BANK OF CANADA
BANQUE DU CANADA

Working Paper/Document de travail
2009-14

Testing for Financial Contagion with Applications to the Canadian Banking System

by Fuchun Li

Bank of Canada Working Paper 2009-14

May 2009

Testing for Financial Contagion with Applications to the Canadian Banking System

by

Fuchun Li

Financial Stability Department
Bank of Canada
Ottawa, Ontario, Canada K1A 0G9
fuchunli@bankofcanada.ca

ISSN 1701-9397

Acknowledgements

The author is grateful to Jason Allen, Ian Christensen, Allan Crawford, Toni Gravelle, Pierre St-Amant, Greg Tkacz, and seminar participants at the Bank of Canada for helpful comments and suggestions. The author would also like to thank Glen Keenleyside for his editorial assistance.

Abstract

The author proposes a new test for financial contagion based on a non-parametric measure of the cross-market correlation. The test does not depend on the assumption that the data are drawn from a given probability distribution; therefore, it allows for maximal flexibility in fitting into the data. Simulation studies show that the test has reasonable size and good power to detect financial contagion, and that Forbes and Rigobon's test (2002) is conservative, suggesting that their test tends not to find evidence of contagion when it does exist. The author's new test is applied to investigate contagion from a variety of recent financial crises to the Canadian banking system. Three empirical results are obtained. First, compared to recent financial crises, including the 1987 U.S. stock market crash, 1994 Mexican peso crisis, and 1997 East Asian crisis, the ongoing 2007 subprime crisis has been having more persistent and stronger contagion impacts on the Canadian banking system. Second, the October 1997 East Asian crisis induced contagion in Asian countries, and it quickly spread to Latin American and G-7 countries. The contagion from the East Asian crisis to the Canadian banking system was not as strong or as persistent as that of the ongoing subprime crisis. However, it had a stronger impact on emerging markets. Third, there is no evidence of contagion from the 1994 Mexican peso crisis to the Canadian banking system. Contagion from that crisis occurred in Argentina, Brazil, and Chile, but the contagion effects of that crisis were limited to the Latin American region.

JEL classification: C12, G01, G15
Bank classification: Financial stability; Central bank research; Econometric and statistical methods

Résumé

L'auteur propose un nouveau test de détection de la contagion financière, fondé sur une mesure non paramétrique de la corrélation intermarchés. Comme les données exploitées ne sont pas supposées issues d'une loi de probabilité donnée, le test offre une souplesse maximale en matière d'estimation. En outre, les simulations réalisées montrent que son niveau de signification et son pouvoir de détection sont satisfaisants et que le test de Forbes et Rigobon (2002) pêche par prudence puisqu'il a tendance à ne pas déceler de contagion là où il en existe. L'auteur a recours à son nouveau test pour analyser l'effet de propagation de crises financières récentes au système bancaire canadien. Les résultats empiriques font ressortir trois grands constats. Le premier concerne la crise des prêts hypothécaires à risque amorcée en 2007, dont les retombées sur le système bancaire canadien se révèlent plus persistantes et plus fortes que celles d'autres crises récentes comme le krach du marché boursier américain en 1987, la crise du peso mexicain en 1994 ou la crise asiatique de 1997. Deuxième constat : la crise qui a secoué l'Asie orientale en octobre 1997 a contaminé d'autres pays asiatiques et rapidement atteint l'Amérique latine et les pays du G7. Cette contagion, dont l'incidence fut moins aiguë au

Canada que dans les économies émergentes, a pesé moins longtemps et moins lourd sur les banques canadiennes que ne le fait la crise actuelle du crédit hypothécaire. Troisièmement, rien n’indique que la crise du peso mexicain de 1994 se soit transmise au système bancaire canadien. La contagion a gagné l’Argentine, le Brésil et le Chili, mais elle ne s’est pas répandue hors d’Amérique latine.

