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▶ **To cite this version:**

Imen Zorgati, Faten Lakhal. Spatial contagion in the subprime crisis context: Adjusted correlation versus local correlation approaches. Economic Modelling, 2020, 92, pp.162 - 169. 10.1016/j.econmod.2019.12.015 . hal-03492235

HAL Id: hal-03492235

https://hal.science/hal-03492235v1

Submitted on 5 Sep 2022

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Version of Record: https://www.sciencedirect.com/science/article/pii/S026499931930286X
Manuscript_9f5fe229b701121924b9ac7dbef48edc

Spatial contagion in the subprime crisis context: Adjusted correlation versus local correlation approaches

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Abstract

This paper investigates the influence of the spatial dimension on financial contagion in the subprime crisis based on adjusted and local correlation measures. Daily series of stock indexes of American and Asian countries are used from January 1, 2003, to December 30, 2011. We consider two groups of countries: the first group includes the United States and countries that are geographically close: Brazil, Argentina, Mexico, and Canada. The second group includes countries that are geographically distant from the United States: Hong Kong, India, Australia, Indonesia, Malaysia, South Korea, China, and Singapore. The results show that simple and adjusted correlations are not enough to explain the spatial effect of contagion. Using local correlations and polynomial regressions, the results show the existence of spatial contagion between the United States and all countries in the American region. As for countries that are geographically distant from the United States, we prove the existence of spatial contagion between only some groups of countries (United States/India, United States/Australia, United States/Indonesia, United States/Malaysia, United States/China). These results have international diversification, and within-industry implications.

Keywords: contagion, adjusted correlation, local correlation, spatial effect, polynomial local regression

JEL Classification: G010, C1, C14, C58

1. Introduction

Since the Asian crisis (1997), the contagion phenomenon has attracted growing attention, and become the most debated topic in international finance. Several studies have investigated financial contagion (Eichengreen et al. 1996; Forbes and Rigobon, 2001; Marais and Bates, 2006; El Ghini and Saidi, 2015; Roy and Roy, 2017). However, the definition and measurement of contagion are still controversial.

The most commonly used definitions of financial contagion are provided by Eichengreen et al. (1996) and Forbes and Rigobon (2001). According to Eichengreen et al. (1996), contagion is "a significant increase in the likelihood of a crisis in one country, conditional on the occurrence of a crisis in another country." Forbes and Rigobon (2001) define contagion as "a significant increase in cross-market linkages after a shock to an individual country (or group of countries)." Contagion occurs when the degree of the co-movement between two markets is high during the stability period and continues to increase after the shock.

An extensive literature investigates the financial contagion phenomenon, its measures and the associated market volatility. Samarakoon (2011) examines the transmission of shocks between the U.S. and foreign markets. He finds that there is interdependence and contagion in emerging markets, with important regional variations. Baur (2012) studies contagion for major stock markets and their real economy sectors during the global financial crisis. He finds that no country and sector were immune to the adverse effects of the crisis, but some sectors were less severely affected. Bekaert et al. (2014) analyze the transmission of the subprime crisis to 415 country-industry equity portfolios. They use a factor model to predict crisis returns, and show evidence of contagion from the U.S. and the global financial sector, where the effects are small.

Using asymmetric conditional correlation dynamics across stable and crisis periods, Kenourgios (2014) shows the existence of contagion in market volatilities across U.S. and European stock markets during the global financial crisis. More recently, Kenourgios and Dimitriou (2015) test different channels of financial contagion using a dynamic conditional correlation from the multivariate fractionally integrated asymmetric power ARCH (FIAPARCH) model. They find that the subprime crisis was associated with contagion effects across regional stock markets, and regional financial and non-financial sectors. Jondeau and Rockinger (2006), Dimitriou et al. (2013), and Kenourgios (2014) use alternative approaches such as copulas, the copula-GARCH model, a multivariate regime-switching Gaussian copula

model, and the asymmetric generalized dynamic conditional correlation (AG-DCC) approaches.

This paper differs from previous papers as it focuses on the spatial aspect of contagion. Bradley et al. (2004) and Fabrizio (2014) argue that spatial contagion between two financial markets X and Y occurs when there is a high dependence between X and Y. Several methods have been adopted to test the presence of the spatial aspect of contagion. The existing literature on financial contagion relies mostly on the classical correlation approach (King and Wadhwani, 1990; Baig and Goldfajn, 1999; Forbes and Rigobon, 2001; Corsetti et al. 2002; Forbes and Rigobon, 2003 and Chiang et al. 2007). Contagion effects are commonly measured with correlation coefficients. Contagion exists when the correlation coefficient increases during the crisis period. Inversely, there is only a financial interconnection. In this context, King and Wadhwani (1990) show that the correlation between US markets, the United Kingdom, and Japanese markets increases significantly after the U.S. crisis in 1987.

However, the correlation coefficient used to measure contagion is biased because of the heteroscedasticity problem (Corsetti et al. (2002), Forbes and Rigobon (2001) and Lehnert and Verschoor (2003)). In such a case, there will be a change in market volatility from which the crisis originates. To avoid this bias, Forbes and Rigobon (2001) recommend the use of adjusted correlations. In addition to the heteroscedasticity concern, the correlation coefficient is associated with endogenous and omitted variables issues.

Forbes and Rigobon (2001) adopt the adjusted correlation coefficient to overcome the problem of heteroscedasticity, and test the increase of this correlation coefficient. The results show that there is no contagion, but instead, a simple interconnection between countries. The authors argue that the Thai crisis in 1997, for example, was transmitted to other countries via permanent channels that already exist in periods of stability. Similarly, Rigobon (2001) uses adjusted correlation coefficients to overcome issues related to simple correlations and finds similar results. A year later, Forbes and Rigobon (2002) test the significance of increasing the adjusted correlation coefficient to solve the heteroskedasticity problem. The authors show weak correlation tests in the presence of endogenous bias and concern about omitted variables.

To overcome the problems associated with simple and adjusted correlation coefficients, the dependence between X and Y can be measured with the local correlation approach. Bradley et al. (2004) document that local correlation provides a better understanding of the degree of dependence between financial markets.

