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Impact of COVID-19, from the U.S. stock market to the Mexican stock market and its sectoral effects: An analysis via elliptical copulas

Impacto del COVID-19, del mercado accionario de USA hacia el mercado accionario de México y sus efectos sectoriales: un análisis vía cópulas elípticas

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Abstract

The objective of this research is to analyze the degree of contagion in the Mexican stock market and its stock market sectors due to the movements of the U.S.A. stock market prior to (August 2018 to December 2019), and during (January 2020 to August 2021) the crisis caused by the covid pandemic, as well as, before and after the vaccination campaign. Traditional correlation techniques and refined correlation techniques are applied via elliptical copulations. The results are a proof of the sensitivity degree of the U.S.A. stock market towards the Mexican stock market and its incremented sectors through the crisis, although such degree of return to similar levels exhibited in the crisis is highlighted since the vaccination campaign. The originality lies in the refined mechanism of measurement and in the evaluation of the response degree of the vaccination campaign.

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Resumen

El objetivo de esta investigación es analizar el grado de contagio en el mercado accionario mexicano y en sus sectores bursátiles debido a los movimientos del mercado accionario estadounidense, antes (agosto 2018 – diciembre 2019) y durante (enero 2020 – agosto 2021) de la crisis originada por la pandemia covid, así como adicionalmente, antes y después de la campaña de vacunación. Se aplican técnicas de correlación tradicional y técnicas de correlación refinadas vía cópulas elípticas. Los resultados muestran que el grado de sensibilidad del mercado accionario estadounidense hacia el mercado accionario mexicano y sus sectores incrementó durante la crisis, aunque se resalta que a partir de la campaña de vacunación dicho grado regresó a niveles símiles a los exhibidos antes de la crisis. La originalidad recae en el mecanismo refinado de medición y en la evaluación del grado de respuesta de la campaña de vacunación.

Código JEL: G15, D53, C58
Palabras clave: efecto contagio; índices sectoriales invertibles; COVID-19; cópulas

Introduction

The current health crisis associated with the COVID-19 pandemic, in addition to the severe health problems and death rates, has seriously affected international economic activity, leading to a global crisis with particular negative socioeconomic effects for each country. This crisis has mainly manifested itself with high unemployment rates, and severely unbalanced economies in general, with a loss of efficiency and a decrease in the growth of their real and financial sectors. There has been a decrease in both supply and demand, fueled by the perennial presence of the crisis, policies of isolation, and efforts to prevent the contagion of the disease.

One of the most affected sectors has been the financial sector. Its contribution to development by promoting savings and investment has been deeply affected. The performance of financial markets and institutions has been characterized by profound volatility and disconnection from the productive sectors. Moreover, stock markets have become spaces of high speculation, not only diverting large amounts of resources that could be used for investment but also affecting the value of companies and inhibiting their investment projects, as well as raising the prohibitive level of private and public indebtedness.

The crisis began as a health risk. However, it must be recognized that since 2018, global markets had performed erratically and COVID-19 only aggravated these problems, creating a crisis even greater than that of 1929 (Ortiz et al. 2021; Avelé, 2021). Its impacts have been considered catastrophic for markets and the global economy (Chowdhury, 2021). According to official reports, the Chinese government alerted the World Health Organization (WHO) about a new disease being spread in the city

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of Wuhan. In Western countries, such an event was seen as distant and relatively inconsequential. However, on January 7, 2020, it was already recognized globally as a new disease, and a couple of weeks later, on January 21, 2020, the United States registered the first patient with a new coronavirus variant. Almost a month later, Mexico City officially registered a patient zero, a man returning from a trip to Europe to the center of Mexico. Finally, on March 11, 2020, the WHO declared the spread of this disease as a pandemic, recommending that all countries strengthen their health systems and, in general, implement protection and personal hygiene measures for their citizens. Most countries adopted drastic measures to contain the crisis, such as home isolation of citizens and closures of economic activity.

Thus, the set of government policies and the fast and extensive spread of COVID-19 caused nervousness, uncertainty, and greater risk aversion among investors (Shear et al. 2021), causing real collapses in the stock markets that led to the contagion of economic difficulties among countries.

Considering the impacts of the crisis caused by the COVID-19 pandemic, this research aims to make a propositional and exploratory analysis of the contagion effect on the Mexican Stock Exchange and five of its stock market sectors. Due to the changes in the U.S. financial market—represented by the S&P 500 index—and considering the context in which the crisis has unfolded, the result of governmental vaccination policies, and what has been learned from these measures, it is important to point out that the effects of this crisis are not yet over. Concrete proposals are needed for a future based on the steps that the governments of both countries are taking. Contagion and the outcome of vaccination policies are measured by examining correlation patterns using both traditional methodologies and the elliptical copula methodology through four specific periods: pre-crisis (before the pandemic), crisis (after the pandemic), and during the crisis in two periods, one pre-vaccine and one post-vaccine. This is because one of the main contributions of this research to the literature on COVID-19 and its impact on financial markets is the evaluation of the level of sensitivity or response of markets to vaccination campaigns and how this fact has direct repercussions on financial activity.

This paper hypothesizes that the correlation between the U.S. stock market and the Mexican Stock Exchange and its economic sectors has increased due to the COVID-19 crisis. Nonetheless, it is relevant to identify in what proportion this has happened and specifically what has been the increase or decrease in the correlation before and after the vaccination campaigns. This increase in correlation would be a positive symptom of the integration of these markets, particularly considering that Mexico and the United States are member partners of the regional T-MEC Treaty, a trade agreement between Mexico, the United States, and Canada since 2018, which replaces the previous North American Free Trade Agreement (NAFTA). On November 30, 2018, the three nations signed a new agreement to strengthen their integration process. The justification for the analysis of these two markets is based on three aspects: firstly, Mexico is highly dependent in terms of its trade relations on the United States (main trading partner);

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secondly, vaccination campaigns, which are a key element in this research, started in both countries within days of each other; and thirdly, throughout the pandemic, there have been bilateral agreements in both nations on the shipment of millions of vaccines to accelerate vaccination campaigns.