Classification JEL : C12, G01, G15
Classification de la Banque : Stabilité financière; Recherches menées par les banques centrales; Méthodes économétriques et statistiques

1 Introduction

Since 1987, international financial markets have experienced a series of financial crises such as the U.S. stock market crash in 1987, the Mexican peso crisis in 1994, the East Asian crisis in 1997, the Russian crisis in 1998, and the ongoing 2007 subprime crisis. A common characteristic of these financial crises is that dramatic movements in the financial market of a crisis country, such as large drops in asset prices and increases in market volatility, can quickly spread to other markets with different sizes and structures around the world. Do these periods of highly cross-market co-movements provide evidence of contagion? And what are the policy implications of these strong cross-market relationships?

To answer these questions, it is necessary to define contagion. In this paper, we adopt Forbes and Rigobon's (2002) definition: contagion is a significant increase in cross-market linkages after a shock to one country or group of countries.[1] According to this definition, contagion does not occur if two markets show a high degree of linkage during both stable and crisis periods. Contagion occurs only if cross-market linkage increases significantly after the shock. If the linkage does not increase significantly after a shock, then any high level of cross-market linkage after a shock suggests only strong correlation between the two markets. To differentiate this situation from contagion, Forbes and Rigobon (2002) refer to these strong transmission mechanisms, which exist in all states, as interdependence.

Given the above definition, although a test for contagion does not shed light on the nature of the international transmission mechanism, it enables one to perceive that there are two different channels in the international transmission of financial shocks: crisis-contingent and non-crisis-

[1] It is important to note that there are different definitions of contagion in the literature. For example, some economists argue that contagion occurs whenever a shock to one country is transmitted to another country. Forbes and Rigobon (2002) and Dornbusch, Park, and Claessens (2000) give more detailed explanations of the advantages of Forbes and Rigobon's definition of contagion.

contingent channels. Crisis-contingent channels imply that transmission mechanisms change during a crisis (contagion exists), and non-crisis-contingent channels imply that transmission mechanisms do not change during both stable (contagion does not exist) and crisis periods. If cross-market linkages do not change significantly during financial crises, then financial shocks are transmitted through non-crisis-contingent channels, such as trade and financial sector linkages.

From a policy perspective, it is important to discriminate between these two alternative channels. For example, if crises are transmitted largely through crisis-contingent channels, which exist only after a crisis, then short-run isolation strategies, such as capital controls, could be highly effective in reducing the effect of a crisis. On the other hand, if crises are transmitted mainly through non-crisis-contingent channels, which exist before and after a crisis, then these short-run isolation strategies will only delay a country's adjustment to a shock and not prevent it from being affected by the crisis.

The most common method of testing for contagion is based on cross-market correlation coefficients.[2] These tests measure the correlation coefficient between two markets during a stable period and then test for a significant increase in this correlation coefficient after a shock. If the correlation coefficient increases significantly, this suggests that the transmission mechanism between the two markets has increased after the shock and contagion occurs. King and Wadhwani (1990) were the first to use correlation coefficients as a measure of contagion. They show that the correlation coefficient between the New York and London markets increased during the stock market crash in 1987. Also, Calvo and Reinhart (1996) find significant increases in the correlation for the Latin American market during the Mexican peso crisis in 1994, while Baig and Goldfajn (1998) report

[2] In the literature, there are a number of other ways to measure cross-market linkages, such as the probability of a speculative attack, or the transmission of volatility. Although these other ways can provide some important evidence (for example, volatility is transmitted across markets, and specific cross-country transmission channels are important predictors of financial crises), they do not explicitly test whether the transmission changes significantly after the relevant crisis.

correlation shifts for several East Asian stock markets during the East Asian crisis in 1997.