The purpose of this paper is then to examine the influence of the spatial dimension on financial contagion in the context of the subprime crisis using the local correlation approach. The local correlation coefficient is similar to the classical correlation one. However, the local correlation coefficient is a nonparametric measure designed for the treatment of nonlinear forms of dependence. Besides, previous studies by Cappiello et al. (2006), Jondeau and Rockinger (2006), Kenourgios et al. (2011), Okimoto (2008), Patton (2009), and Pelletier (2006) measure contagion using methods that require the specification of crisis and non-crisis periods. The local correlation approach does not require the specification of crisis and non-crisis periods or the use of heteroscedasticity adjustment.

Thus, this paper contributes to the existing literature in the following aspects. First, we extend previous studies that investigate the contagion phenomenon and its intensity (Einchengreen et al. 1996; Horta et al. 2008; Zorgati et al. 2019). The focus is on the spatial aspect of the contagion phenomenon in the subprime crisis context, that is, the geographic links between markets (American and Asian countries). Second, we propose a novel approach for measuring spatial contagion that does not require the specification of crisis and non-crisis periods. Third, we compare simple and adjusted correlations, and the local correlation approach results. Most studies use either simple and adjusted correlations approaches (Forbes and Rigobon, 2001; Forbes and Rigobon, 2002; Collins and Biekpe, 2002) or the local correlation approach only (Bradley and Taqqu, 2004; Bradeley and Taqqu, 2005a; Bradley and Taqqu, 2005b).

The sample includes data for two groups for the period from January 1, 2003, to December 30, 2011. The first group includes countries that are geographically close: the United States, and Brazil, Argentina, Mexico, and Canada. The second group includes countries that are geographically distant from the United States: Hong Kong, India, Australia, Indonesia, Malaysia, South Korea, China, and Singapore. For more robust results, we compare the results using adjusted and local correlation approaches.

The results show the absence of contagion for all stock markets, except for China based on adjusted correlation. There is then a financial interconnection between the markets, not financial contagion. However, using the local correlation approach, we find that for the first group of countries, the results show a spatial contagion between the U.S. and the countries in the American region. For countries that are geographically distant, the results also reveal the existence of spatial contagion effect for some Asian countries (the U.S and India, the U.S. and Australia, the U.S. and Indonesia, the U.S. and Malaysia, and the U.S. and China). These

findings suggest that spatial proximity plays a significant role in the contagion phenomenon, and therefore, the links between countries are geographic.

The remainder of this paper is organized as follows. In Section 2, we describe the data and methodology. In Section 3, we present the results and discussion. In Section 4, we conclude the paper.

2. Data and methodology

2.1. Data

We use daily series of stock indexes of American and Asian countries (five days a week)[1]. Although Narayan and Sharma (2015) and Narayan et al. (2015) argue that hypotheses tests in finance are data frequency dependent, a recent study by Narayan and Bannigidadmath (2016) asserts that daily data are better than monthly data when the objective is to obtain as much information as possible from the data.

As we examine the U.S. subprime mortgage crisis of 2007-2008, the studied period covers 9 years, from January 1, 2003, to December 30, 2011. The sample is divided into two groups of countries. The first group includes countries that are geographically close: the United States (SP500) and four countries in the American region (Brazil (BVSP), Argentina (Merv), Mexico (MXX), and Canada (SP & TSX)). The second group includes countries that are geographically distant from the United States: countries in the Asian region (Japan (Nikkei 225), Hong Kong (Hangseng HSI), India (BSESN), Australia (AORD), Indonesia (JKSE), Malaysia (KLSE), South Korea (KS11), China (China Shanghai Composite Index SSE), and Singapore (STI), with the United States (SP500) a country from which the subprime crisis originated.

Various techniques are used in the literature to distinguish between crisis and stable periods. Forbes and Rigobon (2002) use ad-hoc definitions of the crisis period, and Boyer et al. (2006) and Rodriguez (2007) use a regime-switching model to identify the crisis period endogenously. In addition, Baur (2012) uses timelines provided by the Federal Reserve Board of St. Louis (2009) and the Bank for International Settlements (BIS, 2009) to separate the global financial crisis into four phases, based on major key economic and financial events. Other studies combine statistical and economic approaches to specify the length of the crisis (Baur, 2012; Dimitriou et al., 2013; Kenourgios, 2014). Other researchers consider the crisis period from August 2007 until March 2009. We use the wavelet technique on the series stock market

[1] When data are not available due to bank holidays, vacation days, or other reasons, the price of the stock index is assumed to be equal to the price of the previous trading day.

returns' indexes of the U.S. market (the originating crisis market). The dissociation of the American index according to the Haar wavelet at level 4 shows that the first sign of crisis begins on July 17, 2007. For sensitivity checks, we also use all series stock market returns' indexes to identify the first crisis date. The results show that the first day of the crisis is near August 1, 2007, for all the markets affected by the subprime crisis. Hota et al. (2010) also consider August 1, 2007, as the first day of the subprime crisis. We use this date to distinguish between two types of periods (crisis and stable) as we first apply the simple and adjusted correlation approaches to test for the contagion phenomenon.

Second, for the local approach used to test the spatial contagion, the specification of crisis and stable periods is not required. Therefore, this study is based on the whole period.

2.2. Methodology

We rely on adjusted and local correlation approaches and compare them to conclude about the existence of spatial contagion.

2.2.1. The correlation approach

a. Simple correlation

Drawing on the work of Forbes and Rigobon (2001), we find that the correlation coefficient measures co-movements between two markets. There is a contagion effect when this coefficient increases significantly during the crisis period.

Forbes and Rigobon (2001) propose the following correlation coefficient:

$$\rho_{(x_t, y_t)} = \frac{\mathrm{cov}(x_t, y_t)}{\sigma_{x_t} \sigma_{y_t}} \quad ,$$

with x_t and y_t as two financial series.

b. Adjusted correlation

To test the financial contagion in the stock markets, Forbes and Rigobon (2002) adjust the preceding correlation. The adjusted correlation coefficient is calculated as follows:

$$\rho^* = \frac{\rho}{\sqrt{1 + \delta\left[1 - (\rho)^2\right]}} ,$$

where $\delta = \frac{v^c(x_t)}{v^t(x_t)} - 1$.

c and t are the crisis and stability periods, respectively. δ refers to the increase between the crisis and stability periods.