It should be stated that this work is exploratory, given that the effects of the pandemic continue at both the global and local levels. Mexico and many countries have begun to implement massive vaccination campaigns and restart economic activities. Little by little, changes toward economic recovery are occurring. However, getting "back to normal" economically and socially, at least at the pre-crisis economic and social level, will take a few more years.

For the analysis of this phenomenon, the daily closing prices of the Standard & Poor's 500 index, as well as the Prices and Quotations Index (IPC) and the investable sector indices of the Mexican Stock Exchange, Telecommunications, Financial, Consumer, Materials and Industrial, corresponding to the period from August 9, 2018, to August 2, 2021, have been considered. It was decided to analyze the indices mentioned above because the intention is to analyze the level of sensitivity between markets (S&P 500 vs. IPC) and each specific sector in Mexico in relation to the movements of the U.S. market in general. This is because the United States has the main developed capital market, and the purpose is to identify how the evolution of this market impacts the Mexican market and its various sectors. Four relevant stages are defined for the analysis, one prior to the crisis, from August 9, 2018, to December 31, 2019; the second during the crisis period from January 2, 2020, to August 2, 2021; and within the latter, the base has been split into two to measure the effect of the response to the vaccination policies that began on December 14, 2020, in the United States.

The sensitivity of the markets to the COVID-19 phenomenon, the S&P 500 index for the indices already indicated, and the degree of correlation using traditional techniques such as Pearson's correlation coefficient, Kendall's rank correlation coefficient (Kendall's tau), and Spearman's rank correlation coefficient (Spearman's rho) are taken as reflecting variables. The three coefficients are compared with the dependence parameters of the Normal and t-Student copulas and their respective rank correlation implementations via these copulas, further complementing the analysis by estimating the tail dependence of these proposed copulas. The copulas of the elliptical, Normal, and t-Student types have been chosen because, as mentioned above, this is an exploratory analysis of various stock market sectors' sensitivity to the U.S. stock market instability caused by the COVID-19 pandemic for the identification of proposals for improvement in specific sectors.

This paper is structured as follows: after this introduction, there is a review of the literature on the economic effects of COVID-19 and the main models for measuring this phenomenon in different economies. The third section shows the methodology used, the fourth section has the empirical evidence, and finally, the conclusions and recommendations derived from the research are presented.

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Review of the literature

There are several works in the literature on the analysis of the economic impact of COVID-19 on different economic sectors. Bonet et al. (2020) carry out a sectoral and regional analysis of the consequences of the isolation policies implemented by the Colombian government in the face of the COVID-19 crisis. They use an input-output model, highlighting the service sector as the most affected. Prades and Tello (2020) analyze the effect of the Spanish government's social distancing measures and the application of these measures in different Euro Zone countries. They use input-output matrices to analyze the effects of the pandemic on various economic sectors. One of the most relevant elements in this research is the fact that COVID-19 may have a heterogeneous impact depending on the differences in the productive structure and intersectoral connections. Hossain (2021) analyzes the effects of COVID-19 on the collaborative economy (shared accommodation, carpooling, food prepared by locals, etc.) and uses various publications such as news articles, television, YouTube videos, and blog posts as data sources. The findings reveal that, although COVID-19 has affected all sectors globally, it has had especially serious consequences in this collaborative sector of the economy.

In the case of the analysis of the effects of COVID-19 on the Mexican economy, Esquivel (2020) carries out a descriptive analysis of the effects of the pandemic on the different sectors, and offers some considerations on the monetary and fiscal policies of the country in a context of an emerging economy. Provencio (2020) analyzes the Government of Mexico's various economic and fiscal policies in an international context affected by COVID-19 and the economic changes it has given rise to. The National Council for the Evaluation of Social Development Policy (Spanish: Consejo Nacional de Evaluación de la Política de Desarrollo Social, 2020) makes a detailed analysis of the effect of the pandemic on Mexico's economy, pointing out the impact on the most vulnerable groups, as well as the structural weaknesses of the economy in the face of the health crisis, the increase in poverty, and the lack of public policies to serve the middle and low-income population. Likewise, Nájera and Huffman (2020) estimate the variations in poverty during the pandemic period (February to the last quarter of 2020), considering two levels of poverty: poverty and extreme poverty, evaluated based on income level, with information from surveys conducted by the National Institute of Statistics and Geography (Spanish: Instituto Nacional de Estadística y Geografía, INEGI), using Bayesian hierarchical models, and obtaining as results a generalized increase in the levels of poverty and extreme poverty.

Regarding the analysis of the effect of COVID-19 on stock markets, Alqaralleh et al. (2020), who analyzed six stock markets using the GARCH copulas approach, found strong evidence of contagion during the pandemic. Among the indices used for the analysis were the S&P 500 for the United States, the S&P/TSX for Canada, the FTSE100 for the United Kingdom, the Nikkei 225 for Japan, the Hang Seng

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for Hong Kong, and the Shanghai Share Index for China, with the movement of the S&P 500 for the other markets taken as a numeral. Hanif et al. (2021) analyze the correlation and contagion of COVID-19 effects between the S&P 500 (U.S.) and CSI 300 (China Securities Index, China's main stock index) indices, considering the aggregate of the ten component sectors using copula theory and conditional value-at-risk. Their findings show that the energy, finance, and materials sectors exhibit tail independence, while the remaining sectors exhibit tail dependence (in some sectors the upper tail and in others the lower tail, as they analyze several copula families).

Another interesting result is the creation of a linear correlation table among sectors, where the highest correlation is found between the financial and industrial sectors, and the periods of greatest propagation are identified. Benavides et al. (2021) analyze the dependence structure in the behavior of the three main Latin American economies (Argentina, Brazil, and Mexico) using Clayton bivariate copulas. Among their results is the difference between the dependence patterns, suggesting that the Brazilian and Mexican markets are more dependent than the Argentinean one. Lyócsa and Molnár (2020) use an autoregressive model to analyze abnormal Google searches from November 2019 to May 2020 on COVID-19 and its volatility, finding that the autoregressive coefficient was negative throughout the study period and that as market uncertainty and the impact of the virus increased, the magnitude of the autoregressive coefficient also increased.

