)			Regression coefficient	Parameters (neutrality assumption)		
	ξ_2^{VK}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)	ξ_2^{VL}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)
1	0.0211*** (0.0029)	0.0196	0.0443	0.0351	0.0162*** (0.0019)	0.0194	0.0486	0.0322
2	0.0014 (0.0013)	0.0030	0.0060	0.0059	-0.0089*** (0.0005)	-0.0258	-0.0371	-0.0845
3	-0.0034*** (0.0008)	-0.0464	0.0735	-0.0285	0.0115** (0.0045)	0.0637	0.0262	-0.0446
4	-0.0207*** (0.0075)	-0.1163	0.0416	-0.0306	0.0434*** (0.0023)	0.0708	0.0273	-0.0445
5	0.0057*** (0.0021)	0.0107	0.0115	0.1456	0.0061*** (0.0013)	0.0132	0.0195	0.0413
6	-0.0049*** (0.0017)	-0.0401	0.0261	-0.0158	0.0229** (0.0099)	-0.0492	0.0243	-0.0163
7	0.0049*** (0.0013)	0.0040	0.0058	0.0128	0.0010*** (0.0003)	0.0046	0.0133	0.0071
8	0.0020** (0.0008)	0.0029	0.0053	0.0063	-0.0010 (0.0009)	-0.0091	-0.0800	-0.0103
9	-0.0218*** (0.0064)	-1.7842	0.0229	-0.0226	0.0112*** (0.0010)	0.0462	0.0178	-0.0291
10	0.0034 (0.0063)	0.0046	0.0054	0.0285	0.0232*** (0.0021)	0.0342	0.0184	-0.0399
11	0.0007 (0.0018)	0.0008	0.0015	0.0019	0.0025** (0.0011)	0.0066	0.0113	0.0158
12	-0.0179*** (0.0066)	-0.0812	0.0398	-0.0267	0.0172*** (0.0024)	0.0884	0.0278	-0.0406
13	-0.0357** (0.0166)	-0.3068	0.1055	-0.0785	0.0197 (0.0135)	-0.1121	0.0733	-0.0443
14	-0.0114*** (0.0041)	-0.0303	0.0523	-0.0192	0.0146*** (0.0042)	0.5978	0.0269	-0.0281
15	-0.0054 (0.0044)	-0.0086	-0.0284	-0.0123	0.0165*** (0.0048)	0.0654	0.0297	-0.0543
16	0.0049** (0.0019)	0.0070	0.0091	0.0301	0.0098*** (0.0019)	0.0315	0.0217	-0.0694
17	-0.0046 (0.0060)	-0.0084	-0.0138	-0.0216	0.0071*** (0.0015)	0.0962	0.0347	-0.0543
18	0.0106** (0.0052)	0.0163	0.0181	0.1612	0.0124*** (0.0028)	0.0339	0.0362	0.5328
19	0.0051* (0.0026)	0.0082	0.0123	0.0245	0.0083*** (0.0014)	0.0185	0.0239	0.0807
20	-0.0137 (0.0123)	-0.0463	0.0247	-0.0161	0.0132*** (0.0023)	0.0881	0.0235	-0.0321
21	0.0245*** (0.0034)	0.0202	0.0195	-0.6005	0.0104*** (0.0018)	0.0196	0.0193	-1.1704
22	0.0020 (0.0042)	0.0014	0.0026	0.0033	0.0017 (0.0019)	0.0029	0.0046	0.0079
23	0.0004*** (0.0000)	0.0005	0.0007	0.0014	-0.0054*** (0.0011)	-0.0202	0.0462	-0.0141
24	-0.0085** (0.0040)	-0.0416	-0.4096	-0.0463	0.1001*** (0.0098)	-0.3386	0.0557	-0.0478
25	0.0357*** (0.0038)	0.0475	0.0293	-0.0762	0.0324*** (0.0068)	0.0363	0.0281	-0.1244
26	-0.0103*** (0.0028)	0.0812	0.0165	-0.0207	0.0040*** (0.0010)	0.0160	0.0119	-0.0467
27	0.0054** (0.0022)	0.0066	0.0136	0.0128	0.0120*** (0.0016)	0.0210	0.0269	0.0963
28	0.0004 (0.0028)	0.0004	0.0008	0.0009	-0.0005 (0.0023)	-0.0015	-0.0038	-0.0024
29	0.0182*** (0.0043)	0.0674	0.0318	-0.0603	0.0013 (0.0021)	0.0052	0.0067	0.0238
30	0.0235*** (0.0043)	0.0208	0.0247	0.1332	0.0184*** (0.0026)	0.0258	0.0268	0.7060
31	-0.0020 (0.0039)	-0.0184	0.0354	-0.0121	0.0005 (0.0064)	-0.0019	0.0099	-0.0016
32	0.0153*** (0.0024)	0.0130	0.0132	0.7410	0.0037*** (0.0005)	0.0119	0.0101	-0.0645
33	0.0106*** (0.0010)	0.0157	0.0315	0.0313	0.0313*** (0.0098)	0.0199	0.1069	0.0244

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Industry	VES$_1$				VES$_2$			
	Regression coefficient	Parameters (neutrality assumption)			Regression coefficient	Parameters (neutrality assumption)		
	ξ_2^{VK}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)	ξ_2^{VL}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)
34	0.0155*** (0.0044)	0.0667	0.0345	-0.0716	-0.0549* (0.0311)	0.0906	0.0353	-0.0578
35	0.0176*** (0.0026)	0.0208	1.9833	0.0210	0.0012 (0.0035)	0.0020	0.0064	0.0029
36	0.0135*** (0.0008)	0.0181	-0.1274	0.0159	-0.0043 (0.0028)	0.0187	-0.0066	0.0049
37	-0.0028 (0.0024)	-0.0088	-0.0129	-0.0276	-0.0044* (0.0023)	-0.0188	0.0272	-0.0111
38	0.0079*** (0.0027)	0.0590	0.0369	-0.0988	0.0034 (0.0046)	0.0095	0.0108	0.0799
39	0.0210*** (0.0039)	0.0585	0.0401	-0.1276	-0.0171 (0.0120)	-0.0541	0.0496	-0.0259
40	-0.0076*** (0.0016)	-0.0132	-0.0187	-0.0444	-0.0333*** (0.0015)	-0.3179	0.1515	-0.1026
41	0.0044*** (0.0010)	0.0108	0.0125	0.0814	-0.0053*** (0.0018)	-0.0126	-0.0249	-0.0254
42	0.0191* (0.0100)	-0.0395	-0.0609	-0.1124	-0.0038** (0.0019)	-0.0372	-0.0716	-0.0777
43	0.0089*** (0.0018)	0.0112	0.0121	0.1585	0.0161*** (0.0039)	0.0137	0.0145	0.2501
44	0.0061 (0.0041)	-0.0325	0.0145	-0.0100	0.0051*** (0.0014)	0.0148	-0.0793	0.0125
45	0.0008*** (0.0001)	0.0077	0.0152	0.0155	0.0023*** (0.0005)	0.0024	0.2691	0.0024
46	0.0016*** (0.0003)	0.0402	0.0248	-0.0647	-0.0079*** (0.0014)	0.1017	0.0336	-0.0502
47	0.0227*** (0.0020)	0.0688	0.0360	-0.0755	-0.0218*** (0.0021)	-0.1317	0.0933	-0.0546
48	0.0019 (0.0043)	0.0025	0.0030	0.0184	-0.0184*** (0.0021)	-0.0331	-0.0508	-0.0949
49	0.0222*** (0.0022)	0.0249	0.0238	-0.5295	0.0005 (0.0019)	0.0010	0.0011	0.0087
50	-0.0325* (0.0169)	-0.0564	0.0703	-0.0313	-0.0233*** (0.0046)	-0.0421	-0.1351	-0.0613
51	0.0306*** (0.0016)	0.0456	0.0335	-0.1260	-0.0110*** (0.0020)	-0.0456	-0.2663	-0.0551
52	0.0141*** (0.0006)	0.0210	0.0309	0.0658	0.0077*** (0.0024)	0.0096	0.0114	0.0599
53	0.2974 (0.5834)	-0.0405	0.7204	-0.0383	-0.0042 (0.0036)	-0.0191	-0.0334	-0.0447
54	-0.0102*** (0.0022)	-0.0082	-0.0139	-0.0200	-0.0023** (0.0009)	-0.0067	-0.0102	-0.0199
55	-0.0427*** (0.0039)	-0.0335	0.6097	-0.0318	-0.0138*** (0.0013)	-0.0244	-0.0795	-0.0353
56	0.0261*** (0.0056)	0.1097	0.0534	-0.1040	-0.0035*** (0.0010)	-0.0833	0.1162	-0.0485
57	0.0195*** (0.0005)	0.0229	0.0230	5.8790	0.0202*** (0.0017)	0.0196	0.0190	-0.6293
58	0.0048*** (0.0009)	0.0094	0.0098	0.1888	-0.0065*** (0.0010)	-0.0207	-0.0200	0.5991
59	0.0055*** (0.0015)	0.0099	0.0128	0.0434	0.0020 (0.0013)	0.0084	0.0111	0.0351
60	0.0013 (0.0010)	0.0013	0.0030	0.0024	0.0030*** (0.0002)	0.0128	0.0131	0.6287
61	-0.0059*** (0.0012)	-0.0061	-0.0063	-0.2368	0.0003 (0.0008)	0.0006	0.0006	-0.0242
62	0.0005 (0.0007)	0.0005	0.0014	0.0008	-0.0024*** (0.0007)	-0.0026	-0.0083	-0.0038
63	0.0309*** (0.0061)	-0.0956	0.0509	-0.0332	-0.0186** (0.0088)	-0.0535	0.0806	-0.0322
64	0.0071** (0.0030)	0.0907	0.0228	-0.0305	-0.0084*** (0.0045)	-0.0158	-0.0182	-0.1177
65	0.0022*** (0.0003)	0.0018	0.0028	0.0052	0.0005 (0.0005)	0.0006	0.0010	0.0013

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.24.3: Estimates of industry rates of factor augmentation from GIV regressions – VES production function, single equation

Industry	VES_1				VES_2			
	Regression coefficient	Parameters (neutrality assumption)			Regression coefficient	Parameters (neutrality assumption)		
	ξ_2^{VK}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)	ξ_2^{VL}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)
1	0.0087*** (0.0013)	0.0199	0.0316	0.0538	0.0105*** (0.0016)	0.0187	0.0562	0.0281
2	0.0000 (0.0003)	-0.0001	-0.0005	-0.0002	-0.0016*** (0.0003)	-0.0201	-0.0359	-0.0456
3	-0.0018*** (0.0006)	-0.0121	-0.0243	-0.0243	-0.0007 (0.0011)	-0.0015	-0.0025	-0.0042
4	0.0012 (0.0010)	0.0059	0.0089	0.0178	0.0115*** (0.0012)	0.0528	0.0289	-0.0636
5	0.0033*** (0.0007)	0.0133	0.0140	0.2524	0.0037*** (0.0007)	0.0160	0.0171	0.2345
6	-0.0027* (0.0014)	-0.0175	0.0414	-0.0123	0.0009 (0.0043)	0.0023	0.0029	0.0112
7	0.0002 (0.0002)	0.0012	0.0012	-0.1066	0.0004** (0.0002)	0.0063	0.0087	0.0235
8	0.0006* (0.0003)	0.0030	0.0053	0.0068	0.0012** (0.0005)	0.0094	0.0106	0.0812
9	0.0005 (0.0011)	0.0014	0.0025	0.0031	0.0069*** (0.0008)	0.0370	0.0169	-0.0312
10	0.0050*** (0.0013)	0.0120	0.0108	-0.1150	0.0087*** (0.0009)	0.0232	0.0156	-0.0474
11	0.0006** (0.0002)	0.0052	0.0062	0.0332	0.0011*** (0.0003)	0.0210	0.0212	2.5332
12	0.0017*** (0.0005)	0.0138	0.0167	0.0780	0.0025*** (0.0009)	0.0300	0.0184	-0.0474
13	0.0021 (0.0120)	0.0059	0.0087	0.0183	0.0134 (0.0112)	0.5823	0.1321	-0.1709
14	0.0002 (0.0004)	0.0013	0.0033	0.0022	0.0006 (0.0010)	0.0068	0.0069	0.4358
15	0.0039* (0.0020)	0.0132	0.0141	0.2067	0.0029*** (0.0007)	0.1040	0.0326	-0.0475
16	0.0009*** (0.0003)	0.0083	0.0099	0.0526	0.0016 (0.0011)	0.0243	0.0195	-0.0990
17	0.0026** (0.0012)	0.0065	0.0075	0.0465	0.0038*** (0.0009)	0.1092	0.0361	-0.0539
18	0.0094*** (0.0020)	0.0176	0.0234	0.0712	0.0059*** (0.0013)	0.0249	0.0296	0.1560
19	-0.0002 (0.0003)	-0.0045	-0.0080	-0.0102	0.0027** (0.0011)	0.0209	0.0303	0.0672
20	0.0042*** (0.0009)	0.0201	0.0207	0.7334	0.0038*** (0.0011)	0.0539	0.0248	-0.0460
21	0.0031*** (0.0011)	0.0100	0.0121	0.0582	0.0039*** (0.0010)	0.0156	0.0167	0.2249
22	-0.0007 (0.0015)	-0.0019	-0.0045	-0.0032	0.0033** (0.0016)	0.0085	0.0100	0.0601
23	-0.0002 (0.0007)	-0.0009	-0.0016	-0.0021	-0.0037*** (0.0009)	-0.0101	-0.1287	-0.0109
24	-0.0070* (0.0038)	-0.0314	-0.1348	-0.0409	0.0421*** (0.0059)	0.2944	0.0481	-0.0575
25	0.0064*** (0.0016)	0.0348	0.0246	-0.0836	0.0040 (0.0033)	0.0125	0.0194	0.0353
26	-0.0011 (0.0010)	-0.0035	-0.0143	-0.0046	0.0020*** (0.0008)	0.0122	0.0105	-0.0759
27	0.0007 (0.0005)	0.0046	0.0102	0.0084	0.0028*** (0.0008)	0.0280	0.0313	0.2651
28	0.0011 (0.0008)	0.0060	0.0087	0.0192	0.0006 (0.0008)	0.0047	0.0080	0.0111
29	0.0051*** (0.0010)	0.0226	0.0209	-0.2656	0.0046*** (0.0016)	0.0148	0.0160	0.2037
30	0.0053*** (0.0014)	0.0166	0.0218	0.0699	0.0075*** (0.0012)	0.0239	0.0257	0.3505
31	0.0091*** (0.0015)	0.0136	0.0212	0.0381	0.0128*** (0.0012)	0.0165	0.0221	0.0649
32	0.0014*** (0.0003)	0.0094	0.0105	0.0862	0.0019*** (0.0004)	0.0114	0.0103	-0.1125
33	0.0073*** (0.0006)	0.0120	0.0381	0.0176	0.0108*** (0.0011)	0.0118	0.0724	0.0141

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Industry	VES$_1$				VES$_2$			
	Regression coefficient	Parameters (neutrality assumption)			Regression coefficient	Parameters (neutrality assumption)		
	ξ_2^{VK}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)	ξ_2^{VL}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)
34	0.0217*** (0.0033)	0.0490	0.0373	-0.1559	0.0206*** (0.0060)	0.0333	0.0428	0.1498
35	0.0009** (0.0004)	0.0109	0.0244	0.0197	0.0032** (0.0012)	0.0090	0.0233	0.0148
36	0.0028*** (0.0003)	0.0191	0.0340	0.0435	0.0005 (0.0004)	0.0403	0.0102	-0.0136
37	0.0008 (0.0008)	0.0042	0.0069	0.0105	-0.0021 (0.0019)	-0.0193	0.0228	-0.0105
38	0.0012 (0.0009)	0.0125	0.0310	0.0208	0.0032 (0.0022)	0.0133	0.0169	0.0624
39	0.0093*** (0.0020)	0.0230	0.0349	0.0674	0.0074*** (0.0024)	0.0164	0.0337	0.0321
40	-0.0007 (0.0006)	-0.0042	-0.0053	-0.0198	-0.0044*** (0.0007)	0.1100	0.0614	-0.1389
41	0.0013** (0.0006)	0.0131	0.0146	0.1326	-0.0034*** (0.0012)	-0.0299	-0.1370	-0.0382
42	0.0064 (0.0047)	0.0176	0.0227	0.0787	-0.0011 (0.0016)	-0.0154	-0.0227	-0.0474
43	0.0038*** (0.0013)	0.0111	0.0120	0.1476	0.0040* (0.0020)	0.0179	0.0186	0.4952
44	0.0105*** (0.0019)	0.0476	0.0377	-0.1814	0.0027*** (0.0009)	0.0168	-0.1822	0.0153
45	0.0000** (0.0000)	0.0089	0.0082	-0.1122	0.0003*** (0.0001)	0.0028	-0.2281	0.0028
46	0.0002* (0.0001)	0.0123	0.0130	0.2307	-0.0007 (0.0005)	-0.0172	-0.0434	-0.0285
47	-0.0004** (0.0002)	-0.0144	-0.0235	-0.0370	-0.0018*** (0.0004)	-0.0515	-0.2080	-0.0684
48	-0.0009** (0.0004)	-0.0110	-0.0136	-0.0570	-0.0007* (0.0004)	-0.0102	-0.0118	-0.0735
49	0.0041*** (0.0007)	0.0222	0.0266	0.1337	-0.0006 (0.0014)	-0.0022	-0.0027	-0.0133
50	-0.0004 (0.0008)	-0.0047	-0.0077	-0.0124	-0.0032* (0.0018)	-0.0185	-0.0248	-0.0735
51	0.0007* (0.0004)	0.0081	0.0100	0.0418	-0.0011*** (0.0003)	-0.0317	-0.0869	-0.0498
52	0.0010*** (0.0002)	0.0159	0.0323	0.0314	-0.0004 (0.0004)	-0.0049	-0.0055	-0.0418
53	0.0223*** (0.0077)	0.0238	0.0180	-0.0739	-0.0010 (0.0033)	-0.0030	-0.0036	-0.0181
54	-0.0086*** (0.0013)	-0.0141	-0.0316	-0.0254	-0.0021** (0.0008)	-0.0088	-0.0147	-0.0221
55	-0.0115*** (0.0015)	-0.0235	-0.2522	-0.0259	-0.0073*** (0.0010)	-0.0213	-0.0606	-0.0330
56	0.0040* (0.0023)	0.0121	0.0190	0.0333	-0.0019** (0.0009)	-0.0538	0.1844	-0.0416
57	0.0028*** (0.0002)	0.0194	0.0384	0.0391	0.0015*** (0.0002)	0.0189	0.0478	0.0313
58	0.0005* (0.0003)	0.0020	0.0021	0.0386	-0.0014*** (0.0004)	-0.0033	-0.0033	-0.3313
59	0.0037*** (0.0004)	0.0097	0.0127	0.0418	0.0046*** (0.0007)	0.0094	0.0124	0.0385
60	0.0003* (0.0002)	0.0015	0.0044	0.0022	0.0009*** (0.0001)	0.0091	0.0137	0.0272
61	-0.0008*** (0.0002)	-0.0052	-0.0051	0.5250	-0.0006*** (0.0002)	-0.0039	-0.0037	0.0674
62	-0.0002 (0.0001)	-0.0008	-0.0023	-0.0012	-0.0004** (0.0002)	-0.0014	-0.0042	-0.0021
63	0.0223*** (0.0038)	0.1076	0.0286	-0.0389	0.0018 (0.0051)	0.0039	0.0043	0.0482
64	-0.0011* (0.0006)	-0.0083	-0.0340	-0.0109	-0.0024*** (0.0006)	-0.0128	-0.0781	-0.0154
65	0.0013*** (0.0001)	0.0032	0.0049	0.0092	0.0015*** (0.0002)	0.0026	0.0041	0.0073

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.24.4: Estimates of industry rates of factor augmentation from OLS regressions of differenced variables – VES production function, single equation

