Economics Bulletin

Volume 45, Issue 1

A wavelet coherence approach to analyze contagion between equity markets during three major crises

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Abstract

Financial crises and their contagion are a major area of financial market research. Our study makes a twofold contribution. Not only does it analyze the interdependence between markets in countries that are source of contagion and those suffering from it, but it innovates by focusing on three recent crises, namely the 2008 global financial crisis (GFC), the Covid-19 and the Russian-Ukrainian War. To this end we use the wavelet coherence method on a sample of G7 country indices plus the Chinese Shanghai Stock Exchange and the Russian Moscow Exchange indices. The results indicate the presence of contagion from the US market to other financial markets, and significant co-movements between stock market indices during the GFC. As regard the Covid-19 crisis, we find that contagion effects are less noticeable, making us unable to identify leader and follower markets. During the Russian-Ukrainian War, the Russian market shows a lower degree of interdependence with other financial markets, and that there is no real contagion from this market to the G7 or Chinese markets.

Citation: Montassar Riahi and Sophie Nivoix and Olfa Belhassine, (2025) "A wavelet coherence approach to analyze contagion between equity markets during three major crises", *Economics Bulletin*, Volume 45, Issue 1, pages 139-149
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Submitted: October 30, 2024. **Published:** March 30, 2025.

1. Introduction

In recent years, the world economy and finance have been more and more integrated. Indeed, the markets become interconnected, risks on the financial markets may spread wider due to a contagion effect (Lin et al., 2023). It is therefore essential to understand the interdependence between financial markets, and the contagion effects to help investors manage risks and optimize their portfolios in times of crisis. Several major events of the 21st century, such as the global financial crisis GFC, the sovereign debt crisis, the Brexit agreement, the Covid-19 pandemic, the Russian-Ukrainian War and the recent Israeli-Palestinian conflict, have highlighted the concept of contagion, encouraging academic researchers to study the contagion effect during these events. Several researchers have studied the contagion effect between different markets during a single crisis. Zorgati et al. (2019) used the copula approach to study financial contagion and its intensity between five American and nine Asian countries during the GFC. The results revealed the existence of the contagion phenomenon for all American countries as well as for five Asian countries, namely India, Australia, Indonesia, Malaysia, China and Singapore. Hassan et al. (2020) applied several contagion tests to determine whether Islamic equities are immune to the GFC. They found a strong evidence of contagion effects of the financial crisis on Islamic stock indices. Nguyen et al. (2021) investigated the presence of financial contagion and the effects of US and Chinese equity markets on international stock markets, in particular on BRICS and G7 markets, during the Covid-19 crisis. The results confirmed the existence of significant contagion effects of the Chinese and US stock markets on the majority of the markets studied. Using the wavelet approach, Karamti and Belhassine (2022) showed that there were contagion effects between the Covid-19 epidemic and different financial assets (Bitcoin, Ethereum, gold, WTI oil, SP500, CAC40, FTSE, DAX, NIKKEI and SSE). Benkraiem et al. (2022) used a copula approach on daily stock market indices for ten Asian countries and four American countries. The findings indicated the presence of financial contagion for all American and Asian countries. The results also showed that the contagion phenomenon is more intense in the Americas than in Asia. Liu et al. (2022) applied the connectedness approaches of Diebold and Yilmaz (2012) and Baruník and Křehlík (2018) to examine the risk contagion between sixteen international stock markets during the Covid-19 pandemic. Their results indicated that the Covid-19 crisis amplified risk contagion on stock markets significantly and the risk transfers between European and US stock markets increased rapidly, in contrast to the Asian markets. Other researchers analyzed the contagion effect during several crises simultaneously (Caporin et al., 2021; Ben Amar et al., 2023; Atasoy and Özkan, 2024). For exemple, Nguyen et al. (2022) discussed the question of financial contagion between the US, Chinese, Japanese and Asian stock markets during the GFC and the Covid-19 epidemic. Their study revealed the presence of contagion effects between the US stock market, advanced and emerging markets during the GFC. However, during the Covid-19 epidemic, the contagion effects from the US markets appeared only in four Asian markets (Japan, China, Thailand, Pakistan). Boroumand and Porcher (2023) used the wavelet approach to analyze the risk contagion between WTI crude oil prices and numerous commodity markets, and studied the correlation sign, speed, intensity and causality of contagion between these markets during oil shocks and crisis periods. The authors found evidence of contagion from WTI crude oil to other commodities. They measured the intensity of volatility contagion and demonstrated that it could limit the risk mitigation benefits of portfolio diversification. The results also showed that the speed, duration and intensity of contagion differed according to macroeconomic factors.

Our article aims to investigate the contagion effect during three major crises between countries that are sources of crises and other stock markets in developed countries at different time scales. It contributes to the existing literature in two ways. First, we analyzed the contagion effect during three major crises of this 20th century, including the GFC, the Covid-19 crisis, and the Russian-Ukrainian War). Second, to our knowledge, this is the first study that analyzes the contagion effects between stock markets of countries that are sources of crises (SP500, Shanghai Stock Exchange (SSE) and Moscow Exchange (MOEX)) and other stock markets (France, Germany, United Kingdom, Italy, Japan and Canada) in the time-frequency domain.