One of the main contributions of this research to the literature on COVID-19 and its impact on financial markets is that it evaluates the level of sensitivity or response of the markets to vaccination campaigns and how this had direct repercussions on financial activity. It is a fact that the economic-financial environment has changed and may not be the same again for many years to come. For this reason, the measures or strategies used by governments to promote growth and an eventual recovery must be thoroughly evaluated and analyzed to consider their degree of effectiveness, learn from them, and establish a precedent for future eventualities.

Official data from Johns Hopkin University[1] indicate that before the start of the vaccination campaign, the number of deaths in the United States was close to 300 000 and 114 000 in Mexico. Approximately 72 000 000 people had been infected, and 1 600 000 deaths had been recorded worldwide.

Methodology

The methodological justification for this research is based on the importance of measuring the correlation or dependence between economic, financial, and social variables. Furthermore, it must be considered that

[1]Official data were taken from https://coronavirus.jhu.edu/map.html, but it should be noted that there may be divergence with other sources due to estimates and mortality excess.

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traditional techniques assume linearity or certain characteristics of the observations, which are difficult to satisfy in the financial world. This paper proposes the copula theory to measure these phenomena in response to these limitations since traditional techniques would underestimate or overestimate them.

Pearson's correlation coefficient

This coefficient is calculated as the quotient of the covariance of two random variables (X, Y) divided by the product of their standard deviations.

$$\rho = \frac{Covarianza\ (X, Y)}{\sigma_x \sigma_y} \tag{1}$$

Where $-1 \leq \rho \leq 1$. The closer this is to zero would imply the absence of linear correlation; if, on the contrary, it is equal to 1, it reflects a perfect linear relation and if equal to -1, an inverse relation between the variables. The problem with this statistic is that $\rho = 0$ does not necessarily imply independence since there could be some other type of relation between the variables, and this statistic does not capture it.

Kendall's tau rank correlation coefficient (τ)

Kendall's tau (τ) statistic is defined in terms of the concordance of pairs of variables, where these are independent and must be analyzed on ordinal or interval scales.

$$\tau = \frac{number\ of\ condordant\ pairs - number\ of\ discordant\ pairs}{\frac{n(n-1)}{2}} \tag{2}$$

Where n is the number of pairs and $-1 \leq \tau \leq 1$

Spearman's rho (ρ) coefficient of rank correlation

This statistic is based on the same assumptions as Kendall's τ, and allows the calculation of correlation between characteristics of ordinal scale variables. It is calculated as follows.

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$$\rho = 1 - \frac{6\sum_{i=1}^{n}(Rango_{xi} - Rango_{yi})^2}{n(n^2-1)}$$

(3)

Where the resulting rho is between -1 and 1

Copulas

As seen in previous paragraphs, there are several measures of correlation, with certain characteristics and restrictions on the behavior that the observations must have so that their interrelation can be calculated. A considerable limitation is that they only generate a real value between -1 and 1. An alternative way proposed in this research to measure this phenomenon is copula theory. The word copula comes from the Latin "copulare" which means union or connection. The advantage of these models is that they not only generate a numerical value to measure the correlation or dependence but also generate a whole dependence structure, and there are no limitations to the behavior of the variables (marginal distributions) to be analyzed, that is, they may or may not present a linear behavior.

Sklar's theorem (1959) establishes the characteristics for generating a copula function, which allows the union of random variables.

Sklar's theorem

With an n-dimensional distribution function F with continuous marginal distributions $F_1, \ldots, F_n$, there exists a unique n-copula, C: $[0,1]^n \rightarrow [0,1]$, such that:

$$F(X_1, \ldots, X_n) = C\,(F_1(X_1), \ldots F_n(X_n))$$

(4)

Therefore, the copula function "C" unites the marginals to generate a multivariate distribution function.

There are families of copulas, such as elliptical and Archimedean, as well as bivariate and multivariate. This research focuses only on bivariate elliptical copulas as a complement to traditional correlation measures to analyze the sensitivity of response of the different economic sectors in Mexico to the movements of the S&P500 and to the characteristics of the financial series to be analyzed.

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Elliptical copulas

This family of copulas is named after the Normal and t-Student copulas, which are derived from elliptical distributions, are widely used in the financial field due to their characteristics, and analyze relations of symmetrical dependence. They are not advisable for the analysis of extreme events.

Normal copula

The d-dimensional normal copula is generated from a multivariate standard Normal distribution Φ_d, N(0,P), with a P correlation matrix.

$$C(u_1,\ldots,u_d,P) = \Phi_d[\Phi^{-1}(u_1),\ldots,\Phi^{-1}(u_d)] \tag{5}$$

Where P represents the correlation matrix and Φ^{-1} the inverse of the standard univariate normal distribution.

For the bivariate case d=2, with correlation matrix ρ, the density is:

$$C(u_1,u_2,P) = \Phi_2[\Phi^{-1}(u_1),\Phi^{-1}(u_2)] = \frac{1}{\sqrt{det\rho}}\exp\left(-\frac{1}{2}z^t(u)(\rho^{-1}-Id)(z(u)\right) \tag{5.1}$$

$$\text{Con } z^t(u) = \Phi^{-1}(u_1),\Phi^{-1}(u_2) \tag{5.2}$$

This copula is completely determined from knowledge of ρ

t-Student copula

In this copula, the correlation structure is determined by the multivariate t-Student distribution. The copula for the bivariate case, a 2-dimensional t-Student distribution with v degrees of freedom and with correlation matrix ρ, is:

$$C(u_1,u_2) = T_{2,\rho,v}[T_v^{-1}(u_1),T_v^{-1}(u_2)] \tag{6}$$

With t-Student copula density

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$$C(u_1,u_2)=\frac{1}{\sqrt{det\rho}}\frac{\Gamma\left(\frac{v+2}{2}\right)[\Gamma(\frac{v}{2})]^{2-1}}{[\Gamma(\frac{v+1}{2})]^2}\frac{\prod_{k=1}^{n}(1+\frac{zk^2}{v})^{\frac{v+1}{2}}}{(1+\frac{z^t\rho^{-1}z}{v})^{\frac{v+2}{2}}}$$

(6.1)

$$\text{Con } z^t(u)=(T_v^{-1}(u_1),T_v^{-1}(u_2))$$

(6.2)

The determination of the t-Student copula depends on two parameters: the correlation matrix ρ and the degrees of freedom v.

