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An Empirical Validation of Financial Contagion by A Multivariate VAR Model

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Abstract

Financial contagion was first introduced in July 1997 when there was a crisis in Thailand's exchange market that quickly spread to many other East Asian markets. Our empirical study thus aims at finding evidence of financial contagion between exchange markets, monetary markets, and stock markets in seven countries. Like Primiceri (2005) and Koop and Korobilis (2010), we use the VAR model to detect contagion between markets and intra-markets. We first study the correlations between the different markets of the same kind and then employ tests of the unitary root ADF and PP to determine the offset to be used in the VAR model.

Our study highlights the presence of contagion between these markets (intra-market contagion) and contagion in the same market across countries (inter-market contagion). Moreover, we find that contagion largely explains anomalies in markets contrary to conventional finance. However, behavioral finance is still unable to predict future events.

Key words: Financial Contagion , Behavioral Finance, Financial Markets, Monetary Markets, Stock Markets , Exchange Markets, VAR Model.

JEL classification: G01,G1, G4.

1. Financial Market Contagion: A Theoretical and An Empirical Debate

Many emerging economies experienced several periods of crisis during the 1990s. These crises have been linked to domestic economy weakness or to external global shocks (such as Mexico's market turbulence caused by U.S. interest rate shocks, sudden reversal of capital flows in Asia, or external factors in Russia). However, in a short time, these crises spread to other countries not only in the region, but also to other emerging economies elsewhere. Researchers have suspected that

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some crises are caused by regional economic and market integration, but the occurrence of a financial crisis in a specified country cannot be attributed to a single factor.

The Asian financial crisis began when the Thai baht, which had been pegged to the US dollar, was freely floated in July 2, 1997. It is argued that Asia's growth during the last quarter of the previous century depended on an abroad-directed strategy and a continuous process of economic reforms that included the financial sector liberalization. As a result of these policies, many Asian economies sought to secure economic growth reaching double digits. However, the 1997 crisis completely changed this growth trend after a few weeks of the Thai baht's freefall in July 1997. Several countries with the highest growth rates were threatened by recession.

The International Monetary Fund (IMF) in 1999 was invited to help these economies when their domestic policies failed to overcome the adverse shocks. The IMF intervened first in Thailand and the Philippines, then South Korea, and finally Indonesia. For a year, deep recessions replaced double-digit growth rates.

The dramatic and rapid volatility of the Thai baht and the consequent devaluations of currencies throughout the region eventually led to one of the worst crises in Asia. This can be explained by several factors. Many economists believed that strong financial and commercial ties provided the channel for the currency contagion. First, the crisis affected the currencies of countries that were neighbors in Asia. It then spread to equity markets and to the rest of the world, as the Asian financial crisis began to have a global dimension by the end of 1998. Details of the Asian crisis and its impact on regional economies are well presented in the literature. It should be noted that the crisis began in July 1997, and the first six months of the same year saw normal currency movements, whereas most currencies in the region severely decreased during the second half. However, the hypothesis of the possibility that this phenomenon was a currency contagion or a result of common factors that affected regional currencies is still testable. This is the main target of this study's empirical validation. However, before starting on our empirical investigation, it is necessary to examine both the theoretical and the empirical literature on contagion.

Various economists have studied this phenomenon by highlighting several factors likely to lead to contagion. Financial contagion can be defined as a systematic effect of the probability of a speculative activity on a country’s financial market (such as currency market, stock market, or monetary market) arising from a similar activity in the financial markets of another country.

The literature has identified some important factors that can lead to contagion. Common shocks may simultaneously affect exchange rates or stock markets in several countries, which may cover a reaction of an acute decline in global aggregate demand, significant changes in asset prices, or large changes in exchange rates between major currencies. Currency crises can also take place due to strong trade relationships. For example, currency (or foreign exchange market) contagion began with a real depreciation of the currency of country A, because of speculative attacks. Such depreciation strengthens its export competitiveness and produces a trade deficit for rival country B. This results in a depletion of foreign currency in country B and increases the likelihood of speculative attacks on the currency of country B. Pressure on the domestic currency may reduce the strength of the financial market and may increase the volatility of returns of the stock market and interest rates.

Another source of contagion is attributed to strong financial relationships. Edwards (1988) suggests that financial ties can be considered as contagion channels when domestic investors in country B readjust their portfolios and revise their risk management strategies as a result of a negative shock and exposure to the high risk of financial assets in country A. If financial markets in a group of countries are closely connected, then a crisis in one country will increase the probability of a crisis in the region. This will push investors to change their portfolios. Therefore, some countries may experience capital outflows even if their basic macroeconomic indicators remain stable.

Finally, currency contagion may take place from reversals in investor sentiment. According to this definition, a country with low basic indicators of financial market is more likely to suffer from external shocks. Any speculative attack of another country will make the country more vulnerable to similar attacks. This can also be intensified by herding behaviour where investors react to a shock in one country in a similar manner based on some expectations of movements in market variables throughout the region.