Industry	VES$_1$				VES$_2$			
	Regression coefficient	Parameters (neutrality assumption)			Regression coefficient	Parameters (neutrality assumption)		
	ξ_2^{VK}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)	ξ_2^{VL}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)
1	0.0107 (0.0080)	0.0245	0.0258	0.4921	0.0077 (0.0139)	0.0138	0.0729	0.0171
2	-0.0021 (0.0051)	-0.0037	-0.0207	-0.0045	-0.0081 (0.0057)	-0.0179	-0.0388	-0.0331
3	0.0033 (0.0063)	0.0061	0.0067	0.0625	0.0051 (0.0080)	0.0055	0.0107	0.0113
4	-0.0007 (0.0047)	-0.0013	-0.0021	-0.0033	0.0193** (0.0086)	0.0425	0.0329	-0.1454
5	0.0174 (0.0110)	0.0208	0.0211	1.4597	0.0190* (0.0098)	0.0284	0.0246	-0.1829
6	0.0079* (0.0047)	0.0164	0.0142	-0.1069	0.0133* (0.0069)	0.0145	0.0148	1.0184
7	0.0057 (0.0038)	0.0060	0.0069	0.0470	0.0029 (0.0025)	0.0109	0.0135	0.0565
8	0.0022 (0.0044)	0.0027	0.0043	0.0072	0.0091* (0.0047)	0.0217	0.0166	-0.0706
9	0.0073*** (0.0024)	0.0109	0.0111	0.4603	0.0125** (0.0061)	0.0240	0.0159	-0.0469
10	0.0101 (0.0066)	0.0117	0.0105	-0.1071	0.0167** (0.0066)	0.0205	0.0147	-0.0520
11	0.0054* (0.0028)	0.0071	0.0082	0.0571	0.0044 (0.0031)	0.0180	0.0162	-0.1587
12	0.0087*** (0.0033)	0.0141	0.0157	0.1332	0.0047 (0.0047)	0.0233	0.0181	-0.0816
13	0.0420*** (0.0109)	0.0437	0.0660	0.1290	0.0206* (0.0114)	0.0234	0.0934	0.0312
14	-0.0025 (0.0036)	-0.0041	-0.0098	-0.0071	-0.0008 (0.0065)	-0.0024	-0.0033	-0.0093
15	0.0136 (0.0097)	0.0241	0.0199	-0.1142	0.0180** (0.0086)	0.1423	0.0423	-0.0602
16	0.0069** (0.0034)	0.0107	0.0120	0.0955	0.0018 (0.0075)	-0.0393	-0.0154	0.0253
17	0.0103*** (0.0035)	0.0116	0.0123	0.1957	0.0069 (0.0044)	0.0195	0.0166	-0.1110
18	0.0105 (0.0072)	0.0111	0.0176	0.0305	0.0133** (0.0064)	0.0199	0.0260	0.0852
19	0.0050 (0.0039)	0.0100	0.0135	0.0388	-0.0046 (0.0080)	-0.0555	0.0138	-0.0110
20	0.0168*** (0.0053)	0.0222	0.0244	0.2514	0.0061 (0.0049)	0.0289	0.0199	-0.0633
21	0.0058 (0.0047)	0.0063	0.0087	0.0232	0.0099** (0.0049)	0.0125	0.0151	0.0725
22	0.0040 (0.0034)	0.0070	0.0092	0.0291	0.0104 (0.0074)	0.0179	0.0129	-0.0463
23	0.0036 (0.0050)	0.0037	0.0053	0.0127	0.0046 (0.0046)	0.0058	0.0077	0.0234
24	-0.0223 (0.0178)	-0.0588	0.0645	-0.0308	0.0520* (0.0271)	0.1085	0.0402	-0.0638
25	-0.0017 (0.0034)	-0.0050	-0.0113	-0.0088	0.0094 (0.0094)	0.0656	0.1191	0.1462
26	0.0056* (0.0032)	0.0092	0.0099	0.1399	-0.0010 (0.0064)	-0.0058	-0.0178	-0.0086
27	0.0061 (0.0037)	0.0091	0.0152	0.0228	0.0040 (0.0050)	0.0174	0.0259	0.0525
28	0.0092* (0.0053)	0.0100	0.0127	0.0460	0.0031 (0.0050)	0.0054	0.0086	0.0147
29	0.0246** (0.0104)	0.0306	0.0334	0.3628	0.0176* (0.0096)	0.0265	0.0281	0.4714
30	0.0148* (0.0081)	0.0163	0.0211	0.0712	0.0183** (0.0072)	0.0228	0.0240	0.4535
31	0.0167 (0.0107)	0.0192	0.0180	-0.2977	0.0151 (0.0108)	0.0166	0.0240	0.0539
32	0.0123** (0.0052)	0.0160	0.0212	0.0657	0.0036 (0.0039)	0.0091	0.0104	0.0690
33	0.0043 (0.0048)	0.0045	0.0074	0.0117	0.0048 (0.0050)	0.0049	0.0097	0.0098

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Industry	VES$_1$				VES$_2$			
	Regression coefficient	Parameters (neutrality assumption)			Regression coefficient	Parameters (neutrality assumption)		
	ξ_2^{VK}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)	ξ_2^{VL}	ζ (Hicks-neut.)	ζ_L (Harrod-neut.)	ζ_K (Solow-neut.)
34	0.0214 (0.0155)	0.0289	0.0542	0.0618	0.0246 (0.0189)	0.0266	0.0687	0.0434
35	0.0101 (0.0063)	0.0130	0.0288	0.0237	0.0060 (0.0075)	0.0064	0.0107	0.0160
36	0.0129*** (0.0048)	0.0159	0.0258	0.0412	-0.0033 (0.0041)	-0.0903	-0.0277	0.0400
37	0.0107*** (0.0031)	0.0179	0.0196	0.2125	-0.0026 (0.0113)	-0.0120	0.0270	-0.0083
38	-0.0023 (0.0061)	-0.0066	-0.0365	-0.0080	0.0004 (0.0131)	0.0006	0.0012	0.0011
39	0.0075 (0.0059)	0.0090	0.0210	0.0158	0.0104 (0.0068)	0.0107	0.0252	0.0187
40	-0.0015 (0.0052)	-0.0033	-0.0040	-0.0171	-0.0257*** (0.0076)	0.1068	0.0668	-0.1786
41	0.0043 (0.0038)	0.0113	0.0132	0.0766	-0.0118* (0.0070)	-0.0394	0.4590	-0.0363
42	0.0236 (0.0226)	0.0332	0.0373	0.3005	-0.0069 (0.0137)	-0.0331	-0.0450	-0.1257
43	0.0026 (0.0074)	0.0032	0.0041	0.0157	0.0015 (0.0119)	0.0026	0.0038	0.0084
44	0.0456** (0.0212)	0.0736	0.0349	-0.0664	0.0068 (0.0114)	0.0164	-0.0705	0.0133
45	0.0007*** (0.0002)	0.0134	0.0135	1.5118	0.0022 (0.0019)	0.0024	0.2063	0.0025
46	0.0008 (0.0013)	0.0059	0.0071	0.0356	-0.0001 (0.0061)	-0.0002	-0.0005	-0.0004
47	0.0037 (0.0037)	0.0062	0.0114	0.0134	-0.0126** (0.0049)	-0.0698	-0.6225	-0.0786
48	0.0016 (0.0058)	0.0016	0.0019	0.0104	-0.0013 (0.0056)	-0.0015	-0.0017	-0.0139
49	0.0004 (0.0043)	0.0006	0.0013	0.0010	-0.0206*** (0.0053)	-0.0371	0.6058	-0.0350
50	0.0065 (0.0088)	0.0075	0.0103	0.0271	-0.0068 (0.0077)	-0.0136	-0.0146	-0.1883
51	0.0197*** (0.0046)	0.0255	0.0281	0.2718	-0.0067* (0.0035)	-0.0334	-0.0921	-0.0525
52	0.0139*** (0.0042)	0.0257	0.0381	0.0786	-0.0030 (0.0056)	-0.0073	-0.0063	0.0475
53	0.0049 (0.0063)	0.0049	0.0066	0.0193	0.0042 (0.0060)	0.0045	0.0060	0.0174
54	-0.0153*** (0.0046)	-0.0158	-0.0442	-0.0247	-0.0097* (0.0050)	-0.0130	-0.0290	-0.0235
55	-0.0066 (0.0042)	-0.0069	-0.0134	-0.0140	-0.0041 (0.0041)	-0.0047	-0.0075	-0.0130
56	0.0195* (0.0098)	0.0216	0.0297	0.0792	-0.0054 (0.0060)	-0.0246	0.3765	-0.0231
57	0.0149*** (0.0045)	0.0152	0.0316	0.0292	0.0132*** (0.0046)	0.0138	0.0318	0.0243
58	0.0006 (0.0038)	0.0007	0.0009	0.0036	-0.0015 (0.0057)	-0.0015	-0.0020	-0.0062
59	0.0084* (0.0045)	0.0088	0.0103	0.0605	0.0082* (0.0045)	0.0089	0.0106	0.0570
60	0.0007 (0.0034)	0.0008	0.0010	0.0027	0.0023 (0.0025)	0.0076	0.0073	-0.2152
61	-0.0041 (0.0030)	-0.0041	-0.0042	-0.4772	-0.0023 (0.0028)	-0.0029	-0.0028	0.0645
62	-0.0015 (0.0012)	-0.0015	-0.0047	-0.0023	-0.0021* (0.0011)	-0.0021	-0.0068	-0.0031
63	0.0030 (0.0095)	0.0054	0.0058	0.0807	-0.0031 (0.0121)	-0.0037	-0.0052	-0.0129
64	-0.0030 (0.0048)	-0.0043	-0.0123	-0.0066	-0.0062 (0.0053)	-0.0067	-0.0257	-0.0091
65	0.0023** (0.0010)	0.0023	0.0049	0.0045	0.0022** (0.0010)	0.0022	0.0047	0.0043

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

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Table 3.25: Simple and value-added weighted averages of industry-level estimates in VES production function normalized system estimates

Equation		Method	
		NLSUR	**GMM**
VES_L	υ, SA	0.6236	0.0697
	υ, WA	0.6061	0.2761
	ζ_K, SA	0.0246	0.0400
	ζ_K, WA	0.0055	0.0083
	ζ_L, SA	0.0020	-0.0029
	ζ_L, WA	0.0032	0.0013
	Implied σ_0, SA	1.9425	2.9626
	Implied σ_0, WA	0.7645	2.0357
VES_K	υ, SA	0.2269	-1.3347
	υ, WA	0.3539	-2.2254
	ζ_K, SA	-0.0204	0.0081
	ζ_K, WA	-0.0070	0.0075
	ζ_L, SA	0.0157	0.0053
	ζ_L, WA	0.0102	-0.0073
	Implied σ_0, SA	0.6913	0.8314
	Implied σ_0, WA	0.5986	0.9045

Note: SA and WA denote single average and weighted average, respectively.

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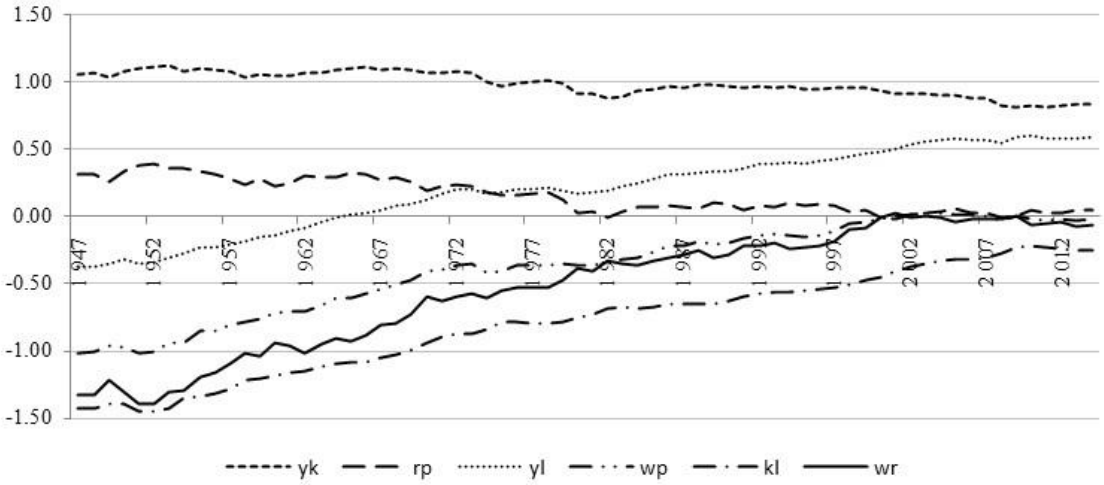

Figure 3.1: Variables used in the aggregate regressions

Source: KLEMS database and own calculations

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4. Biased technological change and the labour share decline in OECD countries

4.1. Introduction

Although the debate remains open due to technical considerations such as the treatment of capital depreciation, indirect taxes, and housing (Rognlie, 2016; Bridgman, 2018; Cette et al., 2019), the apportionment of mixed income (Cette et al., 2019; Gutiérrez and Piton, 2020), and intangible capital (Koh et al., 2020), the consensus is that the labour share has declined in many countries in recent decades. Brada (2013) reviews the literature on the functional distribution of income in developed and developing countries and reports that the labour share increased from the end of World War II until the late 1970s, and then declined until now. Blanchard (1998) was the first to report a decline in the labour share in several European countries. Jones (2003) reports empirical evidence of an increase in the capital shares in OECD countries. Rodriguez and Jayadev (2013) estimate a declining trend in the labour share using an equally-weighted average of 129 countries. Karabarbounis and Neiman (2014), using a dataset of 59 countries, report that the labour shares in the corporate sector have declined significantly in most countries since the early 1980s. This downward trend was confirmed by Piketty and Zucman (2014), who also find an increase in the capital share. Cho et al. (2017) reported a significant decline in the gross labour share since the mid-1970s in OECD countries, while the net labour share remained within its historical range. Elsby et al. (2013) show that the labour share decreased in most US industries from 1987 to 2011. Del Río and Lores (2019) report that the labour share decreased in 44 of 65 US private industries between 1998 and 2015 and argue that, despite this heterogeneity, changes in the industrial composition of the US economy do not account for changes in the US labour share. Oberfield and Raval (2021) report that the decline in the US manufacturing labour share was greater than the decline in the overall economy labour share. Using data from European firms in 19 industries over the period 2011-2019, Bellocchi et al. (2023) find that the labour share in the European Union has fallen both between and within firms.

In this work, we estimate the elasticities of capital-labour substitution and factor augmentation rates for a set of 29 OECD countries for two purposes. On the one hand, we assess whether technological change is capital- or labour-biased, which implies assessing whether the gross complementarity ($\sigma < 1$) or the gross substitutability ($\sigma > 1$) hypothesis between capital and labour holds, and whether technological change is net labour-augmenting or net

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capital-augmenting. On the other hand, we assess the ability of technological bias, capital deepening and changes in the firm labour wedge to account for the evolution of the labour share and, in particular, its decline in the last decades.

A relevant contribution of the present study is that we apply the normalized supply-side system approach developed by Klump et al. (2007) to estimate the elasticity of capital-labour substitution and the rates of factor-augmenting technological change for 29 OECD countries, allowing us to provide a comparative analysis of the results. Previous works have typically applied the methodology to a single country (an exception is the work of Mućk, 2017, who analyses 12 advanced economies). The main advantages of a system approach (rather than a single equation approach) are the ability to simultaneously include optimising behaviour (from the first-order conditions) and technology (from the production function); in addition, the inclusion of cross-equation parameter constraints increases the degrees of freedom and may improve parameter identification. Normalization enhances these advantages by allowing some parameters to be preset, thus simplifying the estimation of the elasticity of substitution and factor augmentation rates (León-Ledesma et al., 2010). Normalization consists in expressing the production relations in an indexed number form (Klump et al., 2012, p. 770). The importance of normalizing CES production functions stems from the seminal work of de La Grandville (1989), further elaborated by Klump and de La Grandville (2000), Klump and Preissler (2000) and de La Grandville and Solow (2006).

We find that, for most OECD countries, the elasticity of substitution is likely to be less than one and technological change is net labour-augmenting, implying that technological change is capital-biased. The former conclusion has also been obtained in recent studies (Table 4.1) not only for the US economy (e.g. Klump et al., 2007; Herrendorf et al., 2015; Del Río and Lores, 2019), but also for different geographical scopes (e.g. Klump et al., 2008; Mallick, 2012a; Bellocchi and Travaglini, 2023). Moreover, the net labour-augmentation result is also consistent with other studies focusing on the American economy (e.g. Young, 2013; León-Ledesma et al., 2015) or with different geographical scopes (e.g. Luoma and Luoto, 2010, for Finland, or Mućk, 2017, for 12 advanced economies, who also estimated negative rates of capital-augmenting technological change).

[TABLE 4.1]

Despite the strong capital deepening observed in all OECD countries, the prevailing finding of net labour-augmentation is reflected in a decline in the effective capital-labour ratio for most

OECD countries, which, in a context of gross complementarity, accounts for a large part of the decline in the labour share. Technological change bias thus appears to be the key factor accounting for the decline in the labour share, rather than capital deepening or changes in the firm labour wedge. Indeed, we find that capital deepening worked in the opposite direction, contributing to an increase in the labour share, and that the contribution of the firm labour wedge to the decline in the labour wedge was negligible. On average, the bias of technological progress contributed to reducing the labour share by about 0.33 per cent per year and capital deepening contributed to increasing it by about 0.28 per cent per year. Moreover, on average, in countries where the decline rate of labour share was greater, the rate of labour- (resp. capital-) biased technological change was smaller (resp. greater), while the contribution of capital deepening was greater.

Looking at the whole trend movement of the labour share and not just its decline, we find that the perfect competition model with capital-biased technological change accurately captures the trend component of the labour share in seven OECD countries: Australia, Belgium, Ireland, Spain, Sweden, the United Kingdom, and the United States. Moreover, we also find that in these countries, the firm labour wedge appears to have played a minor role in accounting for the trend component of the labour share. For the Czech Republic, the perfect competition model also correctly adjusts the trend component of the labour share, but according to our estimates, technological change in this country was labour-biased. The perfect competition model with only neutral technological change (i.e. without biased technological change) performs quite well for the United Kingdom, the Czech Republic and Sweden, although taking account of technological bias improves the fit.

It is worth highlighting that the perfect competition model has limited predictive capacity regarding the evolution of the functional distribution of income in the two largest euro area economies, namely France and Germany. In these countries, as well as in Italy, Japan and Canada, the firm labour wedge seems to have played a significant, even prominent role in accounting for the evolution of the trend component of the labour share. The same applies to other European countries: Finland, Latvia, Lithuania, Luxembourg, the Netherlands, Slovakia and Slovenia.

Since approximately 2008, the firm labour wedge has been on a downward trajectory in numerous countries. In particular, it underwent a pronounced decline in eighteen countries (Austria, Canada, the Czech Republic, Estonia, France, Germany, Japan, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Slovenia,

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Spain, and the United States) and exhibited a discernible increase in only two (Greece and Ireland). In many countries, this decrease coincides with an increase, or at least a stabilization, in the labour share. The analysis therefore suggests that in many countries the reduction in the firm labour wedge in recent years has counteracted the negative effect of capital-biased technical change on the labour share.

Focusing on the United States, it is clear that the decrease in the firm labour wedge contributed to halting the decline in the labour share from around 2011. Using firm-level data, some works find an increase in the labour wedge of US firms in recent decades (see Miller, 2024). In particular, De Loecker et al. (2020) find that the US firm labour wedge has increased since the early 1980s and that the increase has intensified since the Great Recession. However, our results do not fully support those of these authors. We find that the US firm labour wedge increased in the 1970s and the first decade of this century, but declined in the 1980s and from around 2012.

The labour wedge is usually defined as the gap between the firm's marginal product of labour and the household's marginal rate of substitution, but it reflects both the gap between the firm's marginal product of labour and the real wage, which Karabarbounis (2014) calls the firm labour wedge, and the gap between the real wage and the household's marginal rate of substitution, which he calls the household labour wedge. The firm labour wedge includes all factors that deviate the wage rate from the calculated marginal productivity of labour; taxes, mark-ups or adjustment costs would be the most obvious examples, but we should also recognise other less obvious ones, such as model specification errors or measurement errors. The firm labour wedge is therefore a black box that can be filled with a wide variety of concepts (see Gali et al., 2007). However, an important set of factors potentially included in the firm labour wedge relate to market frictions and distortions.

Our results therefore suggest that these market frictions and distortions might have played a relatively important role in the trend adjustment of the labour share in Japan, Canada and most European countries, including the three largest euro area economies (France, Germany and Italy). However, for the Anglo-Saxon economies of the US, Australia and the UK, as well as for some European countries (Belgium, the Czech Republic, Spain and Sweden), competitive forces appear to be more important.

The remainder of this essay is organised as follows. Section 4.2 contextualizes our work. Section 4.3 describes the production function and the corresponding first-order conditions that will be used to estimate the elasticities of substitution and rates of technological change, as well

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as the econometric estimation framework. Section 4.4 describes the data used in the estimations, while the estimation results are presented and discussed in Section 4.5. Section 4.6 analyses the cross-country relationship between the decline in the labour share and technological bias. Section 4.7 assesses the suitability of the neoclassical model for predicting changes in the labour share across countries. Finally, a summary of the main results is presented in Section 4.8.

4.2. The functional distribution of income: capital deepening, technological bias, or firm labour wedge

According to the neoclassical economic theory, movements in the functional distribution of income can be driven by changes in capital intensity, the direction of technological change or changes in the firm labour wedge. Moreover, the elasticity of substitution between capital and labour, which plays an important role in a wide range of topics, is a key variable in determining the response of the functional distribution of income to these changes; indeed, the concept itself was first introduced by Hicks (1932, p. 117) to study how the functional distribution of income changes with an increase in the supply of any factor: *"An increase in the supply of any factor will increase its relative share (i.e., its proportion of the National Dividend) if its "elasticity of substitution" is greater than unity"*.

Given an arbitrary production function with constant returns to scale, output is given by $Y_t = f(k_t)A_t^L L_t$, where $k_t = A_t^K K_t / A_t^L L_t$ represents the effective capital-labour ratio. The labour share is $s_t = \mu_t^{-1} \frac{f(k_t) - k_t f'(k_t)}{f(k_t)}$, where μ_t is the firm labour wedge. Given the definition of the elasticity of capital-labour substitution $\sigma(k_t) = -\frac{f'(k_t)[f(k_t) - k_t f'(k_t)]}{k_t f''(k_t) f(k_t)}$, then the evolution of the labour share, $d\ ln(s_t)$, can be expressed as

$$d\ ln(s_t) = (1 - s_t)\left[\frac{1 - \sigma(k_t)}{\sigma(k_t)}\right] d\ ln\ (k_t) - d\ ln(\mu_t), \tag{30}$$

where $d\ ln\ (k_t)$ is equal to the rate of capital deepening minus the rate of net labour-augmenting technological change,

$$d\ ln\ (k_t) = d\ ln\ (K_t/L_t) - d\ ln\left(\frac{A_t^L}{A_t^K}\right). \tag{31}$$

Therefore, if capital and labour are gross substitutes (complements), i.e., $\sigma > 1$ ($\sigma < 1$), then the labour share decreases (increases) with the effective capital-labour ratio. The rate of change of the effective capital-labour ratio depends positively on the rate of capital deepening and

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negatively on the rate of net labour-augmenting technological change. If $d\ ln\left(\frac{A_t^L}{A_t^K}\right)$ is greater (resp. less) than zero, technological change is said to be net labour- (resp. capital-) augmenting. Irrespective of the elasticity of capital-labour substitution, an increase in the firm labour wedge reduces the labour share. When the elasticity of capital-labour substitution is equal to one (the Cobb-Douglas case), the labour share does not depend on the effective capital-labour ratio and only changes in the firm labour wedge affect the labour share.

