



US biopharmaceutical companies' stock market reaction to the COVID-19 pandemic. Understanding the concept of the 'paradoxical spiral' from a sustainability perspective

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ABSTRACT

In an uncertain and finite world, actions towards the development of a green economy are attracting wider support. The damaging anthropogenic impact on earth systems is leading humanity to devastating situations, jeopardizing its very survival. A new world scenario has emerged with COVID-19, where the biopharmaceutical sector has arisen as a powerful effective solution for the health, economic and social crisis derived from the pandemic. This research aims to study the stock market reaction of the two US biopharmaceutical companies that first developed messenger RNA vaccines against COVID-19 (Pfizer and Moderna), considering two time periods, before and during COVID. In the analysis, the influence of the technological market index, market volatility, and investor sentiment are also considered. The results show an unequal influence of market volatility and market sentiment on the returns of both companies, as well as a different volatility behaviour. Furthermore, a contagion effect is observed during the COVID period between both companies and the technological market. The study's findings provide investors, organizations, policy-makers and society with useful information for the design of policies and strategies that ultimately are called to ensure sustainable growth for future generations.

1. Introduction

In recent years, the importance of the planet's sustainable development embodied in initiatives such as the goals proposed in the 2030 Agenda for Sustainable Development (United Nations, 2015) has aroused increasing interest and concern amongst society and the scientific community. Social and economic agents have tried to offer new answers and solutions to contribute to the achievement of these relevant goals from multiple perspectives, such as green bond issuance (Piñeiro-Chousa et al., 2021), business strategy evaluation (Calabrese et al., 2021), or the design of initiatives in different territories, such as the nature-based solutions promoted by the European Commission (Faivre et al., 2017). Unfortunately, the unlimited growth of the population and the development of the economy based on the intensive use of limited resources have generated multiple negative effects on the planet, such as climate change, with very negative consequences for human survival (Haines and Ebi, 2019). Anthropogenic activities have resulted in increased human exposure to frequent occurrences of natural disasters

and the emergence of new infectious diseases (Myers, 2017). The most recent example of the detrimental impact of these activities is the COVID-19 pandemic, which has resulted in the largest global health crisis in recent times.

The COVID-19 disease has forced the design of policy responses and government interventions across regions within countries worldwide. The adopted actions range from containment and closure policies, such as movement restrictions or school and workplace closures; economic policies, such as income support for those who lost their jobs or international aid expenditure for COVID-19 consequences; or health policies, such as emergency spending on health care, mass testing and contact tracing policies, or public investment in vaccine development (Hale et al., 2020). These measures, in some cases belated, that have tried to reduce the transmission of the virus, have in turn generated new economic and social problems.

At the same time, financial markets, including the US market, have reacted in an unprecedented way to the evolution of the virus and the containment measures implemented by countries, reaching or

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surpassing levels of volatility similar to other major previous events (Baker et al., 2020). Essential sectors, such as agriculture, water, energy, and food, have also been seriously affected both directly by COVID-19 and indirectly by the consequences that COVID-19 has had on other related sectors. This gives sense to the concept of the 'paradoxical spiral', according to which anthropogenic actions can provoke changes and damage in systems and sectors that are in one way or another interconnected. All this generates large imbalances between sectors that imply uncertain consequences for humanity. This requires considering the implications of the nexus between sectors and the allocation of large amounts of resources in those that can offer effective and innovative solutions in preventing and solving negative situations such as the COVID-19 pandemic.

The search for an effective vaccine has attracted the attention of the media and financial markets in the biopharmaceutical sector as one of the principal solutions to restore a state of "new normalcy". The biopharmaceutical sector, called to develop innovative solutions aimed at preventing and solving problems related to human health, has faced the enormous challenge of developing a vaccine in a short period of time (Krammer, 2020), emerging as one of the great bets of governments, companies, citizens, and investors. As this sector is called to play a decisive role in the fight against the pandemic, this study aims to analyse the stock market behaviour before and during COVID-19 of the two most relevant US biopharmaceutical companies to date, Pfizer and Moderna. Specifically, this study aims to analyse the influence of market volatility and market sentiment on Pfizer and Moderna returns and to compare the volatility behaviour of these companies before and during the pandemic outbreak. It also aims to analyse whether the technological market has been influenced by these companies, which have committed to the development of innovative messenger RNA vaccines. Variables including market volatility (VIX), the technological market index (NASDAQ), and investor sentiment (ISEE) were considered in the analysis. To this end, GARCH (1,1) (Bollerslev, 1986) and DCC-GARCH (1,1) models (Engle, 2002) have been used. The study period considered covers 3rd January 2019 to 12th February 2021, distinguishing between pre-COVID (3rd January 2019 until 10th March 2020) and COVID (from 11th March 2020 to 12th February 2021) periods.

This study contributes to the advancement of the knowledge related to the influence of the COVID-19 pandemic on financial markets, specifically if the biopharmaceutical sector is considered. The study results shed light on the role played by variables such as market volatility and investor sentiment on the returns of the studied companies. This research calls for action at different levels (governments, organizations, investors, society) to work on a natural transition towards a green economy to achieve a joint commitment to avoid and reduce the conditions that favour the occurrence of natural disasters and diseases. Governments to design strategies able to ensure current and future human health and well-being; organizations to comply with strict sustainable protocols and rules; investors to make decisions aimed at rewarding or punishing organizations depending on their responsible behaviour; and society to include sustainability as a cultural value that guides any action.

The remainder of this manuscript is structured as follows. Section 2 develops the theoretical background and states the hypotheses under study. Section 3 explains the research design, data sources and methodology. Sections 4 and 5 present the main results of the study and their discussion. Finally, Section 6 presents the practical implications, limitations, and future lines of research.

2. Literature review

The growing concerns and worries of citizens about environmental protection and care for the planet have been transferred to the business, institutional and governmental spheres, placing sustainability as a priority element for global economic growth. This social awareness has been reflected amongst others in the Global Risks Perception Survey

(World Economic Forum, 2021), where for the first time in history, the five risks identified in 2019 as most likely to occur in the next ten years were environmental. In the 2020 survey, four of these environmental risks (extreme weather, climate action failure, human environmental damage, and biodiversity loss) remained amongst the top five risks, with infectious diseases emerging in fourth place. All these environmental risks are related in different ways to human action. The planetary health approach points out human activities as a source of strong biophysical changes in earth systems that severely affect human health and well-being. According to multiple scientists, these changes have given rise to a new geological era, the Anthropocene, characterized by damaging human impacts on the planet (Planetary Health Alliance, 2021) and concretized in six dimensions – climate change; global air, water and soil pollution; biodiversity loss; altered biogeochemical cycles; changes in land use and land cover; and resource scarcity, especially freshwater and arable land –. These changes are increasing human exposure to infectious diseases and other naturally occurring hazards, such as heat waves, floods, droughts, fires or tropical storms (Myers, 2017). According to all this, the main concern relates to the fact that incessant economic growth and the lack of awareness of the connection between humans and nature make the continuity of the current model of life unsustainable in the future.

The results of human and economic activity have had (and will continue to have) multiple negative effects in many areas, sectors, and industries. The concentration of large quantities of greenhouse gases in the atmosphere has led to one of the greatest human-induced consequences, climate change, which has become a serious threat to human health (Haines and Ebi, 2019). In recent years, climate change has been strongly associated with the occurrence of major natural disasters such as hurricanes, heavy rains, floods, fires, heat waves and even diseases. The increased frequency and severity of these events and the remarkable effects of climate change have made visible its influence on human welfare and health, as well as on the supply of one of our most precious commodities, freshwater (Bandh et al., 2021). Ensuring universal access to fresh, clean, and affordable water has become a goal that is unlikely to be achieved in the near future. Inadequate water resource management in the face of an incessant population and economic growth leads to an increase in, for example, energy consumption or the demand for agricultural products. In fact, the close link between these three key industries for human survival, water, energy, and agriculture can be at risk since the changes or bad practices in one of these industries can significantly affect the others, and consequently human and planetary health (Piñeiro et al., 2020).