However, these tests for contagion based on statistically significant increases in correlation coefficients are challenged by Forbes and Rigobon (2002). Using a simple linear framework, they show that an increase in cross-market correlation coefficients around crises may not necessarily indicate contagion due to econometric problems with heteroskedasticity, which can cause calculated cross-market correlations to increase after a crisis, even though there is no increase in the underlying linkages. Forbes and Rigobon (2002) suggest one method of correcting for this heteroskedasticity by adjusting the cross-market correlation coefficients. When the adjusted correlation coefficient is used to test for contagion, they find that no contagion occurred during the 1997 East Asian crisis, 1994 Mexican peso crisis, and 1987 U.S. stock market crash. Instead, they find a high level of market co-movement during these crises periods, which reflects a continuation of strong global cross-market linkages. Their conclusion is that "there is no contagion, only interdependence."

Obviously, this adjustment is based on the assumptions that there are no omitted variables and endogeneity, and the correlation analysis is limited to the case of bivariate normal distribution between the two markets. However, changes in omitted variables, such as economic fundamentals, risk perceptions, and preference, can cause an increase in asset-price correlations, even when contagion is not present. It is also difficult to control for any endogeneity or feedback effects when estimating the effect on one country of a crisis in another. Even though the correlation coefficient can indicate the strength of a linear relationship between two variables, its value may not be sufficient to evaluate this relationship, especially in the case where the assumption of normality is incorrect.[3] As a result, the measure based on the correlation coefficient misses a potentially im-

[3]If the variables are independent, then the correlation is zero, but the converse is not true, because the correlation coefficient detects only linear dependencies between two variables. For example, suppose the random variable x is uniformly distributed on the interval from -1 to 1, and $y = x^2$. Then, y is completely determined by x, so that x and y

portant dimension of the contagion phenomenon, such as non-linear dependence. Consequently, Forbes and Rigobon's (2002) correlation-adjusted test is still inaccurate and should be used with caution.

In this paper, we develop a test for financial contagion based on a non-parametric correlation. Unlike Forbes and Rigobon's test (2002) (hereafter, FR's test), our test does not rely on the assumption that the data are drawn from a given probability distribution (e.g., a bivariate normal distribution), so that it allows for maximal flexibility in fitting into the data. Our test avoids the problem of omitted variables associated with FR's test, because we do not impose the restriction that there exists a regression relationship between two variables.[4] Since the non-parametric correlation used in our test is based on the measure of the concordance between two variables, which reflects the direction of their co-movement and is not related to their variances, our test does not suffer from the heteroskedasticity associated with the Pearson correlation coefficient.[5]

It is important to note that, as with all correlation coefficient-based contagion tests, the limitation of our test is that the market generating the crisis is known and the timing of the crisis period is given. Consequently, the change in the definitions of the stable period and the crisis period will affect the results.

To investigate the finite sampling properties of our test for financial contagion, we conduct Monte Carlo simulation studies. The simulation results show that our test has reasonable size and good power to detect financial contagion, and FR's test (2002) is conservative, suggesting their test tends not to find evidence of contagion when it does exist.

Subsequently, our test is applied to investigate contagion from a variety of recent financial

are dependent. Even though x and y are dependent, their correlation is zero, i.e., they are uncorrelated. It is only when x and y are jointly normal, uncorrelation is equivalent to independence.

[4]The problem of omitted variables in FR's test arises from a linear specification between the two variables.

[5]It is important to note Forbes and Rigobon (2002) correct the heteroskedasticity by an arbitrary and unrealistic restriction on the variance of the market where the crisis originates.

crises to the Canadian banking system. Three empirical results are obtained. First, compared to recent financial crises, including the 1987 U.S. stock market crash, the 1994 Mexican peso crisis, and the 1997 East Asian crisis, the ongoing 2007 subprime crisis is having a more persistent and stronger contagion impact on the Canadian banking system. Second, the October 1997 East Asian crisis induced contagion in Asian countries, and it quickly spread to Latin America, and G-7 countries. The contagious persistency of this crisis to the Canadian banking system was not as persistent as that of the ongoing subprime crisis. However, it had a stronger impact on emerging markets. Third, there is no evidence of contagion from the 1994 Mexican peso crisis to the Canadian banking system. Although contagion occurred in Argentina, Brazil, and Chile, the contagion effects of the 1994 crisis were limited to Latin America region.