When technological change increases the relative share of capital (resp. labour), it is capital (resp. labour)-biased. Thus, technological change is capital (resp. labour)-biased if $\sigma < 1$ (resp. $\sigma > 1$), and $d\ ln\left(\frac{A_t^L}{A_t^K}\right) > 0$ or if $\sigma > 1$ (resp. $\sigma < 1$) and $d\ ln\left(\frac{A_t^L}{A_t^K}\right) < 0$. That is, if capital and labour are gross complements (resp. substitutes), then, if technological change increases labour efficiency faster than capital efficiency, technological change is capital (resp. labour) biased and reduces (resp. increases) the labour share.

Equations (30) and (31) can be used as a guide to examine different explanations for the decline in the labour share observed in many countries in recent decades:

i. Many works have attributed the decline in the labour share to changes in the firm labour wedge, reflecting market frictions and distortions, such as imperfect competition or search frictions, and labour market institutions and policies. The literature has highlighted the role of changes in the worker's bargaining power (Blanchard and Giavazzi, 2003), the role of product market competition (Azmat et al., 2012; Autor et al., 2020; Barkai, 2020) and labour market institutions (Bentolila and Saint-Paul, 2003; Bental and Demougin, 2010). Recently, Ibarra and Ros (2023) find that higher unemployment, the erosion of union density and informal labour productivity (domestic factors that weaken workers' bargaining power) play an important role in accounting for the decline of the manufacturing labour share in Mexico after 2002. Some studies of the Chinese economy indicate that alterations in economic policies that influence the firm labour wedge could have had a considerable effect on the labour share. In their study of the Chinese economy, Cheng et al. (2024) identify an increase in the Chinese labour share resulting from improvements in competition policy. Similarly, Si et al. (2024) find that an increase in banking competition led to an increase in the Chinese labour share. Furthermore, Yu et al. (2023) conclude that the implementation of the Social Insurance Law led to a notable reduction in the labour share of Chinese firms.

ii. Several studies have argued that the labour share decline in many countries was caused by capital deepening in a context in where capital and labour are gross substitutes, i.e., $\sigma >$

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1. Karabarbounis and Neiman (2014) argued that the decline in the relative price of investment goods induced capital deepening, which, combined with an elasticity of capital-labour substitution greater than one (around 1.25), implied the observed decline in the labour share. Focusing on the eight largest developed economies, Piketty and Zucman (2014) also linked the decline to an increase in the capital-output ratio (which has increased more than the capital share and implied a decline in the average return to domestic capital), together an elasticity of capital-labour substitution greater than unity. Piketty (2014) even mentions that the historical elasticity of capital-labour substitution should be in the range of 1.3 to 1.6. Bellocchi and Travaglini (2023), while estimating elasticities of capital-labour substitution below unity for six countries (UK, USA, Spain, Italy, France and Germany), attribute a good part of the decline in the labour share in these countries to capital deepening because they assume a production function with a variable and increasing elasticity of capital-labour substitution with capital intensity.[65]

iii. Technological change bias as a possible explanation for the decline in the labour share has received attention from some authors. The dominant conclusion of empirical studies has been an elasticity of capital-labour substitution of less than one (see Chirinko, 2008). Under gross complementarity, net labour-augmenting technological change is capital-biased and, if it is sufficiently rapid, it offsets capital deepening and reduces the labour share. Therefore, strong net labour-augmenting technological change makes it possible to reconcile capital deepening with the decline in the labour share in the context of gross complementarity, as the effective capital-labour ratio falls despite the increase in capital intensity. Lawrence (2015) argues that, despite the increase in capital intensity of the US economy, the effective capital-labour ratio has declined because of faster labour-augmenting technological change in the sectors and industries that account for most of the decline in the labour share. Del Río and Lores (2019) also find that the decline in the US labour share was mostly caused by the decline in the effective capital-labour ratio due to a large decline in capital efficiency. Alvarez-Cuadrado et al. (2018) develop a two-sector model with different, but less than unity, elasticities of capital-labour substitution and find that net labour-augmenting technological change and structural change drove the decline in the labour share in several developed economies (including the US). Guimarães and Mazeda Gil (2022) conclude that technological factors are the more promising candidate to explain the fall in the US labour share. Zhang et al. (2024) identify a reduction in the labour share in Chinese firms following

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[65] They also find that increasing markups played a relevant role in accounting for the decline in the labour share.

the application of industrial robots, and Yang et al. (2023) find a comparable impact of digital transformation.

Economic globalization interacts with the three drivers of the evolution of the functional distribution of income described above. Globalization can influence the capital intensity of firms, the firm labour wedge and the direction of technological change in very different ways. Using data for a large sample of companies from six European countries, Perugini et al. (2017) find that the labour share is lower in exporting companies, in firms with greater foreign direct investment or in firms with more intense offshoring. Their results suggest that globalisation has played an important role in accounting for the decline in the labour share. Focusing on the Chinese economy, Zhang et al. (2017) analyse the impact of road infrastructure on labour share. The expansion of road infrastructure is both a sign and a driver of greater economic integration. Zhang et al. (2017) find that road infrastructure has a negative impact on the labour share. Using the standard Heckscher-Ohlin-Samuelson model, Decreuse and Maarek (2017) analyse the impact of globalisation on the labour share. They find that trade openness with developing countries reduces the labour share in rigid wage countries because it induces a reallocation of factors towards capital-intensive sectors in rigid wage countries, but does not affect the labour share in free wage countries. Like us, they find differences between some Anglo-Saxon countries and continental European countries. In particular, using the KLEMS dataset for 8 OECD countries over the period 1970-2005, they find that the weight of capital-intensive sectors increased substantially in continental European countries, while it did not change or even decreased in the United States and the United Kingdom.

We find that the main cause of the decline in the labour share has been capital-biased technological change. However, we also find that the firm labour wedge has played an important role in accounting for the evolution of the labour share in many OECD countries. In particular, the decline in the firm labour wedge since around 2008 has contributed to increasing or at least stabilising the labour share in many OECD countries. Parisi (2017) assesses the impact of social policies and labour market institutions on the labour share for a group of countries with different labour market and education structures, and welfare regimes. She finds significant differences between four groups of developed countries: Continental European countries, Southern European countries, Scandinavian countries and Anglo-Saxon countries. According to her findings, the first three groups of countries have been more successful in halting the decline in the labour share through different types of social policies. Moreover, after

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the financial crisis of 2007, social policies, especially welfare spending, played an important role in preserving labour income in many countries.

4.3. Model specification and estimation methods

The normalized Constant Elasticity of Substitution (CES) production function including the factor efficiency parameters is given by:

$$Y_t = Y_0 \left[(1 - s_0) \left(\frac{A_t^K K_t}{A_0^K K_0} \right)^{\psi} + s_0 \left(\frac{A_t^L L_t}{A_0^L L_0} \right)^{\psi} \right]^{\frac{1}{\psi}}$$

where s_0 is the labour share in the normalization point, and the elasticity of substitution between capital and labour is $\sigma = \frac{1}{1-\psi}$ with $\psi < 1$.

The first-order conditions for capital and labour state that the real rental prices of capital and labour ($\frac{R_t}{P_t}$ and $\frac{W_t}{P_t}$, respectively) are equal to their marginal productivities. Therefore, the normalized first-order conditions for capital and labour are

$$\frac{R_t}{P_t} = (1 - s_0) \left(\frac{\frac{Y_t}{Y_0}}{\frac{K_t}{K_0}} \right)^{1-\psi} \frac{Y_0}{K_0} \left(\frac{A_t^K}{A_0^K} \right)^{\psi}$$

and

$$\frac{W_t}{P_t} = s_0 \left(\frac{\frac{Y_t}{Y_0}}{\frac{L_t}{L_0}} \right)^{1-\psi} \frac{Y_0}{L_0} \left(\frac{A_t^L}{A_0^L} \right)^{\psi}.$$

The definition of the normalization point is particularly important for the quality of the estimation results. Following Klump et al. (2012), we use sample averages (geometric for growing variables, such as capital and labour, and arithmetic for approximately stationary variables, such as the capital income share) to set the normalization point. However, as the CES production function is non-linear, the sample average of production may not be the same as the level of production implied by the production function using sample averages of each variable. Therefore, Klump et al. (2007) introduced an additional estimated parameter ξ, called the normalization constant and whose expected value is around one.[66] The normalization point is

[66] Note that ξ would be exactly equal to 1 in the case of the log-linear Cobb-Douglas production function.

therefore defined as $Y_0 = \xi\bar{Y}$, $K_0 = \bar{K}$, $L_0 = \bar{L}$, $s_0 = \bar{s}$ and $t_0 = \bar{t}$, where the bar denotes the sample average (geometric in the case of the first three variables, and arithmetic in the case of the last two). As suggested by León-Ledesma et al. (2010) and Klump et al. (2012), a natural choice for the normalization constant is one. If the estimated values of the distribution parameter and the normalization constant differ significantly from their initial values, the estimation results should be questioned. In this sense, normalization is also useful as a means of *a posteriori* validation of the estimated parameters.

Assuming that technological change is represented by factor augmentation at constant exponential rates $\frac{A_t^K}{A_0^K} = e^{\zeta_K(t-t_0)}$ and $\frac{A_t^L}{A_0^L} = e^{\zeta_L(t-t_0)}$, the logarithmic forms of the normalized CES production function and the first-order profit maximisation conditions can be expressed as follows:

$$y_t - \bar{y} = ln\,(\xi) + \frac{1}{\psi} ln\left[(1-\bar{s})\left(e^{\zeta_K(t-\bar{t})}\frac{K_t}{\bar{K}}\right)^{\psi} + \bar{s}\left(e^{\zeta_L(t-\bar{t})}\frac{L_t}{\bar{L}}\right)^{\psi}\right]$$

$$yk_t - \overline{yk} = -\sigma\left[ln\,(1-\bar{s}) + \overline{yk}\right] + (1-\sigma)\,ln(\xi) + \sigma\, rp_t + (1-\sigma)\zeta_K(t-\bar{t})$$

$$yl_t - \overline{yl} = -\sigma\left[ln(\bar{s}) + \overline{yl}\right] + (1-\sigma)\,ln(\xi) + \sigma wp_t + (1-\sigma)\zeta_L(t-\bar{t})$$

where *y*, *yk*, *yl*, *rp* and *wp* represent, respectively, the natural logarithms of *Y*, *Y/K*, *Y/L*, *R/P* and *W/P* respectively. Table 4.2.1 and Table 4.2.2 display the summary statistics for these variables. The next section describes how the data were constructed.

[TABLES 4.2.1 AND 4.2.2]

The estimation is carried out using the Non-Linear Seemingly Unrelated Regression (NLSUR) approach, which is the most used estimation method in the recent literature on this topic (e.g. Klump et al., 2007, 2008; Stewart and Li, 2018; Jiang and León-Ledesma, 2018). Since the first-order conditions are obtained from the same production function, it seems plausible to admit that their errors terms are correlated, so the equations might be seemingly unrelated (Berthold et al., 2002). Furthermore, due to the endogeneity problem within the production function framework (e.g. Petrin et al., 2004; Ackerberg et al., 2006; Horrace et al., 2016), we will also consider the GMM estimator, using the first lags of the dependent and independent variables and the time trend as instruments (Young, 2013; León-Ledesma et al., 2015).

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4.4. Data

The estimation is carried out for the 29 OECD economies listed in Table 4.2.1 (as well as in Table 4.2.2) covering the longest period span for which all data are available for each country until the end of 2019 (before the Covid-19 pandemic). Seasonally adjusted data at the quarterly frequency are taken mainly from the OECD Quarterly National Accounts (QNA) database: in particular, real output (Y_t) is the difference between nominal gross domestic product and taxes less subsidies on production and imports,[67] while real investment (I_t) is derived from gross fixed capital formation, both deflated by the price index of gross output (P_t). The real labour stock (L_t) corresponds to the total hours worked; when this information was not available in the QNA database, it was calculated from the OECD Economic Outlook 110 by multiplying hours worked per worker, total economy (HRS) by total employment, national accounts basis (ET_NA) or, when the latter information was not available, by total employment, labour force survey basis (ET).[68]

To determine total labour compensation, $W_t L_t$, we impute to self-employed workers the same hourly wage received by employees (Kravis, 1959; Giandrea and Sprague, 2017). More precisely, using the QNA variables compensation of employees (CE_t) and hours worked by employees (HE_t), total labour compensation is equal to:[69] $W_t L_t = CE_t \times \frac{L_t}{HE_t}$. Consequently, the labour share in output is obtained as: $s_t = \frac{W_t L_t}{P_t Y_t}$.

To construct the series of capital, we apply the perpetual inventory method (PIM), proposed by Goldsmith (1951) and subsequently used and extended in several studies (e.g. Christensen and Jorgenson, 1969, 1973; Young and Musgrave, 1980; Boscá et al., 2011). Given an initial level of capital for each country, the remaining values of the capital series are computed as $K_t = I_t + (1-\delta)K_{t-1}$, where δ is the depreciation rate. Denoting the investment rate as $i_t = I_t/Y_t$ and g_K as the growth rate of the capital stock, we set the initial stock of capital as follows: $K_0 = \frac{iY_0}{g_K+\delta}$. In order to avoid relying on a single observation for the level of investment in the first

[67] Note that information on taxes less subsidies on productions and imports was not available for Japan, so in this case nominal output was considered at market prices.

[68] This was the case for Australia, Belgium, Canada, Japan, Switzerland and the USA.

[69] In the case of the countries whose worked hours were obtained from the Economic Outlook 110, this expression corresponds to $W_t L_t = CE_t \times \frac{N_t}{NE_t}$, where N_t represents total employment (number) and NE_t is the total number of employees.

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period, since this variable may be subject to short-term fluctuations, and the growth rates of investment and capital accumulation change depending on the position of the country relative to its steady state level, we use the Hodrick-Prescott filter to determine Y_0. Furthermore, we use the first ten years (forty quarters) of the sample to calculate the average of the investment rates (which we use as i_0) and to calculate the average growth rate of real output, which is assumed to approximate the growth rate of the real capital stock. The average depreciation rate for each country is calculated from the Penn World Table 10.0.

The evolution of the labour share and capital intensity in each country is shown in Figure 4.1. Of the 29 OECD countries considered, 17 showed a downward trend in their labour shares, 7 of them by more than 10%: Australia, Finland, Hungary, Ireland, Poland, Slovenia and the United States. Even if shorter time periods are considered for Australia and the United States, significant declines can be observed: in both countries, the labour share has fallen by more than five percentage points since 2001 (5.8 and 5.5 percentage points respectively); however, it should be noted that in the case of Australia, the labour share has shown a clear downward trend since the early 1980s, while in the case of the United States a downward trend can be observed in the early years of the period, after which the labour share remained fairly stable, despite some cyclical fluctuations, until the end of the twentieth century. The largest decline was in Ireland, where the labour share fell by more than 26 percentage points since 1995. Within Europe, Spain also shows a clear downward trend until 2018, while outside Europe, the case of Japan is also noteworthy, where the labour share fell by almost 13% until 2015, but has shown signs of recovery in recent years.

[FIGURE 4.1]

Conversely, several countries experienced strong increases in their labour shares, in particular Eastern European countries such as the Slovak and Czech Republics or the Baltic States. The largest euro area economies, Germany and France, show relatively stable labour shares when comparing the starting and the final situation, despite the overall opposite trends (+1.5 percentage points in the case of Germany and -1.8 percentage points in the case of France). It should be noted, however, that Germany experienced a sharp decline in its labour share from the beginning of the century until 2008, but this figure recovered in the following year and has remained fairly stable over the last decade; a similar trend can also be seen in France, but in this case the decline in the labour share started at the beginning of the period. As far as the United Kingdom and Italy are concerned, their labour shares have been fairly stable over the last decade, although in the case of the latter there has been a slight downward trend since 2015;

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in the case of the United Kingdom, however, there is a clear increase in the labour share in the first half of the period. Outside Europe, the relative stability of the labour share in recent years can also be observed for Canada.

Capital intensity increased in all countries relative to its initial value. Rapid growth rates were observed throughout the period, particularly in Eastern European countries (such as Poland), the Baltic countries, Finland and Ireland. Nevertheless, in recent years capital intensity seems to have stabilised in some countries, such as Germany (since 2005), the Netherlands (since 2013) or Japan (over the last decade), while in other countries, particularly in Southern Europe, a clear downward trend can be observed from 2013 to 2015, namely in Greece, Italy, Portugal and Spain.

4.5. Estimation results

The estimates of the aggregate elasticities of capital-labour substitution and the rates of factor-augmenting technological change are displayed in Table 4.3. The estimated coefficients are almost all statistically significant at the 1 per cent level, and in virtually all countries the normalization constant is almost indistinguishable from unity.

Elasticity of capital-labour substitution. The NLSUR and GMM point estimates of the elasticity of substitution, as well as the 95 (and also the 99) per cent confidence intervals, lie entirely below unity for all countries, corresponding to the case of gross complementarity between capital and labour. Nevertheless, in a few cases the estimated elasticity of substitution is not far from this value, namely in Greece (0.99), Hungary (0.95-0.97) and Sweden (in this case using the GMM method only: 0.99), and therefore the Cobb-Douglas case should not be discarded. The lowest estimates are obtained for Poland (0.16-0.17), Germany (0.24 or 0.31) and Norway (0.26) and consequently the Leontief case (zero elasticity of substitution) is never obtained (not even within the 99 per cent confidence intervals). The estimated elasticity of capital-labour substitution for the US ranges between 0.70 (NLSUR) and 0.76 (GMM), which is not far from the result obtained in the previous essay and in previous studies focusing on this economy (e.g. Klump et al., 2007; León-Ledesma et al., 2015). Besides Germany, the largest European economies, United Kingdom, France and Italy, have estimates in the range of 0.45 to 0.55, while the estimates for Spain are between 0.71 and 0.72. Outside Europe, Australia, Canada and Japan have estimates comprised between 0.36 and 0.41 (with the only exception being Australia using the GMM method, whose result is 0.59).

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[TABLE 4.3]

Factor-augmenting technological change. As far as the estimates of factor augmentation are concerned, the dominant conclusion is the finding of net labour-augmentation rates (in 27 of the 29 countries using the NLSUR method, the exceptions being the Czech Republic and Greece, or in 26 countries using the GMM method, including Sweden as an exception), which generally result from a positive rate of labour-augmenting technological change combined with a negative rate of capital-augmenting technological change. In fact, positive rates of capital-augmentation were found only for a few European countries, namely the Czech Republic, Estonia, Germany, Greece, the Slovak Republic, Sweden and Switzerland, while negative rates of labour-augmentation were estimated only for Greece, Italy (using the NLSUR method), the Czech Republic (using the GMM method, although not statistically significant) and Sweden (using the GMM method).

The estimated rates of capital-augmenting technological change for the US are either 0.0031 or 0.0039, while the estimated rates of labour-augmenting technological change are 0.0054 or 0.0058, resulting in a net labour-augmenting rate of 0.0086 or 0.0097, which is significantly higher in absolute terms than those recorded for the largest European economies (namely Germany, France, the United Kingdom and Italy, although it should be stressed that they have different time periods). Outside Europe, Canada has capital-augmentation rates close to those recorded for the United States, while the same can be observed for Australia in the case of labour-augmentation rates; for Japan, capital-augmentation rates are close to zero (0.0004 or 0.0008), while labour-augmentation rates are either 0.0034 or 0.0039.

Note that the estimates of technological change obtained for Greece are considerably higher than for the other countries, which is probably related to the estimated value of the elasticity of capital-labour substitution close to unity: in the Cobb-Douglas case, the bias of technological change cannot be determined empirically, which may also explain the deviation of the normalization constant from unity. To a lesser extent, this is also the case for the other countries where the estimated elasticity of capital-labour substitution is close to unity, namely Hungary and Sweden (using the GMM method). Beyond these countries, the fastest rates of net labour-augmentation were found for Latvia, Lithuania, Ireland and Spain, while the lowest rates were found for Germany, Italy and Switzerland.

4.6. Technological change and the labour share decline

First, we are interested in analysing what was the main cause of the decline in the labour share in OECD countries. As we argue below, our results show that the main driving force has been

net labour-augmenting technological change, which, in a context of gross complementarity, has led to capital-biased technological change.

Hereafter, we work with the series of the labour share, s and the capital intensity, $\frac{K}{L}$, filtered with the Hodrick-Prescott filter. By paying attention to the trend component of the labour share, we isolate the analysis from high-frequency fluctuations that could cause stochastic technological shocks. We use both the NLSUR and GMM estimates for the calculations. In general, there are no significant differences between using one or the other estimate.

We can decompose the average quarterly rate of change in the labour share, φ_s, over the sample period (which differs across countries) into the contribution of three components: (i) capital deepening, $\varphi_{K/L}$, (ii) net labour-augmenting technological change, $\varphi_{\zeta_L-\zeta_K}$, and (iii) the change in the firm labour wedge, φ_μ. For s and K/L we have data, for $\varphi_{\zeta_L-\zeta_K}$ we use the estimated values and φ_μ is calculated as a residual.