Humanity has entered what it can be called a 'paradoxical spiral' where human actions provoke changes and cause damage in different systems and sectors that in turn affect other systems and sectors with uncertain consequences for humankind. Thus, global warming can lead to an increase in energy demand (a potential source of greenhouse gas emissions), which increases the need for water resources to produce energy that are no longer used in other industries such as agriculture or food, all of which in turn may result in major resource management imbalances amongst these and other industries. As sectors are strongly related to each other, it is difficult to discriminate which are the causes and the effects along the different interconnection processes, giving rise to a spiral of events whose results in cases are very difficult to decipher and therefore paradoxical. For this reason, human-induced imbalances in different industries and sectors require urgent joint multistakeholder actions to design sustainable management and production models capable of meeting socioeconomic demands while preserving resources for future generations. Governments, organizations and the entire society must work to move towards a greener and more sustainable economy, offering innovative solutions to promote an efficient use of natural resources and implementing actions and initiatives, such as EU Nature-Based Solutions aimed at promoting biodiversity conservation, natural disaster reduction, development of circular economy and energy efficiency models, and resilience to climate change (Favre et al., 2017).

Understanding the 'paradoxical spiral', according to which large amounts of resources must be assigned to key sectors to reverse or mitigate the damage caused by others, is useful to explain the causes, consequences and most effective solutions to the COVID-19 pandemic.

2.1. Contextualization of the COVID-19 pandemic

The outbreak of coronavirus disease 2019 (COVID-19) began in the Chinese city of Wuhan in Hubei Province in December 2019, when the first cases of pneumonia of unknown cause were reported. The transmission capacity of the virus and its fast spread through different continents and countries around the globe led the World Health Organization (WHO) to classify the outbreak as a global pandemic on March 11, 2020, when the number of detected cases had already exceeded 118,000 in 114 countries (WHO, 2020).

According to the WHO (2021a) global report on the origins of the virus causing COVID-19 disease, the most likely scenario points to a zoonotic transfer of the virus, that is, transmission from animals to humans. amongst others, the human encroachment of natural ecosystems as a result of the necessary expansion of agricultural land, the hunting of wild animals or the trafficking of animals have increased exposure to zoonotic diseases such as coronaviruses, HIV or Ebola (de Paula and Willetts, 2021). As noted above, the emergence of new infectious diseases is largely related to socioeconomic, ecological, and environmental factors (Jones et al., 2008). In fact, the scientific community has been warning for years about the reduction of biodiversity as a catalyst for the transmission of infectious diseases (Keesing et al., 2010), but no significant action has been taken. The COVID-19 pandemic has once again put the spotlight on the connections between the occurrence of dangerous infectious diseases and environmental, climate and health issues, highlighting the imperative need for designing a global strategy focused on preventing such events (Barouki et al., 2021).

Decreasing the spread of COVID-19 disease and achieving the desired herd immunity depends to a large extent on the mass administration of a worldwide effective vaccine, placing the biopharmaceutical sector as a key player in the global recovery process. During these months, multiple biopharmaceutical companies have been working and developing effective vaccines using new technologies at unprecedented speed (Krammer, 2020). While mass administration of vaccines would help drastically reduce the number and severity of infections in the near future, the impacts of COVID-19 are much more far-reaching and will need to be addressed from multiple perspectives with a vision focused on sustainable growth. A phenomenon of this magnitude opens up new research opportunities to analyse the importance of critical industries acting both as cause and consequence of such phenomenon justifying the concept of the 'paradoxical spiral' and the huge consequences of an event of these characteristics on the economy and society. The serious health, social and economic implications of COVID-19 demand the design of an ethical and responsible action plan to regain 'normalcy' and prevent the emergence of new catastrophic events.

2.2. The COVID-19 pandemic and its implications for market behaviour

Drawing an analogy with other previous diseases and natural disasters that have clearly influenced financial market behaviour, it was expected that the same happened with COVID-19 (Goodell, 2020). This pandemic has brought major challenges that have served to test the resilience of governments, sectors, economies, and society as a whole. Since the declaration of a Public Health Emergency of International Concern announced by the WHO on January 30, 2020, the evolution of the novel coronavirus has shaken global stock markets, leading to a decline in market performance and an increase in nervousness and fear amongst investors (Shaikh, 2020). This reaction to the exceptional event has been reflected in unprecedented market volatility, interpreted by policy-makers, financial sector regulators, investment funds and

individual investors as a measure of the financial risk and the uncertainty generated around investment in financial assets (Baek et al., 2020). One of the most widely recognized and used ways of measuring the frequency and magnitude of the price movements of a financial instrument is the CBOE Volatility Index (VIX), a globally recognized indicator of US stock market uncertainty (CBOE, 2021). Market volatility soared worldwide by mid-March 2020; specifically, US volatility levels reached or surpassed the levels recorded in events such as the Great Depression in 1929, Black Monday in October 1987 or the Global Financial Crisis in December 2008 (Baker et al., 2020). The closer connection between markets resulted in a significant volatility spillover, predominantly from the European continent to the rest of the world (Shaikh, 2020).

In the first months of the coronavirus, figures reported by the WHO influenced financial markets with different intensities. A study conducted by Albuлесcu (2020) with data collected during January and February 2020 concluded that although the Chinese figures related to the spread of the virus slightly influenced the VIX of the US financial markets, the notification of new cases outside China and the increasing global death rate contributed to a clear increase of financial volatility. In fact, beyond China, the focus of attention was first on Europe and then on the US due to the great sensitivity of these markets to unusual events and the great transcendence of these markets worldwide. Stock markets of both regions did not react significantly in the short term to the notification of the first cases of COVID; however, a significant negative reaction was registered with the announcement of the first deaths (Heyden and Heyden, 2021). During the first wave of COVID-19, the worldwide figures on the emergence of new cases of infected or dead people had a greater impact on the volatility and liquidity of the US financial markets than the figures reported for their own country (Albuлесcu, 2021). This situation changed as the number of daily confirmed cases of infected or dead people in the US began to rise, along with the negative sentiment generated by the media and restrictive measures applied by the government on citizens (Baig et al., 2021), all of which provoked an extraordinary reaction of the US stock market to events related to the 2020 pandemic (Baker et al., 2020). According to these authors, the largest daily stock market movements related to pandemics in the last 120 years cannot be attributed solely to the lethality of the virus (at the time of the study, the excess mortality rate of COVID-19 was only 1/25th higher than that recorded during the Spanish flu), but government restrictions on commercial activity and individual mobility, together with the voluntary social distancing of the population. In their study, Zaremba et al. (2020) isolated the effect of restrictive government policies and demonstrated their significant impact on increasing international stock market volatility. From their point of view, two main types of nonpharmaceutical policy interventions have led to this increased volatility. On the one hand, government information campaigns related to COVID-19 have led investors to reposition their portfolios, in some cases with a propensity towards safe assets generating additional trading activity in the market and thus liquidity (Zaremba et al., 2021). On the other hand, the public cancellation of all kinds of events, which was considered an initial response from governments and therefore a sign of possible stricter interventions in the future, was the first opportunity for investors to react to possible future changes (Zaremba et al., 2020). Moreover, in Europe and the US, the monetary policies adopted to reduce the effects of the health emergency proved to have a reassuring effect on the markets, unlike the new fiscal policies that only generated greater uncertainty amongst investors. Some authors have pointed out that the response to these policies depends, amongst other things, on firm-specific features, mainly their relative amount of tangible assets and liquidity (Heyden and Heyden, 2021).