We use wavelet coherence on daily returns of G7 stock indices (SP500, CAC40, DAX, FTSE100, FTSEMIB, NIKKEI225, SP-TSX), the Chinese Shanghai Stock Exchange (SSE) and the Russian Moscow Exchange (MOEX). The sample period runs from January 2000 to January 17, 2024. During the GFC, we find a significant co-movement between the US market and other financial markets, with the presence of contagion. As regard the Covid-19 crisis, we note that the contagion effects are less marked. During the Russian-Ukrainian War, we can see that the Russian market is not source of contagion to the G7 or Chinese markets.

Our results are useful for investors and policymakers, helping them to optimize their portfolio management and propose appropriate policies (Gkillas et al., 2019; Li et al., 2021; Wang et al., 2021). They also provide insight into diversification and its limits, and its consequences for the internationalization of investments. More generally, it is relevant to use this knowledge to extract abnormal returns, in the context of market efficiency. If markets are really efficient, contagion should either be instantaneous (i.e., investors can't extract abnormal returns), or not very prevalent, as each market is determined by its own domestic characteristics. Understanding and measuring contagion allows us to better situate the markets between these two situations, which generally leads to some level of stability after occasional market adjustments.

The remainder of this article is organized as follows. Section 2 presents the methodology used. section 3 describes the data. Section 4 presents and discusses the results. Finally, Section 5 concludes.

2. Methodology

We use the wavelet coherence method, which is interesting for several reasons. Firstly, the Normal distribution of the time series is not necessary. Secondly, the time series can be smoothed to ensure stationarity. Thirdly, this method is able to detect non-linear relationships. The advantage of using the wavelet coherence method over standard time series models lies in the ability to detect the co-movement of pairs of time series in frequency and time simultaneously. The wavelet coherence technique uses a bivariate framework based on a continuous wavelet transform (CWT) (Goodell and Goutte, 2021).

The CWT of a function x(t) at a scale $a \in \mathbb{R}^{*+}$and translational value $b \in \mathbb{R}$ is expressed by the following integral:

$$\boldsymbol{X_w\,(a,b) = \frac{1}{|a|^{1/2}} \int_{-\infty}^{+\infty} x(t)\,\bar{\psi}\left(\frac{t-b}{a}\right) dt} \tag{1}$$

where $\psi(t)$ is a continuous function in both the time and frequency domains, called mother wavelet. Torrence and Compo's (1998) approach uses cross-wavelet transforms (XWT) to define two time series, x(t) and y(t), as follows:

$$\boldsymbol{W_{x,y}(u,s) = W_x(u,s)W_y^*(u,s)} \tag{2}$$

u indicates position index, *s* is the scale, $W_x(u,s)$ and $W_y^*(u,s)$ represent the continuous wavelet transform of two time series *x(t)* and *y(t),* and * is the complex conjugate of the continuous wavelet transform of the time series *y(t)* on the same scale *s* and with the same time lag *u*. The XWT is able to capture the local covariance between two time series at each scale. In fact, the cross-wavelet is expressed in relation to a reference signal used as a time base, and which displays the same periodicities as the signal studied.

According to Torrence and Webster (1999), the coherence of the squared wavelet is presented as follows :

$$\boldsymbol{R^2(u,s) = \frac{\left|S(s^{-1}w_{x,y}(u,s))\right|^2}{S(s^{-1}|w_x(u,s)|^2)S(s^{-1}\left|w_y(u,s)\right|^2)}} \tag{3}$$

Where *S* is the time series and scale smoothing coefficient. Wavelet squared coherence (WSC) values denoted by $\boldsymbol{R^2}$ are positive and lie between 0 and 1. Significant (non-significant) co-movement between the two time series occurs when $\boldsymbol{R^2}$ is high (low).

However, the $\boldsymbol{R^2}$ has the disadvantage of being limited to positive values, and therefore fails to capture negative co-movements of two time series. To overcome this problem, Torrence and Compo (1998) proposed the phase difference, calculated as follows:

$$\boldsymbol{\emptyset_{x,y}(u,s) = \tan^{-1}\left(\frac{\mathrm{Im}\{S(s^{-1}w^{xy}(u,s))\}}{\mathrm{Re}\{S(s^{-1}w^{xy}(u,s))\}}\right)} \tag{4}$$

Where *lm* and *Re* are the imaginary and real operators respectively.

3. Data

In this study, we used the stock indices of the G7 countries (SP500, CAC40, DAX, FTSE100, FTSEMIB, NIKKEI225, SP-TSX), the Chinese Shanghai Stock Exchange (SSE) and the Russian Moscow Exchange (MOEX) as it is preferred by domestic investors. All daily data series are sourced from Investing.com. The sample period extends from January 2000 to January 17, 2024. This timeframe allows us to study the contagion effect between markets during periods of different crisis, namely the GFC, the Covid-19 pandemic and the Russian-Ukrainian War) between different international stock market indices. Asset prices are converted into daily returns as follows: Ln $(P_{it}/P_{it-1}) \times 100$, where P_t is the daily closing price.

