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Exchange rates and the global transmission of equity market shocks

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ABSTRACT

With the capacity to amplify or buffer the effect of shocks between equity markets in different countries, exchange rates play a crucial role in the transmission of shocks. By modelling the dependence structure between exchange rates and equity markets, we quantify the impact of an equity market shock on other equity markets through the cross-expected shortfall and assess the contribution of exchange rates to shock transmission. For emerging Latin American countries (Argentina, Brazil, Chile and Mexico) and two developed markets (the EU and USA), we document (a) that the contribution of exchange rates to shock transmission is time-varying and differs across countries; and (b) that exchange rates diversify (echo) shocks from abroad for investors based in emerging (developed) economies. Our results suggest that investors need to accurately measure the diversification role of their currency when making international portfolio and risk management decisions.

1. Introduction

Exchange rates play a crucial role for the transmission of shocks between equity markets in different countries. When, as a result of a shock, a country's equity market is expected to outperform equity returns in another country, the expected outcome of a foreign investment in that country could be boosted or mitigated by appreciation or depreciation, respectively, in its currency. Therefore, the link between currency value and equity market influences potential capital movements between equity markets resulting from shocks, ultimately determining co-movement between equity markets in different countries. Measuring that dependence between currency and equity market returns is critical, not only to identify equity market co-movements, but also for portfolio and hedging decisions by international equity investors, and for policymakers to evaluate the impact of their policies regarding capital movements.

The non-arbitrage pricing theory fails to clearly state the sign and strength of correlation between currency returns and the difference between domestic and foreign equity returns. In a risk-neutral world, the uncovered equity parity condition (e.g., Cenedese et al., 2016) states that returns in the international equity market expressed in the same currency must be equal in equilibrium, so exchange rates should move to balance any excess returns. As return-chasing investors (e.g., Griffin et al., 2004; Richards, 2005) are willing to increase their holdings in an outperforming foreign equity market, investors' foreign currency demands cause the value of a foreign currency to increase, thus ensuring a positive correlation between currency returns and excess equity returns. Using portfolio rebalancing arguments, in contrast, Hau and Rey (2006) show that when a foreign equity market outperforms the domestic market, investors rebalance their portfolio to reduce their exposure to currency risk by selling some foreign equity, leading to a depreciation in the foreign currency and to a negative correlation between currency returns and excess equity returns. In a non-risk-neutral world, the correlation between equity and currency returns is also shaped by the compensation investors demand for bearing equity and exchange rate risks, and this determine the value of risk premia in international equity markets.

The sign and strength of correlation between equity and currency returns is not clear either at the empirical level: Hau and Rey (2006) find a negative correlation between currency value and equity returns in developed economies, while Cho et al. (2016) document a positive correlation for emerging economies. Therefore, as the sign and strength of dependence between currency and equity returns may diverge across international equity markets, the transmission of shocks may differ depending on the country where the shock originated.

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[1] All errors are my own. The views expressed are those of the author and do not necessarily reflect those of the JRC.

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In this paper, we examine the role played by exchange rates in the propagation of equity market shocks by modelling the dependence structure between exchange rates and the corresponding international equity markets. Previous empirical studies on co-movements between international equity markets (see, e.g., Christoffersen et al., 2012; Chollete et al., 2011; Yang et al., 2015) have analysed, from the perspective of US investors, global equity market co-movement and international diversification benefits by modelling dependence between domestic US equity returns and foreign returns denominated in USD. However, those analyses preclude having accurate information on the role played by exchange rates in the propagation of shocks between international equity markets and on the real potential and impact of diversification strategies. In contrast, we consider that the strength of dependence between currency and equity returns may differ across countries, and that this fact shapes interdependence between two international equity markets, which, in turn, may differ depending on the investors' perspective, e.g., whether the market is domestic or foreign.[2]

We use a trivariate hierarchical dependence structure as given by a vine copula, where the exchange rate plays a crucial role in shaping the conditional dependence between equity markets. From that dependence between equity and currency returns, the transmission of an equity market shock from one market to another is measured as the cross-expected shortfall (C-ES), which is computed as the expected returns in one equity market conditional on a realized shock in another equity market. On the basis of the C-ES, we introduce a measure of the exchange rate contribution to shock propagation between equity markets that facilitates the identification of the portion of the shock that originated from equity or currency fluctuations; this will enable investors to implement more effective hedging strategies for each type of risk so as to increase the benefits of international diversification.

We empirically examine the dependence structure for four emerging Latin American equity markets (Argentina, Brazil, Chile and Mexico) and two developed equity markets (EU and USA) taking into account the roles played by their respective exchange rates. We compute the C-ES from a trivariate copula setup that is assumed to display Markov switching nonlinear dependence features, as in Chollete et al. (2011). Our empirical results for the period 2002–2020 show that while exchange rates play a key role in transmitting shocks between equity markets, this role is time-varying and asymmetric and also varies across currencies. For all the markets except for Argentina, exchange rates make a relevant contribution to shock transmission, which varies across dependence structure regimes. We also document that exchange rates diversify shocks from abroad for investors based in emerging economies (particularly Brazil, Chile and Mexico) and echo the effect of shocks from abroad for investors based in developed markets. Furthermore, we quantify the impact of shocks on the value of investments abroad and document how exchange rates can enhance the diversification benefits of international portfolios, showing that those benefits differ according to where investors are based.

Our research is broadly related to the vast theoretical and empirical literature that relates exchanges rates and equity returns. Macroeconomic (Dornbusch and Fischer, 1980; Meese and Rogoff, 1983) and portfolio balance (Hau and Rey, 2006; Pavlova and Rigobon, 2007; Gabaix and Maggiori, 2015) theories establish a relationship between currency values and equity returns based on arguments regarding international competitiveness and capital flows to rebalance portfolios. Extant empirical evidence (see, e.g., Ning, 2010; Wang et al., 2013; Cho et al., 2016; Reboredo et al., 2016; Dua and Tuteja, 2016; Leung et al., 2017) supports the link between currency values and equity returns in different market scenarios, although evidence on the sign of this dependence is mixed. As a result of return-chasing by investors, Froot et al. (2001), Griffin et al. (2004) and Richards (2005) find a positive relationship between equity returns and local currency values through capital inflows in developing markets. In contrast, using portfolio rebalancing arguments, Hau and Rey (2006) empirically show that currency values and domestic equity returns are negatively correlated for developed economies, whereas Cho et al. (2016) show that these are positively correlated for emerging economies. Using the uncovered equity parity condition, Cenedese et al. (2016) show that the sign and strength of dependence between currency values and equity returns are not clear at the theoretical level and report empirical evidence of independence between them. Our empirical analysis contributes to this current of the literature by providing copula evidence on dependence between equity returns and currency values and by highlighting the role of that dependence in the transmission of shocks between equity markets.

Our study also adds to the systemic risk literature,[3] where expected shortfall (ES) is a widely used measure, typically computed in a bivariate setting so as to account for the adverse impact of a market downturn on returns (see, e.g., Brownlees and Engle, 2017). In order to assess the sensitivity of equity returns to returns in another equity or currency market, we use a trivariate copula-based model to estimate the ES that could be useful for assessing systemic risk in a multivariate setting.

Finally, our findings have implications for investment and risk management decisions by international investors, regulatory authorities and policymakers. Firstly, from the perspective of investors in emerging markets, exchange rates offer diversification opportunities for their investments in developed economies, as the developed-country currency value moves in the opposite direction to developed-country equity returns, and this has the outcome of buffering extreme downward or upward movements in equity returns. Contrarily, for investors in developed markets, diversification opportunities for their emerging market investments are limited, as the emerging-market currency value moves in tandem with equity returns. Secondly, for monetary and supervisory authorities, our empirical setup is useful for building tailor-made stress-test scenarios that specifically take into account exchange rate and equity dependence in protecting economies against crises, like, e.g., the Turkish currency crisis of 2018. Thirdly, policy makers will find our framework helpful in understanding the impact, through exchange rates, of equity market distress scenarios on the main economic indicators (De and Sun, 2020), e.g., on changes in international investment positions.

The remainder of this paper is laid out as follows: in Section 2 we introduce our empirical methods to characterize multivariate dependence between exchange rates and equity markets, and to quantify the contribution of exchange rates to the propagation of shocks across global equity markets; in Section 3 we describe the data for the studied equity and currency markets; in Section 4 we present and discuss our empirical results, and in Section 5 we discuss the implications of our findings for international investors. Finally, Section 6 concludes the paper.

2. Methodology

This section outlines the modelling approach to characterizing dependence and spillover effects between equity markets in different countries, specifically considering the role of exchange rates in shaping co-movement. We describe conditional copula modelling to compute C-ES, marginal models and the copula hierarchical dependence structure with Markov switching dynamics.

[2] Note that currency values and equity returns could be negatively correlated for investors based in developed countries, but positively correlated for investors based on emerging countries (e.g., Cho et al., 2016), so exchange rates buffer (exacerbate) equity shocks that investors in emerging (developed) countries received from developed (emerging) equity markets.

[3] For a survey of this theoretical and empirical literature see Benoit et al. (2017).

2.1. Exchange rates and dependence between equity markets

From the standard no-arbitrage asset pricing framework, the relationship between international equity returns under risk neutrality is given by[4]

$$r_d = r_f + r_e, \tag{1}$$

where r_d and r_f denote domestic (d) and foreign (f) log equity returns, and r_e denotes the log exchange rate (e) returns, with e defined in terms of units of domestic currency per unit of foreign currency. Hence, the transmission of shocks between equity markets in different countries is rather complex as it depends not only on how equity markets co-move (driven by global or common factors) but also on how currency values are tied to equity returns.

The dependence between currency and equity returns could be positive, negative or even zero. Specifically, that dependence may be shaped by two opposite effects: (a) portfolio rebalancing effects, which trigger a depreciation of the currency of countries that experience a positive equity return shock; and (b) return-chasing behaviour, which triggers an appreciation of the currency of the country with outperforming equity returns. Consequently, the impact of a positive shock in domestic equity returns to foreign investors could be amplified (buffered) by an increase in the domestic currency value, with ramifications for capital movements and co-movement between equity markets.

Having information on the dependence structure between r_d, r_f and r_e is decisive for the assessment of spillover and diversification effects of shocks arising in those markets. This information comes from their multivariate joint distribution function, $F(r_d, r_f, r_e)$, which reports information on how the three variables co-move under different market circumstances, such as in times of extreme movements in equity or currency values. Under those extreme circumstances, the dependence relationship between international equity returns as given by Eq. (1) could also be shaped by the risk premia required by international investors (Cenedese et al., 2016).

Using information from the three-way dependence structure, we can quantify the impact of a foreign shock on domestic equity returns (and vice versa). Namely, this impact can be measured as the expected value of domestic equity returns under the condition that the return for foreign equity is equal to or less than a specific threshold value m: $E\left(r_d | r_f \le m; r_e\right)$, which we call C-ES. A usual choice for the threshold m is a quantile like the value-at-risk (VaR), defined for a level of confidence α as $P(r_f \le VaR_\alpha(r_f)) = \alpha$.

We characterize three-way dependence using copula functions.[5] According to the Sklar's theorem (Nelsen, 2006), the multivariate distribution can be obtained from the a copula function C as:

$$F(r_d, r_f, r_e) = C\left(u_d, u_f, u_e\right), \tag{2}$$

where $u_d = F_d(r_d)$, $u_f = F_f(r_f)$ and $u_e = F_e(r_e)$, and where $F_j(r_j)$ is the continuous distribution function of r_j with density $f_j(r_j)$ for $j = d, f, e$. Assuming that the copula function and marginal distribution functions are differentiable, the joint density can be decomposed as the product of the marginal densities of each variable and the copula density, $c\left(u_d, u_f, u_e\right)$, that captures dependence between variables:

$$f(r_d, r_f, r_e) = f_d(r_d) f_f(r_f) f_e(r_e) c\left(u_d, u_f, u_e\right). \tag{3}$$

Thus, copulas characterize the multivariate distribution in a flexible way by separately modelling marginal and joint dependence features, thereby allowing great flexibility in the featuring of complex dependence patterns as exhibited by financial data, such as asymmetric relationships, joint tail dependence and nonlinearities.[6]

Using the copula representation of dependence, we can now compute the conditional expected value of domestic returns for a given shock in the foreign equity market, given by its $VaR_\alpha(r_f)$ –the C-ES– as[7]

$$E\left(r_d | r_f \le VaR_\alpha(r_f); r_e\right) = \int_0^1 \int_0^1 F_d^{-1}(u_d) \frac{C_{f|d}(C_{f|e}(\alpha|u_e)|C_{d|e}(u_d|u_e))}{\alpha} c_{de}(u_d, u_e) du_d du_e, \tag{4}$$

where $c_{de}(u_d, u_e)$ is the copula density that captures dependence between domestic and exchange rate returns, and $C_{j|h}(\cdot)$ is the conditional copula of j given h, obtained from the partial derivative of the copula function as:

$$C_{j|h}\left(u_j | u_h\right) = \frac{\partial C_{j,h}\left(u_j, u_h\right)}{\partial u_h}. \tag{5}$$

Likewise, for an upward movement in foreign equity returns above the VaR at the $1 - \alpha$ confidence level, we obtain the C-ES for domestic equity returns as:

$$E\left(r_d | r_f \ge VaR_{1-\alpha}(r_f); r_e\right) = \int_0^1 \int_0^1 F_d^{-1}(u_d) \frac{1 - C_{f|d}(C_{f|e}(1-\alpha|u_e)|C_{d|e}(u_d|u_e))}{\alpha} c_{de}(u_d, u_e) du_d du_e. \tag{6}$$

Quantifying the impact of shocks from domestic to foreign equity returns is straightforward, i.e., we swap around d and f in Eqs. (4) and (6). Likewise, and following from Eqs. (4) and (6), the impact of downward and upward exchange rate movements on domestic equity returns can be quantified by swapping around e and f.

As shocks from either foreign equity returns or exchange rates may have an impact on the conditional expected value of domestic equity returns, we can assess the contribution of each kind of shock to changes in domestic equity returns by considering the difference between their conditional and unconditional expected values. Thus, the contributions to domestic equity returns of a downward movement in foreign equity returns of sharp foreign currency depreciation and sharp foreign currency appreciation, respectively, are defined as:

$$\begin{aligned} \gamma_f(\alpha) &= E\left(r_d | r_f \le VaR_\alpha(r_f); r_e\right) - E(r_d), \\ \gamma_e^L(\alpha) &= E\left(r_d | r_e \le VaR_\alpha(r_e); r_f\right) - E(r_d), \\ \gamma_e^U(1-\alpha) &= E\left(r_d | r_e \ge VaR_{1-\alpha}(r_e); r_f\right) - E(r_d). \end{aligned} \tag{7}$$

We can therefore define, for scenarios of sharp foreign currency depreciation or appreciation, the relative contribution of a shock in foreign equity returns to the C-ES of domestic equity returns as:

$$\begin{aligned} \theta_f^L(\alpha) &= \frac{|\gamma_f(\alpha)|}{|\gamma_f(\alpha)| + |\gamma_e^L(\alpha)|} \\ \theta_f^U(\alpha) &= \frac{|\gamma_f(\alpha)|}{|\gamma_f(\alpha)| + |\gamma_e^U(1-\alpha)|}, \end{aligned} \tag{8}$$

where $\gamma_f(\alpha)$, $\gamma_e^L(\alpha)$ and $\gamma_e^U(\alpha)$ are taken as absolute values, since they may be positive or negative depending on the conditional dependence

[4] This relationship also holds under no risk neutrality using the stochastic discount factors for domestic and foreign returns and the corresponding risk premia (see Cenedese et al., 2016).

[5] A comprehensive explanation of copula functions can be found in Nelsen (2006).

[6] See, for instance, Reboredo and Ugolini (2016) and Ojea Ferreiro (2020).

[7] The proof of Eqs. (4) and (6) is provided in Appendix 6. Note that the variable after the semicolon, i.e., r_e, in Eqs. (4) and (6), does not imply conditionality. It is merely a way to explicitly show that the exchange rate returns play a pivotal role in the hierarchical dependence structure between variables.