The issue of contagion had been treated by a limited number of empirical studies until the occurrence of the Asian financial crisis, with only a few studies having investigated currency contagion as the source of the crisis in Latin America after the fall of the Mexican peso in 1994. However, research on this issue intensified after the Asian crisis in 1997. Generally, the related literature supports the underlying effect of contagion in the Asian crisis. Individual research suggests that strong trade relationships, common macroeconomic weaknesses, important macroeconomic similarities, and financial markets links were the most likely sources of the spread of the crisis from one country to the entire Latin American (during the Tequila crisis) and Asian (during the Asian crisis) regions. However, existing research has some limitations.

Nagayasu (2000) examines daily observations of exchange rates and prices of several measures of sectoral stocks in the Philippines and Thailand from December 1988 to November 1996. The researcher does not find evidence of a long-term relationship between exchange rates and stock prices. However, he does see evidence of Granger causality between exchange rates and some sectors of stock prices using a VAR approach. Baig and Goldfijn (1998) present evidence of contagion in the Asian currency and equity markets.

The studies above do not, however, pursue an aggregated market analysis, meaning that in their empirical analysis both markets are isolated from each other. Thus, their analysis does not examine the impact of cross-market relationships. Masih and Masih (1999) use a sample of four Asian countries and four industrialized countries, showing evidence of a co-integrating relationship in equity markets after employing a VECM approach to test causality. They also use a Wald procedure as an alternative. Their results indicate that no Asian market (Singapore, Malaysia, Hong Kong, and Thailand) influences changes in other markets of the region. However, using a sample of Asian and other industrialized countries, they find support for inter-country links with the United States as a dominant stock market. It is noticeable that most research studies based on time series are limited to contagion of a region. In other words, existing research confines the impact of crises to one region and ignores effects on other regions. Moreover, most published research focuses on a single market with the currency market as the main source of contagion. Some studies do not take into account stock price in their analysis, but rather only look at cross-country contagion in a single market. Moreover, the literature has not incorporated another important indicator in the financial market in their analysis: the interest rate.

It is argued that financial contagion may influence three major financial markets: the foreign exchange market, the stock market, and the monetary market. For this reason, we extend this research by incorporating the three market indicators of exchange rates, stock market indices, and interest rates. We use daily observations to study financial contagion. Next, we perform econometric tests using VAR to identify cross-country, cross-market, and cross-country-cross-market contagion during periods of crises. Finally, we perform an impulse response analysis to better investigate contagion.

Abbate et al. (2016) reduce the definition of contagion in the context of a temporary change in inter-market links to distinguish temporary changes in inter-market relations that may occur during a crisis of permanent changes in transmission mechanisms including structural breaks. Bachiochi (2017) defines interdependence and contagion in terms of heteroscedasticity by highlighting changes in contemporary cross-correlations of structural shocks. Guidolin et al. (2017) study the dynamics of structural shocks to differentiate between simple interdependencies and episodes of contagion.

2. Presentation of The Model

We begin the analysis by estimating correlation coefficients of daily changes in exchange rates, stock market indices, and interest rates across countries. We utilize the longest time window span to define the entire period of crisis and then reduce the time to identify the exact date of the spread of the crisis outside the country. The period exhibiting the highest correlation across countries is further examined by other econometric analyses. The same approach is repeated to identify inter-market correlations. The study also reports the results of the correlation matrix, which is consistent with the sample period used in the analyses.

The next step is to run unit root tests on the different samples employed in this study. The standard ADF and Phillip-Perron tests help identify the order of integration for each sample period corresponding to a crisis. The results of this step allow us to build an appropriate specification of the VAR model.

The literature commonly uses the VAR model for analyzing the dynamic impact of random errors on a system of variables. The VAR approach models each endogenous variable in the system as a function of lagged values of all the variables in the endogenous system, specified as follows:

$$y_t = A_1 y_{t-1} + \cdots + A_p y_{t-p} + Bx_t + \varepsilon_t, \qquad (1)$$

where k is a vector of endogenous variables, x_t is a vector d of exogenous variables, $A_1, \ldots, A_p$ and B are matrices of the coefficients to be estimated, and ε_t is a vector of the innovations that can correlate in a contemporary way to each other, but do not correlate with their lagged values and with all variables in the right side of the equation.

It is very important to determine lag length before estimating VAR. The common practice is to select an arbitrary lag length allowing for just enough lag to ensure that the residuals are white noise while maintaining the precision of estimates. There are also some procedures that determine an appropriate lag length, like the Akaike information criterion (AIC), the Schwartz information criterion (SIC), and the likelihood ratio test (LR). We use all three methods to determine lag length and find that AIC and SIC suggest a single lag length, while LR is not conclusive. We then select a single lag for all VAR in this study. Since we have the same lag length, the system can be estimated using the method of ordinary least square (OLS).

The main objective of estimating a VAR in this validation is to identify a causal relationship between different markets across the sample countries. For example, we are interested in seeing how changes in the currency of any country affect the other markets in the region. This is usually accomplished by testing Granger causality, using the VAR system of equations and testing zero restrictions on VAR coefficients.