The remainder of this paper is organized as follows. Section 2 reviews the existing theoretical and empirical perspectives on financial contagion. Section 3 provides a statistical test for financial contagion, and a small Monte Carlo simulation is designed to investigate the finite-sample performance of the test statistic. In section 4, the test is applied to investigate financial contagion from a variety of recent financial crises to the Canadian banking system. Section 5 offers some conclusions.

2 Contagion: Theoretical and Empirical Perspectives

2.1 Theoretical Literature

The theoretical literature on why contagion can occur is extensive. This literature can be divided into two broad groups: fundamental causes (including common shocks, trade linkages, and financial linkages) and investors' behaviour (including liquidity problems, incentive problems, informational asymmetries, market coordination problems, and investor reassessment). In this section, we briefly summarize this extensive literature.

Contagion can have a number of different fundamental causes. One type of fundamental cause is a common or global shock. For example, a major economic shift in industrial countries (such as changes in interest rates or currency values), a change in commodity prices, and a reduction in global growth can trigger crises and large capital outflows from emerging markets. Any of these common shocks can lead to increased co-movements in asset prices and capital flows.

A second major group of fundamental causes is trade linkages, which include linkages through direct trade and competitive devaluations. A crisis in one country can cause a reduction in income and a corresponding reduction in demand for imports, thereby affecting exports, the trade balance, and related economic fundamentals in other economies through direct trade links. Moreover, if a crisis in one country causes its currency to be devalued, this can reduce the relative export competitiveness of other countries that compete in third markets. This effect of "competitive devaluations" can put pressure on the other countries' currencies to depreciate or devalue. A series of competitive devaluations can cause larger currency depreciations than required by the initial deterioration in fundamentals.

A final major group of fundamental causes is financial linkages. In a world or region that is highly integrated, a crisis in one country can have direct financing effects on other countries, such as through a reduction in trade credit, foreign direct investment, and other capital flows. More specifically, a crisis in one country can reduce the supply of capital from that country, thereby reducing its ability to provide bank lending and other forms of investment to a second country. The crisis could also indirectly affect the supply of capital through third parties. For countries heavily reliant on external funding, a reduction in capital inflows due to this effect can cause a sharp increase in borrowing costs and put pressure on a currency to depreciate.

The second major group of theories regarding contagion is based on investors' behaviour. Investors' behaviour, whether rational or irrational, allows shocks to spill over from one country to the next. The literature differs on the scope of rational versus irrational investor behaviour, both individually and collectivelly. First, investors can take actions that are, ex ante, individually rational but lead to excessive co-movements, in that they cannot be explained by real fundamentals. Through this channel, which can broadly be called investors' practices, contagion is transmitted by the actions of investors outside the country, each of whom is behaving rationally. Conceptually, this type of investor behaviour can be further brokendown into problems of liquidity and incentives and problems of informational asymmetry and market coordination. Second, cases of multiple equilibrium, similar to those in models of commercial bank runs, can imply contagious behaviour among investors. Third, changes in the international financial system, or in the rules of the game, can induce investors to alter their behaviour after an initial crisis.

2.2 Empirical literature

During international financial crises, financial markets of very different sizes, structures, and geographic locations can exhibit a high degree of across market co-movements in asset prices. The high degree of co-movement suggests the existence of international transmission mechanisms of financial crises. Three approaches are used to test empirically for contagion: GARCH and regime-switching models, cointegration techniques, and cross-market correlation coefficients.