Table 1
Tail dependence and Kendall's rank correlation coefficient for each copula.

Family	Copula model	τ_L	τ_U	Kendall's τ
Gaussian	$\Phi(\Phi^{-1}(u_1), \Phi^{-1}(u_2); \rho)$	–(if $\rho = 1$ then 1)	–(if $\rho = 1$ then 1)	$2\arcsin(\rho)\pi^{-1}$
Student t	$T(T^{-1}(u_1;\eta), T^{-1}(u_2;\eta); \rho, \eta)$	$2t_{\eta+1}\left(-\sqrt{\frac{(\eta+1)(1-\rho)}{1+\rho}}\right)$	$2t_{\eta+1}\left(-\sqrt{\frac{(\eta+1)(1-\rho)}{1+\rho}}\right)$	$2\arcsin(\rho)\pi^{-1}$
Clayton	$(u_1^{-\theta} + u_2^{-\theta} - 1)^{-1/\theta}$	$2^{-1/\theta}$	–	$\frac{\theta}{\theta+2}$
Gumbel	$\exp\left(-\{(-\log u_1)^\theta + (-\log u_2)^\theta\}^{1/\theta}\right)$	–	$2 - 2^{1/\theta}$	$\frac{\theta-1}{\theta}$
BB1 (Clayton-Gumbel)	$\left(1 + \left[(u_1^{-\theta} - 1)^\delta + (u_2^{-\theta} - 1)^\delta\right]^{1/\delta}\right)^{-1/\theta}$	$2^{-\frac{1}{\theta\delta}}$	$2 - 2^{1/\delta}$	$1 - \frac{2}{\delta(\theta+2)}$

Notes. This table summarizes the main features of bivariate copulas that are used in the empirical analysis. τ_L denotes lower tail dependence, defined as $\tau_L = lim_{q\to 0}P(u_2 < q|u_1 < q)$, while τ_U denotes upper tail dependence, defined as $\tau_U = lim_{q\to 1}P(u_2 > q|u_1 > q)$. – represents no tail dependence. $\Phi(\ldots;\rho)$ indicates the normal cumulative distribution function with correlation ρ, whereas $T(\ldots;\eta)$ indicates the student-t cumulative distribution function with η degrees of freedom and correlation ρ. $\Phi^{-1}(\ldots)$ and $T^{-1}(\ldots)$ indicate, respectively, the inverse cumulative distribution function of the normal and the student-t distribution. Ojea Ferreiro (2019) provides formulas for density copulas and conditional copulas for these models.

value. In a similar way, we can obtain the relative contribution of downward and upward exchange rate shocks as $\theta_e^L(\alpha)$ and $\theta_e^U(\alpha)$, respectively, each taking a value between 0 (no contribution) and 1 (maximum contribution). Note that, by construction, $\theta_f^L(\alpha) + \theta_e^L(\alpha) = 1$ and $\theta_f^U(\alpha) + \theta_e^U(\alpha) = 1$.

2.2. Modelling conditional copulas

We now describe how to obtain the conditional and bivariate copulas necessary to compute the impact of the shocks described above. Those copulas can be derived from a hierarchical dependence structure that decomposes the multivariate copula in Eq. (2) into a cascade of bivariate copulas, in a decomposition called a vine copula.[8] Vine copulas are obtained from decomposition of the joint probability density by iterative conditioning. Thus, the joint density for the three variables in Eq. (3), i.e., foreign equity returns, domestic equity returns and exchange rates, can be factorized recursively as:

$f(r_f, f_d, r_e) = f_e(r_e)f(r_f|r_e)f(r_d|r_f, r_e)$,

where, using copulas, the first conditional density can be decomposed as:

$f(r_f|r_e) = c_{fe}(F_f(r_f), F_e(r_e))f_f(r_f)$,

and where the second conditional density can be decomposed as:

$$f(r_d|r_f, r_e) = c_{fd|e}\left(F_f(r_f|r_e), F_d(r_d|r_e)\right) f(r_d|r_e)$$

where $f(r_d|r_e) = c_{de}(F_d(r_d), F_e(r_e))f_d(r_d)$, and where $F_k(r_k|r_l) = C_{k|l}(F_k(r_k)|F_l(r_l)) = u_k|u_l$, with $C_{k|l}(u_k|u_l)$ defined by Eq. (5). Hence, the joint density of the three variables can be written as a function of their marginals and bivariate copulas as:

$$f(r_f, r_d, r_e) = \underbrace{c_{fd|e}\left(u_f|u_e, u_d|u_e\right) c_{fe}(u_f, u_e)c_{de}(u_d, u_e)}_{c(u_f, u_d, u_e)} f_f(r_f)f_d(r_d)f_e(r_e). \quad (9)$$

The main appeal of the decomposition in Eq. (9) is that each bivariate copula can be selected independently from different copula types, ensuring, thus, greater flexibility in capturing multivariate dependence than the use of a trivariate copula as in Eq. (3). Furthermore, this density decomposition can be graphically represented by a hierarchical structure between f, d and e, whether given by a C-vine copula, where e is the pivotal variable, or by a D-vine copula, where e is the central node.[9] Interestingly, from the bivariate or pair copulas in Eq. (9) we can obtain the bivariate and conditional copulas as per Eq. (5) that are necessary to compute the C-ES in Eqs. (4) and (6).

As essential information for the computation of spillover effects, we model bivariate dependence using different copula specifications to capture the main dependence features in time series, including tail independence and symmetric and asymmetric tail dependence. Specifically, we consider: (a) the Gaussian copula, which does not present tail dependence and allows for positive association and negative association; (b) the student-t copula, which (like the Gaussian) allows for positive association and negative association but presents symmetric tail dependence; (c) the Gumbel and the Clayton copulas, which allow for positive asymmetric association with lower tail independence and upper tail dependence, and lower tail dependence and upper tail independence, respectively; and (d) the BB1 copula which allows for positive asymmetric association with lower and upper tail dependence. Table 1 summarizes the main features of the bivariate copulas we use in our empirical analysis.

In addition, as the transmission of shocks between global equity markets may widely differ in terms of size and intensity when markets become more interdependent at specific time periods (e.g., during periods of crisis, negative events, excessive volatility, etc), we consider that the dependence structure may change over time. Specifically, as in Pelletier (2009), Rodriguez (2007), Garcia and Tsafak (2011), Chollete et al. (2009), Girardin and Namin (2019) and Ojea Ferreiro (2019), we take into account that dependence changes according to a regime-switching model with two states. By considering different regimes, we allow for different patterns of tail dependence and dependence asymmetries across time that are featured by the copulas reported in Table 1.[10] Specifically, we consider that state 1 dependence between variables is characterized by symmetric tail dependence, whereas state 2 dependence is characterized by asymmetric tail dependence. Asymmetric dependence between states means that benefits of diversification for international investors may be enhanced or dampened due to changes in the dependence regime.[11]

Accordingly, the joint density of the three variables conditional on being in regime $j (j = 1, 2)$ is given by:

$$f(r_f, r_d, r_e|s_t = j) = c_{fd|e}^{(j)}\left(u_f|u_e, u_d|u_e; \theta_{fd|e}^{(j)}\right) c_{fe}^{(j)}(u_f, u_e; \theta_{fe}^{(j)}) c_{de}^{(j)}(u_d, u_e; \theta_{de}^{(j)}) f_f(r_f)f_d(r_d)f_e(r_e), \quad (10)$$

where $\theta_{(\cdot)}^{(j)}$ denotes the set of copula parameters in state j. Therefore, as in Chollete et al. (2009), we assume that the regime only affects

[8] For an introduction to vine copulas, see Aas et al. (2009).

[9] Fig. 12 in the online appendix represents the graph-based tree structure of the copula decomposition for the three variables, showing that the hierarchical construction under a C-vine copula and under a D-vine copula is the same.

[10] Note that we are assuming that copula parameters remain constant conditional on each state, although unconditionally our copula model presents time-varying features through the inference of each state probability. Alternative specifications like time-varying parameters within each regime are ruled out because of the computational complexity consequence of path-dependence in the process (see Haas et al., 2004; Bauwens et al., 2010).

[11] Asymmetric dependence between states is supported by our data. The online appendix provides empirical results of the structure of dependence under different asymmetric regimes, reporting evidence that favours asymmetry between states 1 and 2 as described above.

the dependence structure, while the marginals behave similarly across regimes. The joint density of the three variables derives as:

$$f(r_f, r_d, r_e) = \sum_{j=1}^{2} P(s_t = j) f(r_f, r_d, r_e | s_t = j), \tag{11}$$

where $P(s_t = j)$ denotes the probability of being in state j.

The dependence structure, as given by the joint density in Eq. (11), is assumed to be unobserved (it does not rely on ad hoc determination) and depends on a latent binary variable s_t that indicates the regime at time t ($s_t = 1$ or $s_t = 2$), with probabilities $P_t = [P(s_t = 1), P(s_t = 2)]'$ that are given by a first order Markov chain ($P_t = P' \cdot P_{t-1}$), with the following transition probability matrix:

$$P = \begin{bmatrix} p_{11} & 1-p_{11} \\ 1-p_{22} & p_{22} \end{bmatrix}, \tag{12}$$

where $p_{ij} = P(s_t = j | s_{t-1} = i)$ refers to the probability of moving from state i at time $t-1$ to state j at time t, with $\sum_{j=1}^{2} p_{ij} = 1$ for $i = 1, 2$.

Finally, as the structure of dependence varies across states, the impact of shocks from one market to another market naturally differs across those states. Specifically, for each state, that impact can be easily computed from Eqs. (4) and (6) by using bivariate copulas that characterize dependence in the corresponding state. Moreover, we can quantify the overall impact of shocks by: (a) considering the mix of copulas that features dependence in each state, with weights reflecting the probability of each state as given by the vector P_t; or, alternatively, (b) computing the weighted average of the impact of shocks in each state, with weights reflecting the probability of each state as given by the vector P_t.

2.3. Modelling marginal densities

We model the marginal densities of d, f and e returns in Eq. (3) by considering that their means and variances display dynamic behaviour characterized, respectively, by an autoregressive moving average (ARMA) model and by a Glosten-Jagannathan-Runkle generalized autoregressive conditional heteroskedasticity (GJR-GARCH) model. Specifically, the returns for asset $h (h = d, f, e)$ at time t can be expressed as:

$$r_{h,t} = \mu_{h,t} + \sigma_{h,t}\varepsilon_{h,t}, \tag{13}$$

where the mean returns are $\mu_{h,t} = \varphi_{h,0} + \sum_{k=1}^{p} \varphi_{h,k} r_{h,t-k} + \sum_{l=1}^{q} \psi_{h,l}\sigma_{h,t-l}\varepsilon_{h,t-l}$, with p and q denoting the number of lags of the AR and MA structures, respectively. ε_h,t is an *i.i.d.* Random variable with zero mean and unit variance that is assumed to follow Hansen's skewed-t distribution (Hansen, 1994), capturing higher moments such as skewness and kurtosis. The skewed-t distribution is given by:

$$F_h(\varepsilon_{h,t}|\eta_h, \lambda_h) = \begin{cases} bc\left(1 + \dfrac{1}{\eta_h - 2}\left(\dfrac{b\varepsilon_{h,t} + a}{1-\lambda_h}\right)^2\right)^{-(\eta_h+1)/2} & \varepsilon_{h,t} < -a/b \\ bc\left(1 + \dfrac{1}{\eta_h - 2}\left(\dfrac{b\varepsilon_{h,t} + a}{1+\lambda_h}\right)^2\right)^{-(\eta_h+1)/2} & \varepsilon_{h,t} \geq -a/b \end{cases}, \tag{14}$$

where $2 < \eta_h < \infty$ and $-1 < \lambda_h < 1$. The constants a, b and c are given by:

$$a = 4c\lambda_h\left(\frac{\eta_h - 2}{\eta_h - 1}\right), b = \sqrt{1 + 3\lambda_h^2 - a^2}, c = \frac{\Gamma\left(\frac{\eta_h+1}{2}\right)}{\sqrt{\pi(\eta_h - 2)}\Gamma\left(\frac{\eta_h}{2}\right)}.$$

note that, for $\lambda_h = 0$, Eq. (14) reduces to the standard Gaussian distribution as $\eta_h \to \infty$, while, for $\lambda_h = 0$ and η_h finite, Eq. (14) is the standardized symmetric-t distribution. Finally, the dynamics of the return variance, $\sigma_{h,t}^2$, is given by:

$$\sigma_{h,t}^2 = \omega_h + \beta_h\sigma_{h,t-1}^2 + (\alpha_h + \gamma_h \mathbb{1}_{\epsilon_{h,t-1}<0})\epsilon_{h,t-1}^2, \tag{15}$$

where ω_h is a constant, β_h and α_h are the parameters of the generalized and autoregressive conditional heteroskedasticity effects, and $\mathbb{1}_{\epsilon_{h,t-1}<0}$ is an indicator function that is valued at 1 if ϵ_h,t−1 < 0 and 0 otherwise. Thus, γ_h captures leverage effects; in other words, negative shocks have more impact on variance than positive shocks. When $\gamma_h = 0$ we have the usual GARCH model.

2.4. Estimation

We estimate the parameters of the copula and marginal models using a two-step procedure called inference function for margins (IFM), whereby marginal distributions and copulas in Eq. (11) are estimated separately (see, e.g., Nelsen, 2006) as follows.

In a first step, the parameters of each marginal model are estimated using maximum likelihood (ML). From the marginal estimations, pseudo-observations for the copula are obtained as $\hat{u}_{h,t} = \hat{F}_h\left(\frac{r_{h,t} - \hat{\mu}_{h,t}}{\hat{\sigma}_{h,t}}\right)$, for $h = d, f, e$.

In a second step, the copula parameters are estimated using ML, where the likelihood value at time t is given by a mixture of two copulas, with weights determined by the probability of being in each state:

$$\begin{aligned} L_t(\hat{u}_{f,t}, \hat{u}_{e,t}, \hat{u}_{d,t}; I_{t-1}, \Theta) = {} & c(\hat{u}_{f,t}, \hat{u}_{e,t}, \hat{u}_{d,t}|\Theta_{s_t=1}, I_{t-1})P(s_t = 1|I_{t-1}) \\ & + c(\hat{u}_{f,t}, \hat{u}_{e,t}, \hat{u}_{d,t}|\Theta_{s_t=2}, I_{t-1})P(s_t = 2|I_{t-1}), \end{aligned} \tag{16}$$

where Θ includes the set of copula parameters that characterize dependence in both states, i.e., $\Theta_{s_t=j} = [\theta_{fd|e}^{(j)}, \theta_{fe}^{(j)}, \theta_{de}^{(j)}]'$, and where $P(s_t = j|I_{t-1})$ is the probability of being in state j at t given the set of information I_{t-1} available at $t-1$. Trivariate copulas in Eq. (16) can be decomposed into bivariate copulas as in Eq. (9). As the Markov chain s_t is not observable, we use the filter proposed by Hamilton (1989) to obtain the probabilities for each state by forward iteration of the Markov chain as:

$$\hat{\xi}_{t+1|t} = P'\hat{\xi}_{t|t}, \tag{17}$$

where $\hat{\xi}_{t+1|t}$ is a (2×1) vector that contains the probabilities of each state at time $t+1$ conditional on information up to t, and $\hat{\xi}_{t|t}$ is Bayesian updating of the probability being in either regime given information up to time t, as given by:

$$\hat{\xi}_{t|t} = \frac{\hat{\xi}_{t|t-1} \odot \eta_t}{1'(\hat{\xi}_{t|t-1} \odot \eta_t)}, \tag{18}$$

where $\odot$ denotes the Hadamard product and 1 is a (2×1) column vector of ones, and where η_t is a (2×1) vector that contains the copula densities for each state at time t.

Parameter estimates from the IFM approach are consistent and asymptotically normal (e.g., Nelsen (2006); however, since those estimates are less efficient than the full estimates (Patton, 2006; Patton, 2012), we use a Monte Carlo procedure to compute the covariance matrix, consisting of simulating and re-estimating the model N times in order to obtain the distribution of the estimated parameters.