In the study of Khalid and Kawai (2003), diagnostic tests reveal that the series have unit roots, but are not cointegrated. A considerable amount of research takes on the question of the Granger causality test under such a scenario. Engle and Granger (1987), Sims, Stock and Watson (1990), Toda and Phillips (1993), Toda and Yamamoto (1995), and Rambaldi and Doran (1996) all propose methods that can be used to test Granger causality. If it is known that the system is I(1) but is not co-integrated, then Sims et al. (1990) and Toda and Phillips (1993) suggest that causality tests different from that of VAR are valid. In this case, causality tests different from VAR are more likely to have greater power in limited samples (Toda and Phillips (1993, p. 1377). This method requires that the variables used to test Granger causality in the equation should be used in first difference. This is the main approach used in our validation.Toda and Yamamoto (1995) suggest an alternative procedure that does not require a preliminary co-integration test. A simple procedure called the MWALD test appears in Toda and Yamamoto (1995) and Rambaldi and Doran (1996). We use the MWALD procedure as an alternative to test the robustness of our results.

We also analyze the impulse responses. An impulse response function traces the effect of a one standard deviation shock to one of the innovations on current and future values of the endogenous variables. A shock at the i^{th} variable directly affects the i^{th} variable and is also transmitted to all endogenous variables through the dynamic structure of VAR. Since innovations are generally correlated, they have a common component that cannot be associated with a specific variable. Consequently, the order of variables becomes very important in this analysis.

Dynamic VAR analysis is usually performed using “orthogonalized impulse responses” as suggested by Sims (1980). In this regard, the literature normally uses Cholesky decomposition when errors are orthogonalized in a way that the resulting innovations’ covariance matrix is diagonal. However, this method is arbitrary and can seriously affect the results if the order is changed.

Pesaran and Shin (1999) propose an alternative procedure called analysis of the generalized impulse response (GIR), which is sensitive to the order of variables in VAR. It may be noted that it is difficult to maintain a proper order of variables in a wide VAR as used in this validation. Therefore, we use IRM analysis. We focus on three markets in the region. First, we introduce a shock in the exchange rate of a country and analyze its impact within and between markets. Second, we repeat the same procedure on the other two markets including the stock market index and interest rates.

3. Presentation of Data and Research Hypotheses

3.1 Data Presentation

The present empirical study uses the time series of three different markets (foreign exchange market, monetary market, and stock market) of seven countries and regions, including the U.S., Japan, the Eurozone, United Kingdom, Australia, Canada, and Mexico.

Data frequency is weekly, and the study period runs from 17/01/1999 until 30/10/2016. Data are extracted from Yahoo! Finance and the official websites of the central banks of each country.

3.2 The Hypotheses

This empirical study targets to validate the following two hypotheses.

• Hypothesis 1: There is financial contagion among the different markets.

• Hypothesis 2: There is no financial contagion among the different markets.

4. Empirical Results and Interpretation

4.1 Descriptive Statistics of Time Series

A. Descriptive Statistics of Interest Rates Time Series

The following table presents the statistical characteristics of interest rates time series of the seven countries and regions.

Table 1. Descriptive Statistics of Interest Rates Time Series

Statistics	TIUSA	TIJAPAN	TIEURO	TIUK	TICANADA	TIAUSTRALIA	TIMEXICO
Mean	2.655876	0.1144461	2.642964	3.813623	2.898578	5.166916	10.53573
Maximum	6.5	0.5	4.75	6	5.75	7.25	775.39
Minimum	0.125	0	1	0.5	0.25	3	-68.41
Skewness	0.2890659	1.442719	0.1332541	-0.8862911	-0.0780731	0.0037239	5.338957
Kurtosis	1.6245	3.62971	1.916571	2.287201	2.039231	3.088684	43.09999
Median	2	0	2.5	4.5	2.75	5	0
Standard Dev.	2.120825	0.17126	1.131097	1.906076	1.58194	0.9615072	75.09873

The descriptive statistics of interest rates time series show that the mean ranges between 0.1144461 (TIJAPAN) and 10.53573 (TIMEXICO). The minimum values range from -68.41 (TIMEXICO) and 3 (TIAUSTRALIA), while the maximum values vary between 0.5 TIJAPAN and 775.39 (TIMEXICO). Standard deviations range between 0.17126 (TIJAPAN) and 75.09873 (TIMEXICO).

As for data distributions, skewness is positive except for TIUK and TICANADA. Therefore, distributions are skewed to the left of the median, and the right tails are thicker. Kurtosis is greater than 3 for (TIAUSTRALIA) and (TIMEXICO), and therefore they are leptokurtic. The remaining distributions are mesokurtic.

B. Descriptive Statistics of Exchange Rates Time Series

The table below presents the statistical characteristics of exchange rates time series of the seven countries and regions.

Table 2. Descriptive Statistics of Exchange Rates Time Series

Statistics	TCUSA	TCJAPAN	TCEURO	TCUK	TCCANADA	TCAUSTRALIA	TCMEXICO
Mean	1	108.1494	0.8550437	0.6031126	1.266731	1.413884	10.91724
Maximum	1	133.87	1.1956	0.7195	1.6088	2.0381	15.2746
Minimum	1	76	0.6294	0.4777	0.9314	0.9134	9.004
Skewness	0	-0.6509941	0.6621197	-0.1380944	0.133118	0.3560784	0.6204681
Kurtosis	0	2.661993	2.224624	1.905932	1.547288	2.133716	2.806217
Median	1	109.775	0.80985	0.6151	1.23255	1.3488	10.84745
Standard Dev.	0	13.24567	0.1503866	0.0637068	0.2078961	0.2915515	1.302719

The descriptive statistics of exchange rates time series indicate that the mean ranges between 0.6031126 (TCUK) and 108.1494 (TCJAPAN). The minimum values vary between 0.4777 (TIMEXICO) and 9.004 (TCMEXICO), while maximum values vary between 0.7195 (TCUK) and 76 (TCJAPAN). Standard deviations range between 0.0637068 (TCUK) and 13.24567 (TCJAPAN).

