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Cointegration Analysis of Financial Market Indices During Financial Shocks

Focus on Global Financial Crisis and COVID-19 Pandemic Crisis

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Abstract

The purpose of this research was to examine cointegration relationships among the stock market indices before and after the global financial crisis. The cointegration effects were analysed also in the context of the COVID-19 pandemic. The sample included 20 years of data at daily, weekly, and monthly frequencies for stock price indices in the United States (S&P 500), Europe (STXE 600), Japan (Nikkei 225), China (SSE composite), Australia (S&P/ASX 200), and Brazil (IBOVESPA).

Two interesting empirical facts were documented. First, the global financial crisis does not seem to have played a significant and uniform role in influencing the cointegration relationship, as only for the monthly sample the number of cointegrating relationships changed after the crisis. Second, the daily sample allowed to explore the period during the COVID-19 pandemic. The findings suggest that this event increased the number of cointegrating relationships, perhaps due to the global nature of such phenomenon which affects both developed and emerging economies contemporaneously. On the other hand, the financial crisis affected mainly developed economies, and the spillovers to emerging markets took place at a later stage as a second-round effect.

In line with the previous findings in the existing literature, the results of the study have shown that cointegration stock market indices is dependent on the period of analysis and the frequency of the data.

JEL classification numbers: C0, C4, G1, F6.
Keywords: Cointegration analysis, stock markets, financial crisis, COVID-19.

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1 Introduction

The concept of cointegration has been present in the empirical literature in economics and finance since the work of Engle & Granger (1987), as it appeared a suitable alternative to study nonstationary time series. However, it was not until the papers by Johansen (1988, 1991) that a methodology was proposed to study cointegration in a multivariate framework, as a special case of the vector autoregressive model proposed by Sims (1980).

Previous literature on the cointegration among international stock markets such as Dimpft (2014) and Gupta and Guidi (2012) indicate that there is interdependence between indices at the international level. However, the number of cointegration relationships seems to be dependent on the period of the sample and the countries. By analysing data across different frequencies and across different indices, we add to the existing literature and research on the topic of cointegration and we narrow the research gap.

This paper's main goal is to apply the Johansen (1988, 1991) cointegration framework to study the following research questions:

(i) What is the cointegration relationship between stock price indices across the world before and after the global financial crisis (GFC)?

(ii) Has such cointegration relationship changed during the COVID-19 pandemic?

(iii) Does cointegration depend on the frequency of the series?

We rely on a battery of tests, including the augmented Dickey-Fuller (ADF), Schmidt-Phillips, and Johansen procedures, along with daily, weekly, and monthly daily data on six stock market indices distributed across five continents.

2 Literature Review

2.1 Co-movement across equity markets

In the financial economics literature, one of the early applications of the cointegration methodology was conducted by Campbell & Shiller (1987), who analysed a real stock price index in the context of present value models. In subsequent work, Campbell & Shiller (1988a) analysed the behavior of dividends in stock markets, following the work of Marsh & Merton (1987). In related research, Campbell & Shiller (1988b) used the same methodology to conclude that the historical average of real earnings is a good predictor of the present value of the future real dividends.

To the same strand of research, one could also add the work of Pindyck & Rotemberg (1993), who argued that the correlations among stock returns of companies in unrelated industries are due to changes (in current or expected values) of macroeconomic variables, but also as a result of company size and the degree of institutional ownership. Nonetheless, all of this research was conducted in the context of the United States economy and did not include any linkage among international stock markets.

From a more international perspective, Forbes & Rigobon (2002) found a high level of market co-movement (which they refrain to call contagion but rather interdependence) between several countries in East Asia, Latin America, and the OECD countries. They evaluated three crisis episodes (the 1987 U.S. stock market crash, the 1994 Mexican Peso crisis, the 1997 East Asia crisis). The key finding of their work is the presence of heteroskedasticity, as they explicitly state that the cross-market relationship is conditional on the market volatility over the period of analysis; during a crisis when the stock market volatility increases, estimates of cross-market correlations will also be biased upwards if heteroskedasticity is ignored. They also introduced a method for correcting this bias.

Bessler & Yang (2003) studied the stock markets of the United States, the United Kingdom, Germany, France, Switzerland, Canada, Australia, Japan, and Hong Kong. They used a combination of the Johansen model and directed graphs theory to conclude that there is only one cointegrating vector and that the United States' market is the only one which has a long-term contribution to stock prices in foreign markets, but the most significant limitation of their study is the fact that they used daily data only from 1997 through 1999, thus the sample is rather short in historical terms.

Kasibhatla et al. (2006) studied the linkages among the FTSE (London), DAX (Frankfurt), and CAC40 (Paris) from 1990 through 2002 at a daily frequency. Using the Johansen methodology, they found one cointegrating vector's existence and found that the indices are correlated in the long run. Out of literature reviewed in this section, this is the only research with a detailed discussion on the structure of the cointegrating vector: the cointegrating equation (normalized to DAX) indicates that DAX and FTSE indices adjust on a one-to-one basis in the long run, and a smaller adjustment process takes places between DAX and CAC40.

Assidenou (2011) investigated the cointegration properties of major capital markets across three sets of economies: the OECD, Pacific, and Asia. The author found that all groups have at least one cointegrating vector, however, the analysis is not extensive enough in statistical terms. On the other hand, Gupta and Guidi (2012) explored the links between the Indian stock market and three developed Asian markets, Hong Kong, Japan, and Singapore. They found that the correlations across markets increased during the periods of crisis and returned to their initial levels after the crisis. Returns are related in the short run, but a strong long-run relationship across the markets is absent.

Yunus (2013) explored the interdependence of ten important equity markets throughout the United States, Canada, Europe, Latin America, and Asia. Her results pointed to strong high relationship across the markets that has increased over time, and that was particularly strong in various crisis periods. Nonetheless, this study followed the recursive cointegration approach developed by Hansen and Johansen (1999) instead of the standard framework by Johansen (1988, 1991).

Yang et al. (2014) conducted a cointegration analysis between the United States and several international markets. The paper inspects the time-varying relationships across stock markets and pays special attention to the impact of the reduction in capital control and the stock market crash of 1987. The main finding is that although there is no long-run relationship between large markets (e.g., Germany, Japan) and the U.S., smaller markets (e.g., Denmark, Sweden, Norway) have an increasing level of financial integration with the U.S. market.

In terms of sample coverage, Dimpfl (2014) conducted the most extensive study on cointegration of international stock markets. He considered 28 stock market indices and a simulation study, and his contributions are mainly methodological. First, although several studies have tried to detect a common stochastic trend among different stock markets (Kasa, 1992; Choudry et al., 2007; Constantinou et al., 2008, Click & Plummer, 2005; and others), there is not economical or financial theory predicting how many stochastic trends should be. Second, the numbers of cointegrating vectors to be found critically depends on how many markets are analysed and the paper puts forward that common stochastic trends contained in stock market indices cannot be identified by cointegration methods. Third, cointegration is inhibited by company-specific innovations that are permanently absorbed by stock indices, these individual random walk components do no cancel in a cointegration regression and such regression residuals are always not stationary. In conclusion, the study posits serious methodological remarks on how the relationship between international stock markets is traditionally studied via cointegration methodologies.