Table I: Descriptive statistics and Spearman correlation

Variables	**SP500**	**CAC40**	**DAX**	**FTSE100**	**FTSEMIB**	**MOEX**	**SP-TSX**	**SSE**	**NIKKEI225**
Mean	0.0002	0.00004	0.0002	0.00002	-0.00005	0.0005	0.0002	0.0001	0.0001
Minimum	-0.128	-0.131	-0.131	-0.115	-0.892	-0.405	-0.132	-0.093	-0.121
Maximum	0.110	0.106	0.108	0.094	0.899	0.252	0.113	0.094	0.132
Std. Dev.	0.012	0.014	0.015	0.012	0.022	0.020	0.011	0.015	0.015
Skewness	-0.370	-0.206	-0.171	-0.319	0.053	-1.533	-0.901	-0.330	-0.378
Kurtosis	13.218	9.375	9.059	10.888	856.679	44.965	19.681	8.372	9.211
Jarque-Bera	261284.69***	10183.07***	9124.665***	15486.23***	181000000***	434203.5***	69418.47***	7008.854***	9282.236***
ADF Test	-85.850***	-79.184***	-78.235***	-34.383***	-67.394***	-75.985***	-80.107***	-74.254***	-77.887***
Observations[1]	5988	5988	5947	5934	5960	5886	5918	5743	5690
SP500	1.0000								
CAC40	0.5264	1.0000							
DAX	-0.0160	0.0123	1.0000						
FTSE100	0.0249	0.0293	0.0063	1.0000					
FTSEMIB	0.0519	0.0589	0.0608	-0.0084	1.0000				
MOEX	0.0150	-0.0087	-0.0047	-0.0075	-0.0069	1.0000			
SP-TSX	0.0356	0.0224	0.0224	0.0289	0.0356	0.0069	1.0000		
SSE	0.0219	0.0048	0.0048	-0.0031	0.0192	0.0049	0.0067	1.0000	
NIKKEI225	-0.0109	-0.0008	-0.0008	0.0184	-0.0090	-0.0087	0.0013	0.0128	1.0000

Notes: Std. Dev indicates standard deviation, ADF indicates Augmented Dickey-Fuller unit root test, * denotes significance at 1% level.**

[1] We synchronized the stock market indices with each other. As a result, the final sample size differs from one market to another. It ranges from 5690 observations for Japan to 5988 observations for the USA and France.

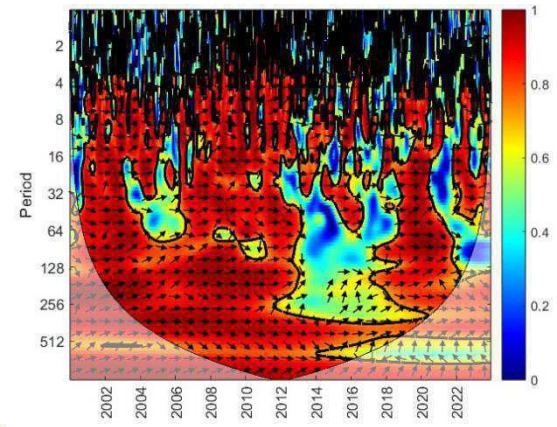
Table 1 shows the descriptive statistics for the G7, Chinese and Russian stock markets. All stock market indices show positive average returns, except for the Italian stock market. The highest and lowest average returns over the sample period were recorded for the Italian stock market. The dispersion of statistical series values from their mean, measured by the standard deviation of daily returns, is lowest for the Canadian stock market, but highest for the Italian stock market. The Jarque-Bera test statistic rejects the normality hypothesis for all return series which is a common result in stock markets. The results of the ADF test reject the null hypothesis of a unit root at the 1% significance level. We therefore conclude that all return series are stationary.

We notice that instantaneous correlations are quite low between markets, even between neighboring countries or major economic partners (France-Germany or USA-Canada, for example). The contagion analysis makes sense here too, as it allows us to finely inspect temporal lags in correlations and detect the markets that initiate trends.

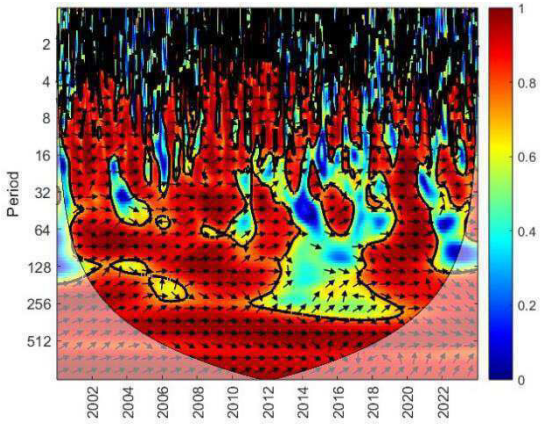
4. Empirical results

In the following figures (1 to 3), the black arrows symbolize the phase difference. When the arrows point to the right (left), this indicates that the two time series are positively correlated (negatively correlated) and therefore in phase (antiphase). We can therefore determine whether the two variables are moving in the same or opposite direction. Arrows up right (↗) or down left (↙) mean that the first time series leads the second. Arrows down right (↘) or up left (↖) mean that the second series leads the first. The absence of arrows means that the correlation is low or non-existent and therefore there is no phase difference. A blue color indicates a weak coherence, whereas an orange or red color indicates a strong coherence.