As for data distributions, skewness is positive except for TCJAPAN and TCUK. Therefore, distributions are skewed to the left of the median, and the right tails are thicker. Kurtosis is less than 3 for all distributions. Therefore, they are all mesokurtic.

C. Descriptive Statistics of Indices Time Series

The table below presents the statistical characteristics of indices time series of the seven countries and regions.

Table 3. Descriptive Statistics of Indices Time Series

Statistics	VIUSA	VIJAPAN	VIEURO	VIUK	VICANADA	VIAUSTRALIA	VIMEXICO
Mean	7083.138	12606.3	3072.172	5380.502	10282.2	4086.272	17340.09
Maximum	10301.49	20434.68	4551	6930.2	14984.2	6760.1	38600.86
Minimum	4284.49	7173.1	1817.24	3491.6	5935.33	2715	3617.77
Skewness	0.4254663	0.4789855	0.6365549	-0.3210972	0.0686297	0.6955323	0.3918592
Kurtosis	2.700795	1.98931	2.425128	1.989333	1.760043	2.47526	1.582401
Median	6858.735	11514.03	2885.58	5460.25	10260.54	3843.05	13613.11
Standard Dev.	1278.294	3235.051	646.9671	833.1431	2404.048	1020.671	11083.05

The descriptive statistics of indices time series show that the mean varies between 3072.172 (VIEURO) and 17340.09 (VIMEXICO). The minimum values vary between 18171817.24 (VIEURO) and 7173.1 (VIJAPAN), while maximum values vary between 4551 (VIEURO) and 38600.86 (VIMEXICO). Standard deviations range between 646.9671 (VIEURO) and 11083.05 (VIMEXICO).

As for data distributions, skewness is positive except for VIUK. Therefore, distributions are skewed at the left of the median, and the right tails are thicker. Kurtosis is less than 3 for all distributions, and they are all mesokurtic.

4.2 Results and Interpretation

A. Correlation between time series

A-1 Correlation of interest rates time series

The table below shows the correlation between the different interest rates of the countries and regions during the study period.

Table 4. Correlation between The Different Interest Rates

	TiUSA	TiJAPAN	Tieuro	TiUK	Ticanada	Tiaustralia	Timexico
TiUSA	1.000						
Tijapon	0.2486	1.000					
Tieuro	0.6988	0.4774	1.000				
TiGB	0.8263	0.2462	0.8168	1.000			
Ticanada	0.9297	0.2497	0.8138	0.9041	1.000		
Tiaustralie	0.5916	0.6327	0.6855	0.7100	0.6589	1.000	
Timexique	-0.1302	-0.2617	-0.1742	-0.2141	-0.0973	-0.2230	1.000

This table shows a strong correlation between interest rates in the Euro zone, U.S., Canada, UK, and Australia. The strongest correlation is between the United States and Canada (0.9297). However, we notice that the Japanese rate highly correlates with that of Australia, with an average correlation in the Euro zone, while the correlation for the rest of the regions is low. However, the Mexican rate has a low negative correlation with all the other rates.

A-2 Correlation of Exchange Rates Time Series

The table below exhibits correlation between the exchange rates of the different countries and regions with the exception of the United States, which is the reference currency:

Table 5. Correlation between Exchange Rates of The Different Countries

	TcUSA	Tcjapon	Tceuro	TcGB	Tccanada	Tcaustralie	Tcmexico
TcUSA	-						
Tcjapon	-	1.000					
Tceuro	-	0.5762	1.000				
TcGB	-	-0.0481	0.6709	1.000			
Tccanada	-	0.6805	0.9340	0.6000	1.000		
Tcaustralie	-	-0.7364	-0.7270	-0.0989	-0.6528	1.000	
Tcmexique	-	0.6415	0.9108	0.5520	0.9487	-0.6839	1.000

We notice a strong correlation between the different exchange rates of the different countries with the exception of three : Australia and UK, Japan and UK , (-0.0989 and -0.0481, respectively) and the Euro and Japan whose average correlation is (0.5762). The strongest correlation is seen between Canada and Mexico (0.9487).

A-3 Correlation of Indices Time Series

The table below shows the correlation between the indices of the different countries and regions.

Table 6. Correlation between the Indices of the Different Countries

	Viaustralia	Vieuro	ViGB	VI mexico	Vijapan	ViUSA	Vicanada
Viaustralie	1.000						
Vieuro	0.8499	1.000					
ViGB	0.9460	0.8314	1.000				
Vimexique	0.7435	0.3239	0.7291	1.000			
Vijapon	0.7627	0.9468	0.7563	0.2110	1.000		
ViUSA	0.9198	08614	0.9288	0.6286	0.7919	1.000	
Vicanada	0.9259	06575	0.9217	08927	0.5705	0.8634	1.000

We see that the correlation between the different indices during the study period is strong. The highest recorded value is that of the relationship between European and Japanese indices (0.9468). However, we find three exceptions. First, there is a low correlation between the Mexican index and the Japanese and European indices (0.2110 and 0.3239, respectively). Second, we see an average correlation between the Canadian and Japanese indices (0.5705).