From equations (30) and (31), using the following approximation $d\ ln(x_t) = \frac{1}{T} ln\ \left(\frac{x_{t+T}}{x_t}\right)$ and assuming that the elasticity of capital-labour substitution and the rates of factor-augmenting technological change are constant, it follows that

$$\underbrace{\frac{1}{T} ln\ \left(\frac{s_{t+T}}{s_t}\right)}_{\varphi_s} = \underbrace{(1-\bar{s})\left(\frac{1-\sigma}{\sigma}\right)\frac{1}{T} ln\left(\frac{\frac{K_{t+T}}{L_{t+T}}}{\frac{K_t}{L_t}}\right)}_{\varphi_{K/L}} \underbrace{-(1-\bar{s})\left(\frac{1-\sigma}{\sigma}\right)(\zeta_L-\zeta_K)}_{\varphi_{\zeta_L-\zeta_K}} \underbrace{-\frac{1}{T} ln\ \left(\frac{\mu_{t+T}}{\mu_t}\right)}_{\varphi_\mu},$$

where $\bar{s}$ is the arithmetic average of the labour share over the sample period. The contributions of these three variables to the rate of change in the labour share are reported in Table 4.4.1 and Table 4.4.2. The first three columns of Table 4.4.1 and Table 4.4.2 display $\bar{s}$, the estimated elasticities of capital-labour substitution and the quarterly average rates of net labour-augmenting technological change. The last columns display the quarterly average rates of change in both capital intensity and the effective capital-labour ratio. In the final columns, we display the contributions of capital deepening, net labour-augmenting technological progress and the firm labour wedge.[70] The periods analysed are the sample periods.

[TABLES 4.4.1 AND 4.4.2]

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[70] A similar procedure was adopted by Lawrence (2015) to study the decline in the US labour share.

The results show that, despite the strong capital deepening in all countries, the predominant finding of net labour-augmentation is reflected in a decline in the effective capital-labour ratio for most OECD countries and, consequently, in the model-predicted labour share. The exceptions are either countries experiencing net capital-augmentation (the Czech Republic, Greece and Sweden, in this case using the GMM method) or countries where the rate of net labour-augmenting technological change was not fast enough to generate a decline in the effective capital-labour ratio (Estonia, Germany, the Slovak Republic, Switzerland, the United Kingdom and Italy, in this last case only using the NLSUR method), which explains the observed increase in the labour share as predicted by the neoclassical model.

The contribution of net labour-augmenting technological change was large and negative for most countries, while the contribution of capital deepening was also large but positive, and the contribution of changes in the firm labour wedge was close to 0. The average contribution of net labour-augmenting technological change is either 0.0035 or 0.0031, depending on the estimation method, while the average contributions of capital deepening are 0.0030 and 0.0025, respectively, and the average contributions of the firm labour wedge are either 0.0001 or 0.0002. In 26 (GMM method) or 27 (NLSUR method) countries, the contributions of capital deepening and net labour-augmenting technological change have opposite signs, positive for the former and negative for the latter.

[FIGURE 4.2]

Figure 4.2 displays the cross-country correlations between the rate of change in the labour share and the contributions from capital deepening, net labour-augmenting technological change and the change in the firm labour wedge. The correlation of the rate of change in the labour share with the contribution from capital deepening is negative, while it is positive with the contributions from net labour-augmenting technological change and the change in the firm labour wedge. Therefore, in countries where the rate of decline in the labour share was higher, the contributions of net labour-augmenting technological change and the change in the firm labour wedge were, on average, larger, while the contribution of capital deepening was smaller.

Therefore, from our analysis it follows that net labour-augmenting technological change — which, in a context of gross complementarity, led to capital-biased technological change — was a common force driving the labour share decline in OECD countries, whereas capital deepening worked in the opposite direction and the contribution of the change in the firm labour wedge was negligible.

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4.7. Technological change and the firm labour wedge

Although technological change appears to have been the common force driving the decline in the labour share across OECD countries, the ability of the neoclassical model with biased technological progress to predict the trend evolution of the labour share varies widely across countries, as we will see in this section.

In this section, as in the previous section, we work with the Hodrick-Prescott filtered labour share and capital intensity series. The firm labour wedge, μ_t, is defined such that the trend component of the labour share, s_t, is equal to the model-predicted labour share,

$$\hat{s}_t = \bar{s}\left[(1-\bar{s})\left(\frac{K_t/K_0}{L_t/L_0}\right)^{\psi} e^{(\zeta_K-\zeta_L)(t-\bar{t})\psi} + \bar{s}\right]^{-1},$$

times the inverse of the firm labour wedge: $s_t = \hat{s}_t \mu_t^{-1}$. The trend component of the labour share and the model-predicted labour share for each OECD country are displayed in Figure 4.3. If the model-predicted labour share does accurately not match the trend component of the labour share, then for some countries other forces reflected in the firm labour wedge play a significant role in accounting for the evolution of the labour share.

[FIGURE 4.3]

We assess the model fit in two ways. First, following a procedure similar to Bellocchi and Travaglini (2023), we regress the trend component of the labour share against the model-predicted value, and compute the residual sum of squares (RSS) and R^2 coefficients (see Table 4.5). Second, we compute Lin's (1989, 2000) concordance correlation coefficient (CCC) for both variables, which is often used as a measure of goodness of fit for non-linear models.

[TABLE 4.5]

For the Anglo-Saxon countries (Australia, the United Kingdom and the United States of America, but not Canada), which have high values for R^2 and CCC, the model accurately accounts for the evolution of the trend component of the labour share. The same can be said for some European countries, namely Spain, the Czech Republic, Ireland, Sweden and Belgium. We do not include Greece and Hungary in the group because, although both countries have high R^2 and CCC values, the results for these two countries should be treated with caution because the estimates of the technological progress rates are very imprecise, as mentioned above. For the same reason, we also doubt the Swedish GMM estimates, but have no reason to be suspicious of the NLSUR estimates. The values of R^2 (with NLSUR and GMM) are around

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0.95 for Australia, 0.84 and 0.86 for the United States, and 0.88 and 0.86 for the United Kingdom. For these countries, the CCC values are also high: 0.98 for Australia, 0.92 for the United States, and 0.93 and 0.87 for the United Kingdom. The R^2 and CCC are also higher than 0.80 for Spain, Czech Republic, Ireland, Sweden, Belgium, Hungary and Greece. However, in Japan, Canada and most European countries, the R^2 and CCC values are significantly lower, suggesting that the firm labour wedge might play a significant, even predominant role in accounting for the evolution of the trend component of the labour share. For some European countries, the R^2 and CCC values are particularly low: for example, in France, the values of R^2 are 0.14 and 0.31 (using the NLSUR and the GMM methods, respectively), while in Germany they are 0.03 and 0.07. For these countries, the values of the CCC are low: France, 0.34 and 0.20, and Germany, -0.17 and -0.21. The CCC values for Germany even reflect a small discordance between prediction and data.

In order to deepen the understanding of the role technological bias in the evolution of the labour share, we carry out a counterfactual exercise. In particular, we calculate for all countries the labour share predicted by the model under the estimated values of the elasticity of capital-labour substitution if the technological change were neutral, $\zeta_K - \zeta_L = 0$,

$$\hat{s}_{n,t} = \bar{s}\left[(1-\bar{s})\left(\frac{K_t/K_0}{L_t/L_0}\right)^{\psi} + \bar{s}\right]^{-1},$$

and evaluate its ability to match the evolution of the trend component of the labour share. The counterfactual exercise needs to be well understood. The exercise is not intended to show that the model with neutral technological change can or cannot accurately match the trend component of the labour share because, as it is likely to provide a better fit under gross capital-labour substitution. The purpose of the exercise is to show whether biased technological change is needed to accurately account for the evolution of the trend component of the labour share under gross capital-labour complementarity. The series are displayed in Figure 4.4.

[FIGURE 4.4]

We calculate the same statistics as above to assess the goodness of fit (see Table 4.6). The R^2 values are generally high and most of the CCC values are negative, reflecting a significant mismatch between the prediction and the data. In particular, if technological progress had been neutral, capital deepening would have moved the labour share in the opposite direction to that observed for its trend component in most OECD countries (see Figure 4.4). However, for a small number of European countries (the Czech Republic, Estonia, Sweden and the United

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Kingdom) both the R^2 and the CCC are positive and high.[71] Therefore, our results suggest that for these countries the biased technological progress may not have played a very important role in accounting for the evolution of the trend component of the labour share.

[TABLE 4.6]

Next, we analyse in more detail the behaviour of the firm labour wedge in OECD countries and its influence on the evolution of the labour share. As mentioned above, the firm labour wedge is defined as the ratio of the model-predicted labour share to the trend component of the labour share, $\mu_t = \hat{s}_t / s_t$. To make the comparison between the trend component of the labour share and the firm labour wedge, we have multiplied the inverse of the latter by $\bar{s}$ — which is the average value of the labour share — and thus overcome the difference in scale between the variables.

[FIGURE 4.5]

The trend component of the labour share and the inverse of the firm labour wedge for OECD countries are displayed in Figure 4.5. Looking closely at Figure 4.5, it can be seen that for most countries the inverse of the labour wedge increased in the latter part of the period analysed, around 2008. In particular, it increased significantly after 2008 in eighteen countries: Austria, Canada, the Czech Republic, Estonia, France, Germany, Japan, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain and the United States. Only in Greece and Ireland has the inverse of the firm labour wedge fallen significantly, although, as we have said, our results for Greece should be taken with a pinch of salt. Moreover, in many countries this increase coincides with an increase, or at least a stabilization, of the labour share. Focusing on the United States, it is clear that the increase in the inverse of the firm labour wedge contributed to halting the decline in the labour share from around 2011. The analysis therefore suggests that in many countries the reduction in the firm labour wedge in recent years has counteracted the negative effect of capital-biased technological change on the labour share.

We calculate the same statistics as above to assess the goodness of fit (see Table 4.7). For both estimation methods, the values of CCC and R^2 are low in Australia, Belgium, Czech Republic, Spain, Sweden and the United States. They are also low in the United Kingdom for the NLSUR

[71] With the exception of the CCC value for Sweden under the GMM estimation, but, as mentioned above, the GMM estimation for Sweden may be problematic.

method.[72] In these countries, the R^2 values are below 0.15 and the CCC values below 0.25, the latter even being slightly negative for Sweden and Belgium. For these countries, the firm labour wedge adjusts the trend evolution of the labour share very poorly, whereas the adjustment of the perfect competition model with biased technological progress is quite precise, so we can venture that for these countries the firm labour wedge has played a minor role in accounting for the trend evolution of the labour share.

[TABLE 4.7]

The three largest economies in the euro area have high R^2 and CCC values. Restricting ourselves to the NLSUR estimates, the values of these statistics are 0.63 and 0.79 for France, 0.44 and 0.55 for Germany, and 0.48 and 0.67 for Italy. The values for Japan, 0.34 and 0.57, respectively, are not very high, but they are not low either. Other economies with particularly high values for these statistics are Canada, Finland, Latvia, Lithuania, Luxemburg, Netherlands, Norway, Slovakia and Slovenia. Bearing in mind that for these economies, the fit of the perfect competition model is not particularly good, we can conclude that in Canada, Japan and most European countries, including the three largest economies in the euro area (Germany, France and Italy), the firm labour wedge played a significant, even prominent, role in accounting for the trend evolution of the labour share.

4.8. Concluding remarks

In recent decades, while capital intensity has increased in most OECD countries, the labour share has undergone important changes, including significant declines in countries such as Australia and the United States or strong increases in some Eastern European and Baltic countries.

We identify capital-biased technological change as the main driving force of the decline in the labour share. If capital and labour are gross complements, net labour-augmenting technological change is capital-biased and, if it is sufficiently rapid, it offsets capital deepening and reduces the labour share.

Our estimated elasticities of capital-labour substitution are well below unity for all countries, corresponding to the case of gross complementarity between capital and labour, being close to unity only in a few countries. Furthermore, our estimation results confirm the net

[72] The values of the CCC and R^2 are also low for Greece and Hungary, but we have some reservations about the results of these countries, as we pointed out above.

labour-augmentation hypothesis for practically all countries. One of the exceptions is precisely the Czech Republic, one of the countries that experienced an increase in the labour share. In a few countries, such as the United Kingdom or Germany, the rate of net labour-augmenting technological change was not fast enough to generate a decline in the effective capital-labour ratio, which would explain the observed increases in the labour share, as predicted by the neoclassical model. However, in the United States and Australia, two countries where the labour share decline significantly, the rate of net labour-augmenting technological change exceeded 3.50% and 2.25% per year, respectively.

We find that, on average, in OECD countries where the rate of decline in the labour share has been greater, the contribution of net labour-augmenting technological change has been larger, while the contribution of capital deepening has been smaller. Therefore, increases in labour productivity can be reconciled with the observed declines in the labour share across countries in a context of a gross complementarity between capital and labour, provided that technological change is in fact increasing the amount of effective labour relatively to effective capital. It also follows from our results that capital deepening has not contributed to reducing the labour share, but rather the opposite.

Our analysis shows that the perfect competition model with biased technological change accurately accounts for the evolution of the trend component of the labour share in the Anglo-Saxon countries of Australia, the United States and the United Kingdom and some European economies (Belgium, the Czech Republic, Ireland, Spain, and Sweden), but it does not in Canada, Japan, and most European countries, including the three largest economies in the euro area (Germany, France and Italy). In these countries the firm labour wedge might have played an important, even prominent, role in accounting for the evolution of the trend component of the labour share. Moreover, in many OECD countries, the firm labour wedge has been declining since around 2008, contributing to an increase or at least a stabilisation of the labour share.

However, the labour wedge is a black box. Filling it in might help explaining changes in the functional distribution of income. Furthermore, exploring the institutional, regulatory and economic determinants of the technological bias may be another fruitful direction for future research.

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4.9. Tables and Figures

Table 4.1: Recent empirical studies of the elasticity of substitution and technological change

Author(s)	Geographical scope	Period	Technological change assumption	Production function	Estimated σ	Estimated annual rate of efficiency change		
						Hicks-neutral: $\widehat{\zeta_L} = \widehat{\zeta_K}$	Labour-augmenting: $\widehat{\zeta_L}$	Capital-augmenting: $\widehat{\zeta_K}$
Karagiannis et al. (2005)	82 countries	1960-1987	Hicks-neutral	VES	$\sigma > 1$	-1.5 to -1.2		
Klump et al. (2007)	USA	1953-1998	Factor-augmenting	Normalized CES	0.50 to 0.60		1.50 to 1.70	0.40
Klump et al. (2008)	Euro area	1971-2005 (quarterly)	Factor-augmenting	Normalized CES	0.70		1971-1997: 1.45 1997-2005: -3.08	1971-1997: 0.56 1997-2005: 4.06
Luoma and Luoto (2010)	Finland	1902-2004	Factor-augmenting	Normalized CES	0.45		2.90	-0.70
Mallick (2012a)	90 countries	1950-2000	Hicks-neutral	Normalized CES	0.34	?		
Young (2013)	USA	1960–2005	Factor-augmenting	Normalized CES	0.18 (norm.) to 0.62 (non-norm.)		6.10	3.50
Karabarbounis and Neiman (2014)	59 countries	1975-2012	Factor-augmenting	CES	1.25		?	0.90
Herrendorf et al. (2015)	USA	1947-2010	Factor-augmenting	Normalized CES	0.84		2.2	-1.0 (not significant)
Kreuser et al. (2015)	South Africa	1994-2012	Factor-augmenting	Normalized CES	1.32		-1.96	5.0
León-Ledesma et al. (2015)	USA	1952-2009	Factor-augmenting	Normalized CES	0.44 to 0.72		2.0	0.2 to 0.5
Mućk (2017)	12 advanced economies	1980-2006	Factor-augmenting	Normalized CES	0.70		2.60 to 2.80	-3.40 to -3.10
Semieniuk (2017)	i) UK ii) France iii) Germany iv) Australia v) Canada vi) Japan vii) Italy	1970-2010	Hicks-neutral	CES	i) 0.08 to 0.33 ii) 0.16 to 0.52 iii) 0.16 to 0.33 iv) 0.26 to 0.59 v) 0.18 to 0.47 vi) 0.41 to 0.96 vii) 0.30 to 1.38	?		
Stewart and Li (2018)	Canada	1961–2012	Factor-augmenting	Normalized CES	0.92 to 2.22		-5.30 to 3.30	-3.40 to 10.70
Jiang and León-Ledesma (2018)	USA	1950-2014	Factor-augmenting	Normalized CES	0.82 to 0.86		0.50 to 1.00	4.00 to 5.90
Del Río and Lores (2019)	USA	1947-2014	Factor-augmenting	VES	$\sigma < 1$		>0	<0
Bellocchi and Travaglini (2023)	i) France ii) Germany iii) Italy iv) Spain v) UK vi) USA	1980-2020	Hicks-neutral	CES and VES	$\sigma < 1$. Exceptions: - Italy (perfect competition) - USA (VES, imp. competition)	i) -0.55 to 0.15 ii) 0.22 to 0.36 iii) -2.05 to -0.39 iv) -0.37 to -0.20 v) -0.06 to 0.61 vi) -0.90 to -0.57		

Table 4.2.1: Summary statistics of regression variables: *y*, *yk* and *rp*

Country		Period	Obs.	*y*			*yk*			*rp*		
				Mean	St. Dev.	Δ	Mean	St. Dev.	Δ	Mean	St. Dev.	Δ
Australia	AU	1978:3-2019:4	166	7.8103	0.3844	1.2485	-3.0280	0.0433	0.0566	-4.0396	0.1425	0.3929
Austria	AT	1995:1-2019:4	100	6.5174	0.1251	0.4356	-2.9224	0.0320	-0.0811	-4.0484	0.0711	0.0991
Belgium	BE	1995:1-2019:4	100	6.7093	0.1357	0.4627	-2.7802	0.0491	-0.1387	-3.9156	0.0484	-0.0272
Canada	CA	1997:1-2019:4	92	8.2295	0.1475	0.5587	-2.7098	0.0870	-0.1899	-3.8193	0.1008	-0.1543
Czech Republic	CZ	1996:1-2019:4	96	9.0924	0.1838	0.6033	-2.9487	0.0407	0.0408	-3.7504	0.0458	-0.0922
Denmark	DK	1995:1-2019:4	100	8.2479	0.0998	0.3819	-2.8456	0.0445	-0.0691	-3.9209	0.0637	-0.0694
Estonia	EE	2000:1-2019:4	80	3.7028	0.1753	0.6794	-2.8520	0.0960	-0.0556	-3.7176	0.1543	-0.1937
Finland	FI	1990:1-2019:4	120	5.9966	0.1953	0.4606	-2.8269	0.0801	-0.2083	-3.9055	0.1829	0.1581
France	FR	1990:1-2019:4	120	8.3183	0.1419	0.4469	-3.0034	0.0421	-0.1062	-4.2362	0.0750	-0.0437
Germany	DE	1991:1-2019:4	116	8.7080	0.1062	0.3516	-3.0643	0.0385	0.0816	-4.1786	0.0712	0.0372
Greece	GR	1995:1-2019:4	100	6.0685	0.1451	0.1050	-2.9562	0.2005	-0.3987	-3.9075	0.2663	-0.4872
Hungary	HU	1995:1-2019:4	100	11.0777	0.1696	0.5922	-2.7841	0.0673	-0.1488	-3.7077	0.0538	0.1421
Ireland	IE	1995:1-2019:4	100	6.0690	0.3459	1.3612	-2.3273	0.1651	-0.3575	-3.0929	0.1999	0.1884
Italy	IT	1996:1-2019:4	96	8.2099	0.0380	0.0929	-3.0040	0.0590	-0.1090	-4.0780	0.0857	-0.1121
Japan	JP	1994:1-2019:4	104	14.0483	0.0601	0.1950	-3.0908	0.0251	0.0231	-3.9729	0.0786	0.1123
Latvia	LV	1995:1-2019:4	100	3.7670	0.2928	0.9171	-2.6766	0.2239	-0.5172	-3.4903	0.2631	-0.7114
Lithuania	LT	1995:1-2019:4	100	4.1514	0.3068	1.0413	-2.4268	0.1132	-0.2134	-3.2260	0.1180	-0.3678
Luxembourg	LU	1995:1-2019:4	100	4.5721	0.2358	0.8113	-2.4637	0.0512	-0.1193	-3.3174	0.0665	-0.0601
Netherlands	NL	1996:1-2019:4	96	7.2600	0.1117	0.4517	-2.7101	0.0523	-0.0910	-3.8370	0.0661	-0.0188
Norway	NO	1995:1-2019:4	100	8.7994	0.1397	0.5218	-2.8066	0.0878	-0.2328	-3.6087	0.1245	-0.2338
Poland	PL	1995:1-2019:4	100	7.9922	0.2816	1.0164	-2.4402	0.0237	0.0188	-3.3585	0.1293	0.1872
Portugal	PT	1995:1-2019:4	100	5.9786	0.0745	0.3328	-3.0895	0.0647	-0.0388	-4.1427	0.0527	0.1107
Slovak Republic	SK	1995:1-2019:4	100	4.8987	0.2825	0.9091	-2.7257	0.0571	0.0780	-3.4472	0.0768	-0.1312
Slovenia	SI	1995:1-2019:4	100	4.2671	0.1862	0.6677	-2.8308	0.0717	-0.0621	-4.2054	0.1384	0.6167
Spain	ES	1995:1-2019:4	100	7.7105	0.1432	0.5032	-2.8224	0.0969	-0.1702	-3.8541	0.0673	-0.0063
Sweden	SE	1993:1-2019:4	108	8.9408	0.1896	0.6652	-2.8319	0.0603	-0.1420	-3.7810	0.0912	-0.0943
Switzerland	CH	1990:1-2019:4	120	7.2101	0.1594	0.4826	-2.9791	0.0829	0.2016	-4.0321	0.1034	0.1229
United Kingdom	UK	1995:1-2019:4	100	8.3030	0.1336	0.4936	-2.5673	0.0510	-0.1197	-3.6034	0.0888	-0.2411
United States of America	US	1970:1-2019:4	200	10.0882	0.4122	1.3711	-2.6611	0.0348	-0.0695	-3.7029	0.0595	0.2071