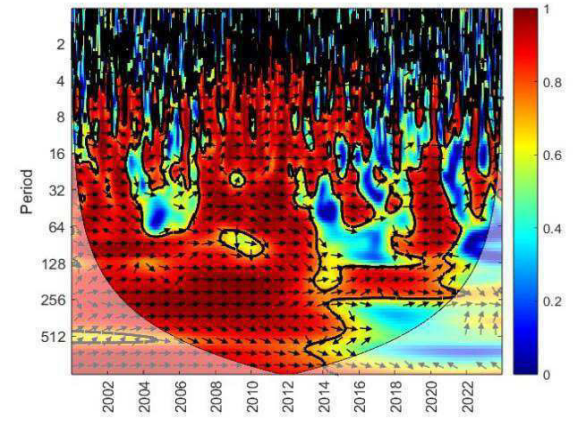
Figures 1, 2 and 3 show the results for the coherence and phase between the SP500, SSE, MOEX and G7 countries, excluding the US market, since the US market was the source of the GFC.



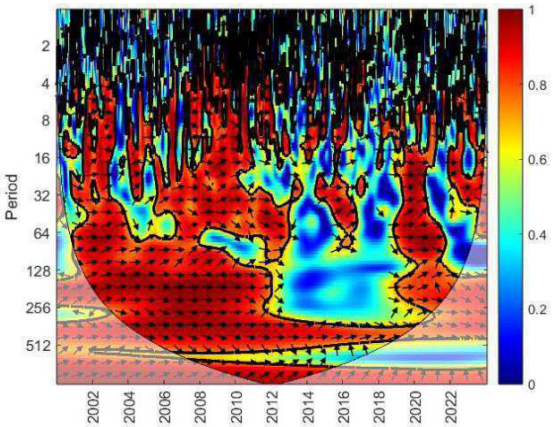
1.a. CAC40 & SP500



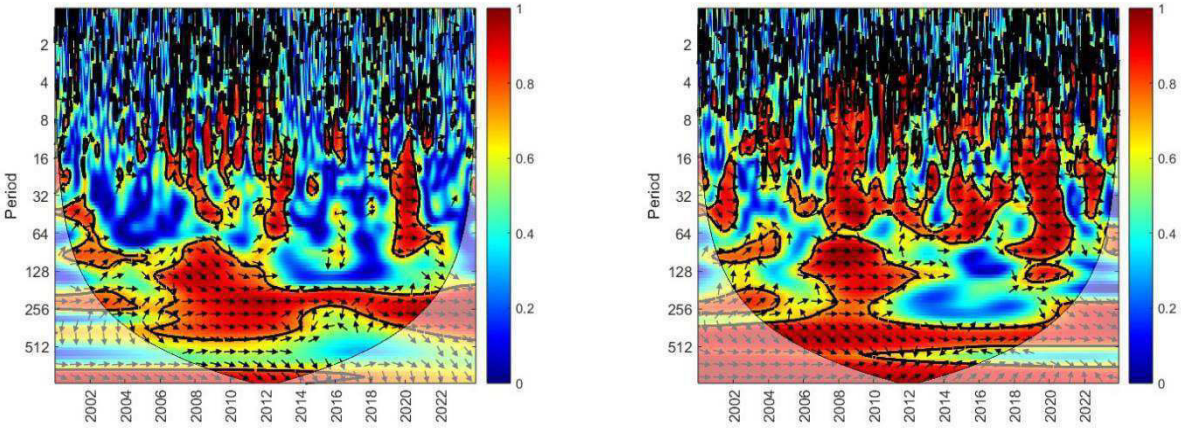
1.b. DAX & SP500



1.c. FTSE100 & SP500

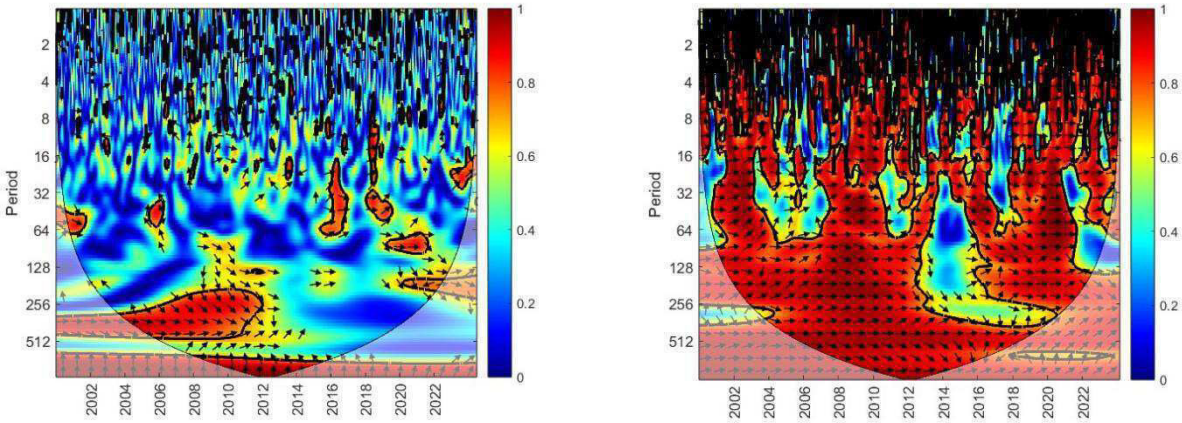


1.d. FTSEMIB & SP500



1.e. MOEX & SP500

1.f. NIKKEI225 & SP500



1.g. SSE & SP500

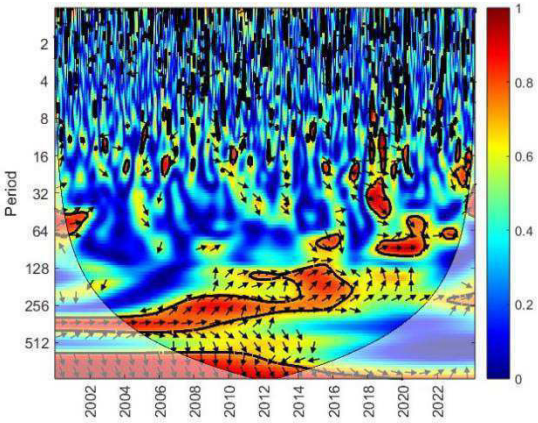
1.h. SP-TSX & SP500

Figure 1: Wavelet coherence and phase for the SP500 and other stock market indices

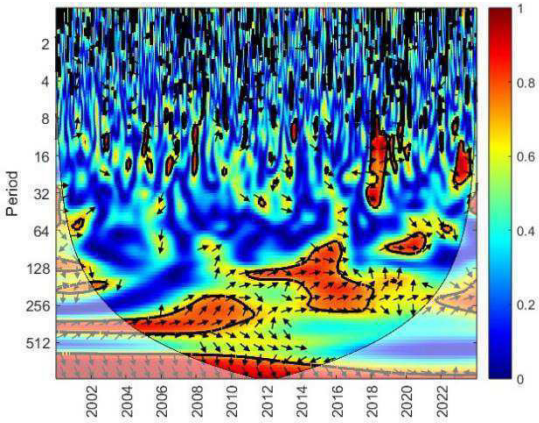
Figure 1 shows the wavelet coherence between the US market and the other G7 countries plus Russia and China. We observe a strong coherency between the SP500 and the other stock markets during the three crises studied. During the GFC, we observe positive co-movements between the SP500 and the G7 stock market indices over all the frequency bands, the Russian and to a low extent the Chinese markets, show positive co-movements with the US stock market mainly in the long term. This indicates the existence of contagion effects in all investment horizons between the US and the G7 country stock markets and especially in the long run for the Russian market and the Chinese stock market. As far as the phase differences are concerned, the overall results show that the US market moves in phase with all the G7 and the Russian stock markets, while it leads the Chinese stock market. This can be explained by the fact that the US market was at the origin of the GFC, and by the persistent financial influence of the US market on the world economy, despite China's economic rise. Our results for the US market confirm the findings of (Dungey and Gajurel, 2014; Wang et al., 2017), who found evidence of contagion during the GFC. However, we show that there is no clear leader or follower market, which contradicts their conclusions. They found that contagion occurs from the US to other G7 countries (except Japan), as well as to India Wang et al. (2017), and from the US to advanced and emerging stock markets (Dungey and Gajurel, 2014).

During the Covid-19 pandemic, we observe positive co-movements between the SP500 and the G7 and Russian stock market indices over most investment horizons. For the Chinese market, we note positive co-movements with the US stock market only between 64 and 128 days. Moreover, all these markets move in phase. Our analysis confirms the results of Alqaralleh et al. (2020) who found evidence of contagion between the US stock market and other international stock markets (Canada, UK, Japan, Hong Kong and China) during the pandemic. More evidence of contagion effects from the US stock markets to the majority of markets studied (G7 and BRICS) was noted by (Nguyen et al., 2021).