B. The Unit Root Tests

After studying the simple correlation, we decide to determine the number of lags to be used in the VAR model by conducting the ADF and PP tests. Indeed, the ADF test is a unit root test in an ARMA model (p, q) of unknown order. This test verifies the null hypothesis that the time series are non-stationary, assuming that the dynamic aspect in the data has an ARMA structure. However, the practical problem in implementing this test is the specification of the offset length p. Thus, we shall use the PP test to reinforce the results. Indeed, the comparative advantage of PP tests over ADF tests is that the former are robust to the general forms of heteroskedasticity in the error terms, and so we do not have to specify an offset length for the regression of the test. The table below presents the results of these two tests.

Table 7. The Unit Root Tests

Country/region	First lags					
	Exchange rates		Indices		Interest rates	
	ADF	PP	ADF	PP	ADF	PP
U.S.A.	-	-	-23.792*	-31.747*	-23.948*	-20.381*
Japon	-21.713*	-30.187*	-23.590*	-19.617*	-21.790*	-29.980*
Euro	-25.168*	-40.471*	-17.502*	-25.042*	-23.309*	-23.413*
GB	-25.274*	-39.214*	-20.017*	-25.816*	-20.205*	-26.709*
Canada	-27.402*	-43.668*	-20.665*	-41.002*	-22.657*	-24.048*
Australia	-24.447*	-36.924*	-25.379*	-43.896*	-17.897*	-24.230*
Mexico	-22.633*	-29.057*	-28.513*	-47.908*	-14.417*	-26.969*

This table leads us to conclude that the null hypothesis of the presence of a unit root in the time series of each of the three markets of the seven countries and regions is rejected at the 1% confidence level. The two tests (ADF and PP) lead us to the same conclusion. Therefore, the examined time series are non-stationary and there is a possibility that they follow a random walk, because there are no predictable components in these series. Therefore, both tests of the unit root assert the possibility of using the VAR model with a single lag.

C. Intra-market Causality Tests

After an intra-series study of stationarity, we now examine causality between the time series of different countries in the same market.

The table below shows the statistics of causality tests between the different time series in the context of a one-lagged VAR model:

Table 8. Intra-markets Causality Tests

Country	U.S.A.	Japan	Euro	GB	Canada	Australia	Mexico
(A) Exchange Rate							
U.S.A.	-	-	-	-	-	-	-
Japan	-	-	51.9174*	-26.3646*	42.8464*	32.5692*	-7.3999*
Euro	-	0.0069*	-	1.6839*	0.6527*	0.4766*	-0.0790*
GB	-	0.0007*	0.2726*	-	0.1606*	0.1329*	-0.0084*
Canada	-	0.0095*	1.1804*	1.3717*	-	0.6519*	-0.0973*
Australia	-	0.0153*	1.7923*	2.7673*	1.3659*	-	-0.1418*
Mexico	-	-0.0728*	-7.0509*	-1.8029*	-4.8345*	-3.3049*	-
(B) Market Indices							
USA	-	0.2036*	1.8756*	1.0450*	0.4667*	1.1119*	0.0709*
Japan	1.0956*	-	4.1249*	2.8420*	0.4984*	0.7036*	-0.0061*
Euro	0.2527*	0.2123*	-	0.4796*	0.1085*	0.3950*	0.0167*
GB	0.4373*	0.2231*	1.1253*	-	0.2441*	0.3526*	0.0207*
Canada	1.4471*	0.2690*	2.0948*	1.7119*	-	2.0490*	0.1891*
Australia	0.6441*	0.0748*	1.2449*	0.5124*	0.3686*	-	0.0693*
Mexico	4.0814*	-0.8540*	2.6002*	0.8133*	3.9708*	8.5284*	-
(C) Interest Rates							
USA	-	2.2059*	1.4061*	0.9085*	1.2381*	1.2480*	-0.0033*
Japan	0.0187*	-	0.0722*	0.0220*	0.0253*	0.1113*	-0.0006
Euro	0.3988*	3.3114*	-	0.5138*	0.6385*	0.8144*	-0.0024*
GB	0.7446*	3.3230*	1.4845*	-	1.0892*	1.4098*	-0.0055*
Canada	0.6979*	2.5624*	1.2610*	0.7506*	-	1.1005*	-0.0019**
Australia	0.2699*	3.5656*	0.5917*	0.3575*	0.3997*	-	-0.0028*
Mexico	-4.4752*	-116.1647*	-11.4574*	-8.3490*	-4.4255**	-17.3612*	-

Concerning exchange markets, the one-lagged VAR causality test indicates that there are causal relationships of different magnitudes. We notice that Japan's exchange rate is well explained by all other interest rates, because the coefficients generated by the tests are well above unity. Particularly, interest rates of the Euro zone, GB, and Canada strongly explain that of Japan. On the other hand, the British exchange rate explains that of the Euro, while the Canadian exchange rate is caused by those of the Euro and GB.