COVID-19 has made the recovery of stock market indices slower and more difficult than other recent disease outbreaks, such as Ebola, MERS and SARS (David et al., 2021). For example, although a rebound occurred between the first and second quarters of 2020 in the stock

indices of the world's top ten economies, only two of them, China and the US, showed a positive return from January to June (Chaudhary et al., 2020). The ongoing rise in global daily infections and deaths recorded during the first and second waves of COVID-19 led to an increase in uncertainty in the US stock market, even when the quarantine restrictions established during the first wave were eased (Yousfi et al., 2021). This situation has led to a greater investor awareness of the importance of sustainability and the minimization of the consequences of natural events of this magnitude. The growing interest in sustainability has been reflected in the investment decisions and the market resilience of some companies and sectors. For example, during the first quarter of 2020, the stock prices of firms with a high rating in environmental and social policies exhibited better performance and lower volatility (Albuquerque et al., 2020).

The impact of the pandemic has been unevenly felt both in essential sectors for global sustainable development and in safe-haven securities that are fundamental in times of financial turbulence. In fact, the COVID-19 outbreak led to a sharp fall in the prices of the main commodity markets (energy, agriculture, metals, etc.), which did not start their recovery until the third quarter of 2020. At the onset of the pandemic, high prices due to production shortfalls led investors to find safe-haven assets amongst the agricultural commodities market, specifically soybean futures (Ji et al., 2020). Agricultural commodities have shown the most balanced performance in 2020 since, despite the restrictions and interruptions in supply chains, food prices have remained broadly stable. Concerning metal commodities, there has been an increase in the price of precious metals due to the application of expansive monetary policies with low interest rates, a weakened US dollar, supply and production disruptions, and the flight of investors to safe-haven assets (World Bank Group, 2020). In particular, gold has been one of the great beneficiaries of the pandemic, demonstrating its safe-haven properties in the face of extreme market conditions (Dutta et al., 2020; Ji et al., 2020). In the same way, the cryptocurrencies market has not been immune to the unfortunate effects of the pandemic. The two main cryptocurrencies, Bitcoin and Ethereum, have exhibited high volatilities in daily returns (higher than those of gold and the S&P 500 index) during the 2020 COVID period (Mariana et al., 2021). Despite the illiquidity, high volatility and high transaction costs associated with these assets, several studies have evaluated their behaviour as potential safe-haven assets. In this sense, Marianna et al. (2021) have shown that Bitcoin and Ethereum show safe-haven features in the short term, with the latter acting as a better safe-haven asset in the face of extreme stock market declines. These results differ from those obtained by Corbet et al. (2020) or Conlon and McGee (2020), who have suggested that during severe economic and financial turmoil periods, cryptocurrencies do not act as safe havens.

The impact of the pandemic on the energy sector has been more severe than in other sectors. In fact, this was the first sector to react to the COVID-19 pandemic, according to the S&P 500 sector indices (Matos et al., 2021). Mandatory shutdowns, travel restrictions or home quarantines have had an apparently unintended effect on reducing energy consumption and greenhouse gas emissions (Sovacool et al., 2020). Border closures and travel restrictions provoked serious problems to the oil demand. In fact, the decrease in energy demand as a result of the paralysis of economic activity has led in turn to a decrease in the profitability of the energy markets, which have also experienced historic volatility levels due to the pandemic (Shaikh, 2021). The crude oil market suffered a serious slump in the first half of 2020 as a consequence of failed negotiations between OPEC member countries and Russia. Insufficient oil storage capacity, along with uncertainty about the future after the pandemic, broke out the potential agreements between both parties. As a result, in April 2020, the West Texas Intermediate crude oil price recorded a negative record for the first time in history (Gharib et al., 2021). The sustainable energy sector has also been severely impacted by the pandemic. In fact, renewable energy manufacturing facilities and businesses have been adversely affected, undermining the

positive trend progress towards green energy (Hosseini, 2020). For example, although the impact of COVID-19 on solar stock prices has been mixed, the stock prices of most solar companies have dropped, mainly due to restrictive policies implemented by governments in response to the health crisis (Wang et al., 2021).

According to the 'paradoxical spiral' already mentioned, the occurrence of natural disasters or the emergence of diseases such as the COVID-19 pandemic require a careful analysis of the implications derived from the connections between different sectors from a sustainability perspective. Logically, it also requires searching and allocating resources in sectors capable of offering effective and innovative solutions for emergency situations. Precisely, the complexity of the COVID-19 context has required paying attention, mainly in a first moment, to these other sectors called to play a key role in the fight against the pandemic. Thus, the biopharmaceutical sector based on knowledge, innovation and technology was called to help mitigate the negative health problems caused by the pandemic in the short and medium term. In turn, it must contribute to solving other economic and social problems, helping increase the awareness of citizens, companies and governments about the need to behave under premises based on sustainable criteria.

2.3. The biopharmaceutical sector as a potential solution to the COVID-19 pandemic

In recent decades, the environment and industries such as food, agriculture, medicine, and energy have benefited from revolutionary technological breakthroughs. amongst the technological advances arising from the ongoing situation characterized by major economic, social, and environmental changes that are affecting, amongst other issues, the survival of humankind itself, advances in the biotechnology field stand out. Traditionally, biotechnology is characterized by the use of biological systems and living organisms for the development of new products and processes. Continuing scientific advances have resulted in modern biotechnology, which goes a step further by employing a set of techniques known as genetic engineering, which enables genetic material to be modified or transferred between different organisms (Amarakoon et al., 2017). The evolution of biotechnology is helping to address global challenges such as efficient, safe and clean production, energy savings, progress towards food security or the fight against diseases that threaten the planet. In relation to this last challenge, the biotechnology revolution applied to the pharmaceutical industry has enabled the establishment of a new era in the struggle against diseases through an accelerated development of novel vaccines (Defendi et al., 2021). The urgency of halting the worldwide spread of COVID-19 disease and the need to monitor the diagnosis, prevention, and control of this infectious disease has placed the biotechnological and pharmaceutical sector (biopharmaceutical) in the spotlight of society, governments and financial markets.

The international scientific community has turned its attention to the development of effective vaccines in an attempt to put an end to the COVID-19 pandemic. According to the monitoring carried out by the WHO (2021b) in February 2021, the number of experimental vaccines in development exceeded 200. Although it was expected that the development of a vaccine to stop the transmission and lethality of this virus could take several years, the previous knowledge acquired by the biopharmaceutical sector in the initial development of vaccines for SARS and MERS diseases has led it to set a milestone, developing vaccines for the COVID-19 disease in record time (Krammer, 2020). This race for a vaccine has been primarily led by two US companies, Pfizer and Moderna. Although the vaccine developed by Moderna was the first of the COVID-19 vaccine candidates to begin human trials, the first emergency use authorization issued by the US Food and Drug Administration (FDA) on December 11, 2020, was for the vaccine developed by Pfizer-BioNTech. Only seven days later, on December 18, 2020, the FDA authorized the second vaccine for coronavirus disease prevention

developed by Moderna Inc. (FDA, 2020).