Contagion tests that are based on a GARCH or regime-switching framework are used to find evidence of significant volatility spillovers from one market to another. For example, Gravelle, Kichian, and Morley (2006) specify a Markov regime-switching model to accommodate structural changes to make inferences and to test for shift-contagion. Two notable features are that the timing of changes in volatility is endogenously estimated and the countries in which crises originate need not be known.[6] The cointegration-based approach (Yang et al. 2006) examines the long-run price relationship and the dynamic price transmission. This approach does not specifically test for contagion, because cross-market relationships over long periods could increase for a number of reasons. Moreover, this approach could miss periods of contagion when cross-market relations only increase briefly after a crisis.

The most common approach of testing for contagion is based on cross-market correlation coefficients. This approach measures the correlation in returns between two markets during a stable period, and then tests for a significant increase in this correlation coefficient after a shock. If the correlation coefficient increases significantly, this suggests that the transmission mechanism between the two markets increased after the shock and contagion has occurred. An influential study by King and Wadhwani (1990) examines the changes in correlation coefficients between different markets after the U.S.stock market crash of October 1987. Their empirical results show that the volatility correlation coefficients of stock markets between the United States, the United Kingdom, and Japan increased significantly after this crash. Calvo and Reinhart (1996) use this approach to test for contagion in stock prices and Brady bonds after the 1994 Mexican peso crisis. They find that cross-market correlations increased for many emerging markets during this crisis. Baig and Goldfajn (1998) analyze the stock market returns, interest rates, sovereign spreads, and currencies of five Asian countries. They find that, for each variable, correlation coefficients across countries are significantly higher in the period July 1997-May 1998 than in period January 1995-December 1996. These tests reach the same general conclusion: there was a statistically significant increase in cross-market correlation coefficients during the 1987 U.S. stock market crash, 1994 Mexican peso crisis, and 1997 East Asian crisis, and contagion occurred. However, using a simple linear

[6]Hamao, Masulis, and Ng (1990) use a GARCH framework to examine stock markets around the 1987 U.S. stock market crash and find evidence of significant price-volatility spillovers from New York to London and Tokyo, and from London to Tokyo.

framework, Forbes and Rigobon (2002) show that the correlation coefficient underlying these tests is actually conditional on market volatility. As a result, during a crisis when market volatility increases, estimates of cross-market correlations will be biased upward. When their test of the adjusted-correlation coefficient is used to test for contagion, there is virtually no evidence of a significant increase in cross-market correlation coefficients during the 1987 U.S. stock market crash, 1994 Mexican peso crisis, and 1997 East Asian crisis.

3 A New Test for Contagion

3.1 The test statistic

The study of financial market co-movements has become an important method of assessing financial crises and their contagious effects. According to Barberis, Shleifer, and Wurgler (2005), co-movement is defined as a pattern of positive correlations. In their paper, the Pearson correlation coefficient is the basic approach used to measure the positive correlations. Though the Pearson correlation coefficient can indicate the strength of a linear relationship between two variables, its value may not be sufficient to evaluate this relationship, especially in the case where the assumption of normality is incorrect. As a result, the measure based on the Pearson correlation coefficient misses a potentially important dimension of the contagion phenomenon, such as non-linear dependence. Going beyond the linear approach, Rodriguez (2007) uses Kendall's tau, a non-parametric measure of correlation, as the main measure of dependence to analyze co-movements, but he does not construct a test statistic to determine whether there is a significant increase during the crisis period. In this section, we use the Kendall's tau as a measure of cross-market co-movement to build a test of financial contagion.

Two points $(x_1, y_1), (x_2, y_2)$ in R^2 are said to be concordant if $x_1 > x_2$ whenever $y_1 > y_2$, and $x_1 < x_2$ whenever $y_1 < y_2$, and discordant in the opposite case. In a similar way, two random vectors

(x_1, y_1) and (x_2, y_2) are said to be concordant if $P[(x_1 - x_2)(y_1 - y_2) > 0] - P[(x_1 - x_2)(y_1 - y_2) < 0] > 0$, and discordant if $P[(x_1 - x_2)(y_1 - y_2) > 0] - P[(x_1 - x_2)(y_1 - y_2) < 0] < 0$.