The causality test leads us to affirm that the Australian interest rate is well explained by those of the Euro, UK, and Canada, and the same is even true for

Mexico adding Australia. However, the Japanese interest rate affects no other rate, and the same is even true for Mexico except with Japan.

A strong causal relationship shows that there is a possibility of transmission of shocks across interest rates, but sometimes in only one direction. It should be noted that all coefficients are significant at the 1% level.

Concerning stock markets, the VAR causality tests indicate that the U.S. index time series during the study period are explained by those of the Euro, UK, and Australia, while the Japanese index is affected by the U.S., European, and UK indices. On the other hand, the Canadian index is explained by the other studied indices with the exception of Japanese and Mexican indices. As for the Mexican index, we find a strong causal relationship with all the other indices with the exception of that of Japan.

The results indicate that the European index is not explained by any index, also the British and the Australian indices are not explained by any index except the European one.

However, the Japanese and Mexican indices are not relevant independent variables. They do not explain any other market, which is relatively the same finding as with the exchange rate. Notwithstanding this, the time series of the European stock market affect all other series, while the U.S. index explains only the Mexican, the Britain and the Canadian. The discovery of some causal relationships between several indices is evidence of the possibility of propagation of shocks between markets, but sometimes in one direction.

Concerning the interest rate, the causality test leads to confusing conclusions. We notice that the time series of U.S. interest rates are strongly explained by the other selected series with the exception of Mexico and the UK. Similarly, the Mexican index is caused by the other indices with the exception of Japan. On the other hand, the British interest rate is largely explained by European, Japanese, Canadian, and Australian interest rates; as for the Australian rate, it is explained only by the Japanese interest rate. Among other things, the Japanese and European interest rates are not caused by any interest rate. However, the U.S. and Mexican interest rates cause no other interest rates (with the exception of the fact that the U.S. rate explains the Mexican rate). The time series of Japanese interest rates cause all the time series of the other countries. Like the other two markets, examining the causal relationships between the interest rates time series of the studied countries leads us to affirm that there is a possibility of diffusion of shocks across markets, but sometimes in one direction.

D. Inter-market Causality Tests

After examining the causal relationship between intra-market time series in different countries, we next examine inter-market causality. This should lead us to either retain or reject contagion between markets.

D-1 Causality Tests of The Exchange Market with The Other Two Markets

The table below presents the results of the causality tests between the exchange market and the other two markets.

Table 9. Inter-markets Causality Tests (TC vs. VI and TI)

Market	TCUSA	TCJapon	TCEuro	TCGB	TCCanada	TCAustralia	TCMexico
VIUSA	-	-11.4512*	-4399.478*	-13304.6*	-4004.326*	-2659.262*	86.4122*
VIJapon	-	65.3722*	3411.897*	-9826.619*	606.6023*	420.0906*	-1159.805*
VIEuro	-	-1.0504*	-1411.862*	-6851.154*	-1038.578*	-823.2201*	-136.6334*
VIGB	-	-0.6971	169.2419***	-2363.55*	-801.3152*	-540.1863*	-235.2842*
VICanada	-	-67.6478*	-9175.221*	-20579.85*	-9346.564*	-5813.786*	479.7229*
VIAustralie	-	-11.7196*	-4153.946*	-9501.847*	-3753.83*	-2220.492*	175.8107*
VIMexique	-	-455.9714*	-51591.67*	-25852.73*	-50113.2*	-30475.2*	4622.704*
TIUSA	-	-0.0874*	-7.5861*	-7.8327*	-4.9557*	-4.2056*	1.0329*
TIJapon	-	0.0043*	0.4369*	0.8306*	0.4126*	0.2515*	-0.0304*
TIEuro	-	-0.0263*	-4.1554*	-0.1511*	-2.1502*	-1.6786*	0.5798*
TIGB	-	-0.0557*	-8.5734*	-11.4311*	-5.6405*	-4.0051*	0.9819*
TICanada	-	-0.0630*	-7.3379*	-8.0224*	-4.9301*	-3.8819*	0.8508*
TIAustralie	-	0.0054**	-1.2609*	-3.3884*	-0.1647	-0.5251*	0.1294*
TIMexique	-	-0.6028**	-80.1358*	-83.1523**	-37.3576**	-42.2147*	1.0940

Concerning the causal relationship between the index as a dependent variable and the exchange rate as an independent variable, we notice high absolute causality coefficients with the exception of the relationship between the UK stock market and the Japanese exchange market. Higher values are recorded especially those of the Mexican stock market and the other markets except for the U.S. and Japanese markets. Moreover, the British exchange rate has strong causal relationships with the U.S. and Canadian stock markets.

Concerning the causal relationship between the interest rate as a dependent variable and the exchange rate as an independent variable, we find relatively low coefficients. Japanese exchange rate time series cause no other interest rates series, and the Japanese interest rate has no causal relationships with any exchange rate of the studied countries. The Mexican and U.S. interest rates are caused by all other exchange rates except that of Japan. On the other hand, the British, European, and Canadian interest rates are caused by the exchange rates of the other countries with the exception of the Mexican and Japanese rates (adding UK for the European interest rate). However, Australian interest rates time series are explained by all exchange rates time series except those of Europe and Britain. All coefficients are significant at the 1% level with the exception of four coefficients: one is significant at the 5% level, one is a coefficient significant at the 10% level, and two others are insignificant coefficients.