These two US companies have been responsible for the development of the first and most advanced RNA-based vaccines against SARS-CoV-2, the coronavirus causing COVID-19 disease. Although the technology used by both companies is similar, the two companies have very different origins. Founded in 1849 in New York, Pfizer Inc. (2021a) is one of the world's largest biopharmaceutical companies. According to the Fortune 500 list published in 2020, the company is ranked 64th amongst the 500 largest corporations in the US (Fortune, 2020). This company has a long history in the discovery, development and manufacture of drugs, vaccines, and consumer health care products. In recent years, Pfizer has undergone a business restructuring process with the aim of focusing entirely on the development of innovative biopharmaceutical products. This reorientation of the company has led it to develop the COVID-19 mRNA vaccine in collaboration with the German biotech company BioNTech, with which it is also working to commercialize the vaccine worldwide except in China, where BioNTech has a strategic collaboration with the health care group Fosun Pharma. In contrast, the biotech company Moderna Inc. (2021a) is a young company established in 2010 in Cambridge, Massachusetts, which is focused on the development of mRNA vaccines and therapies for the treatment and prevention of various diseases. The COVID-19 mRNA vaccine developed by Moderna, which has been supported and funded by the Biomedical Advanced Research and Development Authority (BARDA), is the first and thus far the only product developed by this company that has achieved regulatory agency approval. This vaccine is being commercialized in the US and in other countries around the world. Both companies are listed on the US stock market, while Pfizer's common stock is traded on the New York Stock Exchange, Moderna's shares are traded on the NASDAQ Global Select Market.

This paper is focused on these two relevant companies in the biopharmaceutical sector. The reason that justifies their choice is that these companies have many aspects in common but also substantial differences. In relation to similarities, Pfizer and Moderna are localized and listed on the US market; they have developed the first vaccines approved in the country, they are being administered in many parts of the world, and both vaccines are based on novel messenger RNA technology. The main differences between them relate to the companies' size, the experience and previous achievements, the product portfolio, the collaboration with other companies, or the use of public funding. Therefore, these two companies allow the US market orientated to the research and commercialization of COVID-19 vaccines to be characterized from a wide perspective.

The stock market behaviour of the biopharmaceutical sector in recent decades has shown similarities and differences with pharmaceutical and biotech companies' performance. The study conducted by Thakor et al. (2017) addressed an analysis of the financial performance of 1066 US biopharmaceutical companies from 1930 to 2015 to visualize the main features and behaviour patterns of this sector in the long term. Considering two different sub periods of time, before and after the emergence of modern biotechnology in the 1980s, the authors observed that the pharmaceutical subsector's returns were in general higher (average annual return 3%) than those of the stock market throughout the entire period analysed. Moreover, this performance was very similar to that of the technology sector, which it outperformed from 2000 onwards. The performance of pharmaceutical companies contrasts with biotech companies' underperformance in the period from 1980 to 2015, where less homogeneity is observed in long-term returns along with higher risk and stock volatility. In addition to the companies' product portfolios, general economic factors proved to be a substantial source of risk for the financial performance of the biopharmaceutical sector, which led these companies to show different stock market behaviours. In fact, several studies have suggested that, in the face of health crises such as those resulting from epidemic or pandemic diseases, the stocks of the biopharmaceutical sector are affected in a different way than in other sectors. Chen et al. (2009) showed that during the 2003 SARS epidemic

crisis in Taiwan, while most sectors were negatively impacted by the epidemic, investors and fund managers who bought or held biotech stocks obtained profits and saw reduced their investment risks. Ichev and Marinč (2018) found evidence of a strong positive effect of the 2014–2016 Ebola outbreak events on the returns of the US biopharmaceutical and health care equipment industry, which contrasted with the negative impact experienced on stock returns by most US industries. In the same way, Al-Awadhi et al. (2020) more recently found that the COVID-19 outbreak in China influenced technology and medicine sectors' stock returns, which outperformed other sectors in the Chinese stock market. Therefore, the following hypotheses are proposed:

H1a: Market volatility influences Pfizer and Moderna returns during the pre-COVID period.

H1b: Market volatility influences Pfizer and Moderna returns during the COVID period.

The COVID-19 pandemic has affected the American companies Pfizer and Moderna. Considering the period before the outbreak, it can be observed that the overall behaviour of both companies was relatively flat, and there were no significant variations in their share prices. In this pre-COVID period, Pfizer's common stock price came from an uptrend that began in late 2012 and culminated in December 2018. Following this moment, the company's shares entered a complex decline that spanned two years, with a slight rebound in the second half of 2019, just before the outbreak of the pandemic. Moderna's shares journey has been considerably shorter since the company first began trading on December 7, 2018. Moderna's stock market performance did not differ substantially from that of Pfizer in 2019, as Moderna's share price did not show significant changes, except for a slight downtrend that occurred in mid-2019, from which it started to recover by the end of the year.

The onset of the COVID-19 pandemic in China and its subsequent transmission to other countries affected the performance of these companies but not in the same way. At the beginning of the study period, the share prices of Pfizer and Moderna were 42.04 and 15.05 USD, respectively. On March 11, 2020, the day the WHO officially declared the COVID-19 pandemic, Pfizer recorded a price of 32.17, while Moderna reached 23.61 USD. Finally, on February 12, 2021, Pfizer's share price recovered up to 34.72, while Moderna's share price rose to 183.74 USD. Overall, 2020 was a year in which, despite high investor expectations, Pfizer was an unexpected loser with lower stock returns than the broader market. After the pandemic-related plunge in the first quarter of the year, Pfizer's stock prices managed to rebound but without a sustained recovery. The notification on November 9 of the results of the first analyses (pointing to an efficacy of more than 90%) gave a new boost to its stock performance, which was subsequently followed by the FDA authorization of the emergency use of the vaccine in the second half of the same month. This positive trend changed at the end of 2020 with a drop in the company's stock price that remained until the beginning of February 2021. Based on Pfizer's 2020 Form 10-K (Pfizer Inc., 2021b), some of the reasons that justify the company's financial results are (i) the slowdown in demand for non-COVID-19 prescriptions and vaccines and (ii) the loss of revenue related to the consumer health business, which was developed through a joint venture with Britain's GlaxoSmithKline PLC from the summer of 2019. In addition, following the company's restructuring strategy, in 2020, Pfizer launched the spinoff of its off-patent brands and generics business (Upjohn), which was merged with other US pharmaceutical companies (Mylan). These results clearly contrast with those of Moderna, whose share price followed a vertiginous upward trend in 2020 driven by the positive evolution in the development of its vaccine against the new coronavirus. In early April, Moderna's stock price surpassed Pfizer's and continued to soar until February 2021. Following the release on November 16, 2020, of the results of Moderna's preliminary studies (showing an effectiveness of 94.5%), its stock price skyrocketed, peaking in early December 2020. After the subsequent pullback, the FDA authorization of the vaccine in mid-December led the company's shares to recover their uptrend, reaching new highs in early February 2021. It is interesting to note that

since its inception, the biotech company has been accumulating losses, recording a net loss of \$747.1 million in 2020, higher than the \$514.0 million loss recorded in 2019 (Moderna Inc., 2021b). In 2020, the company's total revenue increased by more than 1200%, largely due to the boost generated by the grant revenue following the BARDA agreement. To date, Moderna's strategy has prioritized the reinvestment of future profits in the development of its own projects and the growth of the company, leaving aside a dividend payout policy such as the one maintained by Pfizer. The success of the messenger RNA technology developed by these two companies is reflected in their stock prices during 2020, although showing very different trends. Those investors with a more aggressive investment style who opted for the more volatile stock performance of Moderna saw the company's shares soar 866% in a year (February 12, 2020 to February 12, 2021). In the same period, Pfizer shares showed a decrease of approximately 8%. Hence, the following hypotheses are proposed:

H2a: Pfizer volatility behaves differently during the pre-COVID and COVID periods.

H2b: Moderna volatility behaves differently during the pre-COVID and COVID periods.