Haque & Shamsub (2015) studied the relationship between the S&P 500 and stock market indices in sixteen G20 countries, at a daily frequency. Their analysis was conducted on a bi-variate basis with the two-step cointegration approach by Engle & Granger (1987) and yielded that fewer stock markets were cointegrated with the S&P 500 during the Global Financial Crisis than before it. Overall, the number of bi-variate cointegrating relationships decreased during the crisis, maybe because the crisis can be thought of as a structural break in the sample, although this is not statistically proven in the analysis.

3 Data and methodology

3.1 Data

I will analyse cointegration between stock market price indices in the United States, Europe, Japan, China, Australia, and Brazil. The sample is therefore global and includes large developed markets (U.S., Europe and Japan), a small developed market (Australia), and two large emerging markets (Brazil and China). Table 1 shows details about the specific series for each country.

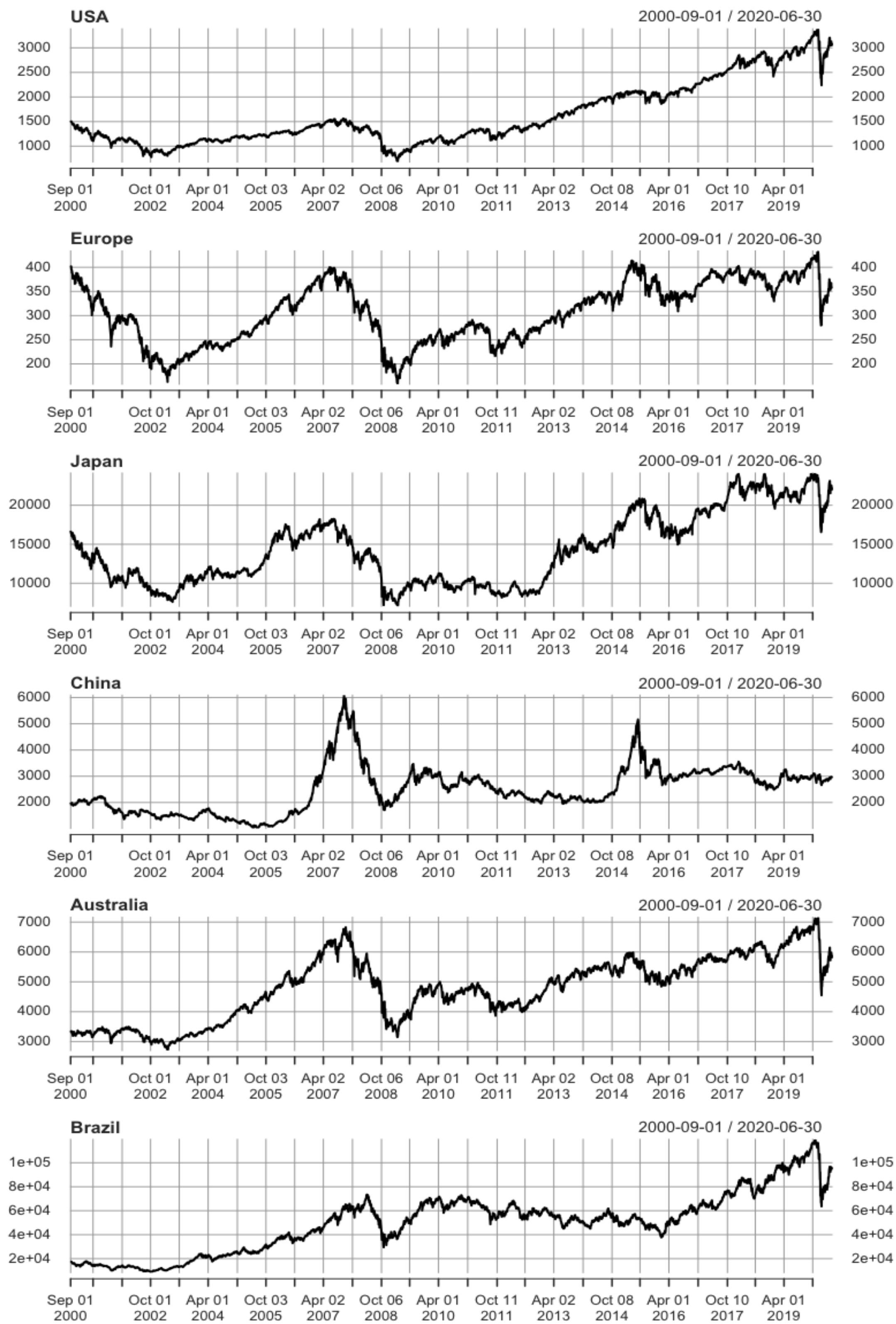
Table 1: Dataset

Series	Description	Source
USA	*S&P 500 (^GSPC)*: market-capitalization-weighted index of the 500 largest U.S. publicly traded companies. The index is widely regarded as the best gauge of large-cap U.S. equities.	Yahoo Finance
Europe	*STXE 600 (^STOXX)*: index derived from the STOXX Europe Total Market Index and a subset of the STOXX Global 1800 Index. With a fixed number of 600 components, the STOXX Europe 600 represents large, mid and small capitalization companies across 17 countries of the European region: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.	Thomson Reuters Datastream
Japan	*Nikkei 225 (^N225)*: is a stock market index for the Tokyo Stock Exchange. It is a price-weighted index, operating in Japanese Yen, and its components are reviewed once a year. The Nikkei measures the performance of 225 large, publicly owned companies in Japan from a wide array of industry sectors.	Thomson Reuters Datastream
China	*SSE Composite Index (000001.SS)*: is a market composite made up of all the A-shares and B-shares that trade on the Shanghai Stock Exchange in China.	Yahoo Finance
Australia	*S&P/ASX 200 (^AXJO)*: market-capitalization weighted and float-adjusted stock market index of stocks listed on the Australian Securities Exchange. It is the benchmark for Australian equity performance. It is based on the 200 largest ASX listed stocks, which account for about 82% of the country's stock market capitalization.	Yahoo Finance
Brazil	*IBOVESPA (^BVSP)*: benchmark index of about 60 stocks that are traded on the B3 (Brasil Bolsa Balcão), which account for the majority of trading and market capitalization in the Brazilian stock market	Yahoo Finance

Source: Own elaboration.