Pseudo-maximum likelihood method

This methodology is taken from Hofert *et al*. (2019) and Bolancé *et al*. (2015). From the marginals F_1, ... F_d., pseudo-observations ($\tilde{U}i_1$,$\tilde{U}i_2$) are generated, and the function to maximize would be:

$$\theta=\sum_{i=1}^{n}\ln(U_{i,n})$$

(7)

It is important to mention that in this parameter estimation method, the likelihood is maximized only partially, on the one hand, the copula and, on the other hand, the marginals. It will be through this method that the parameters will be calculated in this research, due to the practicality of the calculations, unlike the Maximum Likelihood method and other forms of parameter estimation.

Measures of correlation by ranks with copulas

Given the bivariate copula function, the Kendall tau rank correlation coefficient, which is a measure of agreement and can be estimated from the copula, is calculated:

$$\tau=4\int_0^1\int_0^1 C_\theta(u_1,u_2)dC_\theta(u_1,u_2)-1$$

(8)

Likewise, given the bivariate copula function, it is also possible to calculate Spearman's rho rank correlation coefficient, which is also a measure of concordance:

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$$\rho_S = 12 \int_0^1 \int_0^1 u_1, u_2 \, dC_\theta(u_1, u_2) - 3 \tag{9}$$

Table 1 shows Kendall's tau and Spearman's rho for the Normal copula, and the t-Student copula. It is worth mentioning that Kendall's tau and Spearman's rho rank correlation measures can be used similarly for the family of elliptical copulas, so the equation is the same for both.

Table 1
Parameter, Kendall's Tau, and Spearman's Rho for Elliptical Copulas

Copula	Parameter	Kendall's Tau	Spearman's Rho
Normal t-Student	$\theta \in [-1,1]$	$\frac{2}{\pi}\arcsin(\theta)$	$\frac{6}{\pi}\arcsin\left[\frac{\theta}{2}\right]$

Source: created by the authors

Goodness of fit

There are tests to determine which copula best fits the data distribution; among the most commonly used are the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). It is important to mention that depending on the sample size of the data, there may be distortions in the results. For example, as Hofert *et al*. (2019) comment, if the sample size is small, it is common for all copula models to be acceptable, and, on the contrary, when the number of observations is large, all copula families may be rejected. Akaike Information Criterion (AIC)

$$\text{AIC}=-2\ln(\theta) + 2k \tag{10}$$

Where ln, max is the function's logarithm that maximizes the parameter vector, and k is the total number of marginals and parameters of the copula (Hofert *et al*., 2019).

Bayesian Information Criterion (BIC)

This is another goodness-of-fit measure that considers the sample size, unlike AIC.

$$\text{BIC}= -2\log(\theta) + k\log(n) \tag{11}$$

Where $\log(\theta)$ is the function's logarithm that maximizes the parameter vector, n is the sample size, and k, as in AIC, is the number of estimated parameters. In both cases, the selection criterion will be a function of the lowest value yielded by the tests.

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Tail dependence

A relevant statistic within the copulas is that of tail dependence, as it reflects the presence of extreme events; in the case of the elliptical family, this is symmetrical. This dependence is defined as follows: Let (X_1, X_2) be a vector of continuous random variables with marginal distribution functions F and G. And let $u = F(X_1)$, and $v = G(X_2)$.

The upper tail dependence coefficient of (X_1,X_2) is:

$$\lim_{u\to 1} P\{Y_2 > G^{-1}(u) | Y_1 > F^{-1}(u)\} = \lambda_u \tag{12}$$

The upper tail dependence coefficient expressed in terms of a bivariate copula is:

$$\lim_{u\to 1} \frac{1 - 2u + C(u,u)}{1 - u} = \lambda_u \tag{13}$$

The lower tail dependence coefficient of (X_1, X_2) is:

$$\lim_{u\to 0} P\{Y_2 < G^{-1}(u) | Y_1 < F^{-1}(u)\} = \lambda_l \tag{14}$$

The lower tail dependence coefficient expressed in terms of a bivariate copula is:

$$\lim_{u\to 0} \frac{C(u,u)}{u} = \lambda_l \tag{15}$$

Table 2 shows the tail dependence of the proposed elliptical copulas, the Normal copula, and the t-Student copula.

Table 2
Tail dependence

Normal copula	t-Student copula
$\lambda = 2 \lim_{y\to\infty} \Phi\left(\frac{y - \theta y}{\sqrt{1-\theta^2}}\right) = 0$	$\lambda = 2\, t_{\nu+1}\left(-\sqrt{\frac{(\nu+1)(1-\theta)}{1+\theta}}\right)$

Source: created by the authors

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Empirical evidence

The daily closing prices of the Standard & Poor's 500 index and the investable sector indices of the Mexican Stock Exchange, covering the stock market sector in Mexico, were selected from August 9, 2018, to August 02, 2021. From these, the data were homogenized, and the natural logarithm of the returns of these observations was calculated, with the first return on August 10, 2018, and the last on August 2, 2021, with a total of 729 observations. Once the analysis period was determined, the base was segmented. The first pre-crisis interval was from August 10, 2018, to December 31, 2019 (pre-crisis period). The crisis period comprises from January 2, 2020, to August 2, 2021. The third and fourth periods were derived from the latter, considering the period before and after the start of the vaccination campaign in the U.S. and Mexico.