Finally, we choose the most suitable copula function using the Akaike information criterion corrected for small-sample bias (AICc),[12]

$$AICc = 2k\frac{T}{T-k-1} - 2\log(\hat{L}),$$

[12] This criterion has been previously used to select the best copula fit in the conditional risk analysis literature (see, e.g., Reboredo and Ugolini, 2015a; Reboredo and Ugolini, 2015b; Reboredo and Ugolini, 2016; Rodriguez, 2007; Ojea Ferreiro, 2019; Reboredo, 2011 and Ojea Ferreiro, 2020).

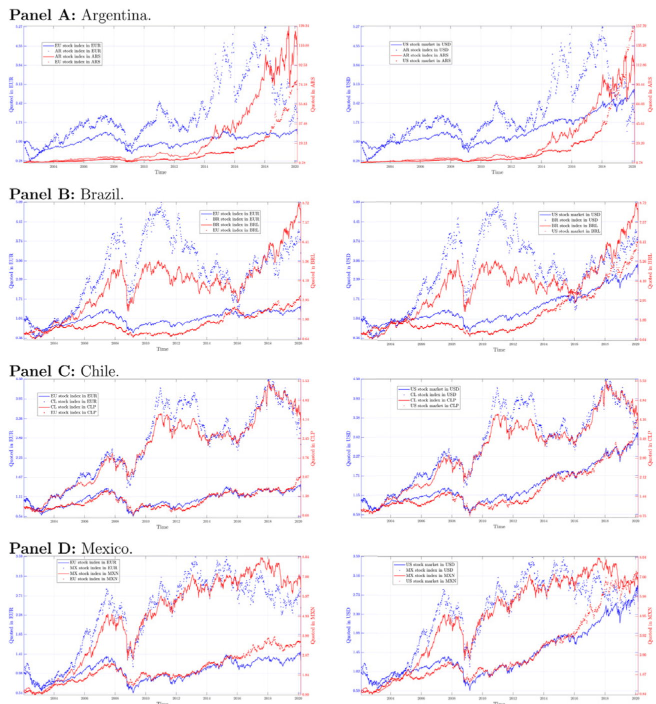


Fig. 1. Time series plot of weekly equity market indices in different currencies. This figure depicts the time series for weekly stock data for the S&P MERVAL INDEX, BRAZIL BOVESPA, S&P CLX IGPA, S&P/BMV IPC, STOXX EUROPE 600 and S&P 500 COMPOSITE indices for Argentine, Brazil, Chile, Mexico, the EU and the USA. The left axis indicates stock quotes in EUR (left column) or in USD (right column), whereas the right axis indicates stock quotes in the emerging-market currency, i.e., Argentine peso (panel A), Brazilian real (panel B), Chilean peso (panel C) and Mexican peso (panel D). The weekly stock markets are set to the value one at the beginning of the sample period to make time series in the same currency visually comparable.

where T is the sample size, k is the number of estimated parameters and $\hat{L}$ is the log-likelihood value. The minimum AICc value indicates the best copula fit.

3. Data

We take equity data for Argentina, Brazil, Chile and Mexico, as key Latin American economies in terms of GDP, and for the EU and the USA, given the close trade and financial relationships with the above-mentioned countries. We also take exchange rates for the EUR and USD against each of the Latin American currencies (Argentine peso, Brazilian real, Chilean peso and Mexican peso).

Equity returns are represented by (log) changes in stock market indices for each market: S&P MERVAL for Argentina; BOVESPA for Brazil; S&P CLX IGPA for Chile; S&P/BMV IPC for Mexico; STOXX EUROPE 600 for the EU; and S&P 500 COMPOSITE for the USA. Exchange rates are defined in terms of developed-market units of currency per unit of emerging-country currency, with an increase in the exchange rate meaning depreciation (appreciation) of the currency of the developed (emerging) market against the currency of the emerging (developed) market.

Data, sourced from Datastream, covers the period January 11, 2002 to February 28, 2020, with the starting date determined by the end of exchange rate pegging of the Argentine peso to the USD.[13] To avoid time zone differences, daily returns data was aggregated to a weekly frequency (Friday-Friday). The sample period includes several crises, including the global financial crisis of 2008 and the European debt crisis of 2010–2011, with large oscillations in equity and currency values that potentially impact on their interdependence.

Fig. 1 depicts temporal dynamics for the equity market indices in emerging and developed economies (values expressed in their different currencies). Visual inspection reveals that the intensity of co-movement between indices differs depending on the investor's perspective. While all the Latin American markets co-move with the two developed markets when equity market indices are expressed in their respective currencies, co-movement for emerging-market investors is considerably lower than co-movement for developed-market investors (indices denominated in the emerging-market currency and in the developed-market currency, respectively). Pairwise correlation analysis presented in Table 2 confirms this graphical intuition. In Table 2, panel A shows that correlations between the Latin American and the EU and US equity market returns expressed in their respective currencies are relatively high, while panel B shows that correlations also remain relatively high from the perspective of developed-market investors, i.e., when emerging market returns are converted to EUR or USD. However, panel C in Table 2 shows that, from the perspective of emerging-market investors, correlations between returns for the emerging markets and the developed markets expressed in the emerging-market currencies are considerably reduced, most especially for Brazil. Diversification benefits, therefore, vary for domestic and foreign investors operating in the same markets.

Table 3 presents correlation evidence for equity returns and currency values. Panel A reports correlations for emerging markets, documenting a positive and high linear dependence between emerging-market equity returns and currency values against the EUR and USD. An exception is Argentina, where there is no linear association between

Table 2
Correlation between equity markets in different currencies, in the same currency and between equity market and currency value.

	AR	BR	CL	MX
Panel A: in their own currencies.				
EU	0.48	0.59	0.55	0.66
US	0.48	0.62	0.52	0.70
Panel B: from developed-market investors' perspective.				
EU	0.46	0.62	0.60	0.73
US	0.45	0.60	0.57	0.72
Panel C: from emerging-market investors' perspective.				
EU	0.39	0.20	0.44	0.53
US	0.36	0.06	0.32	0.43

Notes. This table presents pairwise Pearson linear correlations between equity returns for emerging and developed markets (indicated in columns and rows, respectively). EU, US, AR, BR, CL and MX denote equity returns computed, respectively, for the STOXX EUROPE 600, S&P 500 COMPOSITE, S&P MERVAL, BOVESPA, S&P CLX IGPA and S&P/BMV IPC indices for the EU, USA, Argentina, Brazil, Chile and Mexico. Panel A reports correlations between equity returns denominated in the respective local currencies. Panel B reports correlations between equity returns from the perspective of an investor based in a developed market, i.e., between emerging-market and developed-market equity returns denominated in a developed-market currency (e.g., the first row and column indicate correlation between MERVAL returns in EUR and STOXX returns in EUR). Panel C reports correlations between equity returns from the perspective of an investor based in an emerging market, i.e., between emerging-market and developed-market equity returns denominated in an emerging-market currency (e.g., the first row and column indicate correlation between STOXX and MERVAL returns both in the Argentinian peso).

[13] On 6 January 2002 the Convertibility Law was partially derogated, eliminating currency conversion operations between the Argentine peso and the USD.

Table 3
Correlation between equity returns and currency values.

Panel A: Emerging markets.				
	AR	BR	CL	MX
XXXEUR	−0.07	0.47	0.19	0.26
XXXUSD	−0.04	0.61	0.32	0.47

Panel B: Developed markets.		
	EU	US
XXXARS	−0.05	−0.03
XXXBRL	−0.45	−0.43
XXXCLP	−0.37	−0.38
XXXMXN	−0.47	−0.49

Notes. This table presents pair-wise correlations between equity returns (in columns) and currency values (in rows) in emerging (Panel A) and developed (Panel B) markets. EU, US, AR, BR, CL and MX denote equity returns computed, respectively, for the STOXX EUROPE 600, S&P 500 COMPOSITE, S&P MERVAL, BOVESPA, S&P CLX IGPA and S&P/BMV IPC indices for the EU, USA, Argentina, Brazil, Chile and Mexico. Currency values are denoted by XXXEUR (XXXUSD), indicating the number of EUR (USD) units per monetary unit of the XXX country indicated in the column. Similarly, XXXARS, XXXBRL, XXXCLP and XXXMXN denote units of Argentinian peso, Brazilian real, Chilean peso and Mexican peso, respectively, per unit of EUR or USD.

equity and currency returns, possibly explained by the particular monetary and debt conditions of this country during the sample period (Galindo et al., 2003), and by the large number of highly internationalized companies included in the MERVAL index. The correlation evidence for emerging economies is consistent with the empirical results reported by Cho et al. (2016), even though correlation is not universally positive for all those countries (e.g., not for Argentina). Panel B reports correlations for developed markets, documenting a negative linear association that is consistent with theoretical results reported by Hau and Rey (2006). The fact that the sign of the correlations between currency values and equity returns differs depending on the investor's perspective has implications for the role played by exchange rates in transmitting shocks between international equity markets, as quantified below.

Table 4 presents descriptive statistics for equities and currencies. Panel A contains descriptive statistics for equity returns for each market, showing average annualized returns of 3.3% in developed markets versus 13.6% in emerging markets, with average annual standard deviations of 17.5% and 23.6%, respectively. Return distributions are not normal and exhibit negative skewness and fat tails. Also evident is a wider average interquartile range for returns for emerging markets than for developed markets, with the exception of Chile. All equity return series are heteroskedastic and show autocorrelation, while the null of normality is rejected. Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests for unit roots points to the fact that all equity return series are stationary. Panel B contains descriptive statistics for exchange rates, showing negative average returns and documenting that the Argentine peso and the Brazilian real are more volatile than the values of other currencies. All currency returns show negative skewness and fat tails, but especially the Argentine peso. Normality is rejected, heteroskedasticity and autocorrelation are common across all currency series, and all currency return series are stationary.

4. Results

4.1. Marginal and copula model results

Table 5 presents marginal model parameter estimates according to Eqs. 13–15 for equity returns and exchange rates. Lag parameters in the mean and variance equations were chosen so as to minimize the AICc values. Panel A, referring to equity returns, shows that average returns display no serial correlation and (as is commonly found in the literature) volatility is persistent, with positive leverage effects that are larger in developed markets than in emerging markets. Likewise, we find consistent evidence of asymmetries and fat tails in the distribution functions for equity returns. Goodness-of-fit tests of model residuals indicate that there is no remaining correlation or heteroskedasticity in the model residuals, and that the skewed-t distribution adequately accounts for returns features, as the standardized model residuals are uniform (0,1) according to the Kolmogorov-Smirnov (KS) and Anderson-Darling (AD) tests.

Panel B in Table 5, referring to exchange rates, shows that most exchange rates display no serial correlation and that volatility persistence for the emerging-market currencies is higher against the USD than against the EUR. Likewise, empirical estimates are consistent with positive leverage effects in exchange rate volatility that are of a smaller size than for equity returns. Exchange rates are well characterized by an asymmetric distribution (with the exception of the Argentine and Chilean pesos against the EUR) with fat tails. Goodness-of-fit tests of model residuals indicate that the null hypothesis of correct specification of serial correlation, ARCH effects and the distribution model could not be rejected at the 1% level.

Parameter estimates of the Markov switching paired copulas for the four Latin American countries with the EU and USA are presented in Table 6 (panels A to D, reporting empirical evidence for Argentina, Brazil, Chile and Mexico, respectively), which shows results for the best copula fit according to the AICc. Panel A reports dependence estimates for Argentina that show that the value of the EUR against the Argentine peso in state 1 is negatively correlated with equity returns in Argentina and, to a lesser extent with returns in the EU, whereas the exchange rate in state 2 is independent of equity returns in Argentina and displays positive and asymmetric dependence with equity returns in the EU. Likewise, we find no evidence of tail dependence in state 1 between exchange rates and equity returns. In contrast, the value of the USD against the Argentine peso is independent of equity returns in both states, with no evidence of tail dependence. As for dependence between equity returns conditional on exchange rates, we find evidence of positive dependence between equity returns in Argentina and the EU that is stronger in state 1 than in state 2, and evidence of tail dependence, as given by the student-t copula and the BB1 copula in states 1 and 2, respectively. Likewise, the link between equity returns in Argentina and the USA is significantly positive and stronger in state 1 than in state 2, with no evidence of tail dependence. Finally, transition probabilities show high persistence, while the dynamics of smooth probabilities (Kim, 1994) of each state differ between Argentina with the EU and

Table 4
Descriptive statistics.

Panel A: Equity market returns.						
	EU	US	AR	BR	CL	MX
μ	0.0003	0.0010	0.0049	0.0022	0.0014	0.0020
σ	0.0254	0.0233	0.0490	0.0357	0.0195	0.0265
λ	−1.3593	−1.0018	−1.0034	−0.3739	−1.0560	−0.2114
κ	14.0919	11.5267	9.7926	6.2969	12.6623	9.7818
q_1	−0.0750	−0.0709	−0.1268	−0.0877	−0.0581	−0.0726
q_{25}	−0.0118	−0.0097	−0.0198	−0.0194	−0.0085	−0.0119
q_{50}	0.0026	0.0023	0.0070	0.0046	0.0017	0.0026
q_{75}	0.0144	0.0135	0.0323	0.0248	0.0124	0.0166
q_{99}	0.0515	0.0573	0.1179	0.0833	0.0435	0.0640
KS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
LBQ	0.0002	0.0590	0.5584	0.0353	0.2056	0.0115
ARCH	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
ADF	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
PP	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010

Panel B: Exchange rates.								
	ARSEUR	BRLEUR	CLPEUR	MXNEUR	ARSUSD	BRLUSD	CLPUSD	MXNUSD
μ	−0.0042	−0.0009	−0.0004	−0.0010	−0.0040	−0.0007	−0.0002	−0.0008
σ	0.0274	0.0215	0.0165	0.0178	0.0242	0.0211	0.0155	0.0158
λ	−4.5576	−0.5315	−0.1569	−0.5842	−3.3192	−0.6459	−0.7982	−1.4529
κ	49.5979	5.9970	4.9111	7.1359	32.6874	6.9214	8.5377	16.3589
q_1	−0.0794	−0.0678	−0.0430	−0.0478	−0.0806	−0.0659	−0.0404	−0.0446
q_{25}	−0.0122	−0.0126	−0.0107	−0.0105	−0.0078	−0.0113	−0.0091	−0.0083
q_{50}	−0.0026	0.0000	−0.0006	−0.0006	−0.0008	0.0004	0.0005	0.0001
q_{75}	0.0077	0.0112	0.0098	0.0100	0.0040	0.0120	0.0090	0.0074
q_{99}	0.0439	0.0484	0.0413	0.0393	0.0480	0.0514	0.0379	0.0370
KS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
LBQ	0.0000	0.0009	0.7795	0.0129	0.0000	0.0009	0.0159	0.0050
ARCH	0.0000	0.0000	0.0118	0.0000	0.0002	0.0000	0.0000	0.0031
ADF	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
PP	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010

Notes. This table presents summary statistics for equity market and currency returns. EU, US, AR, BR, CL and MX denote equity returns computed, respectively, for the STOXX EUROPE 600, S&P 500 COMPOSITE, S&P MERVAL, BOVESPA, S&P CLX IGPA and S&P/BMV IPC indices for the EU, USA, Argentina, Brazil, Chile and Mexico. ARSEUR, BRLEUR, CLPEUR and MXNEUR (ARSUSD, BRLUSD, CLPUSD and MXNUSD) denote the EUR (USD) exchange rate against the Argentinian peso, Brazilian real, Chilean peso and Mexican peso: units of EUR (USD) per monetary unit of the emerging market. q_k indicates the k-th quantile of the return series. KS refers to the p-value of the Kolgomorov Smirnov test for the null hypothesis of normality. LBQ indicates the p-value of the Ljung-Box Q-test for autocorrelation performed with 20 lags. ARCH refers to the p-value of Engle's ARCH test for heteroskedasticity run with 1 lag. ADF and PP indicate the p-value of the Augmented Dickey-Fuller and Phillips-Perron tests, with values lower than 0.05 indicating rejection of the null hypothesis of a unit root.