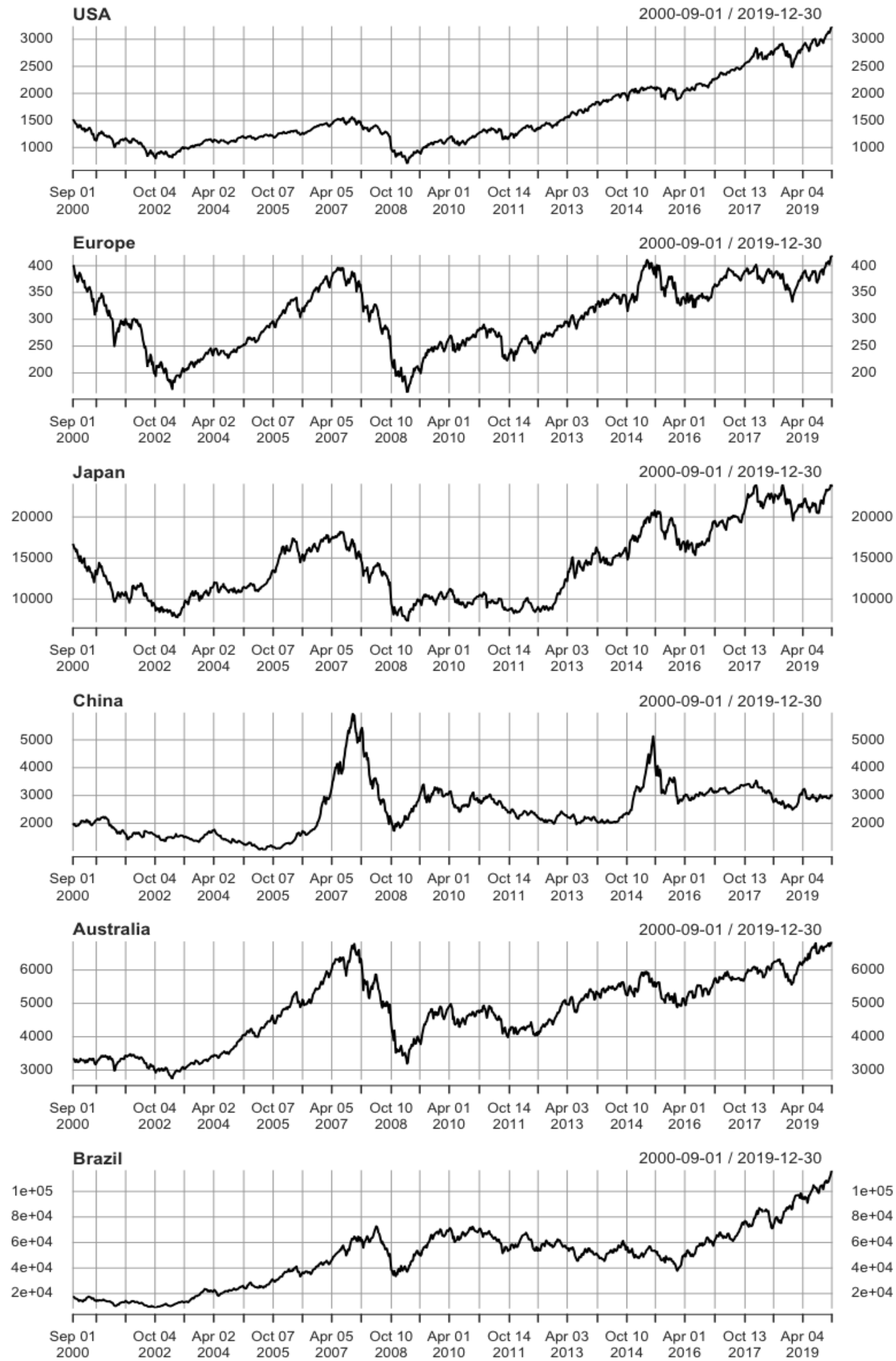
Three primary samples are used in this study: September 1st, 2000 to June 30th, 2020, at daily frequency (4223 observations); September 1st, 2000 to December 30th, 2019, at weekly frequency (988 observations); and September 1st, 2000 to December 30th, 2019 at monthly frequency (232 observations). Initially, the series were gathered from the sources listed in table 1 at daily frequency, however due to differences in trading calendars and number of holidays across countries, the raw series required to be adapted so that the final daily sample has matching dates and no missing values. After the clean daily sample was constructed, I computed weekly and monthly averages to obtain data at those frequencies. Summary statistics and graphical representations for each series are shown in tables 2-4 and figures 1-3, respectively. For the analysis, the samples were subset into different subsamples. Correctly, the daily sample was split into three subsamples covering the period before the global financial crisis (September 1st, 2000 to August 31st, 2008), the period during the global financial crisis and its aftermath (September 1st, 2008 to December 30th, 2019), and the period during the COVID-19 pandemic (January 1st, 2020 to June 30th, 2020). On the other hand, the weekly and monthly samples were split into two samples, covering the period before the global financial crisis (September 1st, 2000 to August 31st, 2008) and during the financial crisis and aftermath (September 1st, 2008 to December 30th, 2019). The battery of subsamples listed above allowed to explore how cointegrating relationships evolve when a disruptive event occurs and how the relationships (if any) hold across different data frequencies. For all the samples, I study how the emergence of the global financial crisis altered the co-movement among stock markets, and for the daily sample, I additionally explore the effects of the COVID-19 pandemic on such relationship. Due to short sample limitations, exploring the COVID-19 period was not possible at weekly or monthly frequencies.

Two important remarks should be made on the selection of the samples: on the global financial crisis, one could argue that the decline of stock prices indices started in late 2007, however, it was not until September 2008 when Lehman Brothers collapsed and this is usually regarded as the start of the crisis; on the COVID-19 pandemic, there seems to be evidence that the virus was first identified in December 2019, but it was not until January 2020 when it was declared a public health emergency of international concern. These two considerations motivated the dates of the subsamples.