Given the innovative and technological nature of the vaccines developed by these companies, it is interesting to analyse their evolution with respect to one of the most popular US indices and a global benchmark for innovation, the NASDAQ. The NASDAQ-100 is a stock market index that lists the 100 largest domestic and international nonfinancial companies listed on the NASDAQ stock market. It includes the world's largest companies belonging to the technology sector, as well as consumer services companies, health care companies (including biopharmaceuticals), consumer goods companies, and some industrial companies (NASDAQ Inc., 2021). Considering the studied period, it is observed that the positive trend maintained by the index in the pre-COVID period disappeared with a downturn at the beginning of the health crisis in the first quarter of 2020 (just the same that happened with other indices). After this drop, the index started to follow a positive trend due to the excellent performance of the values of the index constituents, including a possible contagion effect by Moderna advances with the COVID-19 vaccine. In fact, during the period February 12, 2020, and February 12, 2021, the NASDAQ-100 price experienced a positive variation of 43.63% (higher than the 16.43% reported by the US S&P 500 index). Considering all this, it is necessary to go deeper in the analysis of the relationship between the technological market and Pfizer and Moderna behaviours, mainly if pre- and COVID-19 periods are considered. Therefore, the following hypotheses are proposed:

H3a: There is a contagion effect between Pfizer and NASDAQ during the COVID period.

H3b: There is a contagion effect between Moderna and NASDAQ during the COVID period.

Considering that stock market movements have been strongly impacted by the major events that happened during 2020, it is important to analyse whether nonrational investor behaviour may have had a significant influence on the financial results.

2.4. Market sentiment and its influence on biopharmaceutical companies' returns

Investor sentiment refers to how investors form beliefs (Barberis et al., 1998). In recent years, the analysis of investor sentiment and how it influences financial markets has become very relevant. In fact, the number of studies that have analysed this relationship has increased considerably, and they have shown that investor sentiment can influence US markets, such as the S&P 500 (Zhang et al., 2011) or the Russell 3000 (Da et al., 2011), as well as other international markets (Schmeling, 2009). It is necessary to consider its influence not only on traditional financial markets but also on new markets focused, for example, on cryptocurrencies (Naeem et al., 2021) or sustainable indices (López-Cabarcos et al., 2019). Moreover, investor sentiment has become

a very important variable to be considered when analysing the behaviour of markets under 'normal' conditions, mainly when certain significant events such as economic crises (Wolff, 2013) or pandemics (Chen et al., 2020) occur. One main concern about investor sentiment is how to measure it. Different methods have been used thus far: market proxies such as the closed-end fund discount; NYSE share turnover; the number of and average first-day returns on IPOs; the equity share in new issues, and the dividend (Baker and Wurgler, 2006, 2007); surveys (Giannarakis et al., 2016); news and social networks (Broadstock and Cheng, 2019; López-Cabarcos et al., 2021); or proxies from the China A-share market, Hong Kong stock market and the US market (Zi-long et al., 2021). In 2011, the ISEE Sentiment Index was launched to measure investor sentiment using opening long-call options and opening long-put options purchased on the International Stock Exchange. This index has been used in this paper since it is able to provide a measure of investor sentiment at an international level, unlike other indices that use market-specific variables. In addition, it is based on financial data, its frequency is daily, and it is supported by the International Stock Exchange. The characteristics and evolution of the global crisis of COVID-19 advise considering a measure of investor mood at the international level.

Previous studies have pointed out that events that have a high impact and low probability of happening, such as epidemics or pandemics, tend to be overstated in the media, which leads to irrational behaviours in investors' decisions. The disproportionate media coverage during the severe acute respiratory syndrome (SARS) disease outbreak in Ontario, Canada, in 2003 led to a disproportionate public response in other parts of North America and other Canadian provinces, despite the substantial difference in the number of reported cases (Blendon et al., 2004). The Ebola 2014–2016 outbreak led US stocks with greater media exposure to suffer more intensely than those that received less media coverage due to investors' anxiety and fear (Ichev and Marinč, 2018). The amplified and disseminated information around COVID-19 has significantly influenced investors' behaviour and thus financial markets' performance. In this sense, Baek et al. (2020) concluded that after the onset of the pandemic, the US stock market was more sensitive to news related to COVID-19, especially negative news, than to economic indicators (e.g., expected price fluctuation or monetary policy). Meanwhile, Haroon and Rizvi (2020) found a strong positive association between the huge panic generated by the media and the volatility of indices of sectors severely hit by the pandemic, such as energy, transportation, automobiles, travel and leisure. Smales (2021) proved that retail investors' attention to the COVID-19 crisis (measured by Google search volume for the term 'coronavirus') negatively influenced financial market returns worldwide.

Prior research has analysed how news related to diseases can affect the behaviour of investors interested in biopharmaceutical companies. On the one hand, outbreaks of dangerous diseases can induce fear and anxiety and thus a negative sentiment that affects the stock prices of biopharmaceutical companies; on the other hand, they can also generate just the opposite sentiment, which is a promising investment opportunity (Donadelli et al., 2017). Both potential reactions translate into a polarization of product portfolios of investors, who, in the face of the emergence of an infectious disease, have to consider the positive or the negative influence of the disease on the stocks of biopharmaceutical companies (Ichev and Marinč, 2018). Donadelli et al. (2017) highlighted the positive and significant effect that disease alerts and news published by the WHO can have on investor sentiment and thus on the stock performance of US companies in the biopharmaceutical sector. As the authors pointed out, portfolio investment decisions in this sector are strongly influenced by investors' mood. During health crises with a major impact on the economy and society, some investors are optimistic, as they find profitable investment opportunities; thus, an event of this nature represents good news for certain interest groups. For example, for larger vaccine producers, outbreaks of infectious and dangerous diseases open up new business opportunities, unlike smaller biopharmaceutical

companies, which are at a disadvantage due to the high costs associated with vaccine development. However, as mentioned, the spread of infectious diseases can also generate anxiety and panic amongst the general public and amongst investors, negatively affecting the performance of biopharma stocks. Despite this, the authors demonstrated that both positive and negative investor sentiment induced by disease-related news can have a more pronounced effect on the stock returns of smaller biopharmaceutical companies than large corporations. The latter is consistent with [Ichev and Marinč \(2018\)](#), who found that during the events of the 2014–2016 Ebola outbreak, market sentiment had a stronger effect on the stock returns of smaller companies with higher volatility. [Sun et al. \(2021\)](#) analysed investor sentiment about medical companies in five markets (China, Hong Kong, Korea, Japan and the US) in the first few months of the spread of COVID-19. The authors concluded that, except for the Chinese market, which was the only region where the virus was known to exist thus far, news related to the coronavirus released by China induced positive investor sentiment in the countries considered. According to these authors, the significant and positive effects of COVID-19-related news and economic-related announcements released by China did not trigger irrational investor behaviours but a ‘rational’ desire to invest in medical companies due to the expected increase in demand for pharmaceutical products, including the development of vaccines.

Continuous overexposure to disease-related information in the media can generate significant changes in the share prices of the biopharmaceutical sector, even if there is a time gap between the fact and the publication of the news. In this sense, in the study performed by [Huberman and Regev \(2001\)](#) on the impact on financial markets of media coverage of a major breakthrough in the development of a cancer drug, the authors observed that the public attention generated by a publication of the scientific advance in the New York Times five months after the event led to a significant rise in the stock price of the company, although the information was not truly new. Interestingly, this reaction in turn had an effect on the share price of other biopharmaceutical companies, in particular biotech stocks that experienced a favourable change in their share price.

The very different possible reactions of investors to events and news, especially to high-impact events, make much more in-depth research necessary on this topic. Considering the context surrounding the evolution of the COVID-19 pandemic, this paper aims to examine whether market sentiment has influenced Pfizer’s and Moderna’s stock returns before and during the outbreak. Therefore, the following hypotheses are proposed:

H4a: Market sentiment influences Pfizer’s returns during the pre-COVID and COVID periods.