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Table 4.2.2: Summary statistics of regression variables: *yl* and *wp*

Country		Period	Obs.	*yl*			*wp*		
				Mean	St. Dev.	Δ	Mean	St. Dev.	Δ
Australia	AU	1978:3-2019:4	166	-15.6425	0.1889	0.5782	-16.0995	0.1359	0.3928
Austria	AT	1995:1-2019:4	100	-14.7419	0.0968	0.2772	-15.1357	0.0683	0.1992
Belgium	BE	1995:1-2019:4	100	-15.8531	0.0715	0.2271	-16.2415	0.0575	0.1728
Canada	CA	1997:1-2019:4	92	-15.8466	0.0762	0.2838	-16.2475	0.0699	0.2670
Czech Republic	CZ	1996:1-2019:4	96	-12.4566	0.1758	0.5816	-13.0529	0.1988	0.6898
Denmark	DK	1995:1-2019:4	100	-12.4762	0.0822	0.2734	-12.8941	0.0764	0.2736
Estonia	EE	2000:1-2019:4	80	-15.7862	0.1749	0.6711	-16.3359	0.2125	0.7631
Finland	FI	1990:1-2019:4	120	-14.7182	0.1542	0.4732	-15.1405	0.1111	0.3035
France	FR	1990:1-2019:4	120	-14.7110	0.1065	0.3419	-15.0561	0.1002	0.3170
Germany	DE	1991:1-2019:4	116	-14.7036	0.0929	0.3307	-15.1020	0.0838	0.3530
Greece	GR	1995:1-2019:4	100	-15.5020	0.1075	0.0291	-15.9930	0.1075	0.0870
Hungary	HU	1995:1-2019:4	100	-10.2834	0.1830	0.5348	-10.7930	0.1435	0.3464
Ireland	IE	1995:1-2019:4	100	-14.4906	0.2544	0.9134	-15.1369	0.1487	0.3752
Italy	IT	1996:1-2019:4	96	-14.8924	0.0209	0.0250	-15.3109	0.0187	0.0267
Japan	JP	1994:1-2019:4	104	-11.4109	0.0932	0.3074	-11.9474	0.0565	0.2497
Latvia	LV	1995:1-2019:4	100	-16.2009	0.3529	1.0849	-16.7928	0.3690	1.2101
Lithuania	LT	1995:1-2019:4	100	-16.1345	0.3162	1.0376	-16.7362	0.3025	1.1607
Luxembourg	LU	1995:1-2019:4	100	-14.0798	0.0421	0.1135	-14.6361	0.0337	0.0729
Netherlands	NL	1996:1-2019:4	96	-14.5952	0.0673	0.2116	-14.9873	0.0624	0.1791
Norway	NO	1995:1-2019:4	100	-11.8009	0.0756	0.2483	-12.4000	0.0673	0.2491
Poland	PL	1995:1-2019:4	100	-14.7848	0.2571	0.9614	-15.3041	0.1880	0.8477
Portugal	PT	1995:1-2019:4	100	-15.5742	0.0724	0.2243	-16.0073	0.0381	0.1411
Slovak Republic	SK	1995:1-2019:4	100	-15.7893	0.2566	0.8599	-16.4575	0.2755	1.0405
Slovenia	SI	1995:1-2019:4	100	-15.5351	0.1739	0.6459	-15.8310	0.1385	0.4749
Spain	ES	1995:1-2019:4	100	-15.0624	0.0595	0.1528	-15.5042	0.0438	0.0662
Sweden	SE	1993:1-2019:4	108	-12.3783	0.1289	0.4343	-12.8686	0.1430	0.4062
Switzerland	CH	1990:1-2019:4	120	-15.4678	0.0977	0.2992	-15.8974	0.0942	0.3442
United Kingdom	UK	1995:1-2019:4	100	-14.9194	0.0823	0.2851	-15.3588	0.1076	0.3543
United States of America	US	1970:1-2019:4	200	-16.0410	0.2279	0.7418	-16.4784	0.1912	0.5987

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Table 4.3: Estimates of aggregate elasticities of substitution and technological change rates

Country	NLSUR				GMM			
	σ	ζ_K	ζ_L	ξ	σ	ζ_K	ζ_L	ξ
AU	0.4136*** (0.0035)	-0.0008*** (0.0001)	0.0047*** (0.0000)	1.0021*** (0.0016)	0.5931*** (0.0319)	-0.0023*** (0.0004)	0.0057*** (0.0002)	1.0065*** (0.0014)
AT	0.3046*** (0.0029)	-0.0018*** (0.0000)	0.0037*** (0.0001)	1.0011*** (0.0011)	0.3344*** (0.0136)	-0.0020*** (0.0001)	0.0036*** (0.0001)	0.9975*** (0.0009)
BE	0.3337*** (0.0012)	-0.0022*** (0.0000)	0.0027*** (0.0001)	0.9982*** (0.0013)	0.3616*** (0.0227)	-0.0023*** (0.0001)	0.0028*** (0.0000)	0.9993*** (0.0009)
CA	0.3629*** (0.0016)	-0.0033*** (0.0001)	0.0028*** (0.0001)	1.0021*** (0.0015)	0.3793*** (0.0144)	-0.0035*** (0.0001)	0.0025*** (0.0001)	1.0036*** (0.0011)
CZ	0.7629*** (0.0013)	0.0042*** (0.0002)	0.0032*** (0.0002)	1.0026*** (0.0039)	0.8806*** (0.0271)	0.0087*** (0.0023)	-0.0006 (0.0018)	0.9929*** (0.0028)
DK	0.3588*** (0.0016)	-0.0015*** (0.0001)	0.0030*** (0.0001)	1.0012*** (0.0015)	0.4614*** (0.0377)	-0.0016*** (0.0001)	0.0030*** (0.0001)	1.0032*** (0.0012)
EE	0.6379*** (0.0031)	0.0008** (0.0003)	0.0039*** (0.0004)	0.9949*** (0.0050)	0.6831*** (0.0340)	0.0022** (0.0009)	0.0030*** (0.0007)	1.0014*** (0.0040)
FI	0.3985*** (0.0041)	-0.0020*** (0.0001)	0.0046*** (0.0002)	0.9990*** (0.0040)	0.4598*** (0.0200)	-0.0025*** (0.0002)	0.0043*** (0.0002)	1.0006*** (0.0035)
FR	0.4867*** (0.0008)	-0.0011*** (0.0000)	0.0035*** (0.0001)	0.9986*** (0.0013)	0.5109*** (0.0110)	-0.0009*** (0.0001)	0.0030*** (0.0001)	0.9969*** (0.0014)
DE	0.3094*** (0.0021)	0.0008*** (0.0000)	0.0027*** (0.0001)	1.0003*** (0.0011)	0.2363*** (0.0350)	0.0008*** (0.0001)	0.0026*** (0.0000)	0.9999*** (0.0010)
GR	0.9864*** (0.0011)	0.1545*** (0.0098)	-0.1028*** (0.0061)	1.1029*** (0.0076)	0.9889*** (0.0011)	0.1848*** (0.0140)	-0.1219*** (0.0090)	1.1163*** (0.0081)
HU	0.9492*** (0.0028)	-0.0517*** (0.0029)	0.0389*** (0.0019)	1.0375*** (0.0044)	0.9695*** (0.0030)	-0.0838*** (0.0078)	0.0602*** (0.0051)	1.0579*** (0.0070)
IE	0.3776*** (0.0046)	-0.0067*** (0.0001)	0.0115*** (0.0003)	1.0066*** (0.0039)	0.4556*** (0.0110)	-0.0075*** (0.0002)	0.0111*** (0.0003)	1.0148*** (0.0030)
IT	0.4960*** (0.0010)	-0.0013*** (0.0001)	-0.0002** (0.0001)	1.0003*** (0.0018)	0.5101*** (0.0219)	-0.0014*** (0.0001)	0.0001 (0.0001)	1.0015*** (0.0014)
JP	0.3709*** (0.0041)	-0.0004*** (0.0001)	0.0034*** (0.0001)	1.0013*** (0.0012)	0.4102*** (0.0510)	-0.0008*** (0.0003)	0.0039*** (0.0002)	0.9997*** (0.0012)
LV	0.5114*** (0.0032)	-0.0068*** (0.0003)	0.0118*** (0.0003)	0.9949*** (0.0061)	0.5645*** (0.0382)	-0.0070*** (0.0004)	0.0112*** (0.0004)	0.9907*** (0.0042)
LT	0.4916*** (0.0033)	-0.0035*** (0.0003)	0.0107*** (0.0003)	1.0072*** (0.0056)	0.6059*** (0.0450)	-0.0045*** (0.0004)	0.0117*** (0.0003)	0.9917*** (0.0034)
LU	0.3060*** (0.0019)	-0.0017*** (0.0001)	0.0010*** (0.0001)	1.0023*** (0.0020)	0.5941*** (0.0990)	-0.0028*** (0.0005)	0.0018*** (0.0004)	0.9982*** (0.0018)
NL	0.4136*** (0.0012)	-0.0018*** (0.0001)	0.0021*** (0.0001)	1.0008*** (0.0013)	0.4492*** (0.0246)	-0.0018*** (0.0001)	0.0020*** (0.0001)	1.0023*** (0.0014)
NO	0.2551*** (0.0026)	-0.0029*** (0.0001)	0.0020*** (0.0002)	0.9994*** (0.0020)	0.2612*** (0.0141)	-0.0031*** (0.0001)	0.0018*** (0.0001)	1.0016*** (0.0017)
PL	0.1672*** (0.0074)	-0.0010*** (0.0001)	0.0087*** (0.0001)	1.0015*** (0.0017)	0.1627*** (0.0363)	-0.0014*** (0.0003)	0.0091*** (0.0002)	1.0038*** (0.0015)
PT	0.3818*** (0.0127)	-0.0033*** (0.0002)	0.0033*** (0.0001)	1.0011*** (0.0013)	0.3958*** (0.0506)	-0.0045*** (0.0005)	0.0037*** (0.0003)	1.0039*** (0.0011)
SK	0.5376*** (0.0032)	0.0018*** (0.0002)	0.0088*** (0.0003)	1.0019*** (0.0032)	0.5955*** (0.0349)	0.0024*** (0.0002)	0.0078*** (0.0002)	0.9910*** (0.0027)
SI	0.3073*** (0.0058)	-0.0029*** (0.0002)	0.0053*** (0.0002)	1.0035*** (0.0032)	0.4271*** (0.0465)	-0.0039*** (0.0003)	0.0062*** (0.0002)	0.9896*** (0.0028)
ES	0.7103*** (0.0034)	-0.0068*** (0.0001)	0.0039*** (0.0001)	1.0022*** (0.0012)	0.7191*** (0.0178)	-0.0074*** (0.0004)	0.0041*** (0.0002)	1.0016*** (0.0012)
SE	0.7096*** (0.0015)	0.0004** (0.0002)	0.0025*** (0.0002)	1.0247*** (0.0027)	0.9916*** (0.0014)	0.0897*** (0.0107)	-0.0540*** (0.0067)	1.0377*** (0.0036)
CH	0.3457*** (0.0010)	0.0022*** (0.0000)	0.0029*** (0.0000)	0.9976*** (0.0008)	0.4030*** (0.0144)	0.0022*** (0.0000)	0.0029*** (0.0000)	0.9971*** (0.0007)
UK	0.4546*** (0.0017)	-0.0005*** (0.0001)	0.0020*** (0.0001)	1.0005*** (0.0023)	0.5434*** (0.0205)	-0.0007*** (0.0001)	0.0017*** (0.0001)	0.9985*** (0.0016)
US	0.7017*** (0.0023)	-0.0031*** (0.0001)	0.0054*** (0.0000)	1.0034*** (0.0017)	0.7594*** (0.0307)	-0.0039*** (0.0006)	0.0058*** (0.0003)	1.0063*** (0.0017)
Mean	**0.4773**	**0.0020[a]**	**0.0019[a]**	**1.0053**	**0.5416**	**0.0049[b]**	**0.0000[b]**	**1.0071**

Notes: Figures enclosed in parentheses are the estimated standard errors; *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level; [a]mean excluding Greece: $\zeta_K = -0.0035$ and $\zeta_L = 0.0057$; [b]mean excluding Greece: $\zeta_K = -0.0016$ and $\zeta_L = 0.0043$.

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Table 4.4.1: Contributions to the changes in the labour share (NLSUR method)

Country	$\bar{s}$	Estimation results		Effective capital		φ_s	Contributions		
		σ	$\zeta_L - \zeta_K$	$d\ ln\left(\frac{K}{L}\right)$	$d\ ln(k)$		$\varphi_{K/L}$	$\varphi_{\zeta_L-\zeta_K}$	φ_μ
AU	0.6343	0.4136	0.0056	0.0032	-0.0024	-0.0011	0.0016	-0.0029	0.0001
AT	0.6748	0.3046	0.0054	0.0036	-0.0018	-0.0008	0.0027	-0.0040	0.0005
BE	0.6783	0.3337	0.0049	0.0037	-0.0012	-0.0005	0.0024	-0.0031	0.0002
CA	0.6699	0.3629	0.0061	0.0052	-0.0009	-0.0002	0.0030	-0.0035	0.0003
CZ	0.5511	0.7629	-0.0010	0.0057	0.0067	0.0011	0.0008	0.0001	0.0002
DK	0.6585	0.3588	0.0045	0.0035	-0.0010	0.0000	0.0021	-0.0027	0.0006
EE	0.5780	0.6379	0.0031	0.0092	0.0061	0.0012	0.0022	-0.0007	-0.0003
FI	0.6568	0.3985	0.0066	0.0057	-0.0009	-0.0014	0.0030	-0.0034	-0.0010
FR	0.7083	0.4867	0.0046	0.0038	-0.0008	-0.0002	0.0012	-0.0014	0.0000
DE	0.6715	0.3094	0.0019	0.0022	0.0002	0.0002	0.0016	-0.0014	0.0000
GR	0.6127	0.9864	-0.2573	0.0043	0.2616	0.0006	0.0000	0.0014	-0.0008
HU	0.6016	0.9492	0.0906	0.0069	-0.0837	-0.0019	0.0001	-0.0019	-0.0001
IE	0.5296	0.3776	0.0183	0.0128	-0.0054	-0.0054	0.0100	-0.0142	-0.0012
IT	0.6582	0.4960	0.0011	0.0014	0.0003	0.0000	0.0005	-0.0004	-0.0001
JP	0.5854	0.3709	0.0038	0.0028	-0.0010	-0.0006	0.0019	-0.0027	0.0002
LV	0.5548	0.5114	0.0187	0.0162	-0.0025	0.0013	0.0069	-0.0079	0.0023
LT	0.5490	0.4916	0.0142	0.0126	-0.0016	0.0012	0.0059	-0.0066	0.0020
LU	0.5737	0.3060	0.0028	0.0024	-0.0004	-0.0004	0.0023	-0.0027	-0.0000
NL	0.6757	0.4136	0.0039	0.0032	-0.0008	-0.0003	0.0015	-0.0018	0.0000
NO	0.5503	0.2551	0.0049	0.0049	-0.0001	0.0000	0.0064	-0.0065	0.0001
PL	0.5971	0.1672	0.0097	0.0095	-0.0002	-0.0011	0.0191	-0.0195	-0.0007
PT	0.6494	0.3818	0.0065	0.0027	-0.0039	-0.0008	0.0015	-0.0037	0.0014
SK	0.5133	0.5376	0.0069	0.0079	0.0010	0.0018	0.0033	-0.0029	0.0014
SI	0.7446	0.3073	0.0081	0.0072	-0.0010	-0.0017	0.0041	-0.0047	-0.0012
ES	0.6432	0.7103	0.0107	0.0033	-0.0075	-0.0009	0.0005	-0.0016	0.0002
SE	0.6126	0.7096	0.0021	0.0054	0.0033	-0.0003	0.0009	-0.0003	-0.0008
CH	0.6509	0.3457	0.0007	0.0008	0.0001	0.0004	0.0005	-0.0005	0.0003
UK	0.6447	0.4546	0.0025	0.0041	0.0016	0.0007	0.0017	-0.0011	0.0000
US	0.6462	0.7017	0.0086	0.0041	-0.0045	-0.0007	0.0006	-0.0013	-0.0000
Mean	**0.6233**	**0.4773**	**-0.0001***	**0.0054**	**0.0055**	**-0.0004**	**0.0030**	**-0.0035**	**0.0001**

Note: *mean excluding Greece = 0.0091

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Table 4.4.2: Contributions to the changes in the labour share (GMM method)

Country	$\bar{s}$	Estimation results		Effective capital		φ_s	Contributions		
		σ	$\zeta_L - \zeta_K$	$d\ ln\left(\frac{K}{L}\right)$	$d\ ln(k)$		$\varphi_{K/L}$	$\varphi_{\zeta_L-\zeta_K}$	φ_μ
AU	0.6343	0.5931	0.0080	0.0032	-0.0048	-0.0011	0.0008	-0.0020	0.0001
AT	0.6748	0.3344	0.0056	0.0036	-0.0020	-0.0008	0.0023	-0.0036	0.0005
BE	0.6783	0.3616	0.0051	0.0037	-0.0014	-0.0005	0.0021	-0.0029	0.0002
CA	0.6699	0.3793	0.0060	0.0052	-0.0008	-0.0002	0.0028	-0.0033	0.0003
CZ	0.5511	0.8806	-0.0093	0.0057	0.0150	0.0011	0.0003	0.0006	0.0002
DK	0.6585	0.4614	0.0046	0.0035	-0.0011	0.0000	0.0014	-0.0018	0.0004
EE	0.5780	0.6831	0.0008	0.0092	0.0084	0.0012	0.0018	-0.0002	-0.0005
FI	0.6568	0.4598	0.0069	0.0057	-0.0012	-0.0014	0.0023	-0.0028	-0.0010
FR	0.7083	0.5109	0.0039	0.0038	-0.0001	-0.0002	0.0011	-0.0011	-0.0002
DE	0.6715	0.2363	0.0018	0.0022	0.0003	0.0002	0.0023	-0.0019	-0.0002
GR	0.6127	0.9889	-0.3067	0.0043	0.3110	0.0006	0.0000	0.0013	-0.0008
HU	0.6016	0.9695	0.1440	0.0069	-0.1371	-0.0019	0.0001	-0.0018	-0.0002
IE	0.5296	0.4556	0.0186	0.0128	-0.0058	-0.0054	0.0072	-0.0105	-0.0022
IT	0.6582	0.5101	0.0015	0.0014	-0.0000	0.0000	0.0005	-0.0005	0.0000
JP	0.5854	0.4102	0.0047	0.0028	-0.0020	-0.0006	0.0016	-0.0028	0.0006
LV	0.5548	0.5645	0.0182	0.0162	-0.0021	0.0013	0.0056	-0.0063	0.0020
LT	0.5490	0.6059	0.0162	0.0126	-0.0035	0.0012	0.0037	-0.0047	0.0023
LU	0.5737	0.5941	0.0047	0.0024	-0.0023	-0.0004	0.0007	-0.0014	0.0003
NL	0.6757	0.4492	0.0038	0.0032	-0.0006	-0.0003	0.0013	-0.0015	-0.0001
NO	0.5503	0.2612	0.0049	0.0049	-0.0000	0.0000	0.0062	-0.0062	0.0000
PL	0.5971	0.1627	0.0105	0.0095	-0.0009	-0.0011	0.0197	-0.0217	0.0008
PT	0.6494	0.3958	0.0082	0.0027	-0.0055	-0.0008	0.0014	-0.0044	0.0021
SK	0.5133	0.5955	0.0054	0.0079	0.0025	0.0018	0.0026	-0.0018	0.0010
SI	0.7446	0.4271	0.0101	0.0072	-0.0029	-0.0017	0.0025	-0.0034	-0.0007
ES	0.6432	0.7191	0.0114	0.0033	-0.0082	-0.0009	0.0005	-0.0016	0.0003
SE	0.6126	0.9916	-0.1437	0.0054	0.1491	-0.0003	0.0000	0.0005	-0.0008
CH	0.6509	0.4030	0.0008	0.0008	0.0000	0.0004	0.0004	-0.0004	0.0004
UK	0.6447	0.5434	0.0024	0.0041	0.0017	0.0007	0.0012	-0.0007	0.0002
US	0.6462	0.7594	0.0097	0.0041	-0.0056	-0.0007	0.0005	-0.0011	-0.0001
Mean	**0.6233**	**0.5416**	**-0.0049***	**0.0054**	**0.0103**	**-0.0003**	**0.0025**	**-0.0031**	**0.0002**

Note: *mean excluding Greece, Hungary and Sweden = 0.0063

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Table 4.5: Model-predicted labour shares' fit: R2, RSS and CCC