Argentina with the USA.[14]

Panel B in Table 6 reports dependence estimates for Brazil that show that the value of the EUR against the Brazilian real is positively correlated with Brazilian and EU equity returns in states 1 and 2, although we find tail independence in state 1 and asymmetric tail dependence in state 2. Evidence is rather similar for the relationship between equity returns and the USD against the Brazilian real, even though the dependence is higher in states 1 and 2 for the USD than for the EUR. As for dependence between equity markets conditional on exchange rates, our results indicate that conditional dependence is stronger in state 1 than in state 2 for both the Brazil-EU and Brazil-USA pairs, and also that there is consistent evidence of tail independence in state 1 and asymmetric tail dependence in state 2 for the Brazil-EU pair.

Panel C in Table 6 reports dependence estimates for Chile that show that the value of the EUR against the Chilean peso is associated with equity returns in Chile and the EU; however, there is evidence of tail independence between the exchange rate and the equity markets in the EU and Chile. Empirical evidence is also consistent with a positive link between the USD exchange rate against the Chilean peso with equity returns in Chile and the USA, with an intensity that depletes in state 2. In addition, evidence on dependence between equity markets conditional on exchange rates indicates that this dependence is positive and greater for the link between the Chilean and US equity markets than for the link between the Chilean and EU equity markets in state 1, with dependence in state 2 increasing for the latter and reducing for the former.

Panel D in Table 6 reports dependence estimates for Mexico, showing that EUR and USD exchange rates against the Mexican peso are positively correlated with equity returns in the EU and the USA, respectively. Moreover, this correlation, along with tail dependence, is lower in state 1 than in state 2 for Mexico-EU, and greater in state 1 than in state 2 for Mexico-USA. Likewise, conditional dependence between the Mexican equity market and the EU and US equity markets is strongly positive in both states.

Overall, our dependence results from pair-copulas point to the following: (a) with the exception of the Argentine peso, emerging-market currency values move in tandem with emerging-market equity returns, but not developed-market currency values with developed-market equity returns; (b) dependence between exchange rates and equity returns experiences important changes through states and across countries, which could be explained by differences in the commercial relationships between countries or by differences in investors' perceptions of risks and risk aversion; (c) developed and emerging equity markets show positive dependence, with intensities that differ depending on the state; and finally (d) there is mixed evidence of tail dependence that varies across markets and states. This evidence on dependence between

[14] For a detailed information on the dynamics of the transition probabilities, see Fig. 13 in the online appendix.

Table 5
Parameter estimates of marginal models for equity and currency returns.

Panel A: Equity market returns.

	EU	US	AR	BR	CL	MX
φ_0	0.000	0.001*	0.005***	0.001	0.002***	0.002**
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
ψ_1	−0.282	−0.033	0.027	0.063	0.055	0.002
	[0.69]	[0.04]	[0.04]	[0.03]	[0.03]	[0.03]
Ω	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
α	0.000**	0.004***	0.105***	0.000**	0.167***	0.084***
	[0.15]	[0.13]	[0.03]	[0.04]	[0.04]	[0.04]
β	0.783***	0.752***	0.866***	0.906***	0.766***	0.848***
	[0.05]	[0.05]	[0.05]	[0.03]	[0.06]	[0.03]
Γ	0.345**	0.390***	0.000***	0.120**	0.000***	0.098***
	[0.24]	[0.19]	[0.02]	[0.05]	[0.02]	[0.05]
λ	−0.341***	−0.302***	−0.182***	−0.244***	−0.117***	−0.210***
	[0.07]	[0.06]	[0.04]	[0.05]	[0.05]	[0.05]
ν	9.663***	9.296***	6.568***	16.446***	7.840***	10.126***
	[31.75]	[35.86]	[10.72]	[29.09]	[34.54]	[33.58]
LBQ test	0.8344	0.8968	0.3732	0.8436	0.1458	0.4992
ARCH test	0.3631	0.3281	0.4369	0.3135	0.5329	0.9599
KS test	0.3574	0.0371	0.6428	0.8619	0.7205	0.7949
AD test	0.6015	0.5136	0.1919	0.1632	0.6313	0.2759
K test q = 0.1	0.7107	0.7058	0.8711	0.2955	0.2038	0.2468

Panel B: Exchange rates returns.

	ARSEUR	BRLEUR	CLPEUR	MXNEUR	ARSUSD	BRLUSD	CLPUSD	MXNUSD
φ_0	−0.002***	−0.001	−0.000*	−0.001**	−0.001***	−0.000	−0.000	−0.001*
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
φ_1	–	–	0.017	–	0.142***	0.009	–	–
	–	–	[0.03]	–	[0.03]	[0.04]	–	–
ψ_1	0.037	0.072	–	0.025	–	–	0.022	−0.012
	[0.03]	[0.03]	–	[0.03]	–	–	[0.03]	[0.03]
ω	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
α	0.195***	0.167***	0.055***	0.063***	0.098***	0.138***	0.092***	0.000***
	[0.05]	[0.03]	[0.02]	[0.04]	[0.03]	[0.04]	[0.02]	[0.06]
β	0.657***	0.771***	0.924***	0.825***	0.902***	0.821***	0.883***	0.886***
	[0.14]	[0.06]	[0.04]	[0.05]	[0.02]	[0.05]	[0.04]	[0.03]
γ	0.000***	0.000***	0.000***	0.101***	0.000***	0.000**	0.000*	0.167***
	[0.03]	[0.02]	[0.01]	[0.06]	[0.03]	[0.03]	[0.02]	[0.08]
λ	−0.016	−0.099***	−0.011	−0.112***	−0.087**	−0.167***	−0.109***	−0.189***
	[0.04]	[0.04]	[0.04]	[0.04]	[0.05]	[0.04]	[0.04]	[0.05]
ν	4.176***	10.174***	10.710***	9.291***	3.176***	8.430***	10.064***	6.704***
	[1.71]	[33.75]	[31.98]	[35.90]	[0.67]	[32.72]	[34.85]	[28.30]
LBQ	0.3517	0.3792	0.6936	0.1448	0.1567	0.3355	0.3507	0.1474
ARCH	0.8200	0.4200	0.9075	0.2283	0.2628	0.4450	0.3158	0.4254
KS	0.7949	0.7205	0.9575	0.0782	0.7118	0.3150	0.7584	0.1103
AD	0.6392	0.1798	0.4117	0.6081	0.1835	0.2761	0.6868	0.7466
$K_{q=0.1}$	0.9566	0.9566	0.0884	0.8711	0.2893	0.2320	0.6231	0.9567

Notes. This table presents parameter estimates for the marginal models in Eqs. 13–15 for equity and currency returns. EU, US, AR, BR, CL and MX denote equity returns computed, respectively, for the STOXX EUROPE 600, S&P 500 COMPOSITE, S&P MERVAL, BOVESPA, S&P CLX IGPA and S&P/BMV IPC indices for the EU, USA, Argentina, Brazil, Chile and Mexico. ARSEUR, BRLEUR, CLPEUR and MXNEUR (ARSUSD, BRLUSD, CLPUSD and MXNUSD) denote the EUR (USD) exchange rate against the Argentine peso, Brazilian real, Chilean peso and Mexican peso, i.e., units of EUR (USD) per unit of the emerging-market currency. Standard errors of the parameter estimates (computed through simulation) are reported in brackets, with ∗∗∗, ∗∗ and ∗ denoting significance of the estimates at the 1%, 5% and 10% levels. LBQ and ARCH denote, respectively, the p-value of the Ljung-Box Q-test for autocorrelation computed with 20 lags and Engle's ARCH test for heteroskedasticity computed with 1 lag. KS and AD report the p-values for the Kolgomorov Smirnov and Anderson-Darling tests for the null hypothesis that the residual of the marginal model follows a skewed-t distribution with the estimated parameters. $K_{q=0.1}$ refers to the p-values of the Kupiec (1995) test for the goodness-of-fit of the tails of the distribution. Marginal models for EU equity returns and the ARSUSD and BRLUSD currency returns required a larger number of lags to filter out serial correlation (AR(1)-MA(1,3), AR(1,3,4,6,8,9) and AR(1,3,5,6,8,17), respectively).

exchange rates and equity markets has implications in terms of shock transmission that are quantified below.

4.2. Expected shortfall and relative contribution to shock transmission

This subsection presents estimates of the expected domestic (foreign) equity returns conditional on distress scenarios in the foreign (domestic) equity market or in exchange rates, along with assessments of their relative contributions to conditional expectations. We compute, at each time *t*, the impact of each shock using the conditional expectation, following Eqs. (4) and (6), for a confidence level of 10% ($\alpha = 0.1$), and the relative contribution of an equity shock, following Eq. (8), considering extreme currency appreciation or depreciation scenarios. For each pair formed by a Latin American emerging economy (Argentina, Brazil, Chile, Mexico) and a developed market (EU, USA), we present results on the size and relative contribution of shocks in states 1 and 2, and for both states as the weighted average of shocks in state 1 and 2, using smoothed probabilities (Kim, 1994) for each state as weights.

Table 6
Parameter estimates of copula models.

	State 1						State 2					
	Copula	Parameter		Kendall's τ	λ_L	λ_U	Copula	Parameter		Kendall's τ	λ_L	λ_U
Panel A: Argentina.												
Argentina-EU												
AR-ARSEUR	Student	ρ	−0.293***	−0.19	0.02	0.02	Clayton	θ	0.155***	0.07	0.01	–
			[0.06]						[1.26]			
		η	4.723***									
			[0.81]									
ARSEUR-EU	Gaussian	ρ	−0.088***	−0.06	–	–	Gumbel	θ	1.312***	0.24	–	0.3
			[0.06]						[0.10]			
AR-EU	Student	ρ	0.576***	0.39	0.15	0.15	BB1	θ	0.158***	0.16	0.02	0.13
			[0.04]						[0.21]			
		η	11.816***					δ	1.108***			
			[29.06]						[0.07]			
Transition probabilities		p_{11}	0.994***									
			[0.02]									
		p_{22}	0.992***									
			[0.11]									
		LL	−184.35									
		AICc	−356.62									
Argentina-United States												
AR-ARSUSD	Student	ρ	−0.013	−0.01	0.04	0.04	Gumbel	θ	1.000***	0	–	0
			[0.06]						[0.02]			
		η	6.072***									
			[1.16]									
ARSUSD-US	Gaussian	ρ	0.047	0.03	–	–	Clayton	θ	0.000***	0	0	–
			[0.05]						[0.05]			
AR-US	Gaussian	ρ	0.577***	0.39	–	–	Clayton	θ	0.276***	0.12	0.08	–
			[0.05]						[0.13]			
Transition probabilities		p_{11}	0.974***									
			[0.05]									
		p_{22}	0.951***									
			[0.07]									
		LL	−123.77									
		AICc	−239.5									
Panel B: Brazil.												
	State 1						State 2					
	Copula	Parameter		Kendall's τ	λ_L	λ_U	Copula	Parameter		Kendall's τ	λ_L	λ_U
Brazil-EU												
BR-BRLEUR	Gaussian	ρ	0.357**	0.23	–	–	BB1	θ	0.270***	0.26	0.12	0.21
			[0.13]						[0.10]			
								δ	1.191***			
									[0.58]			
BRLEUR-EU	Gaussian	ρ	0.395*	0.26	–	–	Gumbel	θ	1.276***	0.22	–	0.28
			[0.14]						[0.06]			
BR-EU	Gaussian	ρ	0.653**	0.45	–	–	Gumbel	θ	1.188***	0.16	–	0.21
			[0.16]						[0.12]			
Transition probabilities		p_{11}	0.996***									
			[0.20]									
		p_{22}	0.997***									
			[0.10]									
		LL	−278.64									
		AICc	−549.24									
Brazil-United States												
BR-BRLUSD	Gaussian	ρ	0.601***	0.41	–	–	Clayton	θ	0.560***	0.22	0.29	–
			[0.03]						[0.33]			
BRLUSD-US	Student	ρ	0.455***	0.3	0.01	0.01	BB1	θ	0.001***	0	0	0
			[0.03]						[0.12]			
		η	27.935***					δ	1			
			[32.03]						[0.02]			
BR-US	Gaussian	ρ	0.555***	0.37	–	–	Clayton	θ	0.155**	0.07	0.01	–
			[0.04]						[0.19]			
Transition probabilities		p_{11}	0.945***									
			[0.02]									
		p_{22}	0.780***									
			[0.09]									
		LL	−361.5									

(*continued on next page*)

Table 6 *(continued)*

Panel B: Brazil.												
	State 1						State 2					
	Copula	Parameter		Kendall's τ	λ_L	λ_U	Copula	Parameter		Kendall's τ	λ_L	λ_U
		AICc	−714.95									

Panel C: Chile.												
	State 1						State 2					
	Copula	Parameter		Kendall's τ	λ_L	λ_U	Copula	Parameter		Kendall's τ	λ_L	λ_U
Chile-EU												
CL-CLPEUR	Gaussian	ρ	0.121**	0.08	–	–	BB1	θ	0.170***	0.09	0.02	0.02
			[0.06]						[0.13]			
								δ	1.015**			
									[0.03]			
CLPEUR-EU	Student	ρ	0.541***	0.36	0	0	Clayton	θ	0.195***	0.09	0.03	–
			[0.06]						[0.19]			
		η	100.000***									
			[28.68]									
CL-EU	Gaussian	ρ	0.340***	0.22	–	–	BB1	θ	0.387***	0.37	0.26	0.31
			[0.04]						[0.23]			
								δ	1.328***			
									[0.15]			
Transition probabilities		p_{11}	0.965***									
			[0.05]									
		p_{22}	0.960***									
			[0.12]									
		LL	−191.56									
		AICc	−373.06									
Chile-United States												
CL-CLPUSD	Gaussian	ρ	0.478***	0.32	–	–	Clayton	θ	0.028***	0.01	0	–
			[0.05]						[0.05]			
CLPUSD-US	Gaussian	ρ	0.493***	0.33	–	–	Clayton	θ	0.177***	0.08	0.02	–
			[0.04]						[0.07]			
CL-US	Gaussian	ρ	0.529***	0.36	–	–	Clayton	θ	0.226***	0.1	0.05	–
			[0.05]						[0.08]			
Transition probabilities		p_{11}	0.929***									
			[0.02]									
		p_{22}	0.922***									
			[0.03]									
		LL	−167.68									
		AICc	−327.32									

Panel D: Mexico.												
	State 1						State 2					
	Copula	Parameter		Kendall's τ	λ_L	λ_U	Copula	Parameter		Kendall's τ	λ_L	λ_U
Mexico-EU												
MX-MXNEUR	Student	ρ	0.142***	0.09	0	0	BB1	θ	0.333***	0.31	0.19	0.26
			[0.05]						[0.71]			
		η	25.208***					δ	1.248***			
			[34.45]						[0.35]			
MXNEUR-EU	Gaussian	ρ	0.395***	0.26	–	–	BB1	θ	0.708***	0.33	0.41	0.12
			[0.04]						[0.34]			
								δ	1.097***			
									[3.62]			
MX-EU	Gaussian	ρ	0.599***	0.41	–	–	BB1	θ	0.460***	0.29	0.27	0.16
			[0.02]						[6.31]			
								δ	1.142***			
									[0.64]			
Transition probabilities		p_{11}	0.999***									
			[0.02]									
		p_{22}	0.994***									
			[0.27]									
		LL	−313.45									
		AICc	−616.83									

(*continued on next page*)

Table 6 *(continued)*

Panel D: Mexico.