We test the increase of the adjusted correlation coefficient as follows:

$$\begin{cases} H_0 : \rho_1^* = \rho_2^* \\ H_1 : \rho_1^* \succ \rho_2^* \end{cases},$$

where ρ_1^* is the correlation coefficient of the crisis period, and ρ_2^* is the correlation coefficient of the stability period.

The test of hypothesis H_0 expresses the existence of an increase in the correlation coefficient. This means that there is a simple interconnection between the markets; whereas hypothesis H_1 implies evidence of a pure contagion phenomenon.

To test these hypotheses, we refer to Collins and Biekpe (2002), and use the Student t-test, in which the t-statistic is as follows:

$$t = (\rho_1^* - \rho_2^*)\sqrt{\frac{n_1 + n_2 - 4}{1 - (\rho_1^* - \rho_2^*)^2}} \to t(0.05, n_1 + n_2 - 4),$$

where t follows a student test with degree of freedom is n_1+n_2-4.

2.1.2. Local correlation approach

The local correlation approach is proposed by Bjerve and Doksum (1993) and Doksum et al. (1994). It extends the connection between regression slopes, the strength of the relationships and the variance explained by regression, to nonlinear models. According to these authors, the local correlation approach is appropriate when dealing with non-normal distributions.

First, the authors assume that:

$$(X, Y) \to N\left(\mu_X, \mu_Y; \sigma_X^2, \sigma_Y^2, \rho\right)$$

and $Y / X = X \to N\left\{\mu_Y + \rho(\sigma_Y / \sigma_X)(X - \mu_X); \sigma_Y^2(1 - \rho^2)\right\}$.

The regression model then is as follows:

$Y = \alpha + \beta X + \sigma \varepsilon$,

where $\varepsilon \rightarrow N(0,1)$ is independent of X.

In this case, $m(x) = E(Y / X = x) = \alpha + \beta X$,

where the slope of the regression is $m'(x) = \beta$.

This slope is also given by $\rho = \beta(\sigma_X / \sigma_Y)$.

For linear regression theory, the variance σ_Y^2 of Y is the sum of the variance explained by the regression, namely, $\beta^2 \sigma_X^2$, where the residuals of the variance are noted: $\sigma_Y^2 = \beta^2 \sigma_X^2 + \sigma^2$.

The local correlation coefficient is then calculated as follows: $\rho = \sigma_X \beta / (\sigma_X^2 \beta^2 + \sigma^2)^{1/2}$.

a. Estimation procedure based on local polynomial regression

Bradley and Taqqu (2004) establish a definition of contagion between financial markets based on estimations of local correlation to test the contagion effect. There are two non-parametric regression methods for the estimation: the Kernel regression, also known as the kernel density estimation (Nadaraya, 1964, Watson, 1964), and the polynomial local regression (Cleveland, 1979, Cleveland and Devlin, 1988). According to Nadaraya (1964), the first estimation method lacks robustness in its estimators for the extreme values of X. To overcome this problem, the author suggests the use of the local regression method. Bradeley et al. (2005a) describe an estimation procedure based on nonparametric local polynomial regression. The latter is estimated by dividing the space of the explanatory variables into zones and by applying a regression on each zone.

We refer to Bradeley et al.'s (2004) definition of spatial contagion. There is a spatial contagion from market X to market Y if:

$$\rho(x_L) \succ \rho(x_M),$$

where $x_M = F_X^{-1}(0.5)$ is the median of the X distribution, and $x_L = F_X^{-1}(0.025)$ is the lowest quantile of the distribution[2].

The contagion phenomenon exists when there is a significant high dependence on the tail of the loss distribution, measured with local correlations.

In this study, we use a spatial contagion test that better checks the dependence between X and Y. Formally, we test the following hypotheses:

$$H_0 : \rho(x_L) \leq \rho(x_M) \quad (no\ contagion)$$
$$H_1 : \rho(x_L) \succ \rho(x_M) \quad (contagion)$$

Accordingly, we follow Bradely et al. (2005a), and use the estimation procedure based on local polynomial regression.

The analysis procedure can be summarized in three steps.

Step 1: Apply a local quadratic regression to estimate $\beta(x_0)$ using an estimate of the asymptotically optimal bandwidth value of the regression to reduce the bias.

Step 2: Use a local linear regression on the residual squares to estimate $\sigma^2(x_0)$ using, again, the asymptotically optimal bandwidth associated with this regression. To do this, Bradeley et al. (2005a) use techniques developed by Ruppert et al. (1997).

Step 3: Determine $\hat{\rho}(x_0)$ and show that it is asymptotically normal.

The estimation procedure described above leads to an estimation of the local correlation of the form: $\hat{\rho}^2(x_0) = \dfrac{s(X)\hat{\beta}(x_0)}{\sqrt{s_X^2\hat{\beta}^2(x_0) + \hat{\sigma}^2(x_0)}}$,

where $s_X^2 = \dfrac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X}^2)$ is the variance estimator of σ_X^2 , and $\hat{\beta}(x_0)$ is the result of the quadratic local regression using the bandwidth $h_1 = O \times (n^{-1/(2p+3)})$ [3].

[2] The choice of the 2.5% quantile can be modified in accordance with the notions of crisis. In some cases, the 2.5% quantile can be reached when the data are concentrated around the median.

[3] Bradeley et al. (2005a)

3. Results and discussion

3.1. Simple correlation coefficient results

The simple correlation coefficients for the total period, including the stability and crisis periods, and their *t*-statistics tests are reported in Table 1. During the stability period, the correlation coefficient is small, ranging from 0.0412 for Malaysia to 0.5982 for Canada. This coefficient increases during the crisis period. The results show that there is a strong correlation between the U.S. market and other markets. For instance, the correlation between the U.S. market and the Canadian market is 0.5982 during the stability period and 0.7334 during the crisis period. The significant increase in the correlation coefficient shows the existence of the contagion phenomenon.

In addition, Table 1 shows that the unadjusted correlation coefficient and the Student *t*-statistic test suggest that the financial contagion phenomenon exists for all financial markets, except for China. These results are similar to those found by Baig and Glodfajn (1999), who show a significant increase in correlations during the crisis period.