Country	NLSUR			GMM		
	RSS	**R^2**	**CCC**	**RSS**	**R^2**	**CCC**
AU	0.0101	0.9542	0.9770	0.0102	0.9536	0.9760
AT	0.0284	0.4172	0.6440	0.0269	0.4488	0.6670
BE	0.0031	0.7888	0.8210	0.0030	0.7980	0.8260
CA	0.0046	0.6110	0.6430	0.0046	0.6071	0.6050
CZ	0.0033	0.7989	0.8920	0.0030	0.8168	0.9030
DK	0.0066	0.1392	0.3730	0.0066	0.1461	0.3620
EE	0.0181	0.6087	0.7800	0.0152	0.6719	0.8190
FI	0.1117	0.4150	0.5450	0.1106	0.4210	0.5130
FR	0.0130	0.1383	0.3360	0.0104	0.3144	0.1980
DE	0.0115	0.0310	-0.1660	0.0111	0.0683	-0.2100
GR	0.0078	0.8759	0.9360	0.0078	0.8751	0.9340
HU	0.0016	0.9824	0.9910	0.0018	0.9809	0.9900
IE	0.0724	0.8490	0.9180	0.0775	0.8383	0.8620
IT	0.0052	0.3905	0.5950	0.0052	0.3928	0.5040
JP	0.0342	0.3763	0.6040	0.0226	0.5871	0.7620
LV	0.0716	0.2674	-0.4840	0.0767	0.2153	-0.3990
LT	0.0320	0.4216	-0.6070	0.0524	0.0523	-0.2070
LU	0.0100	0.1815	-0.4260	0.0100	0.1829	0.4270
NL	0.0062	0.1693	-0.4080	0.0061	0.1923	-0.4230
NO	0.0512	0.2072	-0.3340	0.0497	0.2308	-0.3440
PL	0.2416	0.0178	0.1330	0.1928	0.2159	0.4460
PT	0.0604	0.4750	0.6850	0.0399	0.6531	0.7840
SK	0.0427	0.1262	-0.2820	0.0486	0.0044	0.0570
SI	0.0889	0.0158	-0.1250	0.0786	0.1308	0.3550
ES	0.0024	0.9160	0.9570	0.0022	0.9230	0.9590
SE	0.0017	0.8330	0.8290	0.0014	0.8652	0.9300
CH	0.0031	0.6788	0.7890	0.0035	0.6363	0.7250
UK	0.0033	0.8777	0.9340	0.0037	0.8641	0.8700
US	0.0197	0.8400	0.9160	0.0174	0.8587	0.9240
Mean	**0.0333**	**0.4967**	**0.4299**	**0.0310**	**0.5154**	**0.5109**

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Table 4.6: Model-predicted labour shares' fit (neutral technological change): R2, RSS and CCC

Country	NLSUR			GMM		
	RSS	**R^2**	**CCC**	**RSS**	**R^2**	**CCC**
AU	0.0203	0.9079	-0.9010	0.0212	0.9036	-0.8850
AT	0.0122	0.7497	-0.5630	0.0124	0.7462	-0.6210
BE	0.0044	0.7021	-0.3550	0.0044	0.7042	-0.4010
CA	0.0107	0.0935	-0.1110	0.0107	0.0926	-0.1180
CZ	0.0035	0.7893	0.8850	0.0035	0.7893	0.6100
DK	0.0067	0.1304	-0.1310	0.0067	0.1351	-0.1950
EE	0.0145	0.6863	0.7910	0.0145	0.6869	0.8240
FI	0.1172	0.3866	-0.5800	0.1181	0.3817	-0.6130
FR	0.0143	0.0556	-0.1630	0.0143	0.0547	-0.1730
DE	0.0057	0.5239	-0.4190	0.0057	0.5211	-0.3000
GR	0.0020	0.9688	0.0410	0.0020	0.9688	0.0340
HU	0.0168	0.8210	-0.1720	0.0168	0.8212	-0.1020
IE	0.2491	0.4802	-0.5290	0.2454	0.4878	-0.6280
IT	0.0057	0.3293	0.5450	0.0057	0.3292	0.5530
JP	0.0035	0.9359	-0.9080	0.0035	0.9359	-0.9500
LV	0.0929	0.0501	0.1040	0.0928	0.0505	0.1240
LT	0.0432	0.2197	-0.2060	0.0433	0.2169	-0.3000
LU	0.0051	0.5818	-0.3660	0.0051	0.5832	-0.7530
NL	0.0066	0.1192	-0.1630	0.0066	0.1177	-0.1840
NO	0.0595	0.0783	-0.1340	0.0595	0.0781	-0.1370
PL	0.0273	0.8889	-0.3400	0.0268	0.8911	-0.3340
PT	0.0177	0.8462	-0.8680	0.0176	0.8467	-0.8840
SK	0.0408	0.1647	0.3150	0.0408	0.1649	0.3580
SI	0.0193	0.7859	-0.4850	0.0213	0.7640	-0.7070
ES	0.0093	0.6730	-0.8070	0.0093	0.6730	-0.8000
SE	0.0015	0.8513	0.7480	0.0015	0.8515	0.0680
CH	0.0089	0.0678	0.2600	0.0089	0.0676	0.2530
UK	0.0076	0.7184	0.6600	0.0077	0.7147	0.7880
US	0.0066	0.9462	-0.9720	0.0066	0.9461	-0.9210
Mean	**0.0287**	**0.5363**	**-0.1663**	**0.0287**	**0.5353**	**-0.2205**

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Table 4.7: Firm labour wedge's fit: R2, RSS and CCC

Country	NLSUR			GMM		
	RSS	**R^2**	**CCC**	**RSS**	**R^2**	**CCC**
AU	0.2192	0.0049	0.0290	0.2164	0.0178	0.0550
AT	0.0382	0.2166	0.4570	0.0383	0.2134	0.4500
BE	0.0129	0.1329	-0.3280	0.0125	0.1576	-0.3610
CA	0.0029	0.7575	0.8060	0.0022	0.8117	0.8440
CZ	0.0165	0.0056	0.0580	0.0164	0.0123	0.0830
DK	0.0055	0.2854	0.5300	0.0034	0.5537	0.7440
EE	0.0405	0.1237	0.3210	0.0437	0.0557	0.2090
FI	0.0584	0.6941	0.8020	0.0450	0.7643	0.8430
FR	0.0057	0.6258	0.7910	0.0004	0.9720	0.9820
DE	0.0067	0.4391	0.5500	0.0074	0.3751	0.4250
GR	0.0597	0.0467	0.1320	0.0564	0.0996	0.1930
HU	0.0934	0.0026	0.0130	0.0856	0.0865	0.0800
IE	0.3684	0.2312	0.3350	0.1657	0.6541	0.6440
IT	0.0045	0.4793	0.6730	0.0021	0.7514	0.8430
JP	0.0364	0.3362	0.5680	0.0531	0.0312	0.1690
LV	0.0143	0.8538	0.8470	0.0123	0.8743	0.8870
LT	0.0070	0.8736	0.8520	0.0136	0.7532	0.8320
LU	0.0038	0.6925	0.7200	0.0085	0.3104	0.5550
NL	0.0020	0.7368	0.7740	0.0016	0.7870	0.8170
NO	0.0058	0.9104	0.9290	0.0053	0.9179	0.9330
PL	0.1390	0.4348	0.6240	0.2271	0.0764	0.2660
PT	0.0892	0.2247	0.4590	0.1144	0.0063	-0.0780
SK	0.0066	0.8654	0.9040	0.0134	0.7262	0.8470
SI	0.0359	0.6029	0.7280	0.0528	0.4163	0.6440
ES	0.0276	0.0270	0.0900	0.0283	0.0030	-0.0300
SE	0.0101	0.0063	-0.0520	0.0094	0.0732	0.1770
CH	0.0052	0.4540	0.5830	0.0037	0.6119	0.7030
UK	0.0229	0.1470	0.2420	0.0090	0.6668	0.6090
US	0.1176	0.0458	0.1510	0.1068	0.1338	0.2430
Mean	**0.0502**	**0.3882**	**0.4686**	**0.0467**	**0.4108**	**0.4692**

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Figure 4.1: Evolution of the labour share and capital-intensity in OECD countries

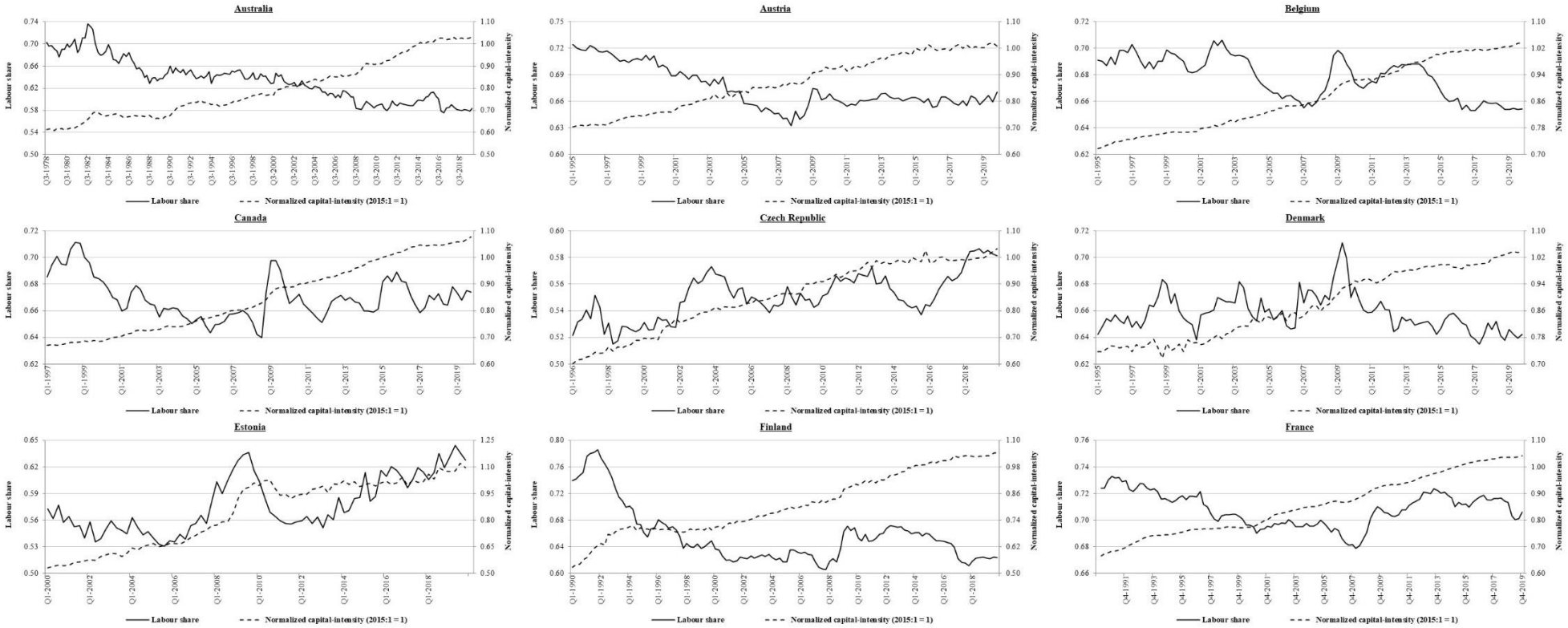


Figure 4.1: Evolution of the labour share and capital-intensity in OECD countries (cont.)

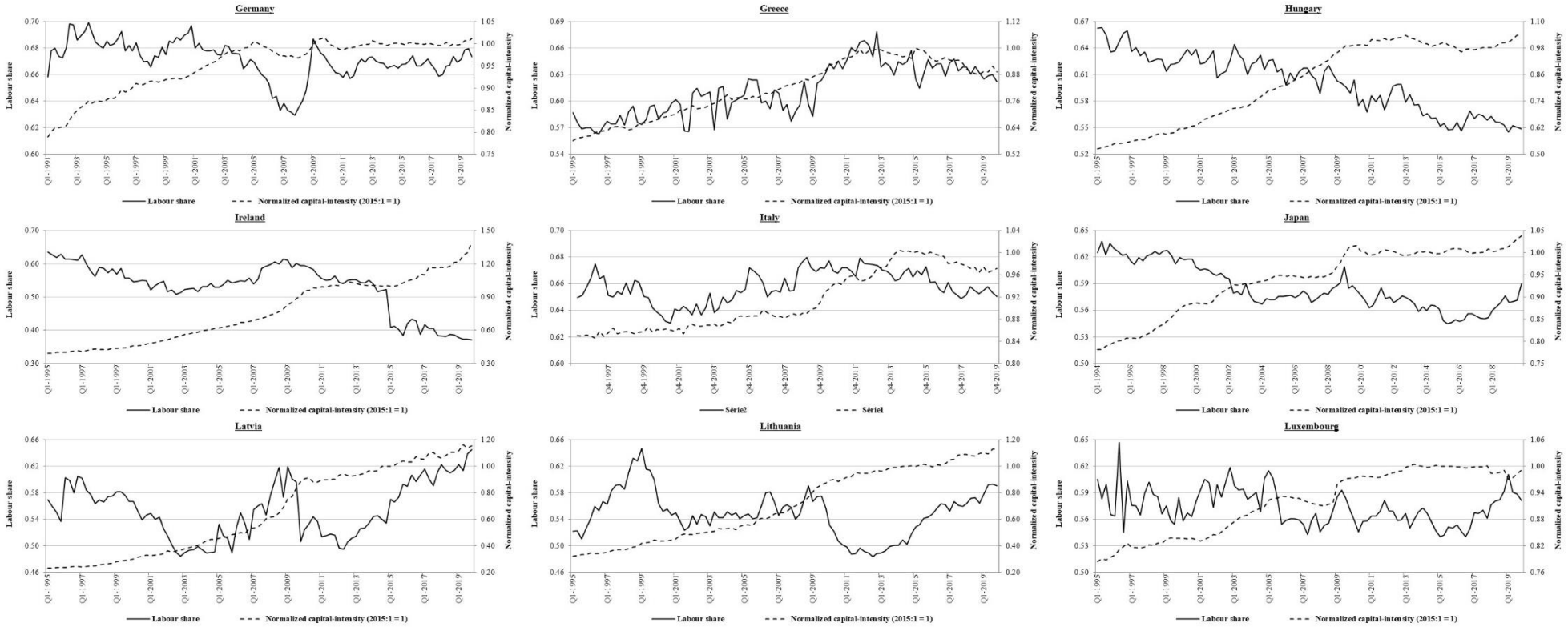


Figure 4.1: Evolution of the labour share and capital-intensity in OECD countries (cont.)

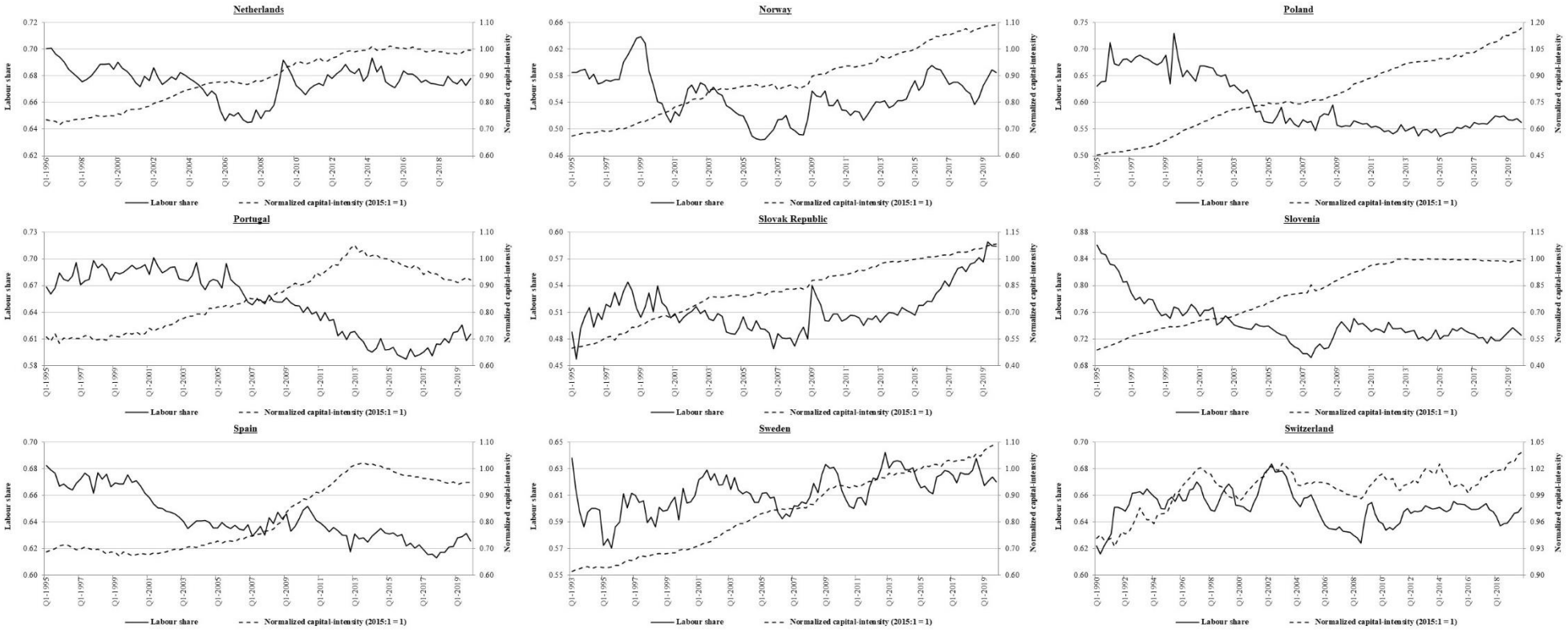


Figure 4.1: Evolution of the labour share and capital-intensity in OECD countries (cont.)

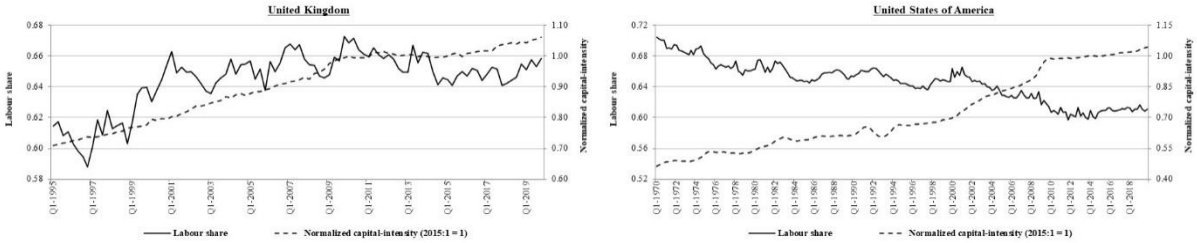


Figure 4.2: Contributions of capital intensity, technological change and firm labour wedge to the evolution of the labour share

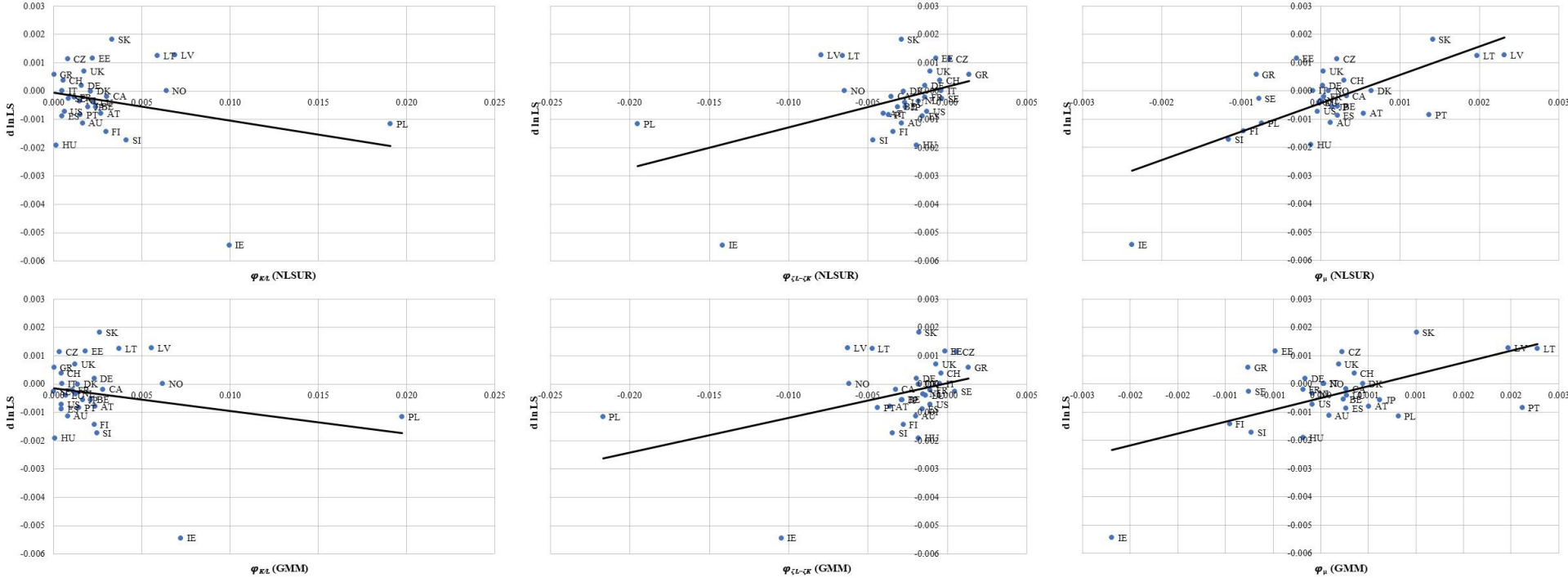


Figure 4.3: Evolution of the trend components of the labour share and the predicted labour share

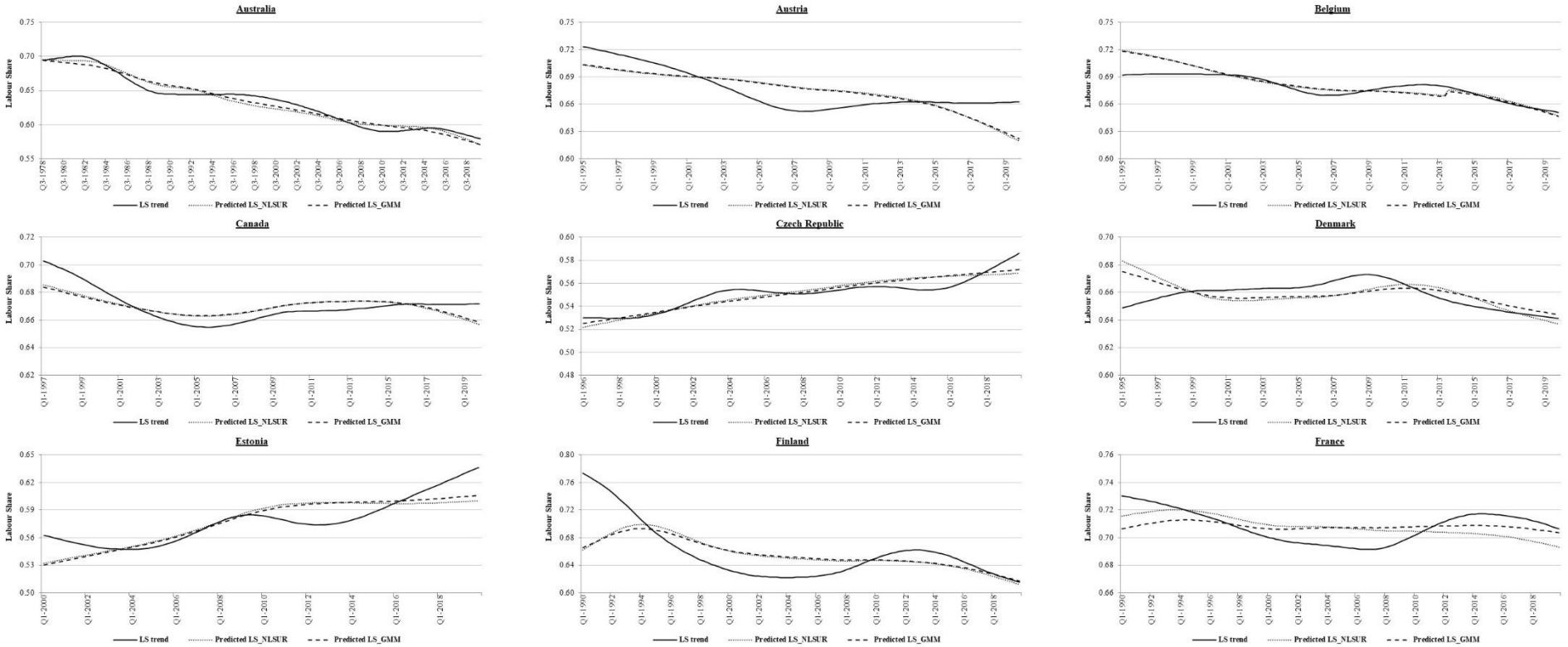


Figure 4.3: Evolution of the trend components of the labour share and the predicted labour share (cont.)