D-2 Causality Tests of The Stock Market with The Other Two Markets

The table below presents the results of causality tests between the stock market and the other two markets.

Table 10. Inter-markets Causality Tests (VI vs. TC and TI)

Market	VIUSA	VIJapon	VIEuro	VIGB	VICanada	VIAustralia	VIMexico
TCUSA	-	-	-	-	-	-	-
TCJapon	-0.0005*	0.0021*	0.0119*	0.0018*	-0.0028*	-0.0026*	-0.0008*
TCEuro	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	-0.0001*	0.0000*
TCGB	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
TCCanada	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	-0.0001*	0.0000*
TCAustralie	-0.0001*	0.0000*	0.0000*	0.0000*	-0.0001*	-0.0002*	0.0000*
TCMexique	0.0000*	-0.0002*	-0.0008*	-0.0007*	0.0001*	0.0005*	0.0000*
TIUSA	0.0000*	-0.0005*	-0.0020*	-0.0013*	0.0000*	0.0003*	0.0000*
TIJapon	0.0000*	0.0000*	-0.0001*	-0.0001*	0.0000*	0.0000*	0.0000*
TIEuro	-0.0002*	-0.0002*	-0.0007*	-0.0009*	0.0000**	0.0001*	0.0000*
TIGB	0.0000*	-0.0004*	-0.0006*	-0.0013*	0.0001*	0.0008*	0.0000*
TICanada	0.0001*	-0.0003*	-0.0009*	-0.0009*	0.0001*	0.0006*	0.0000*
TIAustralie	-0.0001*	-0.0001*	-0.0004*	-0.0006*	0.0000*	0.0000	0.0000
TIMexique	0.0103*	0.0024*	0.0164*	0.0271*	0.0096*	0.0068**	0.0009*

Concerning the causal relationship between the exchange rate as an exogenous variable and the index as an endogenous variable, all coefficients are zero or tend to zero. This finding implies that the index has no effect on the exchange rate. This result is the same in the case of causality between interest rate and the index. All coefficients are significant at the 1% level except for (TIAustralie, VIAustralie) and (TIAustralie, VIMexique), which are not significant and (TIEuro, VICanada) and (TIMexique, VICanada), which are significant at the 5% level.

D-3 Causality Tests of The Monetary Market with The Other Two Markets

The table below reports the results of causality tests between the interest rate and the other two markets.

Table 11. Inter-market Causality Tests (TC vs. TI and VI)

Market	TIUSA	TIJapon	TIEuro	TIGB	TICanada	TIAustralia	TIMexico
VIUSA	-42.4147*	-42.5533*	-299.1276*	45.6415*	54.6117*	-256.3742*	3.2782*
VIJapon	-996.1692*	-5621.291*	-1853.542*	-921.6637*	-1131.073*	-974.1143*	6.2065*
VIEuro	-85.7252*	-815.5436*	-318.1634*	-250.5959*	-132.643*	-85.4610*	2.5287*
VIGB	-220.287*	-2714.82*	-503.4347*	-239.0208*	-253.0166*	-457.1847*	3.6663*
VICanada	126.8632*	-8088.45*	-208.8043*	224.6114*	372.8769*	-359.0301*	35.1039*
VIAustralie	9.6444*	-2505.062*	29.7235*	133.0092*	131.8982*	-64.5350*	1.3459*
VIMexique	1740.088*	-14073.78*	372.951*	2559.685*	3339.862*	311.0331*	8.3594*
TCUSA	-	-	-	-	-	-	-
TCJapon	-3.8061*	26.9162*	-4.2231*	-2.8499*	-4.5829*	0.5548*	-0.0137*
TCEuro	-0.0396*	0.2318*	-0.0642*	-0.0476*	-0.0589*	-0.0298*	-0.0002*
TCGB	-0.0069*	0.1299*	0.0005*	-0.0103*	-0.0117*	-0.0122*	0.0000*
TCCanada	-0.0448*	0.4251*	-0.0725*	-0.0583*	-0.0709*	-0.0136*	-0.0001*
TCAustralie	-0.0887*	0.5835*	-0.1175*	-0.0927*	-0.1253*	-0.0645*	-0.0004*
TCMexique	0.3996*	-1.5696*	0.7360*	0.4496*	0.5600*	0.2340*	-0.0002*

Concerning the causal relationship between the index as a dependent variable and the interest rate as an independent variable, we find coefficients greater than unity for all cases. The absolute values vary between 1.3459 (VIAustralie, TIMexique) and 14073.78 (VIMexique, TIJapon). However, concerning the causal relationship between the exchange rate as a dependent variable and the interest rate as an independent variable, we record zero or almost zero coefficients for all cases except for, on the one hand, the Japanese exchange rate that is caused by the interest rates of all other countries except for Australia and Mexico, and on the other hand, the Mexican exchange rate that is caused by the Japanese interest rate. All coefficients are significant at the 1% level.