Table 1. Simple correlation coefficients

Region	Country	Total Period	Stability period	Crisis period	*t*-statistic	Spatial contagion?
		ρ	ρ	ρ		
	Japan	0.1446	0.0883	0.1600	3.4790	Yes
	Hong Kong	0.2056	0.1199	0.2227	4.997	Yes
Asian	India	0.2296	0.0971	0.2789	8.9402	Yes
	Australia	0.1156	0.0487	0.1295	3.9222	Yes
	Indonesia	0.1280	0.0522	0.1553	5.0119	Yes
	Malaysia	0.1009	0.0412	0.1183	3.7410	Yes
	South Korea	0.1913	0.1221	0.2197	4.7432	Yes
	China	0.0200	0.0559	0.0101	-2.2192	No
	Singapore	0.2631	0.1660	0.2875	5.9221	Yes
	Brazil	0.6655	0.5767	0.7126	6.6356	Yes
American	Argentina	0.5278	0.3235	0.6054	14.2109	Yes
	Mexico	0.7092	0.5724	0.7674	9.6132	Yes
	Canada	0.7107	0.5982	0.7334	6.6000	Yes

$$t = (\rho_1^* - \rho_2^*)\sqrt{\frac{n_1 + n_2 - 4}{1 - (\rho_1^* - \rho_2^*)^2}} \rightarrow t(0.05, n1 + n2 - 4)\ .$$

n_1 and n_2 indicate the stability and crisis periods, respectively.

3.2. Adjusted correlation coefficient results

Previous researchers such as King and Wadhwani (1990), Forbes and Rigobon (2002) and Longin and Solnik (2001) argue that the simple correlation coefficient has several limitations,

Forbes and Rigobon (2002) and Collins and Biekpe (2003) use an adjustment of this correlation coefficient.

We estimate the adjusted correlation coefficient (Table 2) following Forbes and Rigobon (2002). The Student *t* test is then calculated to check for the existence of the spatial contagion phenomenon (Table 3). The adjusted correlation coefficient is measured as follows:

$$\rho^{crise} = \frac{\sigma^{crisis}_{r_j, r_i}}{\sigma^{crisis}_{r_j}\sigma^{crisis}_{r_i}} = \frac{(1+\delta)\sigma^{stab}_{r_j, r_i}}{(1+\delta)^{1/2}\sigma^{stab}_{r_j}(1+\delta(\rho^{stab})^2)^{1/2}\sigma^{stab}_{r_i}} = \rho^{stab}\sqrt{\frac{1+\delta}{1+\delta(\rho^{stab})^2}}$$

$$\rho^{stab} = \rho^{crisis}\sqrt{\frac{1+\delta}{1+\delta(\rho^{crisis})^2}},$$

Where,

$\delta = \frac{v^c(x_t)}{v^t(x_t)} - 1$; *c* and *t* indicate the crisis and stability periods, respectively.

Table 2 shows that the adjustment for heteroscedasticity has a significant impact on correlations. The adjusted correlation coefficient is significantly lower (higher), in absolute value, than the unadjusted correlation coefficient, during the crisis period (stability period). For instance, the simple correlation coefficient for India during the stability period is 0.0971 where the adjustment equals 0.3270 suggesting that there is an increase after the adjustment for heteroscedasticity. The coefficient of the unadjusted correlation is 0.2789 for the same country during the crisis period. After the adjustment, this coefficient decreases to 0.1155.

Table 2. Adjusted correlation coefficients during the stability and crisis periods

Region	Country	Stability period			Crisis period		
		σ^{stab}	ρ	ρ_{adjusted}	σ^{crisis}	ρ	ρ_{adjusted}
	Japan	1.1289	0.0883	0.2094	1.9693	0.1600	0.1153
	Hong Kong	0.9415	0.1199	0.3296	2.1986	0.2227	0.1815
Asian	India	1.3688	0.0971	0.3270	1.9431	0.2789	0.1155
	Australia	0.6379	0.0487	0.1914	1.4219	0.1295	0.0615
	Indonesia	1.2031	0.0522	0.1852	1.7471	0.1553	0.0629
	Malaysia	0.6679	0.0412	0.1535	1.1345	0.1183	0.0537
	South Korea	1.2837	0.1221	0.2592	1.8092	0.219	0.1445
	China	1.4290	0.0559	0.0142	2.5216	0.0101	0.0783
	Singapore	0.8869	0.1660	0.3843	1.7047	0.2875	0.2273
	Brazil	1.5606	0.5767	0.7698	2.1988	0.7126	0.6424
American	Argentina	1.6712	0.3235	0.6747	2.4132	0.6054	0.3800
	Mexico	1.0953	0.5724	0.8254	1.6239	0.7674	0.6499
	Canada	0.7061	0.5982	0.8552	1.6515	0.7334	0.7523

a. Test for the existence of spatial contagion

We draw on work of Collins and Biekpe (2003) and use the Student test whose *t*-statistic is as follows:

$$t = (\rho_1^* - \rho_2^*)\sqrt{\frac{n_1 + n_2 - 4}{1-(\rho_1^* - \rho_2^*)^2}} \rightarrow t(0.05, n1 + n2 - 4)\ ,$$

where *t* follows the Student law with $n_1 + n_2 - 4$ degree of freedom.

Table 3 shows the results associated with this test. The adjustment of heteroscedasticity has a significant impact on the results of the contagion tests. The adjusted correlation coefficient shows the absence of the contagion phenomenon for all stock markets except China. This finding confirms the results found by Forbes and Rigobon (2002). Thus, there is only a financial interconnection between the markets, and not a financial contagion.

Table 3. Test of existence of spatial contagion

Region	Country	Stability period	Crisis period	*t*-statistics	Spatial contagion?
		ρ_{adjusted}	ρ_{adjusted}		
	Japan	0.2094	0.1153	-4.5706	No
	Hong Kong	0.3296	0.1815	-7.2408	No
Asian	India	0.3270	0.1155	-10.4555	No
	Australia	0.1914	0.0615	-6.2690	No
	Indonesia	0.1852	0.0629	-5.9567	No
	Malaysia	0.1535	0.0537	-4.8523	No
	South Korea	0.2592	0.1445	-5.5978	No
	China	0.0142	0.0783	3.1058	Yes
	Singapore	0.3843	0.2273	-7.6879	No
	Brazil	0.7698	0.6424	-6.2143	No
American	Argentina	0.6747	0.3800	-22.5417	No
	Mexico	0.8254	0.6499	-8.6207	No
	Canada	0.8552	0.7523	-5.0053	No

To sum up, simple and adjusted correlations are not powerful enough to explain the spatial effect of contagion. In addition, the contagion between countries can be affected, for example, by trade links. Furthermore, these two approaches are associated with short-term relationships between stock markets without taking into account the direction of causality between them. As these results are inconclusive, we examine spatial contagion via the local correlation approach.