	State 1						State 2					
	Copula	Parameter		Kendall's τ	λ_L	λ_U	Copula	Parameter		Kendall's τ	λ_L	λ_U
Mexico-United States												
MX-MXNUSD	Gaussian	ρ	0.421*** [0.03]	0.28	–	–	Clayton	θ	0.320*** [1.59]	0.14	0.11	–
MXNUSD-US	Student	ρ	0.528*** [0.02]	0.35	0.06	0.06	Gumbel	θ	1.000*** [1.23]	0	–	0
		η	16.783*** [32.40]									
MX-US	Gaussian	ρ	0.583*** [0.02]	0.4	–	–	BB1	θ	0.526*** [1.07]	0.35	0.34	0.23
								δ	1.212*** [7.50]			
Transition probabilities		p_{11}	0.997*** [0.01]									
		p_{22}	0.987*** [0.20]									
		LL	−372.84									
		AICc	−735.61									

This table presents parameter estimates for the paired copulas from the vine construction in Eq. (9) with a Markov switching dynamics that maximize the log-likelihood value in Eq. (16). Dependence for each state is characterized by pair copulas in Eq. (10) and the probability of being in a given state evolves following a Markov switching structure as in Eq. (17) with transition probabilities p_{11} and p_{22} as given by Eq. (12). Panels A–D report results of dependence for equity returns and exchange rates for Argentina, Brazil, Chile and Mexico with the EU and USA. ARSEUR (ARSUSD), BRLEUR (BRLUSD), CLPEUR (CLPUSD), MXNEUR (MXNUSD) denote the units of EUR (USD) per unit of Argentinian peso (panel A), Brazilian real (panel B), Chilean peso (panel C) and Mexican peso (panel D), respectively. Standard errors of the parameter estimates (computed by simulation) are reported in brackets, with $***$, $**$ and $*$ denoting significance at the 1%, 5% and 10% levels. LL and AICc denote, respectively, the maximum log-likelihood and the Akaike information criterion corrected for small-sample bias. Kendall's τ indicates Kendall's rank correlation and λ_L and λ_U refer, respectively, to lower and upper tail dependence for the estimated copulas (see Table 1).

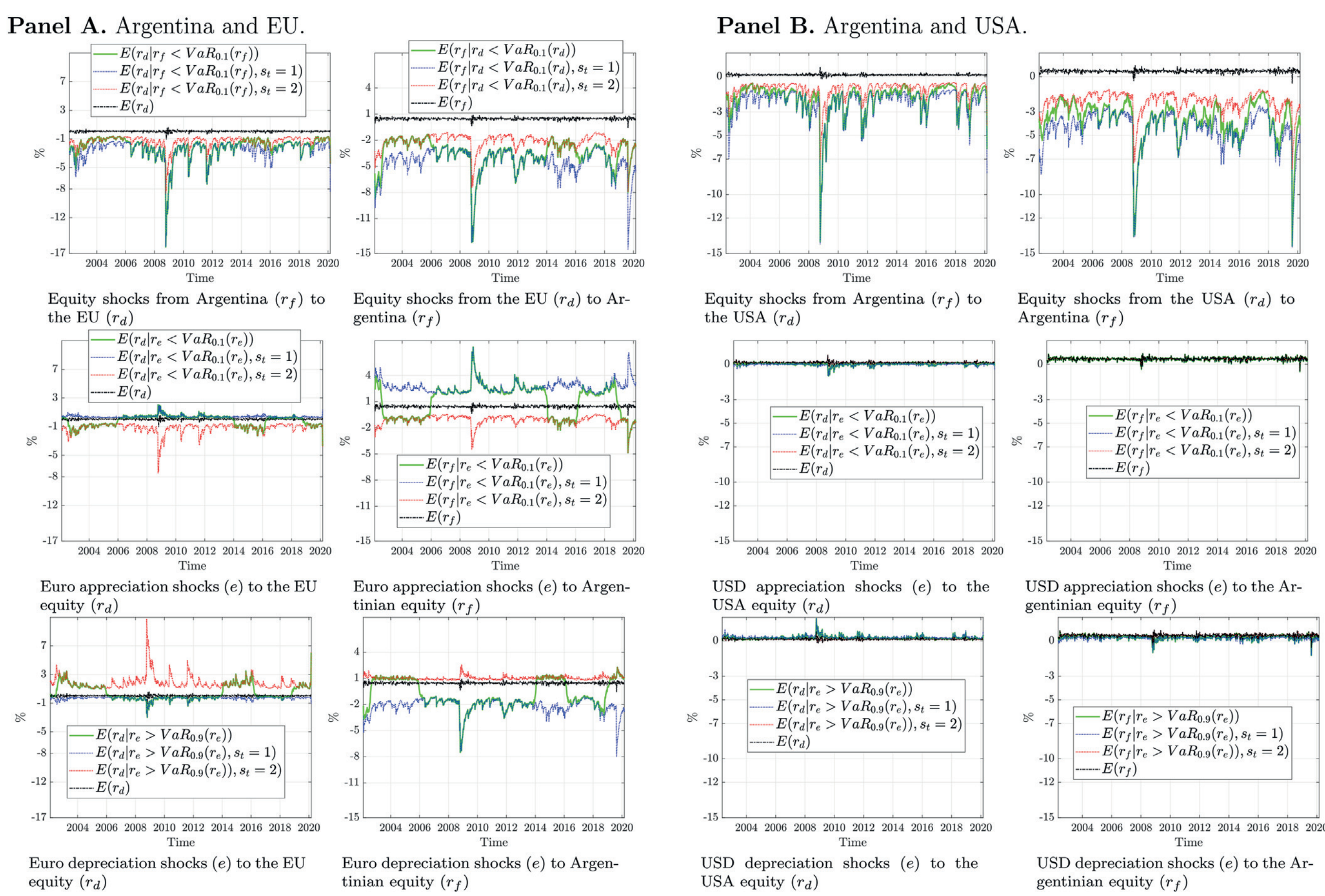


Fig. 2. Equity and exchange rate shock transmission between Argentina and developed markets.

4.2.1. Argentina

Panel A in Fig. 2 depicts the temporal dynamics of shocks from/to Argentina to/from the EU using the C-ES. The first row of graphs shows the dynamics of the conditional expected returns, indicating that the impact of a shock from/to the Argentinian equity market to/from the EU equity market in states 1 and 2 is sizeable with respect to the unconditional expected value, but especially in state 1. The differences in the size of the impact in both states are consistently explained by the fact that the Argentinian and EU equity markets show greater integration in state 1 than in state 2. The dynamics of the C-ES also reflect the impact of the global financial crisis of 2008 and, to a lesser degree, the impact of the EU sovereign debt crisis of 2010–2011. The transmission of the market uncertainty originating in elections in Argentina in the last quarter of 2019 is reflected in an abrupt drop in the value of the C-ES of the EU equity market in both states. The second row of graphs in Panel A shows the impact of a downside movement in exchange rates, i.e., the impact on equity returns of extreme appreciation (depreciation) in the EUR (Argentinian peso). The fact that the size of that shock differs across states and countries is consistent with the dependence structures reported in Panel A of Table 6. More specifically, appreciation (depreciation) of the EUR (Argentinian peso) has a positive effect on equity returns in Argentina and a small positive impact on the EU equity market in state 1, whereas in state 2 in contrast, the impact on both markets is negative. Finally, the third row of graphs depicts the temporal C-ES dynamics of an upward movement in the exchange rate, i.e., extreme depreciation (appreciation) of the EUR (Argentinian peso), showing negative effects for Argentina and a negligible impact for the EU in state 1; in state 2, in contrast, the effect is positive for both the EU and Argentina. Overall, the evidence on the transmission of equity and exchange rate shocks between the Argentinian and EU markets drastically changes across markets and regimes as a result of changes in the dependence structure between states 1 and 2.

The relative contributions of equity and exchange rate shocks are depicted in Panel A of Fig. 6. The impact of an Argentinian equity market distress scenario on the EU equity market remains stable across time, for an average size of 85% in state 1, reduced in state 2. Note that the contribution reaches maximum values at times when the correlation between exchange rates and equity moves from negative values (state 1) to zero or positive values (state 2). The average contribution is high in state 1 during 2006–2014 and 2016–2018, but is reduced for the remaining sample periods. Regarding shock transmission in the reverse direction (EU to Argentina), average values are low during 2006–2014, at around 69% in state 1 and around 63% in state 2. Differences in the contribution across states and periods indicate that optimal diversification strategies should change considerably across countries and time periods.

Panel B in Fig. 2 depicts the temporal dynamics of shocks from/to Argentina to/from the USA using the C-ES. The evidence on shock transmission in this case offers a different picture. Although the temporal dynamics of the conditional expectation shows that the effects of an equity shock are quite similar to those commented previously, given the evidence on the lack of dependence between exchange rates and equity markets in both regimes, downward movement in exchange rates, i.e., extreme appreciation (depreciation) of the USD (Argentinian peso), has negligible effects on the equity markets in states 1 and 2, while upward movement has no impact on the US equity market and a negligible impact on the Argentinian equity market.

As for relative contributions, as depicted in panel B of Fig. 6, values are high (low) for the contribution of equity market (exchange rate) shocks, at above 90% in both regimes, with clear implications for international portfolio risk management in terms of the usefulness of hedging against exchange rate movements.

4.2.2. Brazil

Panel A in Fig. 3 depicts the dynamics of equity returns for the EU (Brazil) conditional on a distress scenario for the Brazilian (EU) equity market or exchange rate. The first row of graphs shows that the C-ES of the Brazilian and EU equity markets for stock-related scenarios is sizeable, especially in state 1 where dependence between equity markets is tighter than in state 2. Moreover, the size of the average impact of a shock from Brazil to the EU is lower than vice versa. The temporal evolution of the C-ES reflects the impact of the global and European sovereign debt crises and the oil glut in mid-2014. Regarding the impact of exchange rate shocks, the second row of graphs displays the impact on equity returns of a downside movement in exchange rates, i.e., of extreme appreciation (depreciation) of the EUR (Brazilian real). Our estimates indicate a similar impact on the EU equity market of EUR appreciation in both states, while, in the Brazilian equity market, the impact in state 2 is slightly greater than in state 1. The last row of graphs shows similar responses, but with the opposite sign, conditional on extreme depreciation (appreciation) of the EUR (Brazilian real). Interestingly, our results indicate that appreciation in the EUR is associated with downward movement in the EU equity market, while the corresponding depreciation in the Brazilian real is associated with downward movement in the Brazilian equity market. Hence, there is an inverse relationship between the value of the EUR and changes in the EU equity market and a direct relationship between the value of the Brazilian real and changes in the Brazilian equity market. This finding is consistent with the correlation evidence reported in Table 3. The implications for the risk diversification strategies of international investors, depending on where they are based, are straightforward.

Relative contributions, as displayed in Panel An of Fig. 6, show that around 64% of the total shock received by the EU market from Brazil is explained by equity price changes in Brazil in state 1, with contributions reduced in state 2. Looking at the contribution of EU equity shocks to the Brazilian equity market, the contribution is stable over time, but with a greater impact in state 1 (around 64%) than in state 2.

Panel B in Fig. 3 shows the results of shock transmission between Brazil and the USA, indicating that the Brazilian equity market is more sensitive to swings in the US equity market than vice versa (in line with findings for Brazil and the EU) and also that the size of shocks is greater in state 1 than in state 2. The impact of exchange rate shocks between Brazil and the USA differs from that between Brazil and the EU. Equity returns in the Brazilian and the US markets fall in state 1 given a scenario where there is extreme appreciation (depreciation) of the USD (Brazilian real), while the same scenario produces negligible movement in the US equity market returns in state 2. In addition, equity returns respond positively to extreme depreciation (appreciation) of the USD (Brazilian real) in state 1, while the same scenario triggers Brazilian equity gains and negligible changes in US equity returns in state 2. Accordingly, the USD value moves in the opposite direction to the US equity market in state 1 and independently in state 2, whereas the Brazilian real moves in tandem with Brazilian equity returns in both states.

Relative contributions, as depicted in panel B of Fig. 6, reflect that between 50% and 95% of the shocks to US equity from Brazil are explained by changes in the value of Brazilian equity, for which higher contributions are observed in state 2, where there is independence between the US equity market and the USD-Brazilian real exchange rate. Similarly, the impact of shocks from the US to Brazilian equity markets changes, depending on exchange rate movements and also movement between states, with contributions of about 50% (between 45% and 55%) for appreciation (depreciation) of the Brazilian real.

4.2.3. Chile

Panel A in Fig. 4 presents the evolution of the C-ES for the EU (Chilean) equity market given a shock from Chile (EU). It can be observed from the first row that both equity markets are more sensitive to shocks in state 2 than in state 1 because of stronger dependence. The impact of shocks in both states is more intense in periods of turmoil (during the global financial and European sovereign debt crises), while impact differences between states are greater in Chile than in the EU.

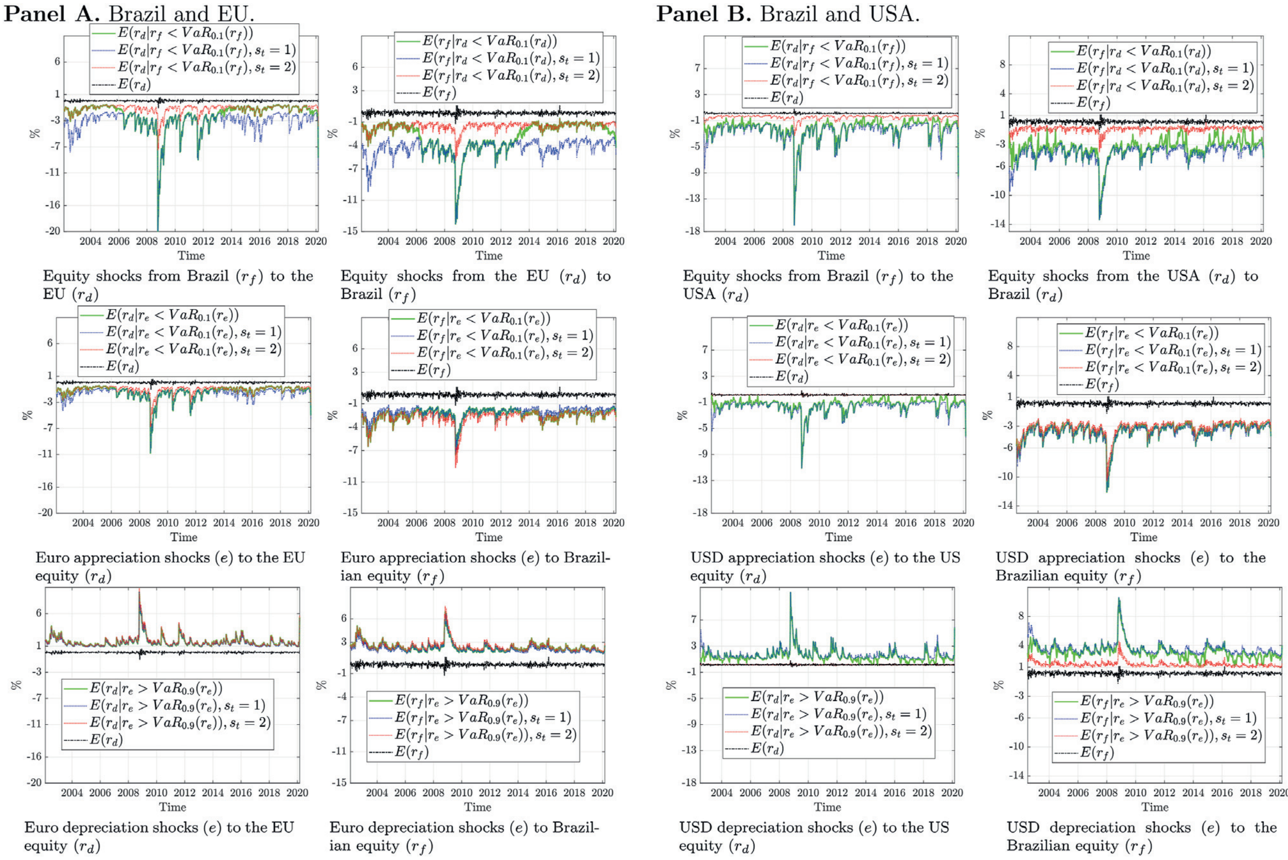


Fig. 3. Equity and exchange rate shock transmission between Brazil and developed markets.