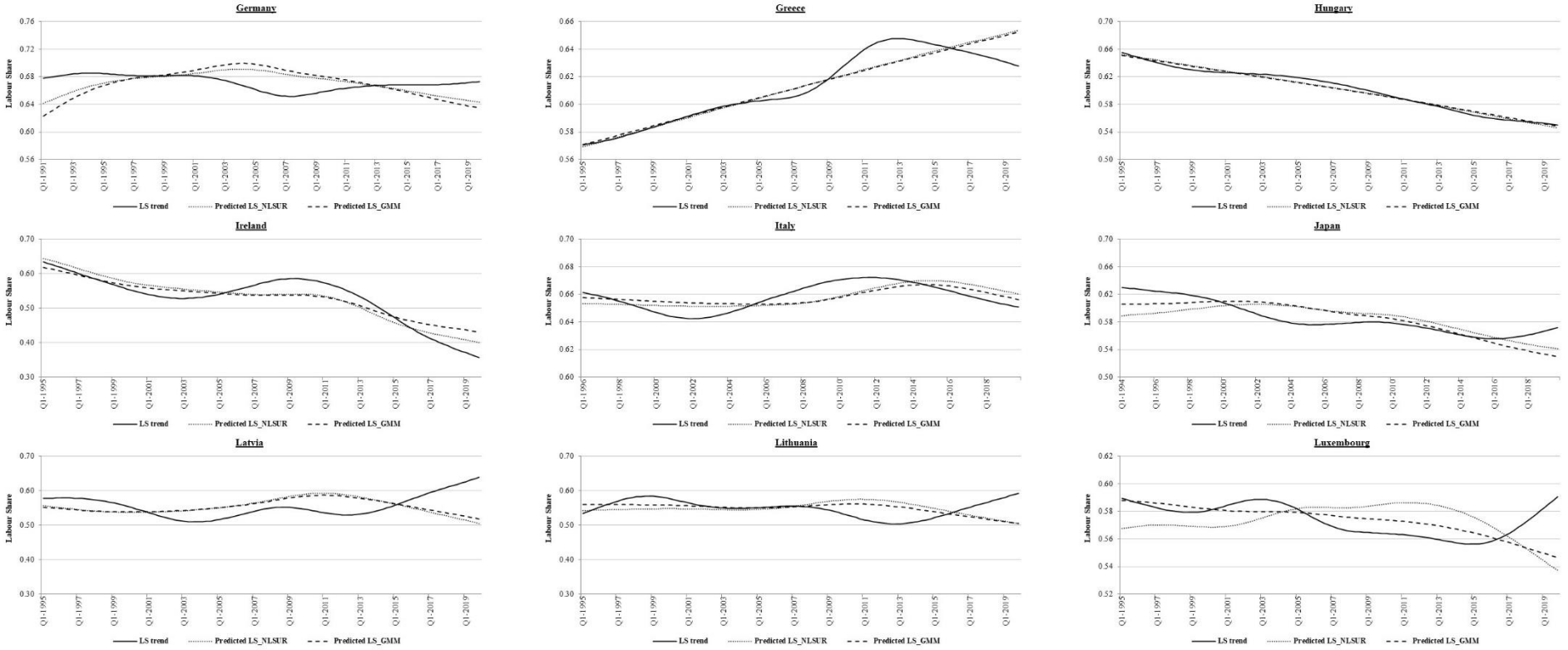


Figure 4.3: Evolution of the trend components of the labour share and the predicted labour share (cont.)

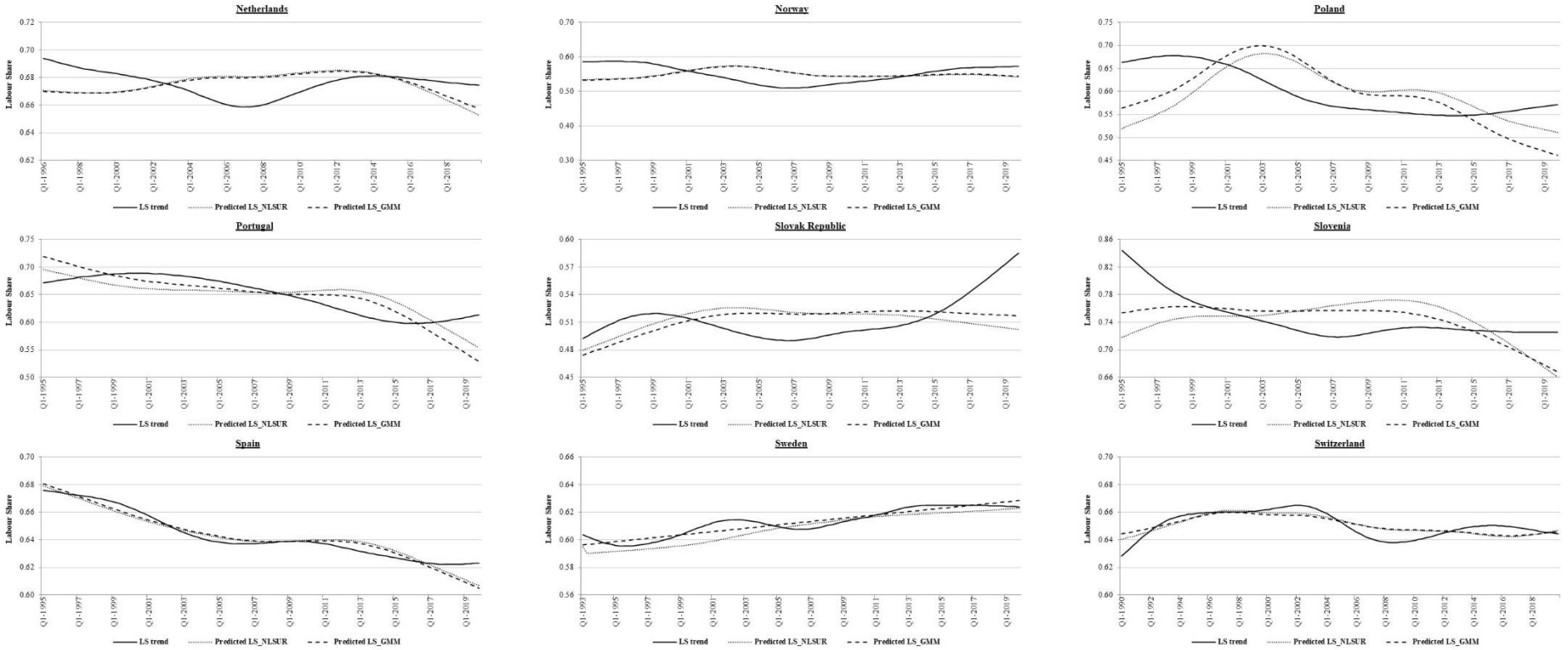


Figure 4.3: Evolution of the trend components of the labour share and the predicted labour share (cont.)

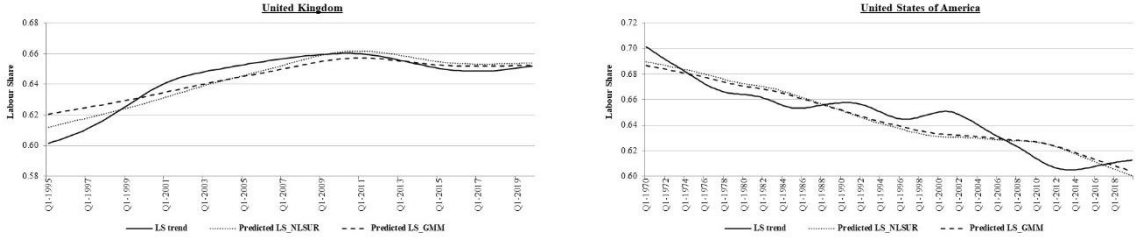


Figure 4.4: Evolution of the trend components of the labour share and the predicted labour share with neutral technological change

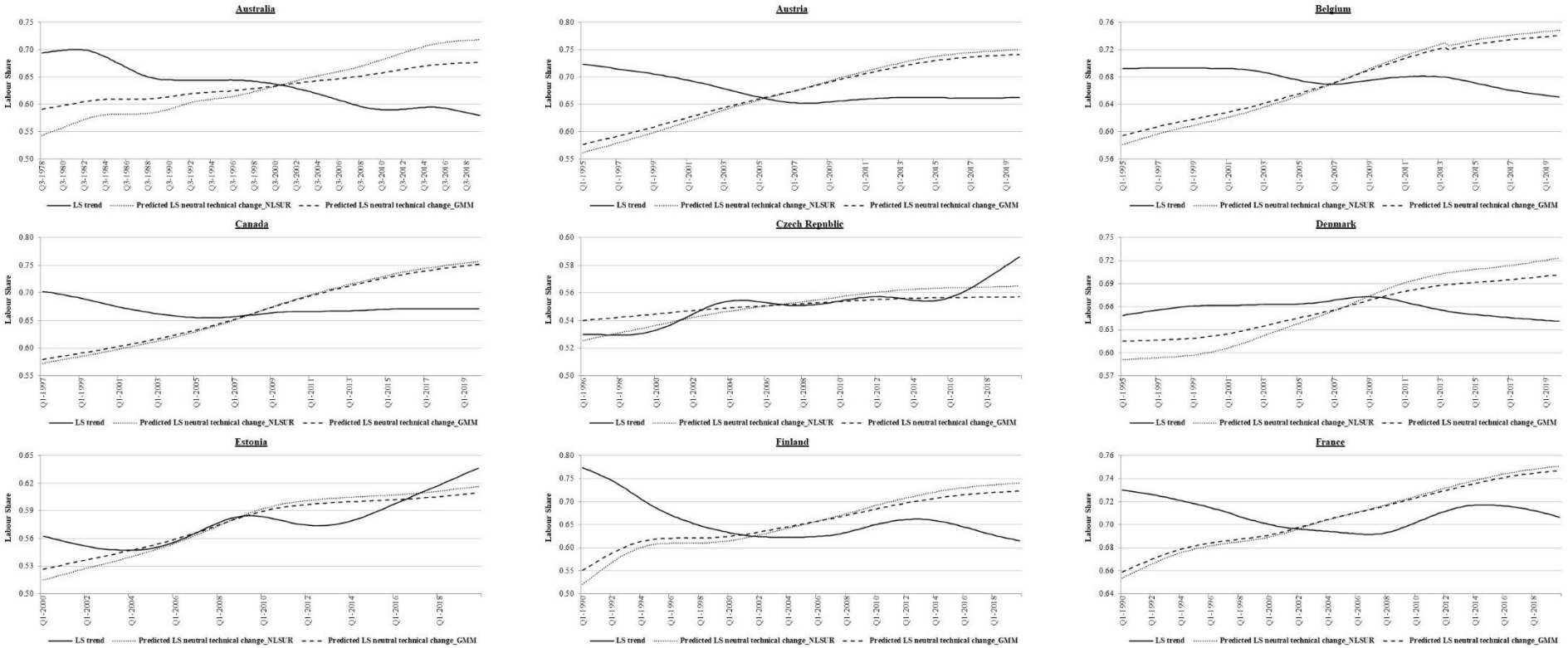


Figure 4.4: Evolution of the trend components of the labour share and the predicted labour share with neutral technological change (cont.)

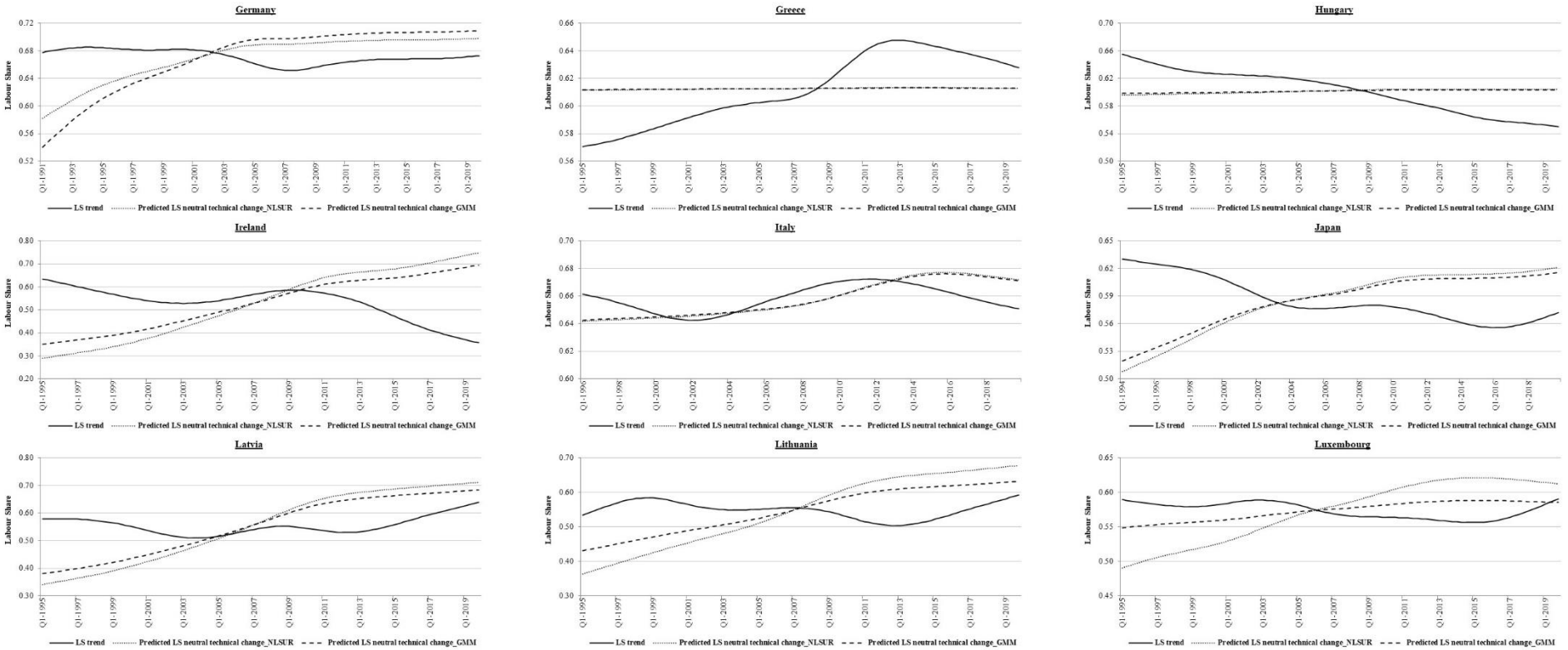


Figure 4.4: Evolution of the trend components of the labour share and the predicted labour share with neutral technological change (cont.)

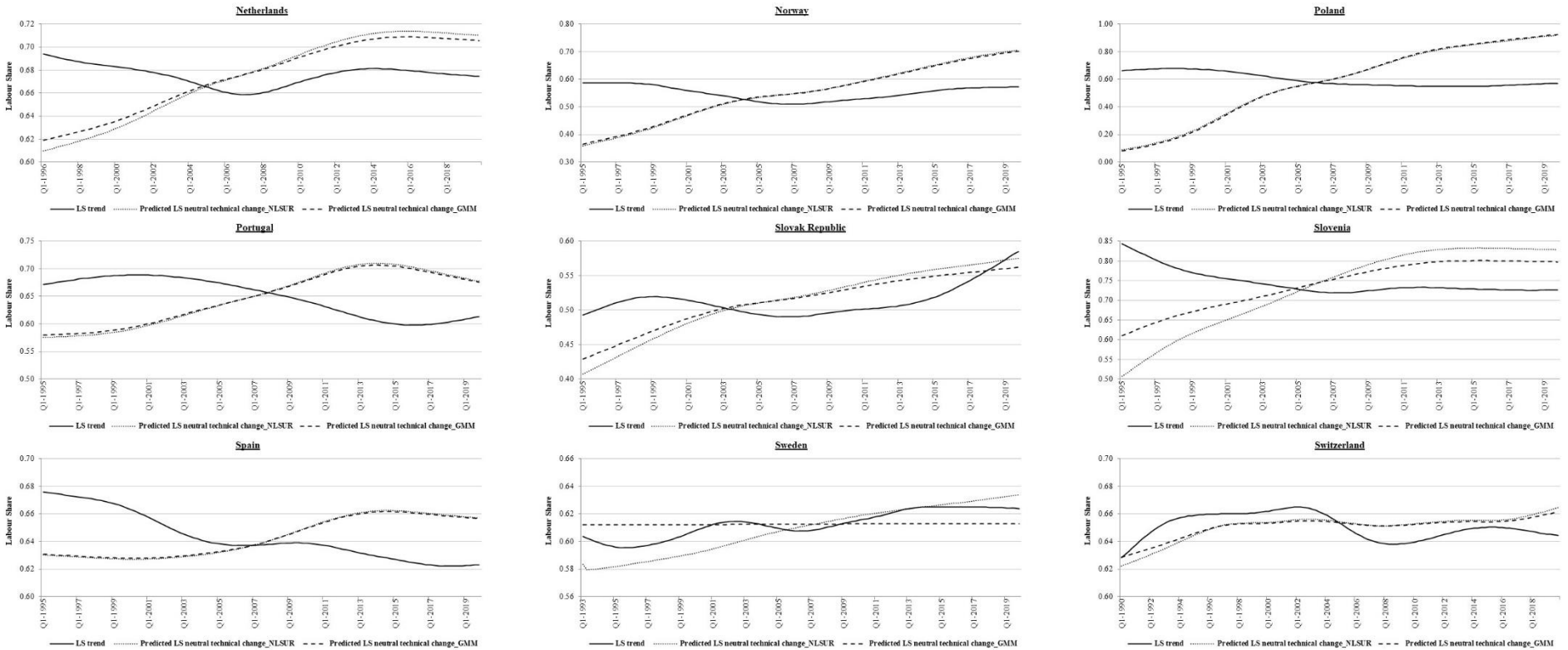


Figure 4.4: Evolution of the trend components of the labour share and the predicted labour share with neutral technological change (cont.)