3.3. The spatial contagion results via the local correlation approach

a. Step 1: Estimating $\beta(x_0)$

According to Bradley and Taqqu (2004), the spatial contagion between financial markets is based on local correlation. The first step then is to make a quadratic local regression to infer $\beta(x_0)$. We select the optimal bandwidth associated with this regression.

To determine the quadratic local regression for the two groups of countries, we try to select the optimal bandwidth associated with this regression. Table 4 shows that for the United States and Asian countries, the bandwidth is between 0.6245 (the U.S. and Australia) and 1.607 (the U.S. and China); while for the group of countries close to the United States, the bandwidth ranges between 0.7453 (the U.S. and Canada) and 1.200 (the U.S. and Brazil). This bandwidth is associated only with this quadratic regression. For the second linear local regression adopted in the next step, the bandwidth changes. It is a piecewise nonparametric local polynomial regression.

Table 4. Identification of optimal bandwidths h1 and h2 for the markets: The United States and Asian countries and countries in the American region (total period)

Region	Markets	*Bandwidth*: h1	*Bandwidth:* h2
	U.S./Japan	1.1757	0.4276
	U.S./Hong Kong	1.1485	0.2926
	U.S./India	1.2465	0.2972
	U.S./Australia	0.6245	0.3542
Asian region	U.S./Indonesia	1.093	0.5495
	U.S./Malaysia	0.7510	0.3082
	U.S./South Korea	1.156	0.5312
	U.S./China	1.6071	0.1161
	U.S./Singapore	0.8560	0.4098
	U.S./Brazil	1.2008	0.5702
	U.S./Argentina	1.1508	0.5230
American region	U.S./Mexico	0.9989	0.3792
	U.S./Canada	0.7453	0.3393

After identifying the optimal bandwidth, we estimate $\beta(x_0)$ under the following condition:

$$\hat{\beta}(x_0) = (X_P(x_0)^T W_h(x_0) X_P(x_0))^{-1} X_P(x_0)^T W_h(x_0) y^4.$$

For a polynomial p that equals to 2 (quadratic regression), and using the bandwidth h1 associated with this regression, we obtain the estimator of $\beta(x_0)$, from which we deduce $\hat{\beta}(x_M)$ and $\hat{\beta}(x_L)$.

$x_M = F_X^{-1}(0.5)$ is the median of the distribution of X, and $x_L = F_X^{-1}(0.025)$ is its lowest quantile.

Table 5 shows that the value of $\hat{\beta}(x_L)$ is higher than the value of $\hat{\beta}(x_M)$. These two estimators are crucial for the next step of the procedure.

[4] See Bradeley et al. (2005a) for more details.

Table 5. Estimation of $\beta(x_0)$: The United States and Asian countries and countries in the American region

Region	Markets	$\hat{\beta}(x_M)$ / $\hat{\beta}(x_L)$
Asian region	U.S./Japan	$\hat{\beta}(x_M)$ = -0.2249 / $\hat{\beta}(x_L)$ = 0.0255
	U.S./Hong Kong	$\hat{\beta}(x_M)$ = -0.5091/ $\hat{\beta}(x_L)$ = 0.0282
	U.S./India	$\hat{\beta}(x_M)$ = -0.6918/ $\hat{\beta}(x_L)$ = 0.0428
	U.S./Australia	$\hat{\beta}(x_M)$ = -0.3714/ $\hat{\beta}(x_L)$ = 0.0257
	U.S./Indonesia	$\hat{\beta}(x_M)$ = -0.2735/ $\hat{\beta}(x_L)$ = 0.0020
	U.S./Malaysia	$\hat{\beta}(x_M)$ = -0.2804/ $\hat{\beta}(x_L)$ = 0.0104
	U.S./South Korea	$\hat{\beta}(x_M)$ = -0.2675/ $\hat{\beta}(x_L)$ = 0.0007
	U.S./China	$\hat{\beta}(x_M)$ = -0.0403/ $\hat{\beta}(x_L)$ = 0.0150
	U.S./Singapore	$\hat{\beta}(x_M)$ = -0.0971/ $\hat{\beta}(x_L)$ = -0.0023
American region	U.S./Brazil	$\hat{\beta}(x_M)$ = -1.8515/ $\hat{\beta}(x_L)$ = -0.003
	U.S./Argentina	$\hat{\beta}(x_M)$ = -1.6314/ $\hat{\beta}(x_L)$ = 0.0315
	U.S./Mexico	$\hat{\beta}(x_M)$ = -1.9115/ $\hat{\beta}(x_L)$ = 0.0607
	U.S./Canada	$\hat{\beta}(x_M)$ = -2.202/ $\hat{\beta}(x_L)$ = 0.0224

b. Step 2: Estimate the residual variance

The second step is to apply a linear local regression (*p = 1*) on the residual squares to obtain $\hat{\sigma}^2(x_0)$. To do this, we use a second bandwidth h2 associated with this regression. Table 4 shows the values of the optimal bandwidth associated with this second regression (local linear regression), which the polynomial (*p = 1*) is different from the one found in the quadratic regression (*p = 2*). We also get a bandwidth h2 different from h1. For the first group of countries, the value of the bandwidth is between 0.1161 (the U.S. and China) and 0.5495 (the U.S. and Indonesia). For the second group of countries, the bandwidth ranges between 0.339 (the U.S. and Canada) and 0.5702 (the U.S. and Brazil).

We then estimate $\sigma^2(x_0)$ through a linear local regression (p = 1) on the residual squares. This estimation procedure is similar to the one used in the first step.