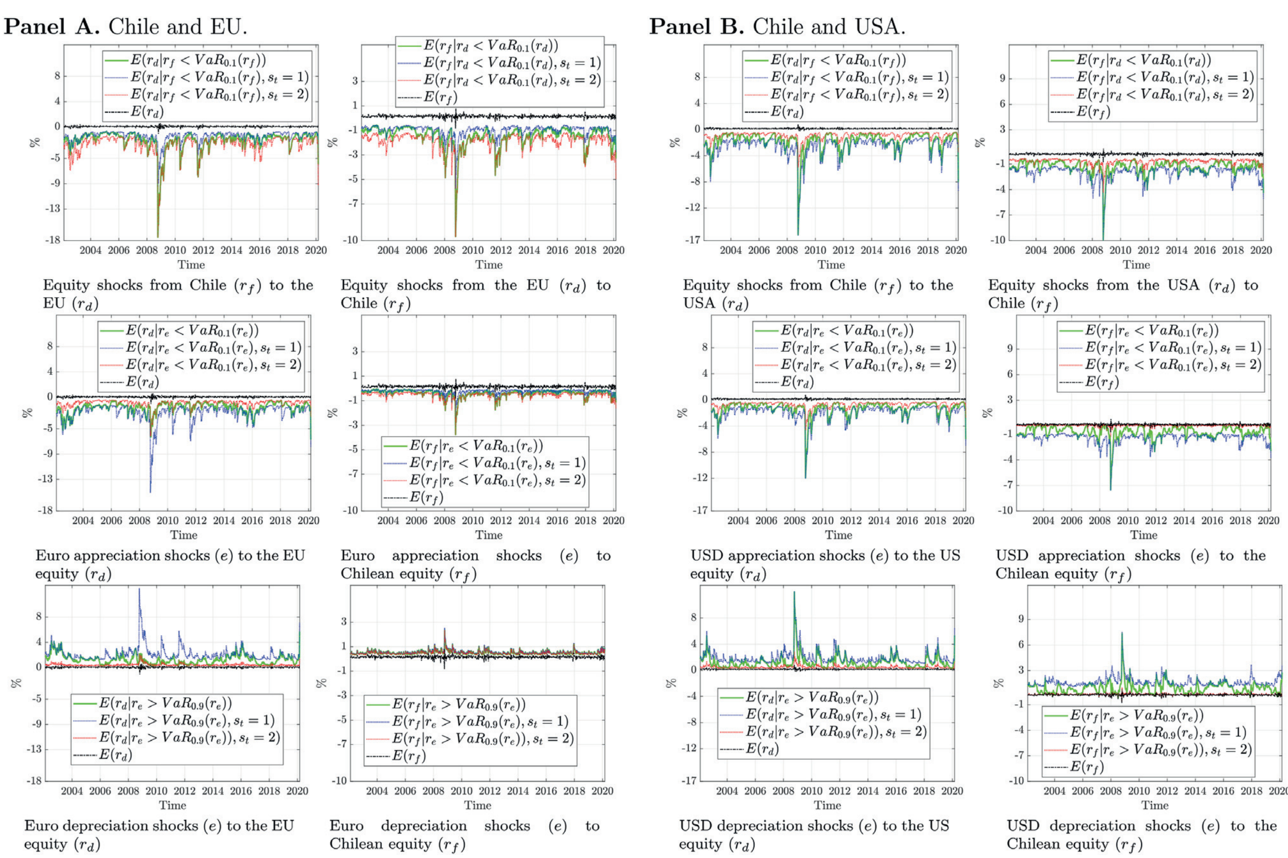


Fig. 4. Equity and exchange rate shock transmission between Chile and developed markets.

The second row provides evidence on the impact of a downside movement in exchange rates, i.e., extreme appreciation (depreciation) of the EUR (Chilean peso). Dependence between exchange rates and equity markets is more intense for the EU than for Chile, with the resulting greater impact on the EU equity market. The third row leads to the same conclusion, as intensity can be extrapolated for a scenario where the EUR experiences strong depreciation. This finding (as for Brazil) points to an inverse relationship between the EUR and EU equity market movements and a direct relationship between the Chilean peso and Chilean equity market movements.

Panel A in Fig. 6 shows that the relative contributions of Chilean equity shocks to the EU equity market differ in size depending on the state, being greater in state 2 (≈74%) than in state 1 (≈40%). Also, shocks in the opposite direction have greater intensity in state 2 than in state 1, with differences depending on the direction of exchange rate movement: for appreciation (depreciation) of the Chilean peso, the contribution is 75% (85%) in state 2 and around 75% in state 1. Consequently, there is little gain for a Chilean investor hedging an equity portfolio of EU investments against exchange rate fluctuations, most especially in state 2.

Panel B in Fig. 4 presents evidence on shock transmission between Chile and the USA. The first row shows that the impact of equity market shocks from/to Chile to/from the USA is similar in size, with no great difference in intensity across states. The C-ES estimates for the Chile-USA equity markets point to greater sensitivity to extreme movements in the exchange rate than in the Chile-EU equity markets. While losses occur in both states when the USD (Chilean peso) appreciates (depreciates) in value, those losses are higher in the US equity market than in the Chilean equity market. Likewise, gains accrue when the opposite occurs, i.e., extreme depreciation (appreciation) of the USD (Chilean peso); in state 2 the exchange rate movement produces no effect on the equity market because dependence is low. Overall, the conditional expectation regarding equity in both states indicates that the Chilean peso and Chilean equity market values move in the same direction, while the USD and the US equity market move in opposite directions.

Panel B in Fig. 6 presents the relative contributions. The relative contribution of an equity shock from Chile is around 58% for USD appreciation, and 75% in state 2 and 60% in state 1 for USD depreciation. The relative contribution of a shock from the US equity market is about 89% (58%) in state 2 (state 1) when the USD appreciates, and 98% (60%) in state 2 (state 1) when the USD depreciates. Average contributions are highly volatile.

4.2.4. Mexico

Panel A in Fig. 5 presents evidence on the C-ES dynamics for shocks from/to Mexico to/from the EU. The first row shows that the EU and Mexican equity markets receive and transmit sizeable impacts in both states. The size of the impact from Mexico to the EU is similar across states, while that from the EU to Mexico is larger in state 2 than in state 1, which is consistent with stronger dependence in state 2 than in state 1. However, the impact of exchange rate shocks on equity markets differs. The second row shows, for extreme appreciation (depreciation) of the EUR (Mexican peso), that there are small differences in impact across states for the EU equity market, whereas there is a greater impact in state 2 than in state 1 for the Mexican equity market. The final row shows conditional expectation of the equity market of a similar size as previously mentioned, but for extreme depreciation (appreciation) of the EUR (Mexican peso). As for Brazil and Chile, an inverse relationship holds between the EUR and EU equity market values and a direct

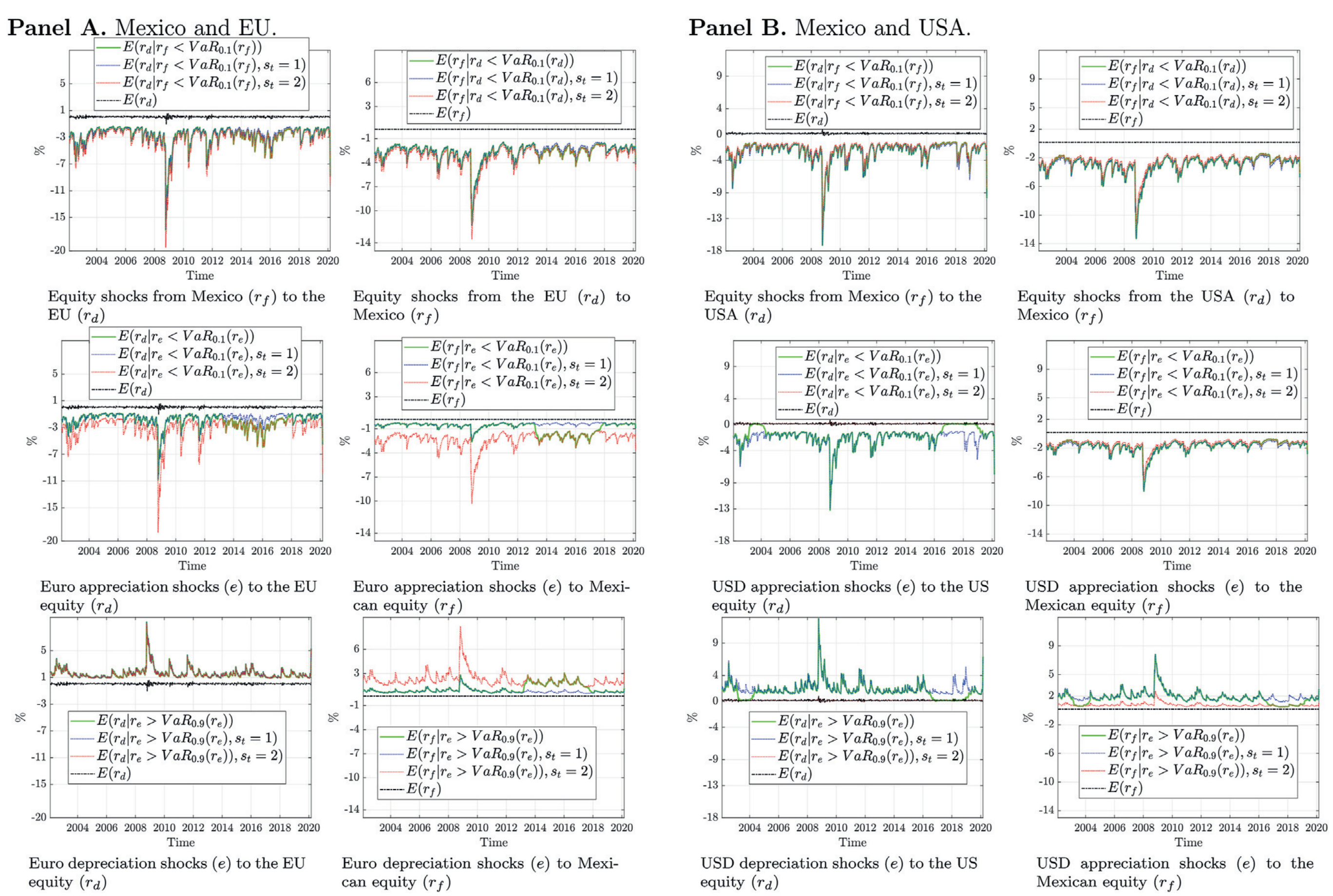


Fig. 5. Equity and exchange rate shock transmission between Mexico and developed markets.

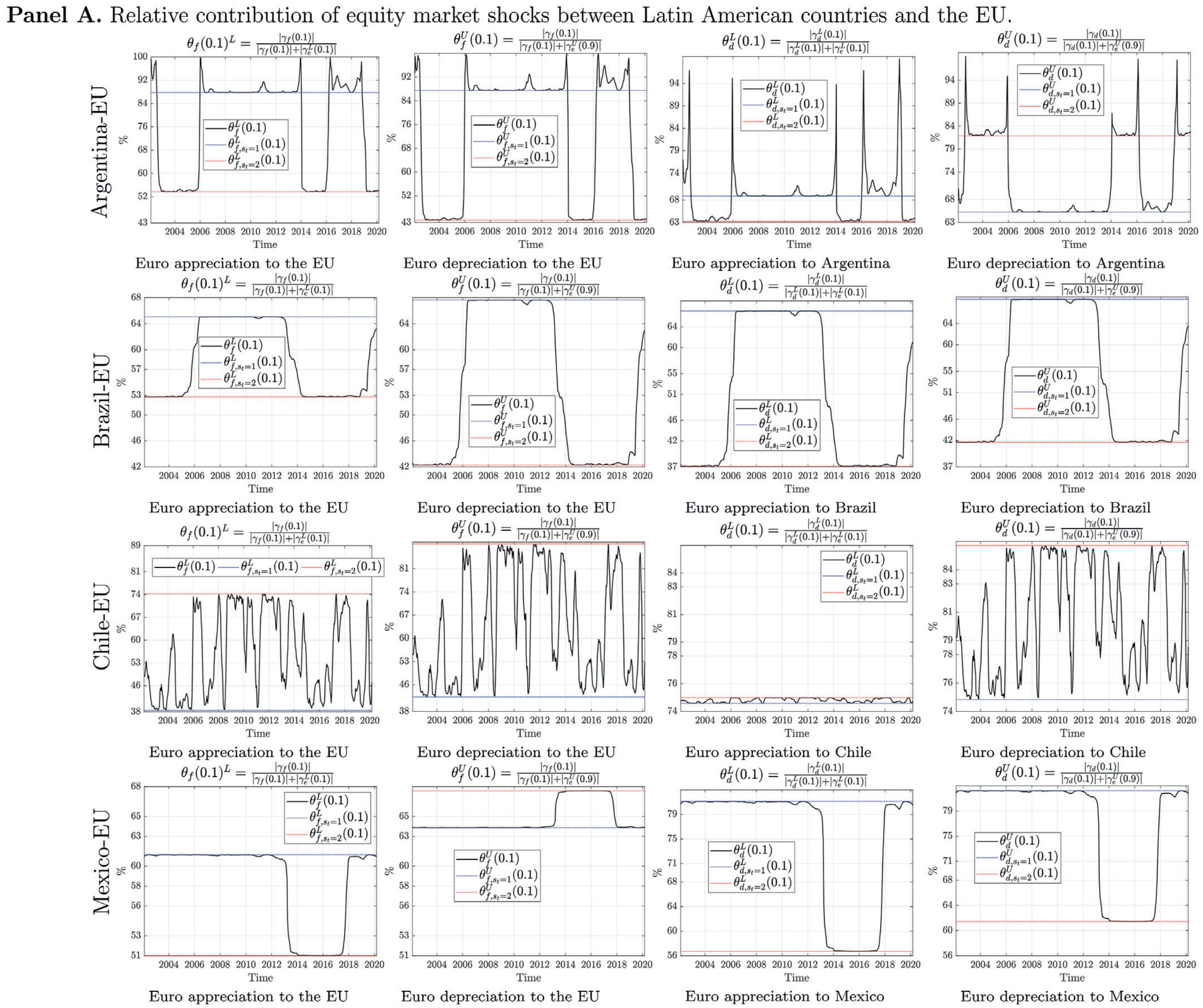


Fig. 6. Equity and exchange rate shock transmission between Latin American countries and developed markets.

relationship holds between the Mexican peso and Mexican equity values.

Panel A in Fig. 6 indicates that the relative contribution of an equity shock from Mexico is around 61% for EUR appreciation and 64% for depreciation in state 1. The contribution of EU equity shocks to changes in Mexican equity returns when the Mexican peso appreciates is around 80% in state 1 and 57% in state 2; this evidence is similar when the Mexican peso depreciates.

Panel B in Fig. 5 indicates that shock transmissions from/to Mexico to/from the USA are similar across states and in intensity. Extreme appreciation (depreciation) of the USD evokes almost no response in the USA equity market in state 2. Extreme depreciation (appreciation) of the USD (Mexican peso) triggers gains in both equity markets in state 1, but has no effect on the USA equity market in state 2. Hence, there is an inverse relationship between the USD-Mexican peso exchange rate and the US equity market, while the relationship between the Mexican equity market and the Mexican peso is positive.

Panel B in Fig. 6 shows that the relative contributions of total shocks received by the US equity market from Mexico differ in size across states, standing at 56% (99%) in state 1 (state 2) for USD appreciation, and at 60% (99%) in state 1 (state 2) for USD depreciation. The Mexican equity market is, in contrast, less affected by US equity shocks: 64% in state 2 and around 62% in state 1 for an USD appreciation, and 64% and 85% in states 2 and 1, respectively, for USD depreciation. Average contributions show volatile behaviour.

5. Implications for international investors

In this section we quantify the implications of our findings for the value of foreign investments. The impact of a shock from a foreign equity market or exchange rate on foreign investment returns ($r_{fe} = r_f + r_e$) can be computed in terms of the C-ES as[15]

$$\begin{aligned}E[r_{fe}|r_f < VaR_\alpha(r_f)] &= E[r_f|r_f < VaR_\alpha(r_f)] + E[r_e|r_f < VaR_\alpha(r_f)],\\ E[r_{fe}|r_e < VaR_\alpha(r_e)] &= E[r_f|r_e < VaR_\alpha(r_e)] + E[r_e|r_e < VaR_\alpha(r_e)],\\ E[r_{fe}|r_e > VaR_{1-\alpha}(r_e)] &= E[r_f|r_e > VaR_{1-\alpha}(r_e)] + E[r_e|r_e > VaR_{1-\alpha}(r_e)].\end{aligned} \tag{19}$$

[15] Note that for a foreign investor based in an emerging market, the conditional expected returns in Eq. (19) are computed in a similar way, except that the value of the conditional expectation of the exchange rate returns (for the exchange rate definition given above) is multiplied by −1.