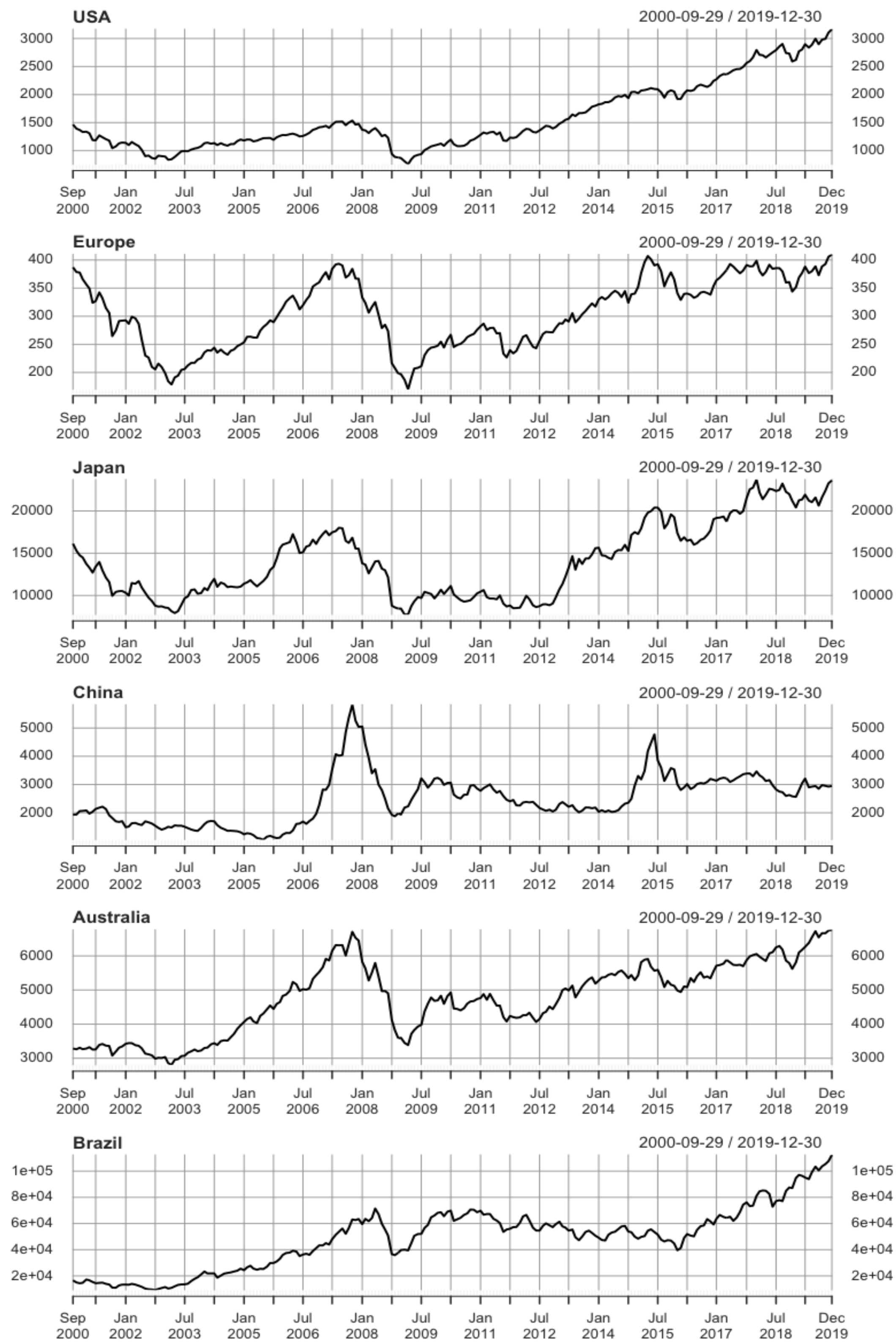
Source: Own elaboration.

Figure 1: Stock indices at daily frequency



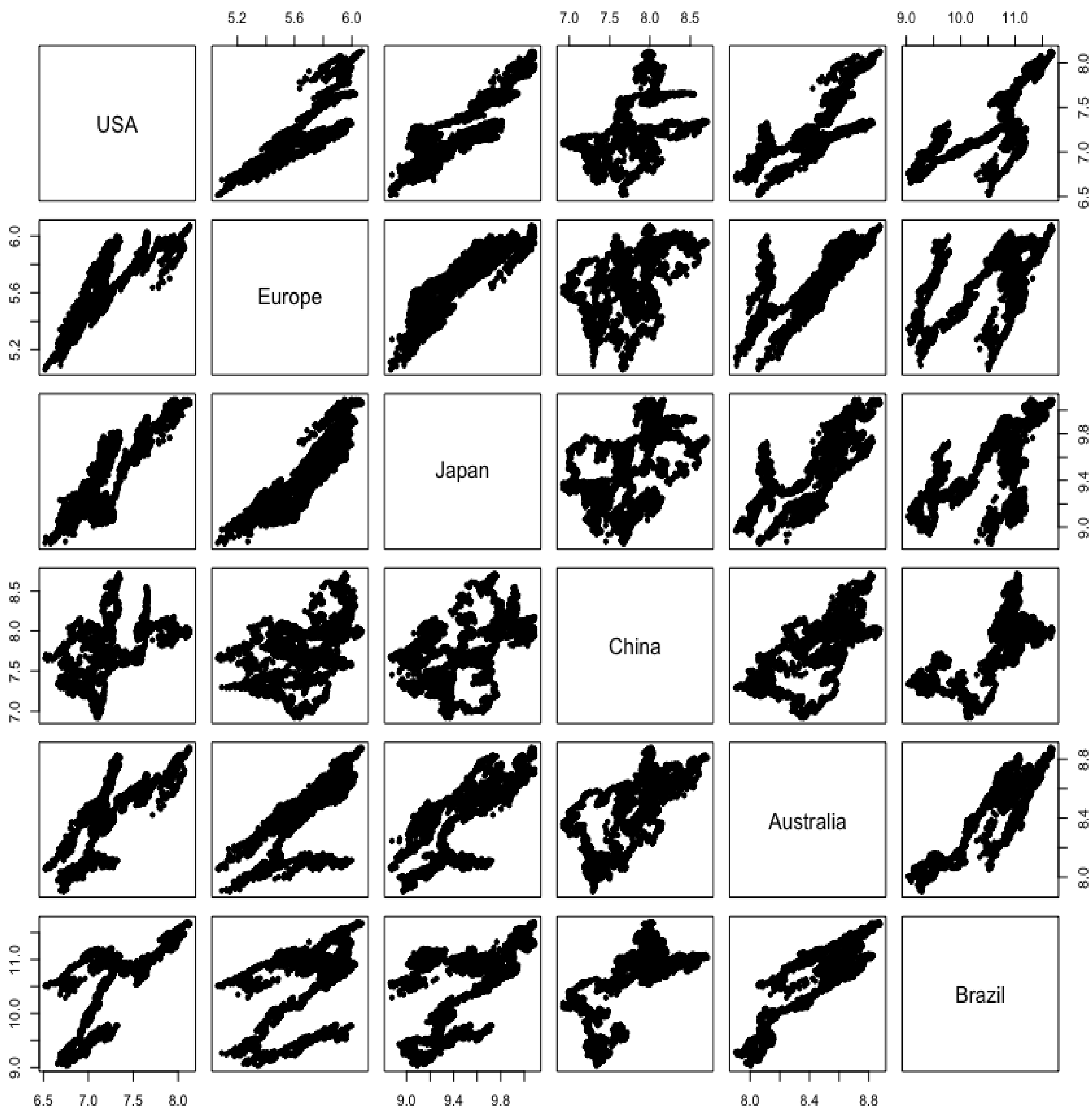
Source: Own elaboration.