Let $\hat{r} = (Y_1 - \hat{m}(X_1), \ldots, Y_n - \hat{m}(X_n))^T$ be the vector of the estimated residuals for the regression function. The residual variance estimator at this point is determined using the following equation:

$$\hat{\sigma}^2(x_0) = \frac{e_1^T (X_{p_2}(x_0)^T W_{h_2}(x_0)(X_{p_2}(x_0))^{-1} X_{p_2}(x_0)^T W_{h_2}(x_0)\hat{r}^2}{1 + e_1^T (X_{p_2}(x_0)^T W_{h_2}(x_0)(X_{p_2}(x_0))^{-1} X_{p_2}(x_0)^T W_{h_2}(x_0)\Delta}$$ [5].

We then deduce the residual variance estimator at X_M and X_L.

Table 6 presents the residual variance estimators for the two groups of countries. We show that the residual variance estimator associated with the X_L point is higher than that of the residual variance at the X_M point. These two estimators are used to compute the local correlation.

Table 6. The residual variance estimators for the two groups of countries $\hat{\sigma}^2(x_L)$ / $\hat{\sigma}^2(x_M)$

Region	Markets	$\hat{\sigma}^2(x_L)$ / $\hat{\sigma}^2(x_M)$
	U.S./Japan	$\hat{\sigma}^2(x_M) = 1.1545/\hat{\sigma}^2(x_L) = 1.234$
	U.S./Hong Kong	$\hat{\sigma}^2(x_M) = 1.083/\hat{\sigma}^2(x_L) = 1.314$
	U.S./India	$\hat{\sigma}^2(x_M) = 0.905/\hat{\sigma}^2(x_L) = 1.459$
	U.S./Australia	$\hat{\sigma}^2(x_M) = 1.014/\hat{\sigma}^2(x_L) = 1.327$
	U.S./Indonesia	$\hat{\sigma}^2(x_M) = 1.1521/\hat{\sigma}^2(x_L) = 1.4440$
Asian	U.S./Malaysia	$\hat{\sigma}^2(x_M) = 1.2257/\hat{\sigma}^2(x_L) = 1.419$
	U.S./South Korea	$\hat{\sigma}^2(x_M) = 1.226/\hat{\sigma}^2(x_L) = 1.289$
	U.S./China	$\hat{\sigma}^2(x_M) = 1.345/\hat{\sigma}^2(x_L) = 1.618$
	U.S./Singapore	$\hat{\sigma}^2(x_M) = 1.324/\hat{\sigma}^2(x_L) = 1.586$
	U.S./Brazil	$\hat{\sigma}^2(x_M) = 0.5864/\hat{\sigma}^2(x_L) = 0.6840$
American	U.S./Argentina	$\hat{\sigma}^2(x_M) = 0.7317/\hat{\sigma}^2(x_L) = 0.7952$
	U.S./Mexico	$\hat{\sigma}^2(x_M) = 0.5139/\hat{\sigma}^2(x_L) = 0.566$
	U.S./Canada	$\hat{\sigma}^2(x_M) = 0.4508/\hat{\sigma}^2(x_L) = 0.5181$

c. Step 3. Estimate $\hat{\rho}(x_0)$ and test for the existence of spatial contagion

In the last step, we check for the existence of spatial contagion. First, we compute the local correlation estimator. We use the estimation procedure described above, which leads to an estimation of the local correlation of the following form:

$$\hat{\rho}(x_0) = \frac{s(X)\hat{\beta}(x_0)}{\sqrt{s_X^2 \hat{\beta}^2(x_0) + \hat{\sigma}^2(x_0)}},$$

[5] Bradeley et al. (2005a)

where $s_X^2 = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X}^2)$ is the variance estimator of σ_X^2 .

Table 7 reports the local correlations associated with the median of X and with the lowest quantile of the distribution of X for the two groups of countries. These estimators take the same sign as $\hat{\beta}(x_M)$ and $\hat{\beta}(x_L)$, and help us conclude about the existence of spatial contagion between countries.

Second, we compute the Z-statistic to check for the existence of spatial contagion between the designated markets.

The Z-statistic is calculated as follows:

$$Z = \frac{\hat{\rho}(x_L) - \hat{\rho}(x_M)}{\sqrt{\hat{\sigma}^2_{\hat{\rho}(x_L)} + \hat{\sigma}^2_{\hat{\rho}(x_M)}}} \quad .$$

We reject H_0 and conclude that spatial contagion exists, whenever $Z \succ z_{1-\alpha} = 1.65$, where $\alpha = 0.05$, and $(1-\alpha)$ is the quantile of a standard normal distribution. $\hat{\rho}(x)$ and $\hat{\sigma}^2_{\hat{\rho}(x)}$ are calculated using two formulas: $\hat{\rho}(x_0) = \frac{s(X)\hat{\beta}(x_0)}{\sqrt{s_X^2\hat{\beta}^2(x_0) + \hat{\sigma}^2(x_0)}}$ and

$$\hat{\sigma}^2_{\hat{\rho}(x_0)} = \hat{\sigma}^2_{\hat{\beta}}(x_0)\frac{S_X^2}{\hat{\sigma}^2_{(x_0)}}\left[1 - \hat{\rho}^2(x_0)\right]^3 .$$

Table 7 shows that the Z-statistic is higher than 1.65 for the countries in the American region. We can conclude that there exists spatial contagion between the United States and the countries in the American region. This result suggests that spatial proximity plays a crucial role in the contagion phenomenon, and therefore, the connections between countries are geographic. For countries that are geographically distant (the United States with Asian countries), the results also reveal the existence of spatial contagion for some countries (the U.S. and India, the U.S. and Australia, the U.S. and Indonesia, the U.S. and Malaysia, and the U.S. and China).

Thus, there are geographic transmission channels between all the countries in the first group (where spatial proximity is high). However, for the second group (where spatial proximity is low), we argue that the links between the countries are economic, financial, and political, and that the geographic nature of the links was confirmed only for some countries. This finding is

consistent with Zorgati et al.'s (2019) evidence of financial contagion between countries that are geographically close (the U.S. and Brazil, the U.S. and Argentina, the U.S. and Mexico, and the U.S. and Canada) using the copula approach. This result suggests that the role of spatial proximity is important in the contagion phenomenon.