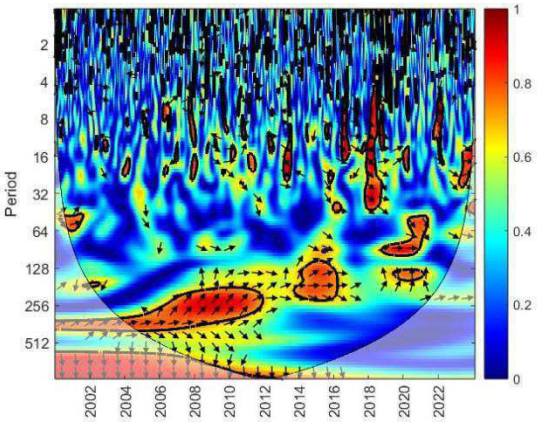
AS regards the Russian-Ukrainian War, we also notice positive and in phase co-movements between the SP500 and the G7 indices mainly for the 64 days investment horizons, indicating the presence of contagion, but none of the markets is leading. Russian and Chinese markets show no evidence of contagion effects between the US stock market. The economic sanctions voted by the UN in 2022 are not really applied, which means that Russian and Chinese economies are less closely linked to the countries that instigated them. Our results are in line with those of Yousfi et al. (2024), who confirmed the presence of a contagion effect between stock markets (US and Canadian) and the various potential assets selected (oil, gold, S&P GSCI and bitcoin) during the Russian-Ukrainian War. Adekoya et al. (2022) also found an increase in the interconnectedness of global stock markets during the Russian-Ukrainian conflict.