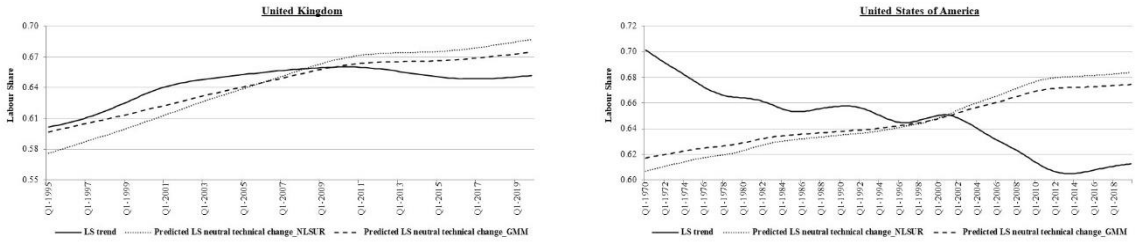


Figure 4.5: Evolution of the trend components of the labour share and the inverse of the firm labour wedge

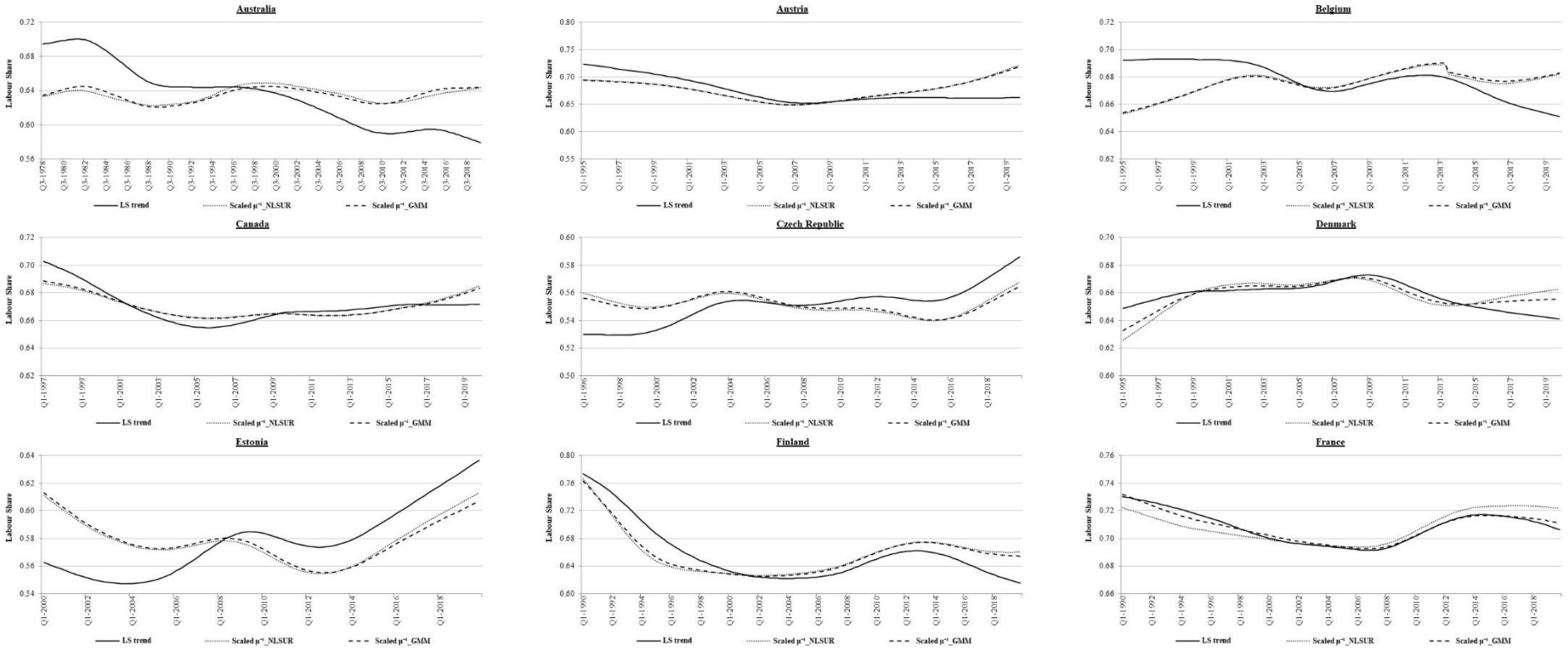


Figure 4.5: Evolution of the trend components of the labour share and the inverse of the firm labour wedge (cont.)

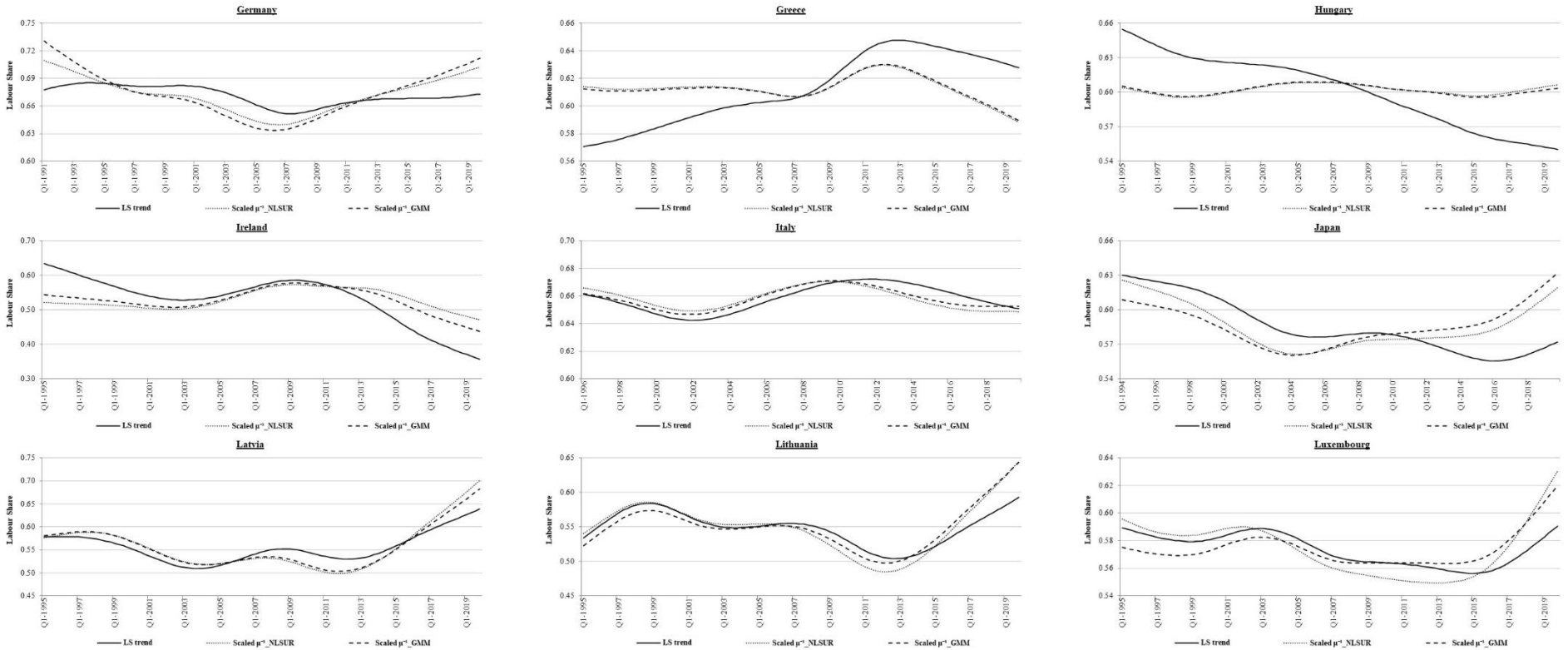


Figure 4.5: Evolution of the trend components of the labour share and the inverse of the firm labour wedge (cont.)

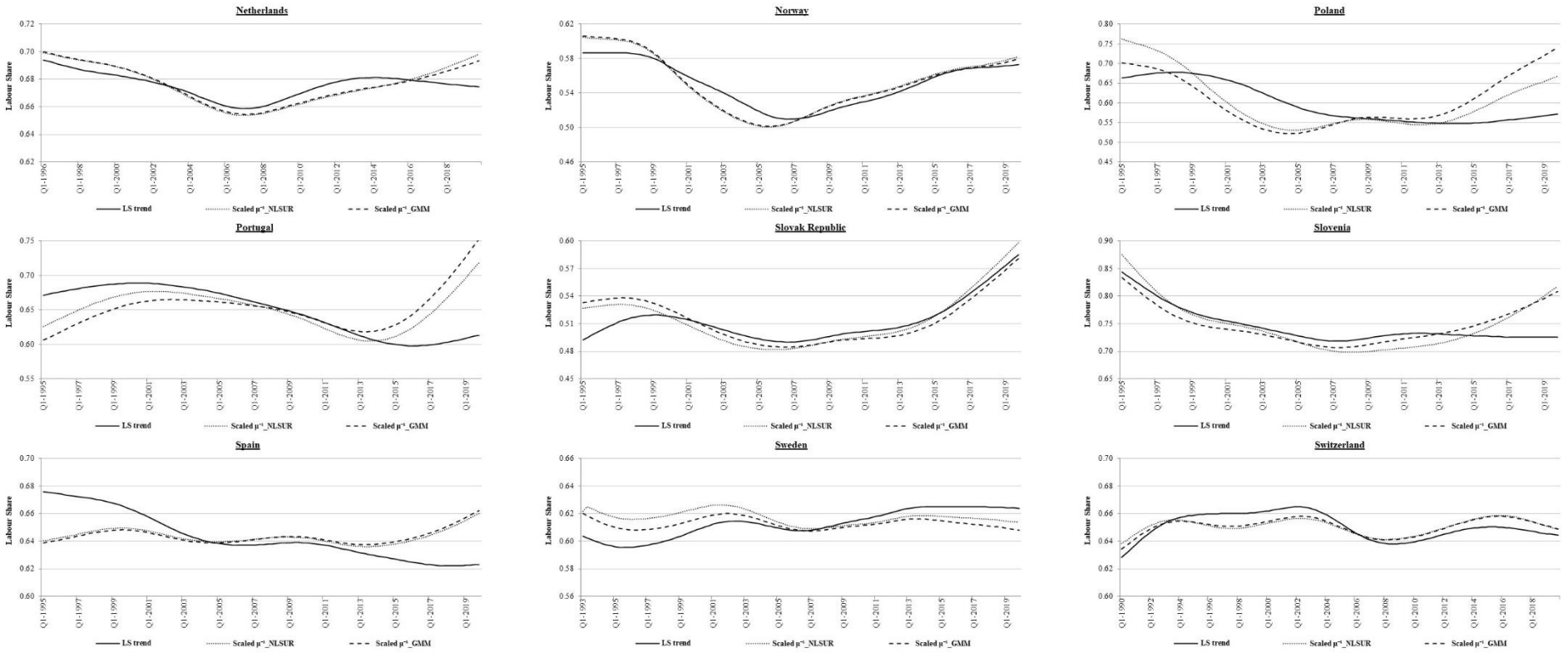
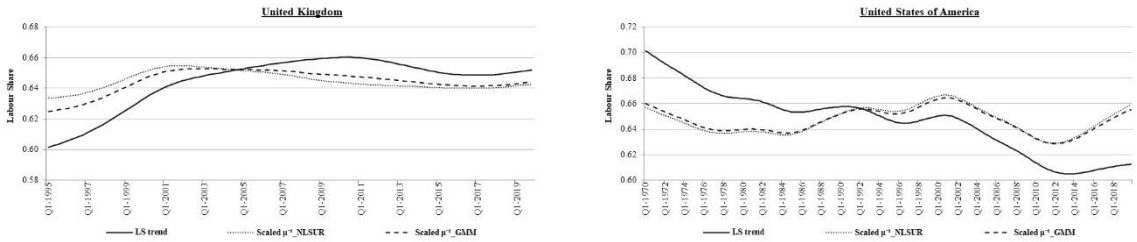


Figure 4.5: Evolution of the trend components of the labour share and the inverse of the firm labour wedge (cont.)



Conclusion

In the neoclassical production theory, the elasticity of capital-labour substitution is a measure of the degree of substitutability between the two factors of production. This concept was introduced independently by John R. Hicks in *The Theory of Wages* (1932) and Joan Robinson in *The Economics of Imperfect Competition* (1933) and, ever since, has been used in several different studies.

The CES production function is one of the most used functional forms to estimate the elasticity of capital-labour substitution, not only at the country's aggregate level, but also at the sectoral level or plant level. A recent development in this field involves the normalization of CES production functions, which implies expressing the production relations in an indexed number form and allows the joint identification of the elasticity of factor substitution and the parameters of technological change with less biased estimates than imposing *a priori* constraints on the structure of technological change. The prevailing conclusion, despite some exceptions, is a lower than unity elasticity of substitution, both for the United States of America and other geographical scopes, consequently rejecting the Cobb-Douglas assumption. In this regard, the technological change assumption plays an importante role, as restricting the analysis to the Hicks-neutral case will bias the elasticity of substitution estimates towards unity. When factor-augmenting technological change is taken into account, the prevailing conclusion is the finding of net labour-augmentation rates.

In line with the majority of these studies, we find that the US aggregate elasticity of substitution is lower than unity, which corresponds to the case of gross complementarity between the production factors. Moreover, the vast majority of the 65 industries represented in the US National Income and Product Accounts also exhibit lower than unity elasticities of substitution. Regarding the single-equation estimates, our work also suggests that the highest elasticities of substitution are obtained from the labour first-order condition, confirming an empirical regularity found in previous studies.

However, the CES production function, as indicated by its denomination, restricts the elasticity of substitution to a constant value (albeit not necessarily unity as the Cobb-Douglas function), even if the relative supply of labour and capital changes in the economy. Consequently, several authors developed alternative functional forms for an economy's production function, which allow the value of the elasticity of substitution to

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be influenced by the economy's input ratio. Despite its relatively limited empirical application since the 1970s, most of these studies agree that the VES production function is more realistic than the Cobb-Douglas and the CES production functions in many specifications and mainly point to lower than unity values of the elasticity of substitution. Extending the normalization procedure to the case of VES production functions, we find that the VES parameter estimates for the US aggregate economy indicate a reduced variation over time, suggesting a tendency towards the CES specification. However, we also conclude that only between a third and 40% of the overall number of industries may be characterized by a time-invariant elasticity of substitution. In the remaining cases, the elasticity of substitution is apparently variable and therefore disaggregated industry-level studies should consider alternative and more flexible functional forms rather than the conventional and widely used CES production function.

Technological change is estimated to be net labour-augmenting at the US aggregate level, irrespective of the production function specification, at an average rate of around 1.1% to 1.5%, resulting from a positive labour-augmentation rate, combined with a decline in the capital efficiency level, which is also the prevailing conclusion at the industry-level. However, these results are not uniform: for example, in some primary industries, there appears to be an increase in capital efficiency and net capital-augmentation is found particularly in a number of service industries.

Over the decades, the elasticity of capital-labour substitution has emerged as a key variable in many macroeconomic issues and economists have paid extensive attention to estimating the elasticity of substitution between capital and labour, since different values of this parameter can lead to significantly different conclusions. Consequently, we have also carried out a survey on the importance of factor substitution across a wide range of macroeconomic topics, namely production and functional income distribution, taxation and resource misallocation, labour, growth theory or equilibrium indeterminacy and complex dynamics.

One of the topics directly affected by the magnitude of this parameter is the functional distribution of income. The capital share increases with capital intensity when the elasticity of substitution is greater than one, whereas an opposite conclusion is reached when the elasticity of substitution is lower than one. Although there is some debate in the literature, the majority of empirical studies estimate the elasticity of substitution to be less than one. This makes it challenging to attribute the recent decline in the labour share

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observed in many countries to an increase in capital intensity. The higher the elasticity of capital-labour substitution, the lower the impact of productivity on factor returns and the lower the impact of capital deepening on the wage-rental ratio. In the case of an elasticity of substitution below one, the relationship between output per capita and capital intensity is concave. Conversely, if the elasticity of substitution is higher than one, the relationship is convex. Empirical evidence from cross-country studies indicates that a concave relationship fits the data better. However, if the elasticity of substitution is lower than one, cross-country differences in productivity lead to significant and unrealistic differences in factor returns. This suggests that differences in total factor productivity (TFP) may be a significant source of cross-country differences in income per capita.

The welfare costs of taxation increase with the value of the elasticity of capital-labour substitution because the price elasticity of the demand functions for the productive factors increases with the value of the elasticity of substitution. Furthermore, a lower elasticity of substitution enhances the productivity gains from better resource allocation and increases the cross-country correlation between output per capita and the distortions that cause resource misallocation.

The elasticity of substitution also plays an important role in the labour market. Firstly, although not immediately apparent, the effect of unionisation on wages and employment depends on the elasticity of capital-labour substitution. Secondly, the impact of technological shocks on hours worked, unemployment and vacancies depends crucially on the nature of the productivity shock and the magnitude of the elasticity of substitution. The incorporation of a substantial capital-labour complementarity within a dynamic stochastic model enables the model to better reflect the cyclical properties of labour market variables in the United States. Furthermore, the lower the elasticity of substitution, the greater the impact of capital deepening on employment. Some authors have proposed that the prolonged period of elevated unemployment in Europe during the 1980s was a consequence of the implementation of capital-intensive technologies in a context where capital and labour were gross substitutes.

Capital-labour substitution is also crucial for some aspects of economic growth. Structural change can be driven by differences in the elasticity of substitution. Sectors with a higher elasticity of capital-labour substitution tend to intensify the use of the productive factor that is becoming more abundant, which can lead to sectoral differences in the growth rates of capital intensity. In the context of the neoclassical growth model, a higher elasticity of

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capital-labour substitution increases the speed of convergence if the economy is above its steady state, but reduces it otherwise. Furthermore, for any given capital intensity, a higher elasticity of capital-labour substitution boosts the growth of capital and output per worker during the transition to the balanced growth path. In the long run, both capital intensity and output per worker are increasing functions of the elasticity of substitution. Even in the absence of technological progress, it is possible to achieve perpetual growth if the elasticity of capital-labour substitution is sufficiently high. However, if the elasticity of capital-labour substitution is sufficiently low, it is also possible to experience a perpetual slowdown. In the neoclassical growth model, if the elasticity of substitution is not unitary, the existence of a balanced growth path necessitates solely labour-augmenting technological progress. An elasticity of substitution inferior to one ensures that the economy converges to a balanced growth path where technological change is exclusively labour-augmenting. While the results are contingent upon assumptions regarding preferences, technology, structure, and market distortions, the elasticity of capital-labour substitution represents a pivotal parameter for the emergence of multiple equilibria and complex dynamics in macroeconomic models.

Finally, we have also estimated the elasticities of substitution and factor augmentation rates for a set of 29 OECD countries. The point estimates of the elasticity of substitution using the normalized CES production function, as well as the 95 percent confidence intervals, lie entirely below unity for all countries, corresponding to the case of gross complementarity between capital and labour. However, in a few cases the estimated elasticity of substitution is not far from unity (Greece, Hungary and Sweden, depending on the estimation method and production function used), and therefore the Cobb-Douglas possibility should not be completely discarded. The Leontief case (zero elasticity of substitution) is never obtained, with the lowest estimates being found for Poland, Germany and Norway. The estimated elasticity of substitution for the USA is either 0.70 or 0.76, depending on the estimation method. Besides Germany, whose substitution elasticity is estimated between 0.24 and 0.31, the largest European economies, United Kingdom, France and Italy, have estimates in the region of 0.45 to 0.55, while the estimates for Spain are between 0.71 and 0.72. Outside Europe, Australia, Canada and Japan have estimates comprised between 0.36 and 0.41 (with the only exception being Australia using the GMM method, whose result is 0.59). Furthermore, our estimation results corroborate the net labour-augmentation hypothesis for practically all countries,

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with the Czech Republic being one of the exceptions. Consequently, since for most OECD countries the elasticity of substitution is likely less than one and technological change is net labour-augmenting, we find that technological change is in general capital-biased.

As previously noted, according to the neoclassical economic theory, the elasticity of substitution between capital and labour is a key variable in determining the response of functional distribution of income to changes in capital deepening or factor-augmenting technological change. Since the labour share underwent considerable changes in most OECD countries in recent years, the majority of which exhibited a clear downward trend, we have also assessed the suitability of the neoclassical model for predicting changes in the labour share across countries. Despite the strong capital deepening in all countries, the predominant finding of net labour-augmentation is reflected in a decline in the effective capital-labour ratio for most OECD countries and, consequently, in the model-predicted labour share. The exceptions are either countries experiencing net capital-augmentation or countries where the rate of net labour-augmenting technological change was not fast enough to generate a decline in the effective capital-labour ratio (such as Germany or the United Kingdom), which explains the observed increase in the labour share as predicted by the neoclassical model. In the United States and Australia, two countries in which the labour share underwent a significant decline, the rate of net labour-augmenting technological change exceeded 3.50% and 2.25% per year, respectively. On average, in the countries where the rate of decline in the labour share has been greater, the contribution of net labour-augmenting technological change has been larger, while the contribution of capital deepening has been smaller. Therefore, we find that increases in labour productivity can be reconciled with the observed declines in the labour share across countries in a context of a gross complementarity between capital and labour, provided that technological change is in fact increasing the amount of effective labour relatively to effective capital. It also follows from our results that capital deepening has not contributed to reducing the labour share, but rather the opposite.

According to our analysis, the perfect competition model with biased technological change accurately accounts for the evolution of the trend component of the labour share in the Anglo-Saxon countries of Australia, the United States and the United Kingdom and some European economies (such as the Czech Republic or Spain), but it does not in Canada, Japan, and most European countries, including the three largest economies in the euro area (Germany, France and Italy). In these countries, the firm labour wedge, which

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includes all factors that deviate the wage rate from the calculated marginal productivity of labour (among which market frictions and distortions), might have played an important, even prominent, role in accounting for the evolution of the trend component of the labour share. Moreover, in many OECD countries, the firm labour wedge has been declining since around 2008, contributing to an increase or at least a stabilisation of the labour share. However, the labour wedge is a black box. Filling it in might help explaining changes in the functional distribution of income. Furthermore, exploring the institutional, regulatory and economic determinants of the technological bias may be another fruitful direction for future research.

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The elasticity of substitution between capital and labour plays a pivotal role in economic literature. In this study, we survey the importance of factor substitution over a broad range of topics, since the conclusions and policy implications of many economic models are highly sensitive to the magnitude of this parameter. At the empirical level, we find that the elasticity of substitution for the US aggregate economy is most likely lower than unity; it also shows a reduced variation over time, contrary to the majority of this country's industries. We also find that rapid net labour-augmenting technological change offset capital deepening and was the main driver of the labour share decline in most OECD countries, in a context of gross complementarity between capital and labour.