The correlation and local correlation approaches suggest that the simple and adjusted correlations, adopted by Forbes and Rigobon (2002) and Collins and Biekpe (2003), have some limitations, and that their results are inconclusive. In addition, these two techniques are applied on short-term relationships between stock markets without considering the direction of causality in these relationships.

Overall, the local correlation approach is more robust than simple and adjusted correlations. Thus, although the local correlation coefficient is similar to the classical correlation one, it remains a nonparametric measure designed for the treatment of nonlinear forms of dependence. The measurement of local correlation does not require the specification of crisis and non-crisis periods or the use of a correction for heteroscedasticity

Table 7. Z-statistics and conclusion about the spatial contagion for the U.S. market with Asian and American markets

Markets	$\hat{\rho}(x_M)$	$\hat{\rho}(x_L)$	$\hat{\sigma}^2_{\hat{\rho}(x_M)}$	$\hat{\sigma}^2_{\hat{\rho}(x_L)}$	Z	Spatial contagion
U.S./Japan	-0.1991	0.0367	0.0473	0.1756	0.4996	No
U.S./Hong Kong	-0.6352	0.0413	0.0383	0.2834	1.1926	No
U.S./India	-0.4631	0.0601	0.0238	0.0239	2.3945	Yes
U.S./Australia	-0.2440	0.0284	0.0046	0.0197	1.7460	Yes
U.S./Indonesia	-0.2341	0.0022	0.0058	0.0131	1.7142	Yes
U.S./Malaysia	-0.6173	0.0082	0.0065	0.0301	3.2659	Yes
U.S./South Korea	-0.2488	0.0011	0.0525	0.2357	0.4654	No
U.S./China	-0.2709	0.0241	0.0018	0.0050	3.5525	Yes
U.S./Singapore	-0.1134	-0.0024	0.0226	0.0261	0.5020	No
U.S./Brazil	-0.977	-0.0073	0.0041	0.0760	3.4257	Yes
U.S./Argentina	-0.9693	0.073	0.0058	0.1144	3.0046	Yes
U.S./Mexico	-0.4662	0.1154	0.0039	0.0804	2.0018	Yes
U.S./Canada	-0.7291	0.0417	0.0034	0.0434	3.5612	Yes

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3.4. Economic implications of the results

The subprime crisis in 2007 was one of the most unanticipated and tumultuous economic events in recent history. The crisis affected equity markets worldwide, with many countries experiencing even sharper equity market crashes than the U.S., making the 2007 crisis an ideal laboratory to revisit the debate about the presence and sources of contagion in equity markets.

In addition, the subprime crisis in 2007 affected several economic sectors. The two most direct effects are the occurrence of an economic crisis and huge losses incurred by banks and hedge funds (Baur, 2012).

The subprime crisis spread to the rest of the world through the phenomenon of financial contagion. European banks were the first to be affected. Furthermore, the uncertainties around the interbank market were transmitted to countries that are geographically close (American financial markets). This is consistent with our findings. Indeed, all American markets were directly affected by the subprime crisis (Canada, Brazil, Argentina, Mexico, and the US). We prove that there is spatial contagion between the U.S. and all American markets.

Finally, regarding Asian market countries, we confirm the non-spatial contagion hypothesis of the subprime crisis for Japan and Hong Kong. This finding is similar to Hatemi-J and Roca (2011) who find that there is no spatial contagion effect between the U.S. market and Japan using the bootstrap technique. In addition to geographic distance, Bonner (2008) argues that the resistance to the crisis is due to Japanese psychology. We may say that after the recession in the 1990s, Japanese analysts are more aware in their decisions and reactions to government announcements.

4. Conclusion

The purpose of this study is to examine the influence of the spatial dimension on financial contagion in the context of the subprime crisis. First, we adopt simple and adjusted correlation measures, and then local correlations based on the polynomial local regression.

We use the daily series of stock indexes of American and Asian countries from January 1, 2003, to December 30, 2011. We consider two groups of countries: The first group includes geographically close countries, and the second group includes geographically distant countries. We study the existence of spatial contagion between the countries in each group.

The results of Collins and Biekpe's (2003) correlation approach show that there is a significant increase in the correlation coefficient during the crisis period. The results further show that the

adjustment for heteroscedasticity has a significant impact on the contagion test results. It shows the absence of contagion for all stock markets, except for China. Based on adjusted correlation, we conclude that there exists a financial interconnection between the markets, not financial contagion.

Using the local correlation approach, results show a spatial contagion between the U.S. and the countries in the American region. This finding suggests that spatial proximity plays a significant role in the contagion phenomenon. As for countries that are geographically distant (the U.S. and Asian countries), the results similarly reveal the existence of a spatial contagion for some countries (the U.S. and India, the U.S. and Australia, the U.S. and Indonesia, the U.S. and Malaysia, and the U.S. and China). there is no spatial contagion effect between the U.S. market and Japan using the bootstrap technique. In addition to geographic distance, Bonner (2008) argues that the resistance to the crisis is due to Japanese psychology. We may say that after the recession in the 1990s, Japanese analysts are more aware in their decisions and reactions to government announcements.

To investigate the contagion phenomenon, future research could focus on the spatial econometrics approach in the context of the 2009 economic crisis.

References

Baig, T., Goldfajn, I., (1999), Financial Market Contagion in the Asian Crisis, IMF Staff Papers, 46, pp. 167–95.

Bank for International Settlements, (2009), The international financial crisis: timeline, impact and policy responses in Asia and the Pacific, Bank for International Settlements (August).

Bannigidadmath, D., Narayan, P. K., (2016), Stock return predictability and determinants of predictability and profits, *Emerging Markets Review*, 26, pp 153-173.

Baur, D. G., (2012), Financial contagion and the real economy, *Journal of Banking and Finance*, 36 (10), pp. 2680-98.

Bekaert, G., Ehrmann, M., Fratzscher, M., Mehl, A., (2014), Global crises and equity market contagion, *Journal of Finance*, 69(6), pp. 2597-2649.

Bjerve, S., Doksum, K., (1993), Correlation Curves: Measures of Association as Functions of Covariate Values, *Annals of Statistics*, 21, pp. 890-902.

Bradley, B., Taqqu, M., (2004), Framework for analyzing spatial contagion between financial markets, *Finance Letters*, 2(6), pp. 8-15.