H4b: Market sentiment influences Moderna’s returns during the pre-COVID and COVID periods.

3. Data and method

3.1. Data and variables

The database used in the analysis consists of daily returns of Pfizer, Moderna, VIX, NASDAQ and ISEE. It comprises 538 observations from 3rd January 2019 to 12th February 2021. For the analysis, two samples were used: the pre-COVID period (from 3rd January 2019 to 10th March 2020) and the COVID period (from 11th March 2020 to 12th February 2021). The day chosen for breaking the sample was the day the WHO officially declared COVID a pandemic (11th March 2020), so the data from 11th March 2020 were included in the COVID period for the analysis.

The daily returns were calculated following the [Campbell et al., p.11](#)) method:

$$R_{i_t} = \ln(P_{i_t}) - \ln(P_{i_{t-1}}) \quad (1)$$

where P_{i_t} is the close price of stock/index i (Pfizer, Moderna, VIX, NASDAQ and ISEE) at moment t .

The descriptive statistics for the pre-COVID period are presented in [Table 1](#). During this period, Pfizer returns had a negative mean, suggesting that the tendency was bearish. However, Moderna returns exhibited a positive mean. This is indicative of the different behaviour between these two companies in the analysed period. In the COVID period, the mean for these companies is positive, but the standard deviation shows that Moderna has had a higher volatility than Pfizer, again suggesting a different behaviour between them ([Table 2](#)).

3.2. Method

A GARCH (1,1) model ([Bollerslev, 1986](#)) was used to test the returns and volatility behaviour of Pfizer and Moderna:

$$y_t = x_t\beta + \epsilon_t \quad (2)$$

$$\sigma_t^2 = \gamma_0 + \gamma_1 \epsilon_{t-1}^2 + \gamma_2 \epsilon_{t-2}^2 + \dots + \gamma_m \epsilon_{t-m}^2 + \delta_1 \sigma_{t-1}^2 + \delta_2 \sigma_{t-2}^2 + \dots + \delta_k \sigma_{t-k}^2 \quad (3)$$

where y_t is the conditional mean; σ_t^2 is the conditional variance; ϵ_t^2 is the squared residuals; γ_i are the ARCH parameters; and δ_i are the GARCH parameters.

Specifically, the model proposed was:

Mean model:

$$R_{i_t} = \beta_0 + \beta_1 ndq_t + \beta_2 vix_t + \beta_3 isee_t + \epsilon_t \quad (4)$$

Variance model:

$$\sigma_t^i = C_i + \gamma_i \epsilon_{t-1}^2 + \delta_i \sigma_{t-1}^2 \quad (5)$$

where R_{i_t} is the daily returns of i in (4) being i Pfizer or Moderna. σ_t^i is the variance of the residuals derived from [Eq. \(4\)](#); C_i is the constant, $\gamma_i \epsilon_{t-1}^2$ is the ARCH parameter, $\delta_i \sigma_{t-1}^2$ is the GARCH parameter, and β_i is the coefficient of the variables (NASDAQ returns, variation of VIX or ISEE).

Dynamic conditional correlations (DCC-GARCH (1,1)) were used to analyse the dynamic co-movements ([Engle, 2002](#)). To secure the covariance stationarity of the conditional variance, parameters γ_0 , γ_1 and δ_1 should be less than one. In the same way, the sum of γ_1 and δ_1 should be less than or equal to one to maintain stability ([Corbet et al., 2020](#)).

4. Results

[Tables 3 and 4](#) show the correlations between the variables during the pre-COVID ([Table 3](#)) and COVID periods ([Table 4](#)). Moderna exhibits a positive and significant correlation with NASDAQ and ISEE and a negative and significant correlation with VIX during the pre-COVID period. However, during the COVID period, these correlations are not significant. This suggests a change in the behaviour of Moderna returns, which could mean that Moderna investors did not take the market situation and market sentiment into account in making their investments during the COVID period. Comparing Moderna returns with Pfizer returns, once again, a different behaviour appears, especially in the COVID period, where Pfizer returns have a positive and significant correlation with NASDAQ returns and a negative and significant correlation with VIX and ISEE.

The results for GARCH estimation are shown in [Table 5](#) (pre-COVID period) and [Table 6](#) (COVID period). The LM test for ARCH effects in the residuals for all models provides a p value equal to 0.000. Therefore, GARCH (1,1) models are supported.

In the pre-COVID period, the correlation between Pfizer and the NASDAQ index is significantly positive, which means that when NASDAQ increased, Pfizer returns also increased. However, VIX is

Table 1
Descriptive statistics for the pre-COVID period.

	Obs	Mean	Std. dev.	Min	Max	Skewness	Kurtosis
PFE	299	-.0007473	.0133622	-.0663252	.0594234	-.4360004	6.390873
MRNA	299	.0012594	.0461579	-.1980474	.2453797	.5853983	7.581680
NDQ	299	.0009189	.0128322	-.0707054	.0520000	-.7507324	8.648072
VIX	299	.0023796	.0836996	-.1981435	.3821669	1.125844	6.017840
ISEE	299	-.0006554	.2142144	-.5868115	.7017312	-.0242080	3.116712

PFE: Pfizer returns; MRNA: Moderna returns; NDQ: NASDAQ returns; VIX: variation of VIX; ISEE: ISEE returns. Period range: January 3, 2019 – March 10, 2020.

Table 2
Descriptive statistics for the COVID period.

	Obs	Mean	Std. dev.	Min	Max	Skewness	Kurtosis
PFE	238	.0000158	.0221361	-.0805016	.0858171	-.1691605	6.382859
MRNA	238	.0088535	.0567308	-.1786761	.2180603	.2897902	4.318710
NDQ	238	.0021021	.0221400	-.1300316	.0959663	-.8889778	11.06380
VIX	238	-.0036230	.0846518	-.2662277	.4802141	1.807824	10.89668
ISEE	238	.0023575	.2672455	-1.005086	1.079194	-.1690345	4.764586

PFE: Pfizer returns; MRNA: Moderna returns; NDQ: NASDAQ returns; VIX: variation of VIX; ISEE: ISEE returns. Period range: March 11, 2020 – February 12, 2021.

Table 3
Correlations pre-COVID period.

	PFE	MRNA	NDQ	VIX
MRNA	0.2213*			
NDQ	0.4905*	0.2144*		
VIX	-0.4531*	-0.1865*	-0.8122*	
ISEE	0.0880	0.1144*	0.1700*	-0.1704*

PFE: Pfizer returns; MRNA: Moderna returns; NDQ: NASDAQ returns; VIX: variation of VIX; ISEE: ISEE returns. Significance level: *0.1. Period range: January 3, 2019 – March 10, 2020.

Table 4
Correlations COVID period.

	PFE	MRNA	NDQ	VIX
MRNA	0.1302*			
NDQ	0.5475*	-0.0166		
VIX	-0.4634*	0.0101	-0.6676*	
ISEE	-0.1146*	-0.0253	0.0551	-0.0288

PFE: Pfizer returns; MRNA: Moderna returns; NDQ: NASDAQ returns; VIX: variation of VIX; ISEE: ISEE returns. Significance level: *0.1. Period range: March 11, 2020 – February 12, 2021.

Table 5
GARCH estimation results pre-COVID period.