Kendall's tau is defined as the difference between the probabilities $P[(x_1 - x_2)(y_1 - y_2) > 0]$ and $P[(x_1 - x_2)(y_1 - y_2) < 0]$:

$$\rho_{x,y} \equiv P[(x_1 - x_2)(y_1 - y_2) > 0] - P[(x_1 - x_2)(y_1 - y_2) < 0] > 0. \tag{1}$$

Kendall's tau is a non-parametric statistic used to measure the degree of concordance between two variables and assess the significance of this concordance. It satisfies axioms (i) to (vii) for a concordance measure in Cherubini, Luciano, and Vecchiate (2004).

If $\rho_{x,y} > 0$, then the concordance is higher than the discordance, indicating that x_1 and y_1 have more opportunities to move up or down together.[7] A high value of Kendall's tau means that most pairs are concordant. We construct a test statistic to determine whether there is a significant increase in Kendall's tau during the crisis period.

We use $\{x_t, y_t\}_{t=1}^{n}$ and $\{x_t, y_t\}_{t=n+1}^{n+m}$ to denote, respectively, the observations of two asset returns during a stable period and a crisis period. Suppose that $\{x_t, y_t\}_{t=1}^{n}$ is identically distributed as $\{x, y\}$ with the distribution function $F(x, y)$.

If we use $\rho_{x,y}$ to express Kendall's tau during the stable period and $\rho^h_{x,y}$ during the crisis period, the null and alternative hypotheses are, respectively,

$$H_0 : \rho_{x,y} \geq \rho^h_{x,y}, \tag{3}$$

[7] Kendall's tau can also be expressed by the copula function $C(.,.)$ between x_1 and y_1. Let U_1 and U_2 be the standard uniform variables and have the joint distribution $C(.,.)$.We then have:

$$\begin{aligned} \rho_{x,y} &= 4E[C(U_1, U_2)] - 1 \\ &= 4\int_0^1 \int_0^1 C(u_1, u_2) dC(u_1, u_2) - 1. \end{aligned} \tag{2}$$

and

$$H_1 : \rho_{x,y} < \rho^h_{x,y}. \tag{4}$$

A non-parametric estimator of Kendall's tau $\rho_{x,y}$

$$\hat{\rho}_{x,y} = \frac{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} Q((x_i,y_i),(x_j,y_j))}{n(n-1)}, \tag{5}$$

where

$$Q((x_i,y_i),(x_j,y_j)) \equiv \begin{cases} 1 & \text{if } (y_j-y_i)(x_j-x_i) > 0 \\ -1 & \text{if } (y_j-y_i)(x_j-x_i) < 0. \end{cases}$$

Let $d_i = \sum_{t=1,t\neq i} Q((x_i,y_i),(x_t,y_t))$ and $\bar{d} = \frac{1}{n}\sum_{i=1}^{n} d_i$. We define

$$B_n \equiv \frac{\hat{\rho}_{x,y} - \rho_{x,y}}{\hat{S}(\hat{\rho}_{x,y})}, \tag{6}$$

where $\hat{S}(\hat{\rho}_{x,y})$ is the estimator of the standard error of $\hat{\rho}_{x,y}$, which is,

$$\hat{S}(\hat{\rho}_{x,y}) = \sqrt{\frac{2}{n(n-1)}[\frac{2(n-2)}{n(n-1)^2}\sum_{i=1}^{n}(d_i-\bar{d})^2 + 1 - (\hat{\rho}_{x,y})^2]}. \tag{7}$$

Theorem 1 *Suppose that the distribution functions of x_t and y_t are continuous and that*

$$P[(y_2-y_1)(x_2-x_1) > 0] + P[(y_2-y_1)(x_2-x_1) < 0] = 1,$$

then we have,

$$B_n = \frac{\hat{\rho}_{x,y} - \rho_{x,y}}{\hat{\sigma}} \xrightarrow{d} N(0,1). \tag{8}$$