Figure 2: Stock indices at weekly frequency



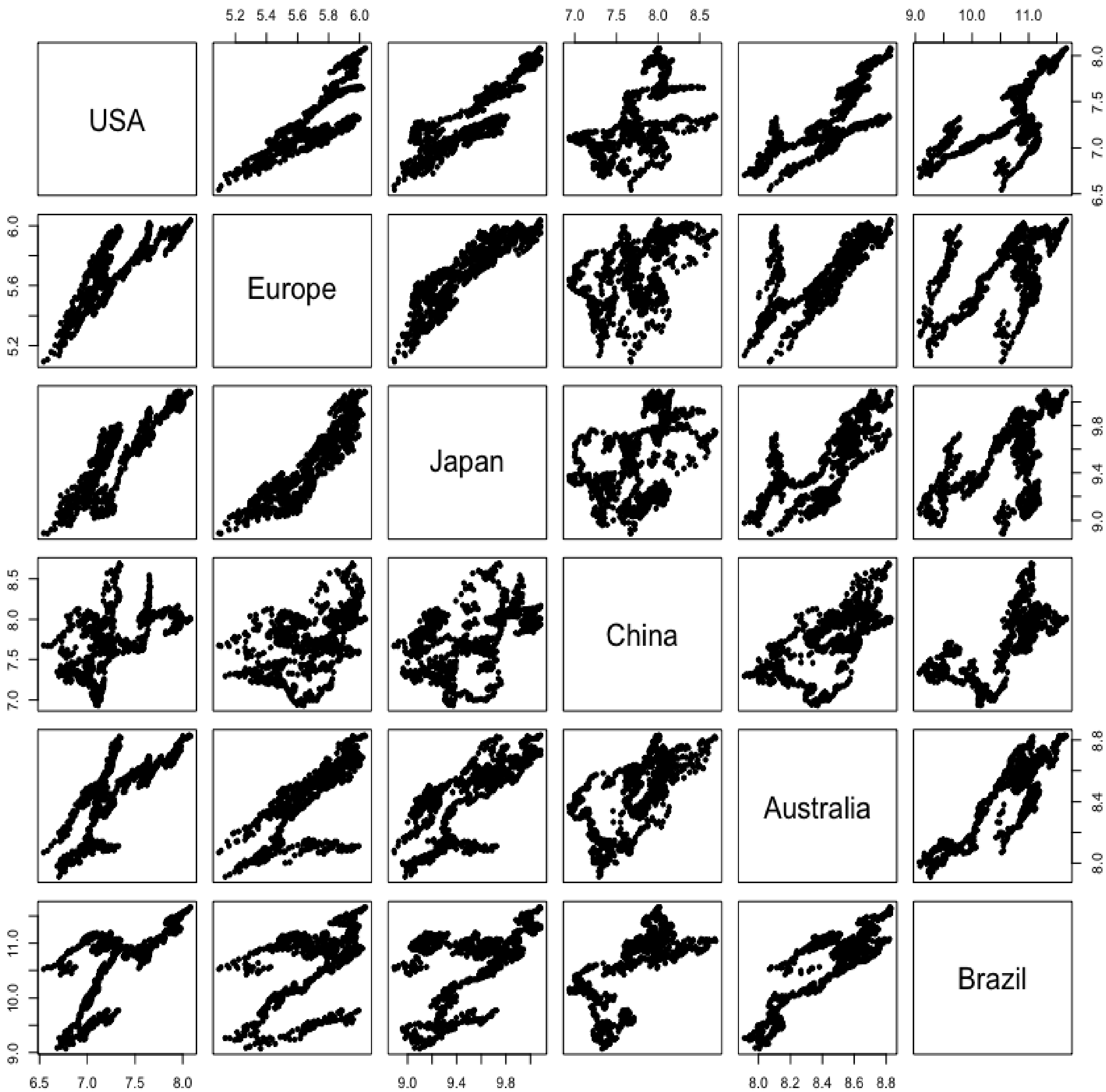
Source: Own elaboration.

Figure 3: Stock indices at monthly frequency



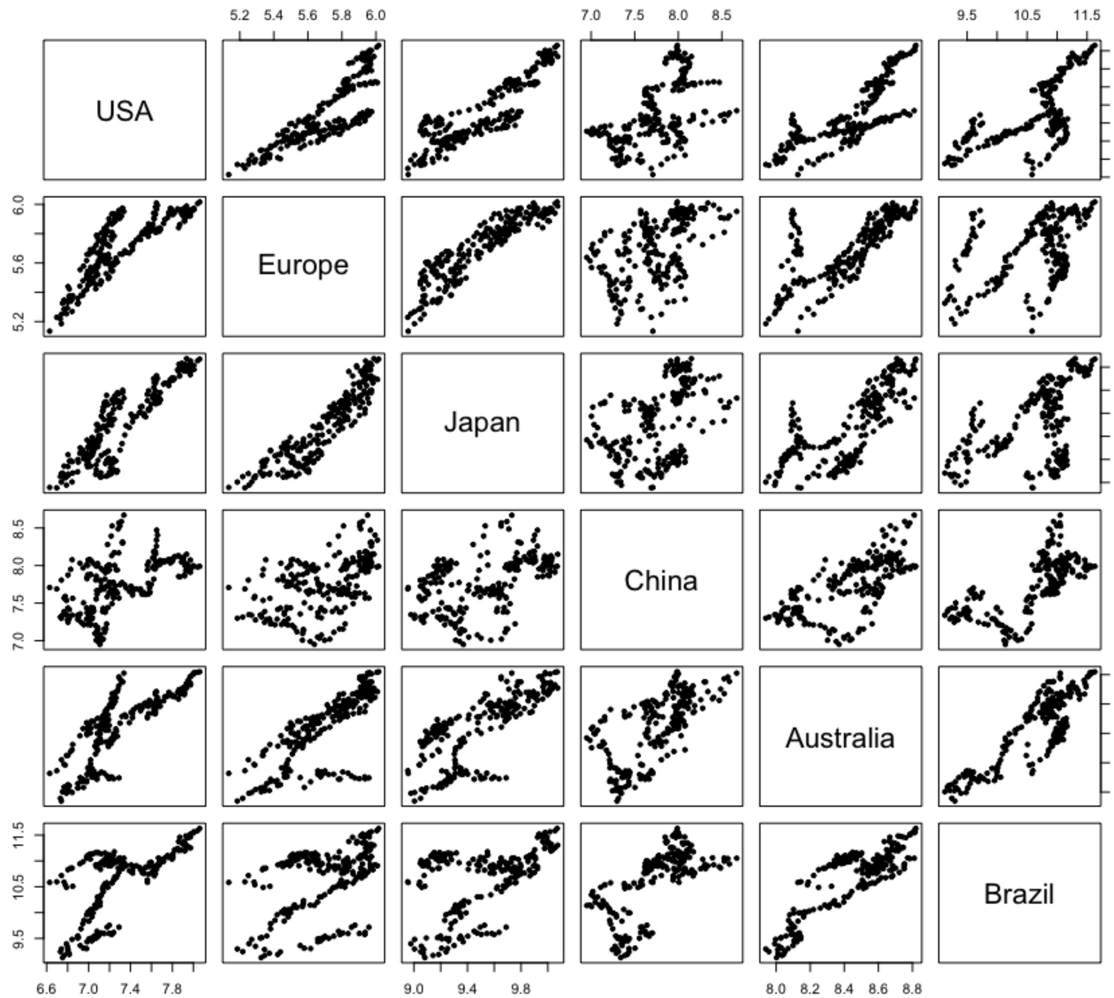
Source: Own elaboration.