Panel B. Relative contribution of equity market shocks between Latin American countries and the US.

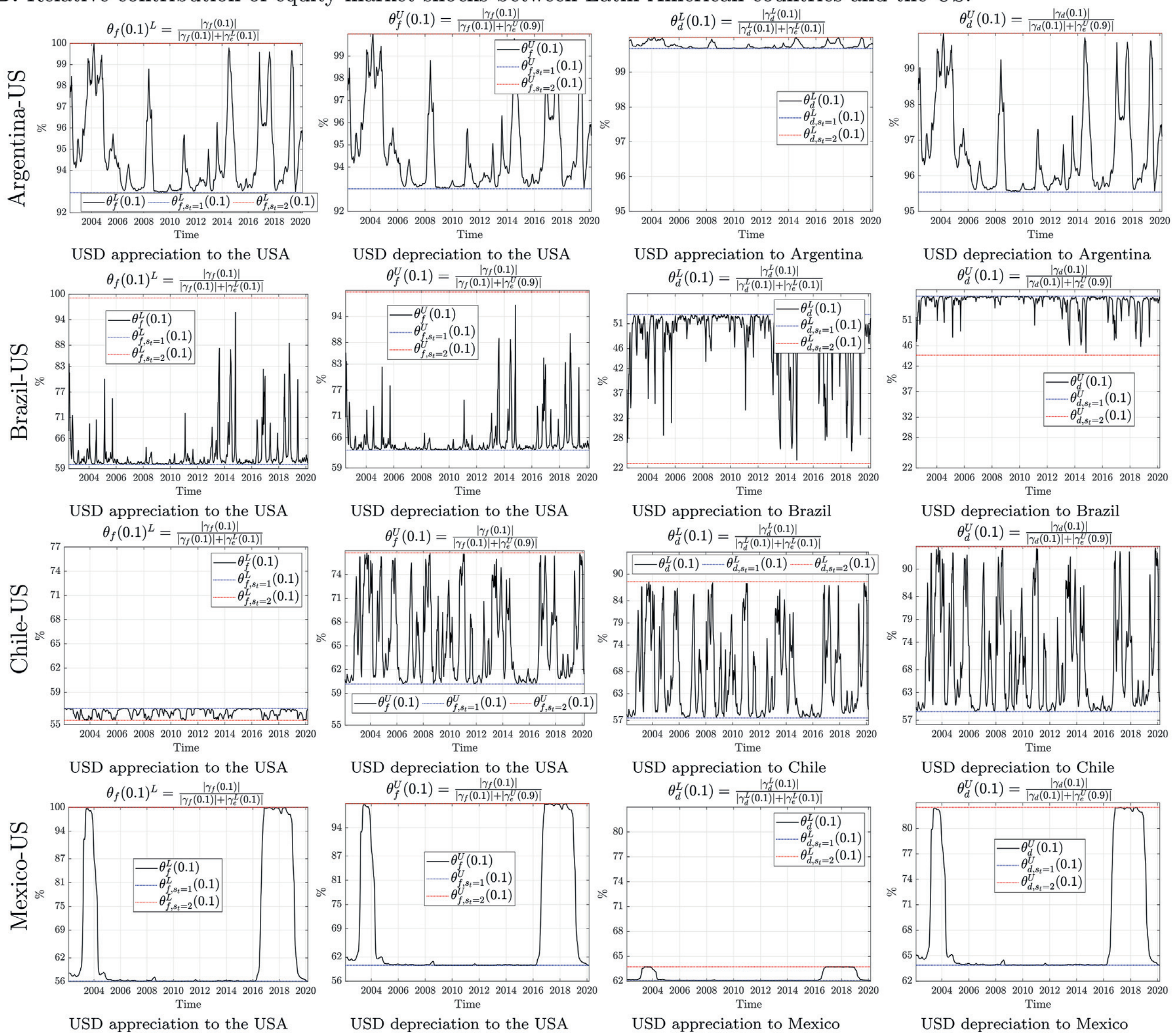


Fig. 6. *Continued*

Figs. 7–10 show the decomposition of the expected foreign investment returns conditional on distress scenarios for the foreign equity market or exchange rate, computed for a level of confidence of 10% and considering the location of the investor (emerging-market and developed-market investors in the left and right columns, respectively). Panel A in Fig. 7, illustrating the temporal evidence for Argentinian investors in the EU and EU investors in Argentina, shows that, for the Argentinian investor, a shock in the EU market has little effect on exchange rates, so the main impact is from the downward movement in equity itself. Likewise, extreme depreciation or appreciation of the Argentinian peso has a minor effect on EU equity, so the main impact, again, is from the currency shock itself. From the EU investors' perspective, the evidence is similar regarding Argentinian equity shocks, while, during 2006–2014, there is some impact for currency shocks for Argentinian equity returns: when the Argentinian peso depreciates (appreciates), Argentinian equity returns increase (decrease), compensating EU investors for Argentinian peso losses. Panel B in Fig. 7, illustrating evidence for Argentinian investors in the USA and US investors in Argentina, indicates that Argentinian and US investors are only affected by shocks transmitted by the US equity market or the exchange rate, and also shows that there is no interaction between equity and currency markets.

Figs. 8–10 display the same kind of information for Brazil, Chile and Mexico, showing the diversification role afforded by currencies in buffering the impact of shocks on investment positions abroad. For the developed markets, in contrast, currencies have an amplifying effect. Panel A in Fig. 8 shows that, in response to a downward shock in the EU equity market, the EUR increases in value against the Brazilian real. Therefore, while Brazilian investors can use exchange rates to compensate for part of their losses, this is not possible for EU investors, as the EUR appreciates when Brazilian equity returns fall. In addition, when the Brazilian real abruptly appreciates (depreciates), EU equity returns increase (decrease), offsetting the loss of Brazilian investors; in contrast, for EU investors, when the EUR appreciates (depreciates), Brazilian equity returns decrease (increase), enhancing thus the negative (positive) impact of the change in currency value on the foreign investment position of EU investors. Similar evidence is reported in Panel B of Fig. 8 for Brazilian and US investors.

Figs. 9 and 10 for Chile and Mexico show similar evidence as reported above for Brazil, although pointing to different intensities. Thus, the Chilean peso and Mexican peso both buffer the impact of

Panel A. Argentina and EU.

Argentinian investment in the EU equity ($r_d - r_e$) under a distress scenario for the EU stock market (r_d)

European investment in Argentinian equity ($r_f + r_e$) under a distress scenario for the Argentinian stock market (r_f)

Argentinian investment in the EU equity ($r_d - r_e$) under a EUR appreciation shocks (r_e)

European investment in Argentinian equity ($r_f + r_e$) under a EUR appreciation shocks (r_e)

Argentinian investment in the EU equity ($r_d - r_e$) under a EUR depreciation shocks (r_e)

European investment in Argentinian equity ($r_f + r_e$) under a EUR depreciation shocks (r_e)

Panel B. Argentina and USA.

Argentinian investment in US equity ($r_d - r_e$) under a distress scenario for the US stock market (r_d)

US investment in Argentinian equity ($r_f + r_e$) under a distress scenario for the Argentinian stock market (r_f)

Argentinian investment in US equity ($r_d - r_e$) under a USD appreciation shocks (r_e)

US investment in Argentinian equity ($r_f + r_e$) under a USD appreciation shocks (r_e)

Argentinian investment in US equity ($r_d - r_e$) under a USD depreciation shocks (r_e)

US investment in Argentinian equity ($r_f + r_e$) under a USD depreciation shocks (r_e)

Fig. 7. Decomposition of international returns: Argentina and developed markets.

EU and US shocks to Chile- and Mexico-based investors, whereas the EUR and USD are unable to cushion the impact of Chilean or Mexican shocks transmitted to EU- and US-based investors.

Overall, the relationship between developed-market exchange rates and equity markets is such that exchange rates amplify the losses of the developed country arising from their investment positions in any of the studied Latin American countries. However, investors in any of the studied Latin American countries would find that the exchange rate operates as shock absorber of potential losses in the developed equity markets.[16]

Finally, we report the diversification benefits of a portfolio comprised of domestic and foreign assets. Let r_p^d and r_p^f denote the returns of an international portfolio denominated in domestic and foreign currencies, respectively, given by:

$$r_p^d = (1-\omega)\, r_d + \omega\left(r_f + r_e\right),$$
$$r_p^f = (1-\omega)\left(r_d - r_e\right) + \omega r_f, \tag{20}$$

where $\omega(1 - \omega)$ denotes the amount invested in the foreign (domestic) market. The diversification benefits that accrue to domestic (foreign) investors from including foreign (domestic) equities in a portfolio can be computed in terms of the ES (see Christoffersen et al., 2012) as $\Delta_{r_p^d}(\alpha)$ ($\Delta_{r_p^f}(\alpha)$):

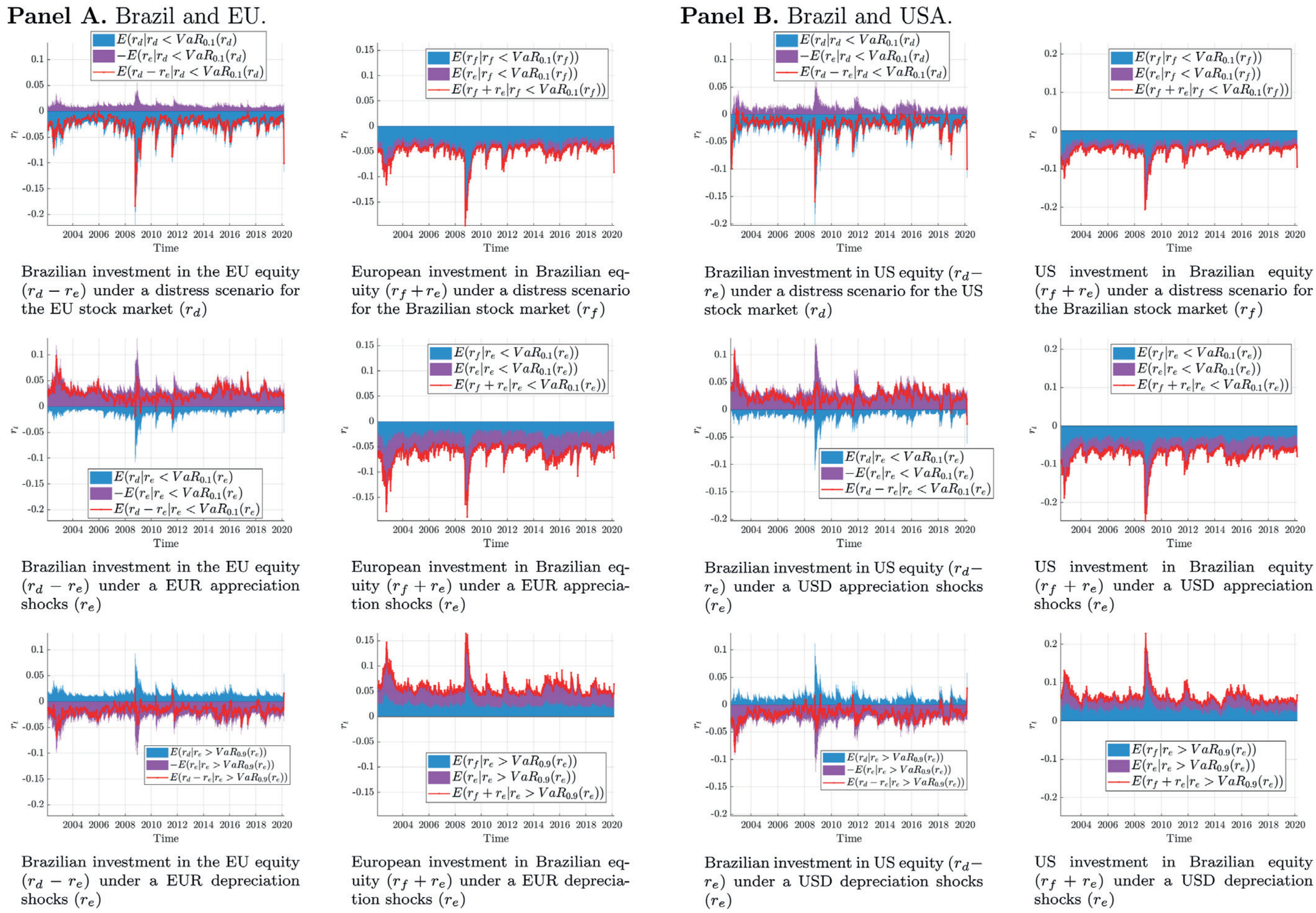
$$\Delta_{r_p^d}(\alpha) = \frac{\omega ES_\alpha(r_f + r_e) + (1-\omega)ES_\alpha(r_d) - ES_\alpha(r_p^d)}{\omega ES_\alpha(r_f + r_e) + (1-\omega)ES_\alpha(r_d) - VaR_\alpha(r_p^d)},$$
$$\Delta_{r_p^f}(\alpha) = \frac{\omega ES_\alpha(r_f) + (1-\omega)ES_\alpha(r_d - r_e) - ES_\alpha(r_p^f)}{\omega ES_\alpha(r_f) + (1-\omega)ES_\alpha(r_d - r_e) - VaR_\alpha(r_p^f)}, \tag{21}$$

where $VaR_\alpha(r_p^d)$ ($VaR_\alpha(r_p^f)$) denotes the α-VaR of portfolio p denominated in the domestic (foreign) currency, which is the lower bound of the portfolio ES, and where $\Delta_{r_p^k}(\alpha)$ for $k = d, f$ takes values in the interval $[0, 1]$, with 0 indicating no diversification benefits, and 1 denoting maximum diversification benefits.[17]

Fig. 11 depicts temporal dynamics for portfolio diversification benefits – from the perspective of Latin American and EU investors (panel A) and from the perspective of Latin American and US investors (panel B) – considering portfolios with weights $\omega = 0.25, 0.5, 0.75$. Panel A in Fig. 11 shows that diversification benefits for Latin American and European investors differ with the portfolio composition and fluctuates over the sample period. Specifically, investors can attain portfolio benefits by including foreign assets in their portfolios and those benefits are greater for Latin American investors than for European investors. The highest value for the diversification index is obtained with $\omega = 0.25$ in the

16 By way of a summary, Table 8 in the online appendix reports average shock effects over the sample period for investors based in emerging and in developed markets, as reported in Figures 7–10.

17 The risk measures for the portfolio are obtained from numerical integration using the cumulative distribution function of the portfolio returns. Detailed explanations are reported in the online Appendix.



Panel A. Brazil and EU.

Brazilian investment in the EU equity ($r_d - r_e$) under a distress scenario for the EU stock market (r_d)

European investment in Brazilian equity ($r_f + r_e$) under a distress scenario for the Brazilian stock market (r_f)

Brazilian investment in the EU equity ($r_d - r_e$) under a EUR appreciation shocks (r_e)

European investment in Brazilian equity ($r_f + r_e$) under a EUR appreciation shocks (r_e)

Brazilian investment in the EU equity ($r_d - r_e$) under a EUR depreciation shocks (r_e)

European investment in Brazilian equity ($r_f + r_e$) under a EUR depreciation shocks (r_e)

Panel B. Brazil and USA.