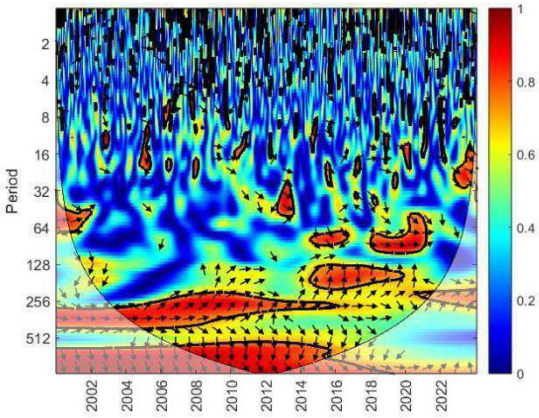
2.a. CAC40 & SSE



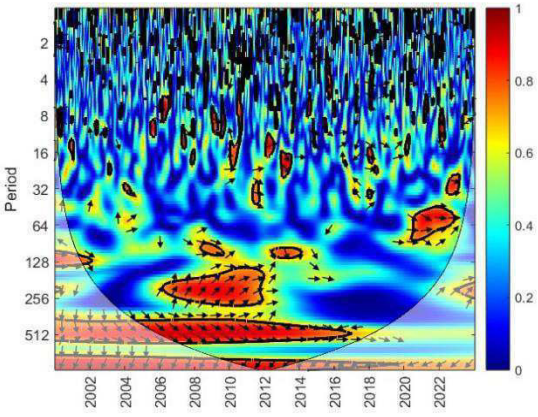
2.b. DAX & SSE



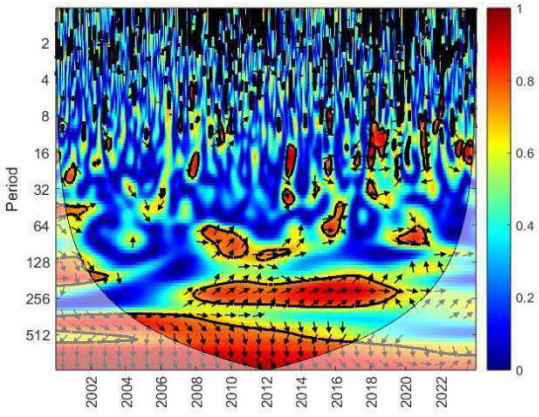
2.c. FTSE100 & SSE



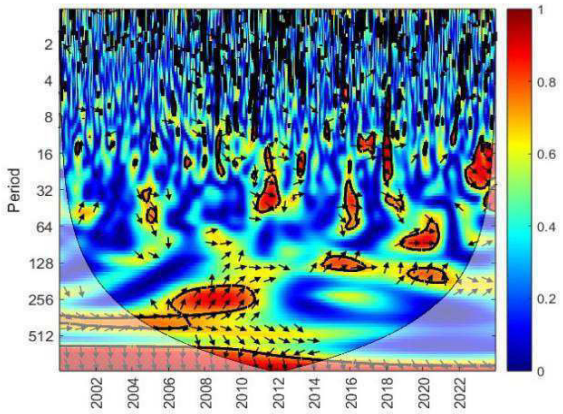
2.d. FTSEMIB & SSE



2.e. MOEX & SSE



2.f. NIKKEI225 & SSE



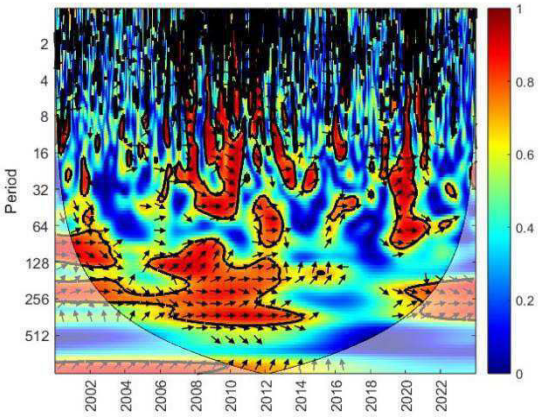
2.g. SP-TSX & SSE

Figure 2: Wavelet and phase coherence for the SSE and other stock market indices

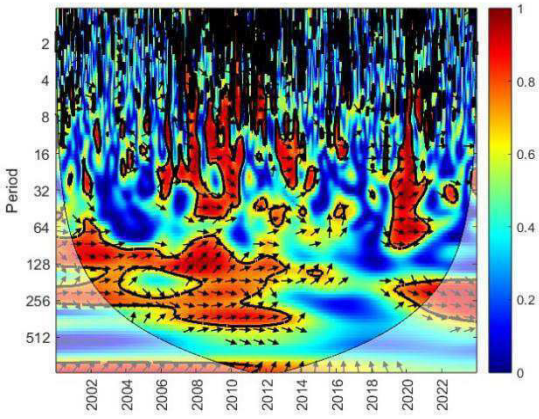
Figure 2 shows the wavelet coherence between the Chinese market and the other studied stock markets. During the GFC, we observe positive co-movements between the SSE with the G7 country indices on the 256-512 day frequency band, and with the Russian market on the 128-512 day frequency band. This result shows the existence of contagion effects between the Chinese market and the G7 and the Russian markets. Considering the phase differences between the SSE and the G7 and Russia markets, the arrows point upwards and to the right (↗), showing that the G7 countries lead the Chinese market, except for the Japanese market This indicates that the Chinese market leads the Japanese one.

During the Covid-19 pandemic, we find positive co-movements between the SSE and the other stock market indices mainly between 64 and 128 days. These results indicate the existence of contagion effects between the Chinese market and the G7 markets and the Russian market. As for phase differences between the SSE and other stock market indices, the overall results of the arrows show that the Chinese market is in phase with all G7 markets and the Russian market, i.e. the Chinese market did not lead the G7 and the Russian markets during the Covid-19 pandemic and vice versa.

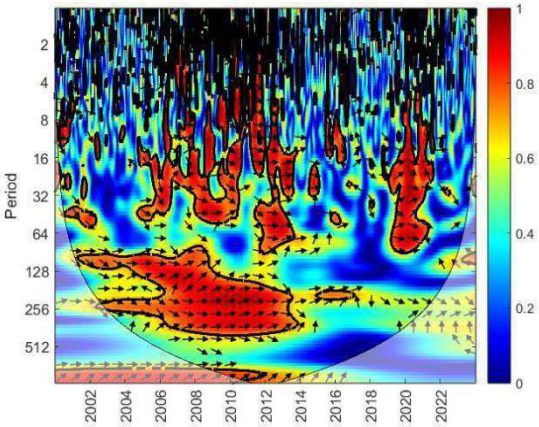
Regarding the Russian-Ukrainian War, the results show positive co-movements between the SSE and all stock indices only for the 16-32 day frequency band, except for Russia and Japan. These findings indicate the presence of contagion effects between the Chinese and the US, French, German, UK, Italian and Canadian stock markets. With arrows pointing downwards and to the right (↘) indicate that the Chinese market is ahead of the other markets. Our findings are in line with those of Pineda et al. (2022), and Ben Amar et al. (2021), who indicated that the Chinese correlation did not show contagion with other developed markets during the pandemic. We can say that the Chinese market appears somewhat disconnected from the other markets, even in times of crisis. This can be explained by the fact that China's domestic market allows for a certain airtightness with regard to external events. Indeed, China's management of covid has been very restrictive and has slightly disconnected China from the post-covid economic recovery observed in many countries. Moreover, with China's geographic proximity to the Russian-Ukrainian war also places China in an economic situation out of sync with other developed countries (trade relations with Russia undisturbed or reinforced since 2022).