E. Interpretation of Results

The main objective of this section is to check the presence of financial contagion within and across three different markets: the stock market, the monetary market, and the foreign exchange market. For this reason, we study the correlation between the different countries and in the same markets. First, we test the random walk hypothesis in these three markets of seven countries and regions. We use two unit root tests (ADF and PP) and find that the markets follow a random walk without exception. Second, we examine intra-market causality using the one-lagged VAR model. Concerning foreign exchange markets, we notice perplexing results in terms of reciprocal causality. The causal relationship is characterized by sometimes causalities in one direction and sometimes by reciprocal causality. For example, the Japanese exchange rate is caused by any other exchange rate as it does not cause any exchange rate. Reversely, the British exchange rate causes all other exchange rates and is caused by none. This finding means that if there is a crisis in Japan, then it will not spread; however, if there is a crisis in the UK, then it will spread to all the studied countries.

Perplexity of reciprocal causality is relevant also to stock markets. The European market causes other markets, but it is caused by no market. In contrast, the Japanese market will not cause any other market, but it is caused by the U.S., UK, and European markets. Therefore, a crash or a bubble in the European market will spread to other markets, but a crash or a bubble in the Japanese market will probably remain local. As for the U.S. stock market, it is caused by the European, British, and Australian markets, and it causes the Japanese, Canadian, and Mexican markets. Beyond the fact that the U.S. market may be contaminated by a crisis in the European, UK, and Australian markets on the one hand, and the fact that a crisis in the U.S. market can spread to the Canadian, Mexican, and the Japanese markets, we find that a crisis may spread indirectly from one market to another via a third market. For example, British stock exchange crisis does not directly affect the Mexican Stock Exchange, which is indirectly affected by the U.S. stock market. This indirect contagion is found in several other cases.

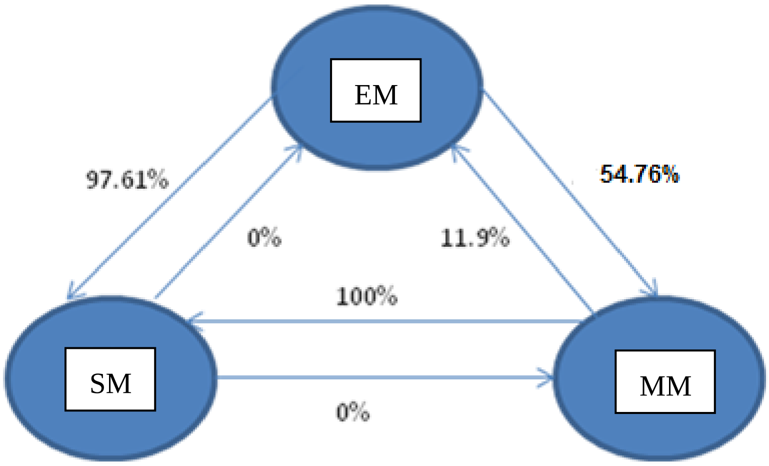
Concerning the monetary markets, contagion is often observed either directly or indirectly. The U.S. market does not cause any other market (except Mexico) and is caused by all other markets. The Mexican market also does not cause any other market. It is obvious that a bubble or a crash in the Mexican market will be local and there will be no contagion.

In summary, a review of the results of intra-market causality leads us to affirm that there is contagion between the various markets of similar nature. However, the cases are rare where contagion is impossible. Generally, the first hypothesis is supported.

If we consider the results of inter-market causality, we notice that there are different interpretations regarding the presence of contagion. The causal relationship between stock markets and currency markets is a one-way relationship. We find 41 of 42 possible cases where contagion takes place from the foreign exchange market to the stock market. However, if there is an abnormality in the stock market, then it does not spread to the currency market. Therefore, contagion between these two markets is one-way (from the foreign exchange market to the stock market).

Concerning the causal relationship between the stock market and the monetary market, the same conclusion is true, but with more certainty. We find in all possible cases (49 cases) the possibility of contagion from monetary markets to stock markets in the case of anomalies. However, there is no contagion in the opposite direction.
The causal relationship between foreign exchange and monetary markets is relatively more complicated. More specifically, if we consider the direction from the foreign exchange market to the monetary market, then we find 23 out of 42 possible cases (54.76%) where there is contagion. In the opposite direction, we find only 5 cases where contagion is possible (11.9%).

Figure 1. Inter-market Contagion



The diagram above summarizes the possibilities of contagion between the three markets. Generally, there is direct and indirect contagions between all markets with the exception of when an abnormality takes place in a stock market, there will be contagion only in stock markets.

In summary, the study of inter-market causality leads us to accept the first hypothesis, which assumes contagion among markets. Contagion takes place when transnational co-movements of prices cannot be explained by fundamentals. This empirical study classifies contagion that is detected into two categories: intra-market and inter-market. The first category occurs through channels of communication between the different markets: trade, hedging, and learning. However, the second category requires channels covering more people and is not specific to the market in question; namely, aggregate shocks, information asymmetry, and media (Rigobon (1999)). The fact that the stock market is affected by the other two markets and does not affect them is explained by stakeholders' mentality and behavior in the monetary and foreign exchange markets. These stakeholders can easily collect information on the stock market (no information asymmetry), while participants in the financial market cannot properly judge a shock to the financial market, because of scarcity of information (information asymmetry). Our results are consistent with those of Reside and Gochoco-Bautista (1999), Rigobon (2001), Van Rijckghem and Weder (1999), Veysov (2012), and Mondria and Quinta-Domeque (2013).

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