Before the estimation via copulas, descriptive statistics and correlation were calculated using traditional methodologies for the performance of the indices under analysis in the proposed periods. Tables 3 and 4 show the results. From a comparative analysis of Table 3, it can be observed that all the series present a behavior dissimilar to that of the normal distribution, and in most cases, there is negative skewness, so that the use of a methodology to measure the correlation between the series that does not consider these characteristics would underestimate or overestimate the relation between the indices' returns. Having determined the above, the correlation coefficients are first calculated using traditional techniques: Pearson's correlation coefficient, Kendall's rank correlation coefficient, and Spearman's rank correlation coefficient.

Through Table 4, in the pre-crisis stage, it can be noted that the sector that showed the highest correlation with all the statistics regarding the movement of the S&P500 was the materials sector. This includes the branches of chemical products, construction materials, packaging and containers, glass and plastic products, metals and mining, wood and paper products, and the manufacture and marketing of materials (BMV, 2015). On the other hand, the sector with the lowest correlation with Pearson's correlation coefficient was telecommunications; with Kendall's Tau, the industrial sector ($\tau = 0.2064$); with Spearman's rho, the Industrial sector ($\rho = 0.3014$).

Table 3
Descriptive Statistics for the S&P 500, CPI, and Sector Indices

Pre-crisis period (08/10/2018 - 12/31/2019)							
	R_S&P500	R_IPC	R_Telc	R_Finan	R_Cons	R_Mats	R_Inds
Mean	0.0004	-0.0004	-0.0004	-0.0001	-0.0001	-0.0007	0.0001
Median	0.0007	-0.0008	-0.0013	-0.0001	0.0002	-0.0008	0.0004
Std. Deviation	0.0096	0.0102	0.0138	0.0115	0.0084	0.0102	0.0104
Variance	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001

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Kurtosis	3.8406	4.6432	0.7539	7.8487	2.1247	1.8784	2.4992
Skewness	-0.4623	-0.6721	0.1243	-1.0413	-0.193	-0.2346	-0.1595
Rank	0.0835	0.0935	0.0894	0.1223	0.0693	0.077	0.0938
Count	340	340	340	340	340	340	340
Crisis period (01/02/2020 - 08/02/2021)							
	R_S&P500	R_IPC	R_Telc	R_Finan	R_Cons	R_Mats	R_Inds
Mean	0.0008	0.0004	0.0003	0.0002	0.0004	0.0014	0.0003
Median	0.0017	0.0003	-0.0006	0.0002	0.0002	0.0017	0.0012
Std. Deviation	0.0173	0.0138	0.0174	0.0183	0.0110	0.0133	0.0174
Variance	0.0003	0.0002	0.0003	0.0003	0.0001	0.0002	0.0003
Kurtosis	8.7563	2.6156	3.1230	5.7470	2.3264	3.2132	4.0819
Skewness	-0.3599	-0.5091	-0.3369	-1.0721	-0.2863	-0.5345	-0.8058
Rank	0.1896	0.1138	0.1395	0.1601	0.0922	0.1193	0.1443
Count	389	389	389	389	389	389	389
Pre-vaccination crisis period (01/02/2020 - 12/11/2020)							
	R_S&P500	R_IPC	R_Telc	R_Finan	R_Cons	R_Mats	R_Inds
Mean	0.0005	0.0000	-0.0003	-0.0004	0.0003	0.0012	-0.0002
Median	0.0027	-0.0004	-0.0020	0.0001	-0.0001	0.0007	0.0001
Std. Deviation	0.0213	0.0160	0.0202	0.0222	0.0127	0.0155	0.0206
Variance	0.0005	0.0003	0.0004	0.0005	0.0002	0.0002	0.0004
Kurtosis	5.5965	1.8933	2.2419	3.6060	1.6759	2.3296	2.8285
Skewness	-0.2938	-0.4679	-0.3444	-0.9625	-0.2548	-0.5392	-0.7411
Rank	0.1896	0.1138	0.1395	0.1601	0.0922	0.1193	0.1443
Count	233	233	233	233	233	233	233
Post-vaccination crisis period (12/14/2020 - 08/02/2021)							
	R_S&P500	R_IPC	R_Telc	R_Finan	R_Cons	R_Mats	R_Inds
Mean	0.0012	0.0010	0.0011	0.0010	0.0007	0.0017	0.0010
Median	0.0011	0.0009	0.0005	0.0004	0.0007	0.0020	0.0019
Std. Deviation	0.0085	0.0096	0.0120	0.0100	0.0079	0.0090	0.0110
Variance	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Kurtosis	1.6571	0.0286	1.1551	1.0929	0.7990	0.2978	0.2092
Skewness	-0.0529	-0.2114	0.2986	0.1956	-0.2118	0.0531	-0.2480
Rank	0.0557	0.0528	0.0742	0.0629	0.0472	0.0516	0.0611
Count	156	156	156	156	156	156	156

Source: created by the authors

Table 4
Traditional Correlation of S&P 500, CPI, and Sector Indices

Pre-crisis period (08/10/2018- 12/31/2019)			
	Pearson's Rho	Kendall's Tau	Spearman's Rho
R_S&P500 vs R_IPC	0.3673	0.2837	0.4077
R_S&P500 vs R_Telc	0.3050	0.2334	0.3415
R_S&P500 vs R_Finan	0.3298	0.2293	0.3303
R_S&P500 vs R_Cons	0.3073	0.2107	0.3092
R_S&P500 vs R_Mats	0.3885	0.2722	0.3950
R_S&P500 vs R_Inds	0.3148	0.2064	0.3014