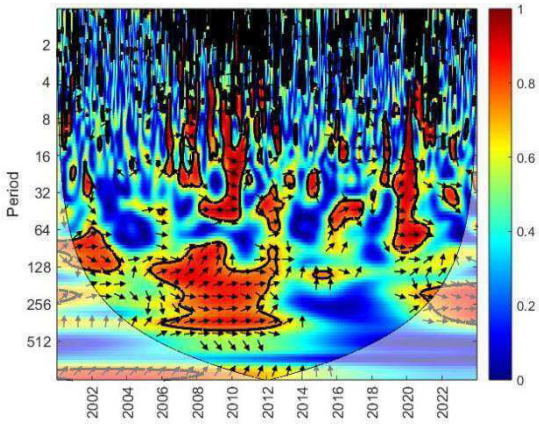
3.a. CAC40 & MOEX



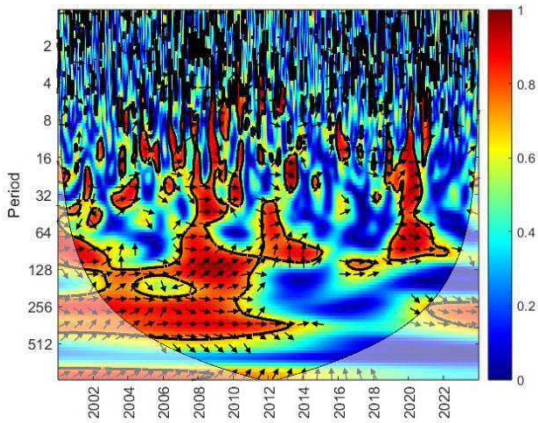
3.b. DAX & MOEX



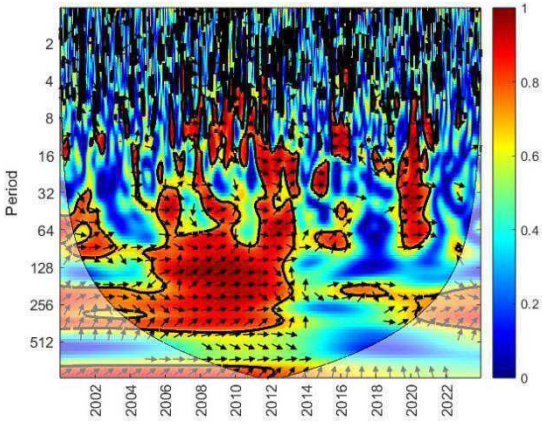
3.c. FTSE100 & MOEX



3.d. FTSEMIB & MOEX



3.e. NIKKEI225 & MOEX



3.f. SP-TSX & MOEX

Figure 3: Wavelet coherence and phase for MOEX and other stock market indices

Figure 3 shows the wavelet coherence between the Russian market and other stock markets studied. During GFC, we observe a positive co-movement between the MOEX and the other stock market indices over the frequency band from 4 to 512 days, indicating the presence of contagion between the Russian and the other stock markets. Moreover, we note that all markets move in phase. In some cases, the Russian market is led by the other stock markets (arrows to the right (↗)) over the 64-128 day frequency band.

During the Covid-19 pandemic, we also note positive and in phase co-movements between the MOEX and the other stock market indices over the 4 to 128-day frequency band. These results demonstrate the existence of contagion effects between the Russian market and the other stock markets.

Concerning the Russian-Ukrainian conflict, we note that coherence between the Russian market and the other stock markets was low dominated by blue color, meaning that there was no contagion effect during this conflict. This can be explained by the resilience that characterizes the international financial system, and the relative weakness of financial integration between the Russian stock market and the rest of the world's stock markets. Our results are in line with the findings of Castagneto-Gissey and Nivorozhkin (2016), who showed that the interdependence between the Russian stock market and 83% of developed, frontier and emerging markets declined significantly during the 2014 Ukraine war. They also mentioned that the Russian stock market decoupled from global stock markets, especially with China, France, Germany, the USA and the MSCI Emerging and Frontier Markets (EFM) index. Contagion effects were present only between the Russian and Brazilian markets among the 18 stock markets under study.

Overall, our results show that the connectedness between market sources of the crises studied, and the rest of the markets in the G7 countries, depends on the market considered and the investment horizon.

4. Conclusion

The wavelet coherence analysis employed in this study offers a complementary and innovative perspective to previous studies of the crises that have affected the financial markets since the beginning of this century. Our results enable us to indentify the characteristics of contagion between markets according to the type of crisis considered, the potentially responsible countries for contagion and the time horizon considered.

It seems that during the GFC, which began in the USA, there was contagion from that market to other financial markets, and a significant co-movement between equity indices. As for the Covid-19 crisis, the contagion effects were more attenuated, and it was not possible to identify leader and follower markets. This result can be explained by the worldwide simultaneity of the pandemic period, and to a lesser extent by the importance of its effects on the various economies. Regarding the crisis related to the Russian-Ukrainian conflict, the interdependence of the Russian market with other financial markets declined, and there was no contagion from this market to the G7 or Chinese markets. The relative low weight of the Russian economy at the world level is undoubtedly an explanatory factor, even though Russia is a major actor on the energy market.

Our results have implications for international investors and policy-makers, as contagion is highly relevant to portfolio management, hedging and safe-haven strategies during periods of market turbulence, as well as risk management. Our findings are useful for investors in helping them to understand contagion phenomena, to better diversify their portfolios, to mitigate their exposure to contagion risks from markets that are sources of crises and also to better anticipate market behavior during futures crises and therefore a new contagion, and reallocate assets depending on countries. Policymakers, on the other hand, should prioritize effective regulation and control of market interactions to minimize the negative effects of contagion during crises. It is also essential for policy-makers to have a clear understanding of the dynamic relationships between their domestic markets and their commercial partners, to take advantage of globalization and stimulate the development of their financial markets.

Our study has limitations and potential areas for further research. We limited our study to identifying the contagion effects between stock markets in countries that are sources of crises and other stock markets, without considering other markets or assets. Future research could therefore extend the number of markets or assets by including additional markets or assets, such as foreign exchange, precious metals, energy and agricultural commodities and other financial assets. Researchers can also examine contagion based on the intensity of economic relations between two countries, the economic size of a country, or assess whether contagion is homogeneous across different sectors of activity.

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