Bradley, B., Taqqu, M., (2005a), Empirical evidence on spatial contagion between financial markets, *Finance Letters*, 3 (1), pp. 77-86.

Bradley, B., Taqqu, M., (2005b), How to Estimate Spatial Contagion between Financial Markets, *Finance Letters*, 3(1), pp. 64-76.

Cappiello, L., Engle, R.H., Sheppard, K., (2006), Asymmetric dynamics in the correlations of global equity and bond returns, *Journal of Financial Econometrics*, 4, pp. 537-572.

Chiang, T. C., Bang, N. J., Huimin, L., (2007), Dynamic correlation analysis of financial contagion: Evidence from Asian markets, *Journal of International Money and Finance*, 26, pp. 1206-1228.

Cleveland, W. S., Devlin, S. J., Grosse, E., (1988), Regression by Local Fitting: Methods, Properties, and Computational Algorithms, *Journal of Econometrics*, 37, pp. 87-1 14.

Collins, D. and Biekpe, N. (2002), Contagion: a fear for African equity markets?, *Journal of Economics & Business*, 55, pp. 285-297

Collins, D., Biepke, N., (2003), Contagion: A fear for African equity markets?, *Journal of Economics and Business*. 55, pp. 285-297.

Dimitriou, D., Kenourgios, D., and Simos, T., (2013), Global financial crisis and emerging stock market contagion: A multivariate FIAPARCH-DCC approach, *International Review of Financial Analysis*, 30, pp. 46-56.

Doksum, K.., Blyth, S., Bradlow, E., Meng, X., Zhao, H., (1994), "Correlation Curves as Local Measures of Variance Explained by Regression", *Journal of the American Statistical Association*, Vol. 89, pp. 571-582.

Eichengreen, B., Rose, A., Wyplosz, C., (1996). "Contagious currency crises: First Tests", Scandinavian Journal of Economics, Vol. 98 (4), pp. 463-484.

El Ghini, A. and Saidi, Y. (2015), Financial market contagion during the global financial crisis: evidence from the Moroccan stock market, *International Journal of Financial Markets and Derivatives*, Vol. 4, (1), pp.78–95.

Fabrizio, D. , Enrico, F., Piotr, J., Hao, W., (2014), A spatial contagion measure for financial time series", Expert Systems with Applications, 41(8), pp. 4023-4034.

Forbes, K., Rigobon, R., (2001). Contagion in Latin America: Definition, Measurement, and Policy Implications, Mit-Sloan school of management and NBER, January 17.

Forbes, K., Rigobon, R., (2002). No contagion, only interdependence: Measuring stock market co-movements. *Journal of Finance*.57 (5), 2223-2261

Hatemi-J, A., Roca, E., (2011). ''How Globally Contagious Was the Recent US Real Estate Market Crisis? Evidence Based on a New Contagion Test'', *Economic Modelling*, 28(6), 2560-2565.

Horta, P., C. Mendes, I. V., (2010). "Contagion effects of the subprime crisis in the European NYSE Euronext markets", Portuguese Economic Journal, 9, 115–140.

Jondeau, E., Rockinger, M., (2006), The copula-garch model of conditional dependencies: An international stock market application, *Journal of International Money and Finance*, 25, pp. 827-853.

Kenourgios, D. (2014). On financial contagion and implied market volatility, *International Review of Financial Analysis*, 34, pp. 21-30.

Kenourgios, D. and D. Dimitriou, (2015), Contagion of the global financial crisis and the real economy: A regional analysis, *Economic Modelling*, 44, pp. 283-293.

Kenourgios, D., A. Samitas and N. Paltalidis (2011), Financial crises and stock market contagion in a multivariate time-varying asymmetric framework, *Journal of International Financial Markets, Institutions & Money*, 21(1), pp. 92-106.

King, M., Wadhwani, S., (1990), Transmission of volatility between stock markets, *Review of Financial Studies*, 3 (1), pp. 5-33.

Longin, F., Solnik, B., (2001), "Extreme Correlation of International Equity Markets", *The Journal of Finance*, Vol. 56(2), pp. 649–676.

Marais, E., Bates S., (2006), An empirical study to identify shift contagion during the Asian crisis", *Journal of International Financial Markets, Institutions and Money*, 16(5), pp. 468-479.

Nadaraya, E. A., (1964), On estimating regression. Theory of Probability and its Applications, 9(1), pp. 141-142.

Narayan, P. K., Sharma, S. S. (2015), Does data frequency matter for the impact of forward premium on spot exchange rate?, *International Review of Financial Analysis*, 39 pp. 45-53.

Narayan, P., Ahmed , H. A., and Narayan, S., (2015), Do Momentum-Based Trading Strategies Work in the Commodity Futures Markets?, *Journal of Futures Markets*, 35, issue 9, pp. 868-891

Okimoto, T., (2008), New evidence of asymmetric dependence structures in international equity markets, *Journal of Financial and Quantitative Analysis*, 43, pp. 787-815.

Patton, A., (2009), Copula-based models for financial time series, In: Andersen, T.G., Davis, R.A., Kreiss, J.-P. and Mikosch, T. (Eds.), Handbook of Financial Time Series, Springer Verlag.

Pelletier, D., (2006), Regime-switching for dynamic correlation", *Journal of Econometrics*, 131, pp. 445-473.

Rigobon, R., (2001), Contagion: how to measure it, MIT Working Paper.

Roy, R.P., Roy, S., (2017), Financial contagion and volatility spillover: An exploration into Indian commodity derivative market, *Economic Modelling*, 67, pp. 368-380.

Ruppert, D., Wand, M., Holst, U., Hössjer, O., (1997), Local polynomial variance function estimation", *Technometrics*, 39(3), pp. 262-273.

Samarakoon, L.P., (2011), Stock market interdependence, contagion and the U.S. financial crisis: The case of emerging and frontier markets, *Journal of International Financial Markets, Institutions & Money*, 21, pp. 724-742.

Watson, G. S., (1964), "Smooth Regression Analysis", Sankhya, Ser. A, 26, pp.359-372.

Zorgati, I., lakhal, F., Zaabi, E., (2019), Financial contagion in the subprime crisis context: A copula approach, *North American Journal of Economics and Finance*, 47, pp. 269-282.