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Crisis period (01/02/2020 - 08/02/2021)			
	Pearson's Rho	Kendall's Tau	Spearman's Rho
R_S&P500 vs R_IPC	0.6701	0.3507	0.4917
R_S&P500 vs R_Telc	0.5078	0.2579	0.3713
R_S&P500 vs R_Finan	0.6307	0.3143	0.4431
R_S&P500 vs R_Cons	0.5657	0.2711	0.3902
R_S&P500 vs R_Mats	0.5752	0.3117	0.4400
R_S&P500 vs R_Inds	0.6373	0.3571	0.5033
Pre-vaccination crisis period (01/02/2020 - 12/11/2020)			
	Pearson's Rho	Kendall's Tau	Spearman's Rho
R_S&P500 vs R_IPC	0.7268	0.4304	0.5965
R_S&P500 vs R_Telc	0.5631	0.3334	0.4739
R_S&P500 vs R_Finan	0.6827	0.4026	0.5588
R_S&P500 vs R_Cons	0.6221	0.3603	0.5081
R_S&P500 vs R_Mats	0.6155	0.3610	0.5073
R_S&P500 vs R_Inds	0.6781	0.4131	0.5764
Post-vaccination crisis period (12/14/2020 - 08/02/2021)			
	Pearson's Rho	Kendall's Tau	Spearman's Rho
R_S&P500 vs R_IPC	0.3612	0.1906	0.2694
R_S&P500 vs R_Telc	0.1915	0.1093	0.1684
R_S&P500 vs R_Finan	0.2043	0.1403	0.2074
R_S&P500 vs R_Cons	0.2701	0.0913	0.1326
R_S&P500 vs R_Mats	0.3484	0.2243	0.3164
R_S&P500 vs R_Inds	0.3760	0.2350	0.3422

Source: created by the authors

Table 4 also shows that, from the statistical analysis, there was an increase in the correlation between the pre-crisis period versus the crisis period of all the Mexican stock market sectors with the S&P Index, measured through these coefficients. The sector that showed the highest correspondence or relation during the crisis period is the industrial sector: with a Pearson's coefficient of 0.6372 (pre-crisis 0.31), Kendall's Tau of 0.3570 (pre-crisis 0.2064), and Spearman's rho of 0. 5032 (pre-crisis 0.3014), followed closely by the Financial Sector with Pearson of 0.6307 (pre-crisis 0.3298), Kendall of 0.3142 (pre-crisis 0.2293), and Spearman of 0.4431 (pre-crisis 0.3303). On the other hand, the sector with the least relation during the crisis stage was the telecommunications sector, with a Pearson correlation coefficient of 0.5077 (previous 0.3050), Kendall's Tau of 0.2578 (previous 0.2334), and Spearman's rho of 0.3713 (previous

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0.3415). With respect to the previous period and already in the vaccination period, it can be observed that in all sectors there was a decrease in terms of the traditional techniques for measuring correlation.

It is important to consider that the industrial sector comprises the capital goods, commercial supplies and services, transportation, and construction subsectors (BMV, 2015). This sector showed greater sensitivity to movements in the S&P 500 index returns during the crisis period. It can be deduced that this was due to the isolation policies that caused a closure and decrease in the activities of these market segments, such as airline and maritime services, land transportation, or construction.

After estimating the traditional correlation, the dependence relation (refined correlation) is estimated from the proposed elliptical copulas. It should be emphasized that this estimation via elliptical copulas is a refinement of traditional correlation methodologies, where, apart from the traditional rank parameters, the copulas have tail dependence, which takes into account the relation in the tails of the marginal distributions of the analyzed data. Therefore, when dealing with elliptical copulas, the estimation via tail dependence takes into account extreme symmetrical data.

Table 5 shows that in all cases there was an increase in the correlation between the pre-crisis period and the crisis period, both estimating the changes with the Normal and the t-Student copulas. Again, it is in the industrial sector where there was greater sensitivity to changes in S&P 500 returns. The copula that presented the highest correlation was the Normal (0.5703) with a likelihood of 74.01, and the t-Student of 0.5466, with the highest likelihood (77.24) and a tail dependence of 0.3407—the highest of all the sectors. The sector with the lowest response sensitivity to S&P 500 movements during the crisis period was the Telecommunications sector. It had a dependence parameter of its Normal copula of 0.4433 with a likelihood of 40.89 and in its t-Student of 0.4041, with a higher likelihood of 46.76. Also, in this sector during this period the best fitting copula according to the goodness-of-fit tests is the t-Student.

The results support the hypothesis proposed in this paper. However, it is important to note that the higher correlation between the U.S. and Mexican stock markets cannot be attributed to a deepening of financial integration between these two countries, which have been members of two economic integration agreements since 1994. Although domestic problems accentuated the crisis, the sudden changes in the prices and returns of the U.S. stock market represented by the S&P Index have constituted the exogenous element whose contagion has pushed the changing patterns of the Mexican stock market closer to the behavior patterns of the U.S. market.

Vaccination period

Once the degree of sensitivity of the markets to COVID-19 movements has been identified, an analysis of the effect of the vaccination campaigns in both countries is proposed. For this reason, the crisis period

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is segmented into two stages—before vaccination and after vaccination—in order to evaluate the impact of this strategy by identifying the degree of sensitivity in the Mexican stock market and in the different stock market sectors given the movements in the main U.S. stock market index. For the vaccination stage, December 14, 2020 has been considered as the starting date of this campaign since it was on that day when the first person was vaccinated in the U.S., and days later, this measure was repeated in Mexico. It should be noted that this vaccine provides only partial protection due to the rapid mutation of COVID-19, which has led to the appearance of several variants.