Brazilian investment in US equity ($r_d - r_e$) under a distress scenario for the US stock market (r_d)

US investment in Brazilian equity ($r_f + r_e$) under a distress scenario for the Brazilian stock market (r_f)

Brazilian investment in US equity ($r_d - r_e$) under a USD appreciation shocks (r_e)

US investment in Brazilian equity ($r_f + r_e$) under a USD appreciation shocks (r_e)

Brazilian investment in US equity ($r_d - r_e$) under a USD depreciation shocks (r_e)

US investment in Brazilian equity ($r_f + r_e$) under a USD depreciation shocks (r_e)

Fig. 8. Decomposition of international returns: Brazil and developed markets.

case of the portfolio being denominated in EUR or with $\omega = 0.75$ in the case of the portfolio being denominated in one of the Latin American currencies, implying that the currency in which the portfolio is denominated introduces a home bias in the portfolio composition. Panel B in 11 shows that similar diversification benefits also hold for Latin American and US investors. Overall, those findings corroborate previous evidence on the diversification benefits of international portfolios, even though those are expressed in terms of downside risk as given by the ES and differ depending on where investors are based.

6. Conclusions

The transmission of shocks between international financial markets depends on whether and how those shocks impact on exchange rates, which thus have the capacity to amplify or buffer the propagation of those shocks. In this paper, the extent to which exchange rates shape the transmission of shocks between international equity markets is explored by modelling the dependence structure between domestic and foreign equity markets, specifically considering the links between exchange rates and international equity returns. Using a trivariate copula model with Markov switching dynamics, we quantify the impact of an equity market shock to another international equity market through the C-ES metric, which measures the mean response of equity returns in one market to shocks in another equity market by taking into account the role of exchange rates in that transmission. We also explore the contribution of exchange rates to that transmission.

Empirical evidence for four emerging Latin American countries (Argentina, Brazil, Chile and Mexico) and two developed markets (EU and USA) over the period 2002–2020 indicates that the contribution of exchange rates to the transmission of equity shocks is time-varying and asymmetric and also differs across countries. We document an inverse relationship and a direct relationship between currency and equity market values for developed markets and emerging markets, respectively, in such a way that exchange rates diversify shocks from abroad for investors based in emerging economies (particularly Brazil, Chile and Mexico), whereas exchange rates echo the effect of shocks from abroad for investors based in developed markets. This evidence is in line with the flight-to-quality foreign capital movements observed in periods of crisis (i.e., capital flight from emerging to developed economies), when equity markets typically face large losses due to the repatriation of foreign investments in emerging economies and the consequent depreciation of the emerging economy's currency. In addition, we assess how exchange rates can enhance the diversification benefits of international portfolios, showing that those benefits differ according to where investors are based.

Our evidence has particular implications for investment and risk management decisions by international investors. In particular, in times of market stress when capital flows usually experience flight-to-quality, investors based in developed markets would face an extra cost of repatriation because of currency depreciation in the emerging market. To reduce such losses, investors may try to secure a first-mover advantage, i.e., repatriating their foreign investment sooner in order to lower the

Panel A. Chile and EU.

Chilean investment in the EU equity ($r_d - r_e$) under a distress scenario for the EU stock market (r_d)

European investment in Chilean equity ($r_f + r_e$) under a distress scenario for the Chilean stock market (r_f)

Chilean investment in the EU equity ($r_d - r_e$) under a EUR appreciation shocks (r_e)

European investment in Chilean equity ($r_f + r_e$) under a EUR appreciation shocks (r_e)

Chilean investment in the EU equity ($r_d - r_e$) under a EUR depreciation shocks (r_e)

European investment in Chilean equity ($r_f + r_e$) under a EUR depreciation shocks (r_e)

Panel B. Chile and USA.

Chilean investment in US equity ($r_d - r_e$) under a distress scenario for the US stock market (r_d)

US investment in Chilean equity ($r_f + r_e$) under a distress scenario for the Chilean stock market (r_f)

Chilean investment in the US equity ($r_d - r_e$) under a USD appreciation shocks (r_e)

US investment in Chilean equity ($r_f + r_e$) under a USD appreciation shocks (r_e)

Chilean investment in US equity ($r_d - r_e$) under a USD depreciation shocks (r_e)

US investment in Chilean equity ($r_f + r_e$) under a USD depreciation shocks (r_e)

Fig. 9. Decomposition of international returns: Chile and developed markets.

Panel A. Mexico and EU.

Mexican investment in the EU equity ($r_d - r_e$) under a distress scenario for the the EU stock market (r_d)

European investment in Mexican equity ($r_f + r_e$) under a distress scenario for the Mexican stock market (r_f)

Mexican investment in the EU equity ($r_d - r_e$) under a EUR appreciation shocks (r_e)

European investment in Mexican equity ($r_f + r_e$) under a EUR appreciation shocks (r_e)

Mexican investment in the EU equity ($r_d - r_e$) under a EUR depreciation shocks (r_e)

European investment in Mexican equity ($r_f + r_e$) under a EUR depreciation shocks (r_e)

Panel B. Mexico and USA.

Mexican investment in US equity ($r_d - r_e$) under a distress scenario for the US stock market (r_d)

US investment in Mexican equity ($r_f + r_e$) under a distress scenario for the Mexican stock market (r_f)

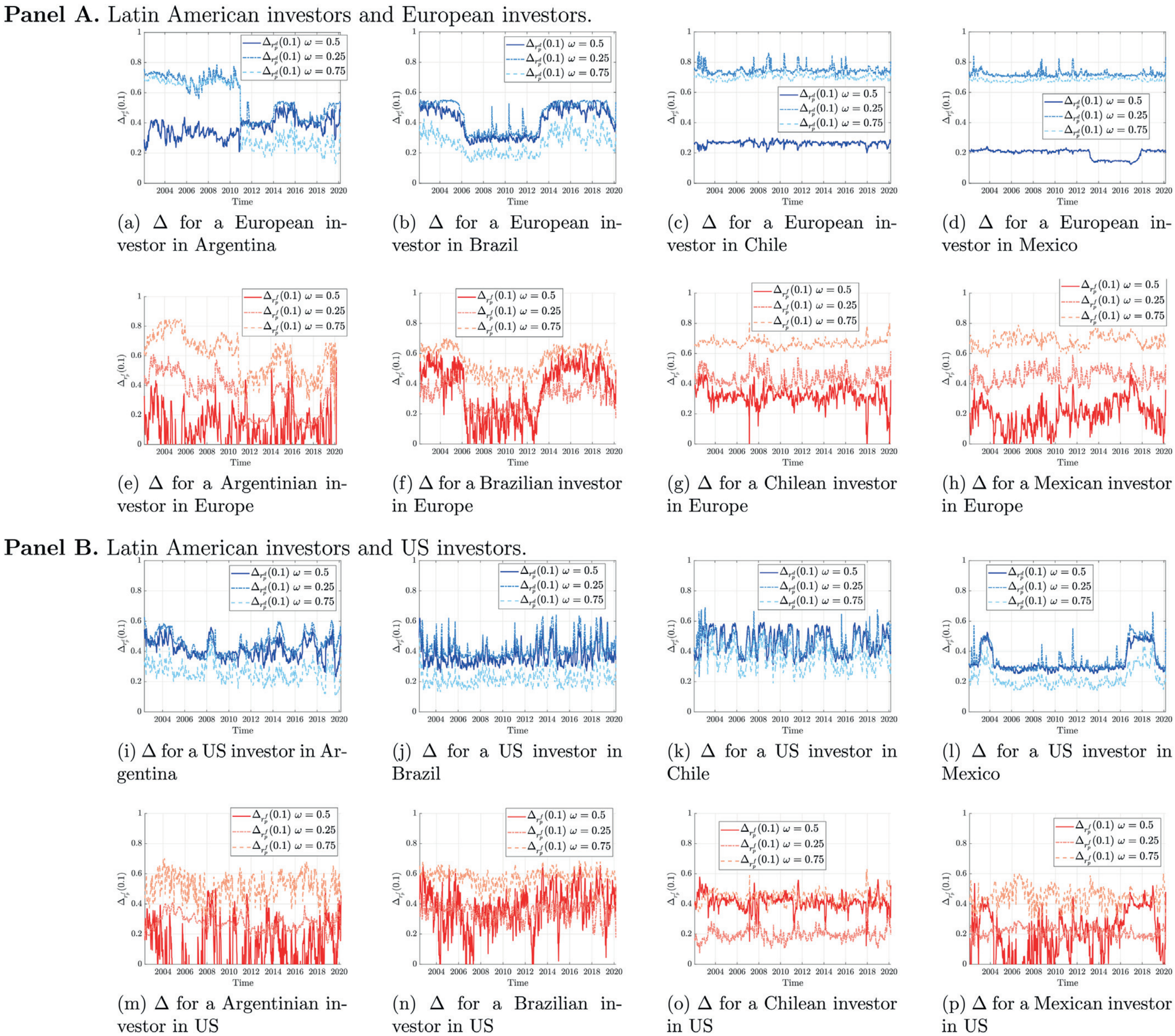
Mexican investment in US equity ($r_d - r_e$) under a USD appreciation shocks (r_e)

US investment in Mexican equity ($r_f + r_e$) under a USD appreciation shocks (r_e)

Mexican investment in US equity ($r_d - r_e$) under a USD depreciation shocks (r_e)

US investment in Mexican equity ($r_f + r_e$) under a USD depreciation shocks (r_e)

Fig. 10. Decomposition of international returns: Mexico and developed markets.



(a) Δ for a European investor in Argentina
(b) Δ for a European investor in Brazil
(c) Δ for a European investor in Chile
(d) Δ for a European investor in Mexico
(e) Δ for a Argentinian investor in Europe
(f) Δ for a Brazilian investor in Europe
(g) Δ for a Chilean investor in Europe
(h) Δ for a Mexican investor in Europe
(i) Δ for a US investor in Argentina
(j) Δ for a US investor in Brazil
(k) Δ for a US investor in Chile
(l) Δ for a US investor in Mexico
(m) Δ for a Argentinian investor in US
(n) Δ for a Brazilian investor in US
(o) Δ for a Chilean investor in US
(p) Δ for a Mexican investor in US

Fig. 11. Measure of portfolio diversification.
This figure shows diversification benefits (bottom right chart) according to Eq. (21), with the blue (red) line indicating the portfolio denominated in the domestic (foreign) currency for the weights **indicated** in the legend. ω indicates the weight in the Latin American market. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

associated costs. Such dynamics could pose a potential systemic risk, leading to instabilities in international markets. Our empirical results also have implications for policymakers as, within our framework, it is possible to assess how abrupt changes in equity market prices may impact exchange rates and, consequently, capital investment flows in international markets – an issue that is particularly relevant in times of crisis such as the COVID-19 pandemic.

Declaration of competing interest

None.

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Appendix. Proofs of key equations

Proof of Eq. (4)

From the definition of conditional expectation, we have that:

$$\begin{aligned} E(r_d|r_f \le VaR_\alpha(r_f); r_e) &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} r_d f(r_d, r_e|r_f \le VaR_\alpha(r_f))\, dr_e dr_d \\ &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} r_d \frac{\int_{-\infty}^{VaR_\alpha(r_f)} f(r_f, r_d, r_e) dr_f}{P(r_f \le VaR_\alpha(r_f))} dr_e dr_d \\ &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} r_d \frac{f(r_f \le VaR_\alpha(r_f), r_d, r_e)}{P(r_f \le VaR_\alpha(r_f))} dr_e dr_d. \end{aligned} \tag{22}$$

Moreover, note that $P\left(r_f \le VaR_\alpha(r_f)\right) = \alpha$ and that:

$$\begin{aligned} f(r_f \le VaR_\alpha(r_f), r_d, r_e) &= f(r_f \le VaR_\alpha(r_f), r_d|r_e) f_e(r_e) \\ &= f(r_f \le VaR_\alpha(r_f)|r_d, r_e) f(r_d|r_e) f_e(r_e) \\ &= P\left(r_f \le VaR_\alpha(r_f)|r_d, r_e\right) f(r_d, r_e) \\ &= P\left(r_f \le VaR_\alpha(r_f)|r_d, r_e\right) c_{de}(u_d, u_e) f_d(r_d) f_e(r_e), \end{aligned} \tag{23}$$

where the third equality follows from $f(r_d|r_e)f_e(r_e) = f(r_d, r_e)$, and the fourth equality follows from $f(r_d, r_e) = c_{de}(u_d, u_e)f_d(r_d)f_e(r_e)$. Next, plugging this last expression into Eq. (22) we have that:

$$E(r_d|r_f \le VaR_\alpha(r_f); r_e) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} r_d \frac{P(r_f \le VaR_\alpha(r_f)|r_d, r_e)}{\alpha} c_{de}(u_d, u_e) f_d(r_d) f_e(r_e)\, dr_e dr_d. \tag{24}$$

Now, taking into account that the conditional probability can be written in terms of the conditional copula function as:

$$P(r_f \le VaR_\alpha(r_f)|r_d, r_e) = C_{f|d}\left(C_{f|e}\left(\alpha|u_e\right)|C_{d|e}\left(u_d|u_e\right)\right), \tag{25}$$

and that $r_d = F_d^{-1}(u_d)$, $du_e = f_e(r_e)dr_e$, $du_d = f_d(r_d)dr_d$, the C-ES in Eq. (24) can be now rewritten in conditional copula terms as:

$$E\left(r_d|r_f \le VaR_\alpha(r_f); r_e\right) = \int_0^1\int_0^1 F_d^{-1}(u_d) \frac{C_{f|d}(C_{f|e}(\alpha|u_e)|C_{d|e}(u_d|u_e))}{\alpha} c_{de}(u_d, u_e)\, du_e du_d.$$

Proof of Eq. (6).

From the definition of conditional expectation, we have that:

$$\begin{aligned} E(r_d|r_f \ge VaR_{1-\alpha}(r_f); r_e) &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} r_d f(r_d, r_e|r_f \ge VaR_{1-\alpha}(r_f))\, dr_e dr_d \\ &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} r_d \frac{\int_{VaR_{1-\alpha}(r_f)}^{\infty} f(r_f, r_d, r_e) dr_f}{P(r_f \ge VaR_{1-\alpha}(r_f))} dr_e dr_d \\ &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} r_d \frac{f(r_f \ge VaR_{1-\alpha}(r_f), r_d, r_e)}{P(r_f \ge VaR_{1-\alpha}(r_f))} dr_e dr_d. \end{aligned} \tag{26}$$

Moreover, note that $P\left(r_f \ge VaR_{1-\alpha}(r_f)\right) = \alpha$ and that:

$$\begin{aligned} f(r_f \ge VaR_{1-\alpha}(r_f), r_d, r_e) &= f(r_f \ge VaR_\alpha(r_f), r_d|r_e) f_e(r_e) \\ &= f(r_f \ge VaR_\alpha(r_f)|r_d, r_e) f(r_d|r_e) f_e(r_e) \\ &= P\left(r_f \ge VaR_\alpha(r_f)|r_d, r_e\right) f(r_d, r_e) \\ &= P\left(r_f \ge VaR_\alpha(r_f)|r_d, r_e\right) c_{de}(u_d, u_e) f_d(r_d) f_e(r_e). \end{aligned} \tag{27}$$

Next, plugging this expression into Eq. (26) we have that:

$$E(r_d|r_f \ge VaR_{1-\alpha}(r_f); r_e) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} r_d \frac{P(r_f \ge VaR_{1-\alpha}(r_f)|r_d, r_e)}{\alpha} c_{de}(u_d, u_e) f_d(r_d) f_e(r_e)\, dr_e dr_d. \tag{28}$$

Now, taking into account that the conditional probability can be written in terms of the conditional copula function as:

$$P(r_f \ge VaR_{1-\alpha}(r_f)|r_d, r_e) = 1 - C_{f|d}\left(C_{f|e}(1-\alpha|u_e)|C_{d|e}(u_d|u_e)\right), \tag{29}$$

and that $r_d = F_d^{-1}(u_d)$, $du_e = f_e(r_e)dr_e$, $du_d = f_d(r_d)dr_d$, the conditional expectation in Eq. (28) can be rewritten in conditional copula terms as:

$$E\left(r_d | r_f \geq VaR_{1-\alpha}(r_f); r_e\right) = \int_0^1 \int_0^1 F_d^{-1}(u_d) \frac{1 - C_{f|d}(C_{f|e}(1-\alpha|u_e)|C_{d|e}(u_d|u_e))}{\alpha} c_{de}(u_d, u_e)\, du_e du_d.$$

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.econmod.2022.105914.

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