Variables	PFE	MRNA
Mean equation		
NDQ	.2057554** (.005)	.7472199** (.005)
VIX	-.0433238*** (.000)	-.0625397* (.059)
ISEE	-.0014641 (.535)	.0205305* (.053)
Cons	-.0001788 (.714)	.0006702 (.750)
Variance equation		
ARCH	.5918407*** (.000)	.4805702*** (.000)
GARCH	.1514514** (.019)	.1975124** (.041)
Cons	.0000488*** (.000)	.0007873*** (.000)
Log likelihood	935.3257	529.0168

PFE: Pfizer returns; MRNA: Moderna returns; NDQ: NASDAQ returns; VIX: variation of VIX; ISEE: ISEE returns; ARCH: ARCH parameter; GARCH: GARCH parameter; Cons: constant. Significance level: ***0.001, **0.05, *0.1. N: 299. Period range: January 3, 2019 – March 10, 2020.

Table 6
GARCH estimation results COVID period.

Variables	PFE	MRNA
Mean equation		
NDQ	.3367661*** (.000)	.400188* (.083)
VIX	-.0491411** (.005)	.0308231 (.641)
ISEE	-.011166** (.008)	-.0027696 (.816)
Cons	-.0008985 (.410)	.0057009 (.114)
Variance equation		
ARCH	.0672161* (.082)	.240279** (.002)
GARCH	.8161816*** (.000)	.6770661*** (.000)
Cons	.0000357 (.254)	.0003265** (.035)
Log likelihood	622.6255	356.9946

PFE: Pfizer returns; MRNA: Moderna returns; NDQ: NASDAQ returns; VIX: variation of VIX; ISEE: ISEE returns; ARCH: ARCH parameter; GARCH: GARCH parameter; Cons: constant. Significance level: ***0.001, **0.05, *0.1. N: 238. Period range: March 11, 2020 – February 12, 2021.

significantly negative, which suggests that when volatility increased, Pfizer returns decreased and vice versa. Market sentiment in the pre-COVID period is not significant, which means that Pfizer was not influenced by market sentiment. During the COVID period, the results are quite different. NASDAQ and VIX are significant (positively and negatively, respectively) as in the pre-COVID period, but in this case, market sentiment is also significant. This suggests that in this period, Pfizer was more sensitive to what was happening. In fact, the sense of the influence is negative, which means that although the sentiment was negative, the Pfizer's returns increased. Thus, although the market sentiment was negative due to the COVID-19 situation, Pfizer's stock prices were not significantly affected. The reason could be the development process of the vaccine.

Regarding Moderna results, in the pre-COVID period, NASDAQ and market sentiment are significantly positive, suggesting that when the sentiment was positive and NASDAQ increased, Moderna returns also increased. In this period, the VIX is significantly negative, which means that when market volatility increased, Moderna returns decreased. During the COVID period, only NASDAQ is significant. In addition, the coefficient of NASDAQ is significantly lower in the COVID period than in the pre-COVID period, suggesting that Moderna behaved differently in both periods. In sum, investors decided to buy Moderna stocks regardless of the crisis situation, volatility, or sense of market sentiment. The reason for this could be their confidence in the development of an

effective COVID-19 vaccine.

The ARCH coefficient is significant in all models, meaning that the volatility of Pfizer or Moderna in the previous day influenced the volatility of Pfizer or Moderna, which is higher in the pre-COVID period. The GARCH coefficient is also significant, indicating that the market volatility of the previous day influenced the volatility of Pfizer or Moderna, which is higher in the COVID period. It can be concluded that the GARCH (1,1) model is suitable for modelling Pfizer and Moderna volatility. Comparing both companies, the market volatility (GARCH coefficients) had a greater influence on Pfizer's volatility than on Moderna's volatility, suggesting a different reaction of them to market volatility during the COVID period.

Fig. 1 shows the dynamic correlations of Pfizer-NASDAQ and Moderna-NASDAQ. During the COVID period, the dynamic correlations increased considerably compared to the pre-COVID period, showing a clear contagion effect between these variables. This result suggests that the biopharmaceutical companies that developed the vaccine could have had a positive effect on the market, avoiding the downturn derived from the lockdown and the activity stoppage in most economic sectors.

5. Discussion

The aim of this paper was to analyse the stock market behaviour of biopharmaceutical companies during the COVID-19 pandemic in comparison with the pre-crisis period. To this end, two companies that were the first to develop the vaccine using the innovative messenger RNA method, Pfizer and Moderna, were considered. Specifically, the paper has analysed the relationship between the returns of both companies and the technology market index (NASDAQ), market volatility (VIX), and market sentiment (ISEE) during the pre- and COVID periods.

The results obtained indicate that the returns of both companies behaved differently depending on the period considered. Before the COVID-19 period, Pfizer's returns were affected by the technology market and market volatility, while during the COVID-19 period, market sentiment also became relevant, affecting the company's returns. This means that investors saw Pfizer's vaccine project as an incentive to invest in the company despite the negative market sentiment and the high market volatility. On the other hand, Moderna's returns in the pre-COVID-19 period were influenced by the technology market, market sentiment, and market volatility, which changed during the COVID-19 period, as they were only affected by the technology market. These

results indicate that, in view of the development of its vaccine, during the COVID period, the company was conceived by investors as a clear choice for investment, despite market volatility or market sentiment. In addition, Pfizer is a more experienced, larger company with more divisions than Moderna, a smaller and younger company whose core business is the development of the COVID-19 vaccine. This could also be a powerful reason to understand why market sentiment and volatility did not affect Moderna during the COVID-19 period. Therefore, the fact that these companies decided to innovate and react early to the crisis in developing a vaccine leads to a different behaviour between pre- and COVID-19 periods. This corroborates the idea pointed out by Donadelli et al. (2017), according to which investors can react in a positive way by taking advantage of what they consider a promising investment opportunity. As market volatility is shown to have influenced Pfizer and Moderna during the pre-COVID period, Hypothesis 1a is supported. The fact that during the COVID period, market volatility only influenced Pfizer partially confirms Hypothesis 1b. These results are in line with other authors who have found that biopharmaceutical companies are not as affected by health crises as companies belonging to other sectors (Chen et al., 2009; Ichev and Marinč, 2018).

The role of market sentiment during the crisis has also been a relevant variable. If during the pre-COVID period, market sentiment influenced Moderna's returns, during the COVID period, it influenced Pfizer, but in a negative way. This means that before the crisis Moderna was a company sensitive to market sentiment; that is, investors were influenced by sentiment when making their decisions. However, during the COVID period, Moderna's investors ignored the negative sentiment of the market to make their decisions, probably influenced by Moderna's news about the development of the new vaccine. Regarding Pfizer, the opposite occurred; before the crisis, market sentiment was not a variable that influenced investment decisions. However, during the COVID period, this variable became an aspect considered by investors when making their decisions. Thus, the more pessimistic the market sentiment, the more investors saw Pfizer and its vaccine as the best, or one of the best, options to get out of the crisis, driving up the price of its stocks. Donadelli et al. (2017) found that in the face of health crises arising from infectious diseases, the mood of investors is reflected in the stocks of US pharmaceutical companies. These results are in line with those obtained by Sun et al. (2021) that the COVID situation prompted investors to invest in medical companies, partially supporting Hypotheses 4a and 4b.