Table 5

Correlation via Elliptical Copulas of S&P 500, CPI, and Sectoral Indices

	S&P500 vs	Copula	Parameter	LogVer.	AIC	BIC	τ Kendall	ρ Spearman	Tail dependence
Pre-crisis period (08/10/2018 - 12/31/2019)	CPI	Normal	0.4183	31.22	-60.44	-56.61	0.2747	0.4024	0
		t-Student	0.4256	32.86	-61.71	-54.05	0.2799	0.4095	0.1887
	Telc	Normal	0.3402	19.88	-37.77	-33.94	0.2210	0.3265	0
		t-Student	0.3454	20.08	-36.16	-28.50	0.2245	0.3315	0.1636
	Finan	Normal	0.3584	22.24	-42.49	-38.66	0.2334	0.3441	0
		t-Student	0.3557	23.76	-43.51	-35.85	0.2315	0.3415	0.1733
	Cons	Normal	0.3300	18.62	-35.25	-31.42	0.2141	0.3166	0
		t-Student	0.3316	19.10	-34.21	-26.55	0.2152	0.3181	0.1645
	Mats	Normal	0.4137	30.45	-58.90	-55.07	0.2715	0.3979	0
		t-Student	0.4159	31.01	-58.03	-50.37	0.2731	0.4001	0.1979
	Inds	Normal	0.3250	18.03	-34.06	-30.23	0.2107	0.3117	0
		t-Student	0.3244	19.23	-34.46	-26.80	0.2103	0.3112	0.1674
	S&P500 vs	Copula	Parameter	LogVer.	AIC	BIC	τ Kendall	ρ Spearman	Tail dependence
Crisis period (01/02/2020 - 08/02/2021)	CPI	Normal	0.5836	78.41	-154.82	-150.86	0.3967	0.5655	0
		t-Student	0.5180	86.58	-169.16	-161.23	0.3466	0.5004	0.3659
	Telc	Normal	0.4433	40.89	-79.78	-75.81	0.2924	0.4269	0
		t-Student	0.4041	46.76	-89.52	-81.59	0.2648	0.3886	0.2575
	Finan	Normal	0.5277	61.26	-120.52	-116.56	0.3539	0.5100	0
		t-Student	0.4757	68.18	-132.36	-124.43	0.3156	0.4587	0.3360
	Cons	Normal	0.4836	49.87	-97.75	-93.78	0.3213	0.4664	0
		t-Student	0.4123	60.10	-116.19	-108.26	0.2705	0.3966	0.2919
	Mats	Normal	0.5212	59.48	-116.95	-112.99	0.3490	0.5035	0
		t-Student	0.4688	67.26	-130.51	-122.58	0.3106	0.4519	0.2980
	Inds	Normal	0.5703	74.01	-146.03	-142.07	0.3863	0.5523	0
		t-Student	0.5466	77.24	-150.47	-142.55	0.3682	0.5287	0.3408
	S&P500 vs	Copula	Parameter	LogVer.	AIC	BIC	τ Kendall	ρ Spearman	Tail dependence
Pre-vaccination crisis period (01/02/2020 - 12/11/2020)	CPI	Normal	0.6760	68.23	-134.46	-131.01	0.4726	0.6585	0
		t-Student	0.6517	69.31	-134.62	-127.71	0.4519	0.6339	0.4145
	Telc	Normal	0.5352	37.25	-72.50	-69.05	0.3595	0.5174	0
		t-Student	0.5125	41.52	-79.05	-72.14	0.3426	0.4949	0.2903
	Finan	Normal	0.6322	56.81	-111.61	-108.16	0.4357	0.6142	0
		t-Student	0.6118	58.78	-113.55	-106.65	0.4191	0.5937	0.3762
	Cons	Normal	0.5816	45.76	-89.52	-86.07	0.3951	0.5635	0
		t-Student	0.5486	50.44	-96.89	-89.99	0.3697	0.5307	0.3298
	Mats	Normal	0.5862	46.69	-91.37	-87.92	0.3988	0.5681	0
		t-Student	0.5628	48.04	-92.09	-85.18	0.3806	0.5448	0.3251
	Inds	Normal	0.6367	57.90	-113.79	-110.34	0.4394	0.6188	0
		t-Student	0.6223	59.48	-114.96	-108.06	0.4276	0.6043	0.3724
	S&P500 vs	Copula	Parameter	LogVer.	AIC	BIC	τ Kendall	ρ Spearman	Tail dependence
Post-vaccination crisis period (12/14/2020 -08/02/2021)	CPI	Normal	0.3327	8.30	-14.60	-11.55	0.2159	0.3192	0
		t-Student	0.2973	12.63	-21.25	-15.15	0.1922	0.2850	0.1861
	Telc	Normal	0.1982	2.80	-3.61	-0.56	0.1270	0.1896	0
		t-Student	0.1946	2.68	-1.37	4.73	0.1247	0.1861	0.1248
	Finan	Normal	0.2234	3.59	-5.17	-2.13	0.1434	0.2138	0
		t-Student	0.2227	3.49	-2.97	3.13	0.1430	0.2131	0.1288
	Cons	Normal	0.2149	3.31	-4.62	-1.57	0.1379	0.2056	0
		t-Student	0.1446	6.30	-8.59	-2.49	0.0924	0.1382	0.1508
	Mats	Normal	0.3583	9.75	-17.49	-14.44	0.2333	0.3440	0
		t-Student	0.3439	12.19	-20.38	-14.28	0.2235	0.3300	0.1808
	Inds	Normal	0.3801	11.10	-20.19	-17.14	0.2482	0.3652	0
		t-Student	0.3791	11.05	-18.10	-12.01	0.2475	0.3642	0.1925

Source: created by the authors

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A general decrease in the level of post-vaccination sensitivity in all sectors is demonstrated by the degree of correlation before and after the start of the vaccination campaign shown in Table 4 (traditional correlation) and Table 5 (correlation via elliptical copulas). A detailed analysis of both stages shows that the sectors with the greatest sensitivity to the vaccination campaigns were the financial and consumer sectors, when the traditional correlation, the parameters of the copulas, and the correlation by ranks via copula, Kendall's τ, and Spearman's ρ are compared.

To highlight the results obtained in Table 5 concerning the correlation via the proposed copulas, the following table shows the sensitivity seen as the difference between the correlation values obtained from one period versus another (pre-vaccination and post-vaccination periods). The importance of analyzing the pre- and post-vaccination stages lies in recognizing that in all sectors there were significant changes depending on the activities of each sector. The empirical evidence of these changes can be seen in Table 6, where the decrease in tail dependence demonstrates the infrequent occurrence of extreme events. Regarding tail dependence, the financial sector had the highest degree of sensitivity, with a difference between both periods of -0.2473. Conversely, the material sector of the vaccination campaigns had the smallest difference in terms of extreme events in the tails, with -0.1442764.