Figure 4: Scatterplot of stock indices at daily frequency



Source: Own elaboration.
Note: Log scale.

Figure 5: Scatterplot of stock indices at weekly frequency



Source: Own elaboration.
Note: Log scale.

Figure 6: Scatterplot of stock indices at monthly frequency

3.2 Tests and Models

The empirical strategy is straightforward. The procedures outlined in this section were conducted after transforming the series into their natural logarithmic form following the convention from the literature. I start by computing the linear correlation coefficient across the series for the different frequencies. Then, I inspect unit roots and stationarity with augmented Dickey & Fuller (1979) and Schimdt & Phillips (1992) tests. With the help of these tests, I assess the order of integration for each series, but the results are still compared against a visual inspection of the series (figures 1-3). The correlation analysis and unit root tests are run on the full samples at the three frequencies and not on the subsamples. The ADF test included 30 lags for the daily frequency, 20 lags for the weekly frequency, and 12 for the monthly one. All tests included a trend. Additionally, the Schimidt & Phillips test was computed to examine whether the series become stationary after adjusting for a trend.

After inspecting stationarity and the existence of unit roots, I proceed with the cointegration analysis. As the Johansen test (1988, 1991) starts from a VAR framework, the common practice is to estimate a VAR which is then used to select the lag order by standard lag length criteria (Lütkepohl, 2005); after the lag length p is selected, the corresponding lag order for the Johansen test is $p - 1$. The way this workflow was applied for our estimation goes as follows: first, I estimated an unrestricted VAR and ran a lag order test for the full samples in order to determine the optimal lag length for each frequency (daily, weekly, and monthly) based on information; second, I used the applicable lag length for subsample-specific Johansen cointegration tests. The selection of the lag order is still a controversial discussion in the literature and there is not a rule that applies to all the cases (see Ivanov & Kilian, 2005). Although in this case I used information criteria motivated by Lütkepohl (2005), other alternatives are ranging from likelihood-ratio tests to the arbitrary selection of the lag order based on the researcher's beliefs. For the daily frequency, the lag length test was run allowing for a maximum of 40 lags. However, the Akaike (AIC) and forecast prediction error (FPE) criteria suggested an optimal lag length of 6, while the Hannan-Quinn (HQ) and Schwartz-Bayesian criteria (BIC) suggested 3 and 2 lags respectively; in this case, I selected 6 lags. For the weekly frequency, the lag length was run allowing for a maximum of 40 lags as well, but the AIC, HQ, and FPE criteria suggested an optimal lag length of 2 lags, while the BIC criterion suggested one lag; in this case, I selected 2 lags. For the monthly frequency, the lag order test was run allowing for a maximum of 12 lags, but the AIC and FPE criterion suggested 2 lags, while the HQ and SC suggested 1 lag; 2 lags were selected in this case. It should be emphasized that the order for Johansen test should be 1 lag less than the order of the underlying VAR (so $p - 1$). Given the popularity of the two-step approach to cointegration by Engle & Granger (1987), it is also important to clarify that I rely on the multivariate approach to cointegration (Johansen, 1988, 1991) given that it allows exploring relationships across multiple time series. It is also important to remark that there are various versions of the Johansen test regarding the inclusion of deterministic trends inside and outside the cointegration relationship; in this case, I allowed for a linear trend in cointegration in all the tests.

4 Results

4.1 Daily Frequency

The correlation coefficients suggest that all the indices are correlated with the U.S., except for China, and this correlation is particularly strong for Japan. Table 5 shows there is no perfect correlation among the indices, and China seems to be not strongly correlated with any other market. Brazil is only correlated with the U.S. and Australia. Furthermore, there seems to be a stronger correlation between the U.S., Europe, and Japan when compared to other markets.

The ADF tests in table 6 suggest that the series are not stationary, as the test statistic was lower (in absolute value) than the selected critical value in all cases. It can be concluded that all the series have unit root in levels. In table 7, once again, the test statistic was lower than the selected critical value in all cases, which means that the series are not stationary even after being adjusted for a trend.

The results from the Johansen test are specific to the period. For the period before the global financial crisis (table 8), there is 1 cointegrating relationship according to the trace statistic, and no cointegration at all according to the maximum eigenvalue statistic. For the period covering the emergence and aftermath of the global financial crisis (table 9), both the trace and maximum eigenvalue statistic indicate the existence of 1 cointegrating relationship. Finally, for the COVID-19 period (table 10), both the trace and maximum eigenvalue statistic point to the existence of 2 cointegrating relationships.

Table 2: Correlation matrix, full daily sample

	USA	Europe	Japan	China	Australia	Brazil
USA	1	0.79	0.90	0.46	0.79	0.74
Europe	0.79	1	0.90	0.55	0.79	0.50
Japan	0.90	0.90	1	0.49	0.80	0.58
China	0.46	0.55	0.49	1	0.68	0.61
Australia	0.79	0.79	0.80	0.68	1	0.82
Brazil	0.74	0.50	0.58	0.61	0.82	1

Source: Own elaboration.

Table 3: ADF tests, full daily sample

	Test statistic	Critical value at 5%	Comment
log (USA)	-2.63	-3.41	The series has a unit root.
log (Europe)	-2.91	-3.41	The series has a unit root.
log (Japan)	-2.39	-3.41	The series has a unit root.
log (China)	-2.27	-3.41	The series has a unit root.
log (Australia)	-2.44	-3.41	The series has a unit root
log (Brazil)	-2.00	-3.41	The series has a unit root

Source: Own elaboration. All tests included 30 lags and a trend.

Table 4: Schmidt-Phillips tests, full daily sample

	Test statistic	Critical value at 5%	Comment
log (USA)	-0.87	-3.02	The series is not stationary after adjusted for deterministic terms.
log (Europe)	-1.54	-3.02	The series is not stationary after adjusted for deterministic terms.
log (Japan)	-1.48	-3.02	The series is not stationary after adjusted for deterministic terms.
log (China)	-2.32	-3.02	The series is not stationary after adjusted for deterministic terms.
log (Australia)	-2.04	-3.02	The series is not stationary after adjusted for deterministic terms.
log (Brazil)	-1.74	-3.02	The series is not stationary after adjusted for deterministic terms.

Source: Own elaboration.