The volatility of Pfizer and Moderna was also analysed through a

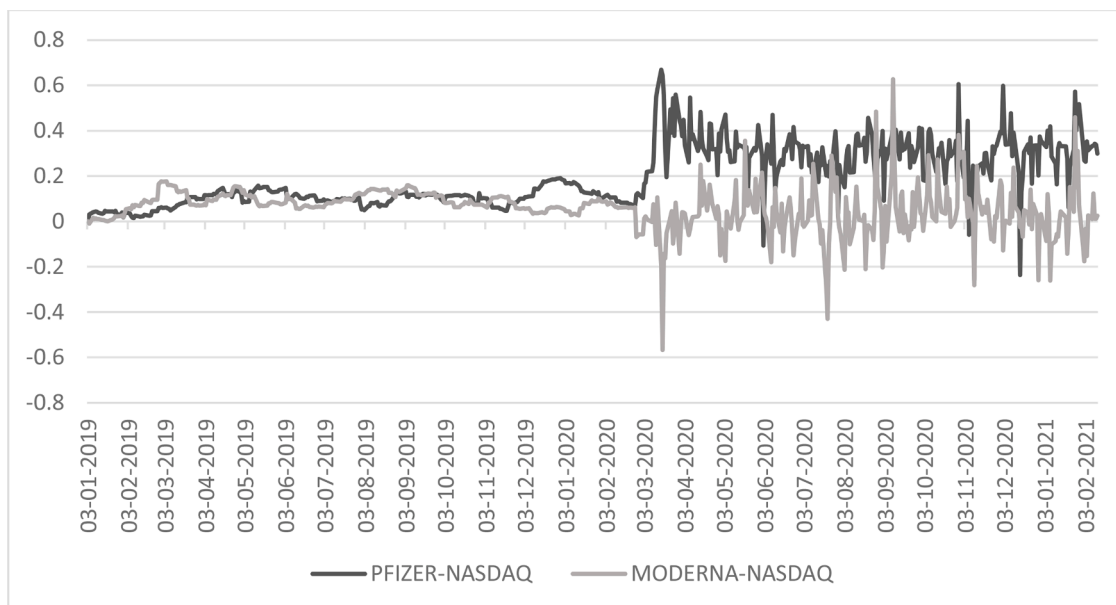


Fig. 1. Dynamic correlations Pfizer-NASDAQ and Moderna-NASDAQ.

GARCH model. The results obtained indicate that the volatility of both companies changed from one period to the next. During the pre-COVID period the influence of the companies' volatilities of the previous day was higher than the influence of the market volatility of the previous day. However, during the COVID period the opposite was true. In line with the study of Baker et al. (2020), this change can be due to the situation of trading and individual mobility restrictions established during the COVID period. Furthermore, it was shown that the influence of market volatility on Pfizer's volatility during the COVID period is greater than the influence on Moderna's volatility, confirming Hypotheses 2a and 2b. Once again, this result highlights that both companies performed differently during the studied period; specifically, Moderna was less affected by market volatility.

These results and the evolution of the stock prices of Pfizer and Moderna and NASDAQ indicate the possibility of the existence of a contagion effect between Pfizer and NASDAQ and between Moderna and NASDAQ. Therefore, an analysis of the dynamic conditional correlations was carried out. The results obtained showed that during the pre-COVID period, there was no co-movement between them. However, during the COVID period, the dynamic correlations increased, demonstrating the existence of a contagion effect between the companies and the technological market index, confirming Hypotheses 3a and 3b. This result means that both companies acted as a kind of "locomotive" for the market, preventing the NASDAQ from dramatic drops and slow recoveries, unlike other market indices.

6. Conclusions and practical implications

According to the 'paradoxical spiral' concept discussed in this article, new scenarios resulting from anthropogenic activities require the action of industries and companies that, based on knowledge, innovation and technological development, are capable of offering new solutions to help mitigate or alleviate the negative impact of disasters on health, the economy and society. In this sense, the biopharmaceutical sector has made an outstanding contribution to the search for effective solutions to the COVID-19 pandemic. Specifically, this study sheds light on the market performance of the American biopharmaceutical vaccine developers Pfizer and Moderna.

The findings of this study have relevant implications for several agents at multiple levels. Despite the unequal influence of volatility and market sentiment on Pfizer and Moderna's returns, as well as the different reactions of their volatility during the pre- and COVID periods, the results highlight the importance of reducing uncertainty and risk in the stock markets. To this end, governments and policy-makers must exercise adequate and accurate control over macroeconomic indicators by formulating policies to soften or avoid extreme volatility situations. Furthermore, policies need to be developed to ensure the stability of relevant sectors, such as those related to water, energy or agriculture, which are key to achieving sustainable development. It is also important to monitor investor sentiment to control potential unjustified panic situations generated by events such as COVID-19. This requires providing investors with accurate and accessible information to help them make decisions according to reality and not assumptions. Above all, the economic, social and environmental policies designed by governments and administrations must prioritize the prevention of such events, establishing effective lines of action to provide a rapid and effective response. The final objective must be the strict observance of the principles capable of guaranteeing sustainable growth. The contagion effect found during the COVID-19 period between Pfizer and Moderna and the NASDAQ-100 index underscores the importance of key technological sectors acting in financial markets to offer solutions to high-impact events beyond traditional safe-haven assets. In this sense, investors must be able to fairly evaluate companies such as Moderna, which have carried out a decided commitment to R&D, innovation and the generation of knowledge to help mitigate the severe effects of the COVID-19 pandemic and other diseases. Investors should consider the existence

of significant differences in the financial performance of companies operating in the biopharmaceutical sector, especially in the face of high-impact events and health care crises. As shown in this study, investors have prioritized investing in biopharmaceutical companies that have innovated during the COVID-19 crisis, rewarding, amongst other things, their initiative. Meanwhile, public agents must work on the design of policies to encourage and facilitate business innovation, the generation of knowledge and the natural transition to a green economy.

In this way, governments, organizations, investors and society must not only try to provide rapid and effective responses to natural disasters and diseases with a strong economic and social impact but also show a strong commitment to avoid and reduce the conditions conducive to the occurrence of these negative events. Organizations must change their business models towards others more responsible and sustainable, and develop and apply technological advances that are environmentally friendly and respectful of natural resources in production and commercialization processes. Policy-makers, investors, and society must support this transition, moving together towards a joint commitment to sustainability as a way to ensure the health and survival of humanity.

As with any empirical study, this research has some limitations. First, the analysis of the COVID period in this study can be considered limited, as it only covers from the development of vaccines up to the approval and the first months of vaccines administration. It would therefore be interesting to analyse how these companies have behaved in the market over time as they have obtained new results on the effectiveness of their vaccines, and new vaccine proposals have appeared from other companies. It would also be interesting to conduct a study analysing the effects of COVID-19-related events on biopharmaceutical companies' returns, considering short periods of time before and after each event. Second, only the two most relevant US companies in the race of the vaccine against COVID-19 were considered. Future research could analyse a larger number of biopharmaceutical companies, considering different countries and markets, to provide a broader view and a better understanding of their behaviour in financial markets. Examples of such companies include Johnson & Johnson, Novavax and AstraZeneca. In addition, future research could address the analysis of sentiment extracted from social networks and their influence on the biopharmaceutical sector over a longer period of time. It would also be interesting to analyse how certain pieces of news extracted from renowned publications, well-known media outlets or international institutions affect the stock price and returns of biopharmaceutical companies. Finally, future research should try to go deeper in the study of the linkages between apparently very different and distant industrial sectors, such as biotechnology and agriculture, energy, or water. In this case, the goal would be to delve into the concept of the 'paradoxical spiral' proposed in this paper and its relevance and implications for achieving sustainable growth.

7. Author Statement

Authors	Individual contribution
Juan Piñeiro-Chousa	Conceptualization, Methodology, Formal Analysis, Investigation, Data curation, Writing-Original draft, Writing-Review & Editing, Supervision
M. Ángeles López-Cabarcos	Conceptualization, Methodology, Formal Analysis, Investigation, Data curation, Writing-Original draft, Writing-Review & Editing, Supervision
Lara Quiñoá-Piñeiro	Conceptualization, Methodology, Formal Analysis, Investigation, Resources, Data curation, Writing-Original draft, Writing-Review & Editing
Ada M. Pérez-Pico	Conceptualization, Methodology, Formal Analysis, Investigation, Resources, Data curation, Writing-Original draft, Writing-Review & Editing

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