Table 6
Differences between pre-vaccination and post-vaccination parameters

S&P500 vs	Copula	Parameters	τ Kendall	ρ Spearman	Tail dependence
CPI	Normal	-0.3433	-0.2567	-0.3393	0
	t-Student	-0.3544	-0.2597	-0.3489	-0.2283847
Telc	Normal	-0.3370	-0.2325	-0.3278	0
	t-Student	-0.3179	-0.2179	-0.3088	-0.1654306
Finan	Normal	-0.4088	-0.2923	-0.4004	0
	t-Student	-0.3891	-0.2761	-0.3806	-0.2473634
Cons	Normal	-0.3667	-0.2572	-0.3579	0
	t-Student	-0.4040	-0.2773	-0.3925	-0.1789419
Mats	Normal	-0.2279	-0.1655	-0.2241	0
	t-Student	-0.2189	-0.1571	-0.2148	-0.1442764
Inds	Normal	-0.2566	-0.1912	-0.2536	0
	t-Student	-0.2432	-0.1801	-0.2401	-0.179895

Source: created by the authors

It can be observed that the correlation values before the crisis, either via the traditional correlation or the correlation via elliptical copulas, are similar to those obtained in the post-vaccine period.

Nevertheless, it should be emphasized that this crisis is not over, and contagion continues worldwide, which leads many governments to restrict certain economic activities.

It is important to highlight that this analysis is based on several measures of dependency to make a comparative study from different perspectives and to verify the Mexican market's degree of sensitivity to the movements of the U.S. stock market. It should also be mentioned that if this phenomenon had been studied through traditional techniques, there would have been an underestimation of this susceptibility to S&P 500 movements due to COVID-19.

The research shows that the Mexican financial market is extremely sensitive to stock market movements in the United States, particularly during periods of instability and financial crisis. Nonetheless, this crisis has exposed serious structural problems in Mexico and most of Latin America. Montenegro (2020) distinguishes Latin America as one of the regions most affected by the COVID-19 health crisis, mainly due to the financial fragility of its economies. Still, the critical situation due to inequality and social problems allows governments and companies to reevaluate their trade policies in a context of economic openness and social responsibility. It is also important for entrepreneurs to consider the possibilities of doing business inside and outside the country since it will take a long time to return to a normal level in the international sphere.

In the social context, the asymmetry of the effects is evident. Since the beginning of the pandemic, the least privileged social classes have been the most affected. Cota (2020) shows this by analyzing the decrease in economic activity in Mexico in the short term through time series models, mainly of the economically active population, and a possible recovery in the first quarter of 2021. Jiménez-Bandala, *et al*. (2020) find that labor informality is a determining factor in the increase in COVID-19 infections. In addition, millions of jobs have been lost, salaries have been affected, and the need for formal sector workers who have migrated to other sources of income has increased.

Conclusions

The motivation and relevance of this research lie in four aspects. First, it identifies the changing correlation between the U.S. stock market and the Mexican Stock Exchange in an exploratory and propositional study of an economic and financial nature. The COVID-19 health crisis produced severe downturns and volatility in global financial markets, particularly in developed country markets. This impact was transmitted to emerging markets. In the case of these two North American regions, the correlation increased, reflecting significant changes throughout the study periods. Moreover, it increased in all Mexican stock market sectors, but the industrial sector was the most affected during the study period. In financial terms, investment strategies incorporating international diversification and assets with lower volatility or less sensitivity to U.S. market movements are suggested.

Second, the relevance of this research is to propose and apply a methodology that differs from traditional correlation measurement techniques since when they are used, there is a risk of underestimating or overestimating the degree of interrelation between markets.

Third, some recommendations to gradually strengthen the domestic market are proposed once the most affected sector has been identified. However, it is important to emphasize that there must be permanent monitoring of the results and their complete economic adaptability. Depending on the results, these recommendations can be continued or changed. The pandemic has exposed all the problems that have existed in Mexico and Latin America for decades with respect to financial fragility and social and economic imbalances. Governments and companies must therefore implement a change of paradigm. The domestic market, international trade, and public policies for job creation must be strengthened, as well as incentives for acquiring mortgage loans, which would stimulate construction, an important part of the industrial sector. These measures must be analyzed and applied fully, avoiding contradictions that could hinder development. Key aspects are interest rates and fiscal stimuli for all sectors. Although the industrial sector presented significant changes throughout the analysis, this crisis affected every economic activity. Household savings and investment by the business sector should be encouraged. An essential issue in the recovery is to identify the aspects on which public finances should be focused, given the economic and social context, to stimulate economic stability and growth. Similarly, it is suggested to continue research on the problems of the post-COVID-19 recovery to determine the differentiated support patterns for the different economic and social sectors.

Fourth, as mentioned throughout this article, one of the contributions of the present study to the literature on COVID-19 and its implications for financial markets is the assessment of the degree of sensitivity or responsiveness of the markets to vaccination campaigns and the direct impact on the stock markets. The economic-financial environment has changed and may not be the same again for several years. For this reason, the measures or strategies used by governments to promote growth and an eventual recovery must be thoroughly evaluated and analyzed to consider their level of effectiveness, learn from them, and establish a precedent for future eventualities. The importance of analyzing the pre-vaccination and post-vaccination stages lies in the fact that, in general, there were significant changes in all sectors, depending on their specific activities. Empirical evidence of these changes can be observed in the decrease in tail dependence, which represents the presence of extreme events, and is indicated in the pre- and post-vaccination stages. Some remedial measures have been proposed for gradual economic improvement based on the experiences gained from this extraordinary event. However, it should be noted that this crisis is not yet over, and the number of infections and deaths remains high both globally and locally.

In future research, an analysis of extreme events will be carried out, including other copula families. It is also necessary to develop lines of research of a regional nature, both internal, considering subnational entities, and external, such as those collaboration and integration schemes among various countries, as is the case of several areas of Latin America. As already stated in this article, it is important to emphasize that this was an exploratory work to measure the degree of sensitivity of the U.S. and Mexican markets to the pandemic and the vaccination campaigns. Further research will measure the impact on sectoral indices in the U.S. and Mexico.

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