Table 5: Johansen cointegration test, daily subsample Sep 2000-Aug 2008

	Trace statistic		**Maximum eigenvalue statistic**	
Hypothesis	Statistic	Critical value at 5%	Statistic	Critical value at 5%
$r \leq 2$	53.08	62.99	19.20	31.46
$r \leq 1$	87.24	87.31	34.16	37.52
$r \leq 0$	129.66	114.90	42.42	43.97

Source: Own elaboration.

Table 6: Johansen cointegration test, daily subsample Sep 2008-Dec 2019

	Trace statistic		Maximum eigenvalue statistic	
Hypothesis	Statistic	Critical value at 5%	Statistic	Critical value at 5%
r ≤ 2	39.90	62.99	19.06	31.46
r ≤ 1	71.81	87.31	31.91	37.52
r ≤ 0	123.52	114.90	51.71	43.97

Source: Own elaboration.

Table 7: Johansen cointegration test, daily subsample Jan 2020-Jun 2020

	Trace statistic		Maximum eigenvalue statistic	
Hypothesis	Statistic	Critical value at 5%	Statistic	Critical value at 5%
r ≤ 2	60.25	62.99	30.95	31.46
r ≤ 1	109.07	87.31	48.82	37.52
r ≤ 0	168.39	114.90	59.32	43.97

Source: Own elaboration.

4.2 Weekly Frequency

The correlation relationships seem to hold when changing from daily to weekly frequency. The coefficients suggest that, apart from China, all the indices are correlated with the U.S. Such correlation is particularly strong for Japan and Europe. In table 11, we can see that none of the indices is perfectly correlated with another one, and China is strongly correlated with any other market. Brazil is only correlated with the U.S. and Australia. Furthermore, there seems to be a stronger correlation between the U.S., Europe, and Japan when compared to other markets.

The ADF tests in table 12 suggest that the series (except for China) are not stationary, as the test statistic was lower (in absolute value) than the selected critical value in such cases. China is the exception in the test, as the results for such a market point to a stationary series in levels; however, when looking at the weekly plot in figure 2, we see that the mean of the series increases is not constant over time. The results for the Schmidt-Phillips test (table 13), match the results of the ADF test: none of the series are stationary in levels after adjusting for a trend, except for China.

Despite the test results, after checking the line plot for China, it is difficult to assert that the series is integrated of order of 0 in levels. Therefore, we assume the series is $I(1)$ as the rest of the sample.

The results from the Johansen test are once again period specific. For the period before the global financial crisis (table 14), there is 1 cointegrating relationship according to the trace statistic, and no evidenced cointegration according to the maximum eigenvalue statistic. For the period covering the emergence and aftermath of the global financial crisis (table 15), both the trace and maximum eigenvalue statistic indicate the existence of 1 cointegrating relationship.

Table 8: Correlation matrix, full weekly sample

	USA	Europe	Japan	China	Australia	Brazil
USA	1	0.80	0.90	0.46	0.79	0.72
Europe	0.80	1	0.90	0.55	0.78	0.48
Japan	0.90	0.90	1	0.48	0.79	0.54
China	0.46	0.55	0.48	1	0.68	0.62
Australia	0.79	0.78	0.79	0.68	1	0.82
Brazil	0.72	0.48	0.54	0.61	0.82	1

Source: Own elaboration.

Table 9: ADF tests, full weekly sample

	Test statistic	Critical value at 5%	Comment
log (USA)	-2.56	-3.41	The series has a unit root.
log (Europe)	-3.08	-3.41	The series has a unit root.
log (Japan)	2.26	-3.41	The series has a unit root.
log (China)	-3.60	-3.41	The series is stationary.
log (Australia)	-2.59	-3.41	The series has a unit root.
log (Brazil)	-1.83	-3.41	The series has a unit root.

Source: Own elaboration. All tests included 20 lags and a trend.

Table 10: Schmidt-Phillips tests, full weekly sample

	Test statistic	Critical value at 5%	Comment
log (USA)	-2.02	-3.02	The series is not stationary after adjusted for deterministic terms.
log (Europe)	-2.32	-3.02	The series is not stationary after adjusted for deterministic terms.
log (Japan)	-2.33	-3.02	The series is not stationary after adjusted for deterministic terms.
log (China)	-3.33	-3.02	The series is stationary after adjusted for deterministic terms.
log (Australia)	-2.80	-3.02	The series is not stationary after adjusted for deterministic terms.
log (Brazil)	-2.47	-3.02	The series is not stationary after adjusted for deterministic terms.

Source: Own elaboration.

Table 11: Johansen cointegration test, weekly subsample Sep 2000-Aug 2008

	Trace statistic		**Maximum eigenvalue statistic**	
Hypothesis	Statistic	Critical value at 5%	Statistic	Critical value at 5%
$r \leq 2$	51.25	62.99	18.11	31.46
$r \leq 1$	82.15	87.31	30.90	37.52
$r \leq 0$	123.69	114.90	41.53	43.97

Source: Own elaboration.

Table 12: Johansen cointegration test, weekly subsample Sep 2008-Dec 2019

	Trace statistic		**Maximum eigenvalue statistic**	
Hypothesis	Statistic	Critical value at 5%	Statistic	Critical value at 5%
r ≤ 2	39.43	62.99	18.23	31.46
r ≤ 1	72.21	87.31	32.78	37.52
r ≤ 0	131.74	114.90	59.53	43.97

Source: Own elaboration.

4.3 Monthly Frequency

At monthly frequency, the correlation relationships are the same with respect to daily and weekly frequencies. Excluding China, the coefficients suggest that all the indices are correlated with the U.S., and this correlation is relatively strong for Japan and Europe. In table 16, we can see that there is no perfect correlation among the stock indices, and China is not strongly correlated with any other market. Additionally, Brazil is particularly correlated with Australia, and up to a lesser extent, with the U.S. Furthermore, there seems to be a stronger correlation between the U.S., Europe, and Japan when compared to other markets.

The ADF tests in table 17 suggest that the series are not stationary, as the test statistic was lower (in absolute value) than the selected critical value in all cases. Like in the daily sample and unlike the weekly sample, China is not stationary in levels in this case. The results for the Schmidt & Phillips test (table 18) indicate that Europe and China are stationary in levels after adjusting for a trend, while the rest of the series are not. Here, the results between tests are conflicting, especially when considering that the ADF test specification included a trend. Based on the plots displayed in figure 3 and the results of the remaining frequencies, we assume that all the series are $I(1)$.

Once more, the results from the Johansen test are specific to the period. For the period before the global financial crisis (table 19), there is 1 cointegrating relationship according to the trace statistic, and no cointegration at all according to the maximum eigenvalue statistic. For the period covering the emergence and aftermath of the global financial crisis (table 15), both the trace and maximum eigenvalue statistic indicate there is no evidenced cointegrating relationship.

Table 13: Correlation matrix, full monthly sample

	USA	**Europe**	**Japan**	**China**	**Australia**	**Brazil**
USA	1	0.80	0.90	0.46	0.79	0.72
Europe	0.80	1	0.91	0.55	0.78	0.48
Japan	0.90	0.91	1	0.48	0.80	0.54
China	0.46	0.55	0.48	1	0.69	0.62
Australia	0.79	0.78	0.80	0.69	1	0.82
Brazil	0.72	0.48	0.54	0.62	0.82	1

Source: Own elaboration.

Table 14: ADF tests, full monthly sample

	Test statistic	Critical value at 5%	Comment
log (USA)	-1.75	-3.43	The series has a unit root.
log (Europe)	-2.54	-3.43	The series has a unit root.
log (Japan)	-1.72	-3.43	The series has a unit root.
log (China)	-2.85	-3.43	The series has a unit root.
log (Australia)	-2.72	-3.43	The series has a unit root.
log (Brazil)	-2.03	-3.43	The series has a unit root.

Source: Own elaboration. All tests included 20 lags and a trend.

Table 15: Schmidt-Phillips tests, full monthly sample

	Test statistic	Critical value at 5%	Comment
log (USA)	-2.48	-3.04	The series is not stationary after adjusted for deterministic terms.
log (Europe)	-3.05	-3.04	The series is stationary after adjusted for deterministic terms.
log (Japan)	-2.65	-3.04	The series is not stationary after adjusted for deterministic terms.
log (China)	-4.12	-3.04	The series is stationary after adjusted for deterministic terms.
log (Australia)	-3.45	-3.04	The series is stationary after adjusted for deterministic terms.
log (Brazil)	-2.43	-3.04	The series is not stationary after adjusted for deterministic terms.

Source: Own elaboration.

Table 16: Johansen cointegration test, monthly subsample Sep 2000-Aug 2008

	Trace statistic		**Maximum eigenvalue statistic**	
Hypothesis	Statistic	Critical value at 5%	Statistic	Critical value at 5%
$r \leq 2$	49.96	62.99	21.30	31.46
$r \leq 1$	84.39	87.31	34.43	37.52
$r \leq 0$	126.18	114.90	41.79	43.97

Source: Own elaboration.

Table 17: Johansen cointegration test, monthly subsample Sep 2008-Dec 2019

	Trace statistic		**Maximum eigenvalue statistic**	
Hypothesis	Statistic	Critical value at 5%	Statistic	Critical value at 5%
$r \leq 2$	38.78	62.99	19.32	31.46
$r \leq 1$	67.08	87.31	28.30	37.52
$r \leq 0$	103.45	114.90	36.36	43.97

Source: Own elaboration.

4.4 Discussion

The results presented in this paper should be put into the context of the general literature on stock market cointegration. With a few exceptions, most studies addressed cointegration among markets with similar characteristics (i.e., developed markets) or just for a limited set of geographically close countries, and for a different period. The sample used here includes six relevant stock market indices distributed across five continents, which on top of including around 20 years of data, also considers three different frequencies.

At daily frequency, the global financial crisis does not seem to have had any impact on the results, and there is 1 cointegrating relationship before and after the crisis. Nonetheless, during the COVID-19 period, I found 2 cointegrating relationships, which could indicate that the co-movement across markets intensified during the pandemic. At weekly frequency, there is 1 cointegrating relationship in the sample before and after the global financial crisis, which once again suggests the crisis had no big impact on market co-movement. At monthly frequency, there is just 1 cointegrating relationship before the global financial crisis (according to the trace test), and no cointegration after the crisis.

The results summarized above suggest that the results are specific to the frequency and the period of analysis, rather than sensitive to the emergence of disruptive events such as the global financial crisis. Drawing on Dimpfl (2014) findings and other literature in the review, the results presented here are not surprising as conclusions depend on the sample and model specification.

Results based on VAR methods are well known to be extremely sensitive to how the model is specified (see Lütkepohl, 2005; Lütkepohl & Krätzig, 2004). Same applies to the Johansen (1988, 1991) procedure which is also VAR-based. Furthermore, the Johansen methodology has the advantage of enabling the researcher to explore cointegrating relationships in a multivariate framework. However, it also requires the variables to be strictly $I(1)$ and requires stronger distributional assumptions than the two-step approach by Engle & Granger (1987), as documented by Hjalmarsson & Österholm (2010). This implies that decisions on the selection of the indices and the frequency, the inclusion or exclusion of a trend in the model, the use of near integrated variables, the lag order, do have an impact on results. Out of the papers included in the review of empirical work on stock markets cointegration, Dimpfl (2014) reviews the Johansen cointegration methodology to the deepest extent. His findings could be important for the results we have obtained here in terms of the number of cointegrating relationships: the number of cointegrating vectors is critically dependent on the number of markets that are analysed and it could be the case that common trends in stock markets cannot be properly identified by cointegration methods because of the way this methods are often implemented (e.g. without a common random walk component or correlated price innovations).

Moreover, the results presented here are also close to Bessler & Yang (2003), who presented a similar global selection of stock indices and they found just 1 cointegrating relationship. However, overall it should be stressed that there is not an universally accepted benchmark in the literature with regard to the number of cointegrating relationships.

5 Conclusion

Drawing on the results presented in this paper, it is clear that the existence of cointegration across the stock indices under consideration is conditional on the period of analysis and the frequency; (a) at daily frequency, there is evidence of 1 cointegrating relationship before and after the global financial crisis and 2 cointegrating relationships for the COVID-19 period; (b) at weekly frequency, there is 1 cointegrating relationship before and after the financial crisis; (c) at monthly frequency, there is 1 cointegrating relationship before the financial crisis (according to the trace statistic) and no evidenced cointegration after the crisis.

Two interesting empirical facts were documented. First, the global financial crisis does not seem to have played a significant and uniform role in influencing the cointegration relationship, as only for the monthly sample the number of cointegrating relationships changed after the crisis. Second, the daily sample allowed to explore the period during the COVID-19 pandemic. The findings suggest that this event increased the number of cointegrating relationships, perhaps due to the global nature of such phenomenon which affects both developed and emerging economies contemporaneously. On the other hand, the financial crisis affected mainly developed economies and the spillovers to emerging markets took place at a later stage as a second-round effect. Nevertheless, the pandemic is still an ongoing event and the analysis would have benefited from a longer time span in the sample.

Additionally, this study has further limitations that are inherent to the methodology. As discussed by Kilian & Lütkepohl (2017), the problem of choosing between a VAR model in levels, a VAR model in differences, and a VECM, cannot be solved by running a battery of tests for unit roots and cointegration. These tests cannot be used to confirm the features specified under the null hypothesis, as the non-rejection of the null hypothesis only means that there is insufficient evidence to rule out the null. Furthermore, the issues raised by Dimpfl (2014) regarding the cointegration methods to study stock markets co-movement are of primary importance to contextualize the results presented here.

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