Proof: We can express $\rho_{x,y}$ as:

$$\rho_{x,y} = \int\int\int\int sign(x_2-x_1)sign(y_2-y_1)dF(x_1,y_1)dF(x_2,y_2),$$

where $s(x)$ is the sign function. $\hat{\rho}_{x,y}$ can be written as a U-statistic:

$$\hat{\rho}_{x,y} = \frac{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sign(x_j-x_i)sign(y_j-y_i)}{n(n-1)}.$$

It can be proven that

$$
\begin{aligned}
E(\hat{\rho}_{x,y}) &= \frac{1}{n(n-1)}\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}[2P[(x_2-x_1)(y_2-y_1)>0]-1] \\
&= \frac{1}{n(n-1)}\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\rho_{x,y}=\rho_{x,y},
\end{aligned}
$$

and

$$
\begin{aligned}
\hat{\sigma} &= v\hat{a}r(\hat{\rho}_{x,y}) \\
&= \sqrt{\frac{2}{n(n-1)}[\frac{2(n-2)}{n(n-1)^2}\sum_{i=1}^{n}(d_i-\bar{d})^2+1-(\hat{\rho}_{x,y})^2]}.
\end{aligned}
$$

Given the U-statistic expression of $\hat{\rho}_{x,y}$, and its limit $\rho_{x,y}$, it is straightforward to use a U-statistic method to verify that the pseudo-t statistic $\frac{\hat{\rho}_{x,y}-\rho_{x,y}}{\hat{\sigma}}$ converges to $N(0,1)$ in distribution (Hollander and Wolfe, 1999).

Our test statistic to test for contagion is

$$
CT_{n,m} \equiv \frac{\hat{\rho}_{x,y}-\hat{\rho}^h_{x,y}}{\hat{\sigma}}, \tag{9}
$$

where

$$
\hat{\rho}^h_{x,y} \equiv \frac{\sum_{i=n+1}^{n+m-1}\sum_{j=i+1}^{n+m}Q((x_i,y_i),(x_j,y_j))}{m(m-1)}. \tag{10}
$$

We reject the null hypothesis for a given significant level α, if $CT_{n,m} < -Z_\alpha$, where Z_α denotes the number for which $P(Z \geq Z_\alpha) = \alpha$ and Z is a standard normal random variable. An equivalent decision rule is that we reject the null hypothesis if $\hat{\rho}_{x,y} < \hat{\rho}^h_{x,y} - Z_\alpha\hat{\sigma}$.

3.2 Finite-sample performance

We use Monte Carlo simulations to examine the finite-sample performance of our test. The experiments are conducted to examine the size and power properties of the test statistic under two different scenarios. One is a linear transmission mechanism of financial contagion, and the other is a non-linear transmission mechanism.

We first outline financial market linkages in a stable period, and then extend the model to include linkages in a crisis period. The crisis model is based on the framework of Dungey et al. (2005, 2007), which is motivated by the class of factor models commonly adopted in finance, where the determinants of asset returns are decomposed into common factors and idiosyncratic factors.

3.2.1 Data-generating processes for non-crisis

The data-generating processes (DGP) in the Monte Carlo experiments consist of two asset returns during a stable period $(x_{1,t}, x_{2,t})$ and a crisis period $(y_{1,t}, y_{2,t})$. Let $u_{i,t} \sim N(0,1), i = 1,2$ and $v_t \sim N(0,1)$. Then the DGP for the stable period can be designed as follows:

$$x_{1,t} = a_1 z_t + b_1 u_{1,t}, \tag{11}$$

$$x_{2,t} = a_2 z_t + b_2 u_{2,t}, \tag{12}$$

where

$$z_t = \rho z_{t-1} + \varepsilon_t, \tag{13}$$

$$\varepsilon_t = \sqrt{h_t}.v_t, \tag{14}$$

and h_t evolves according to an ARCH(1, 1) process,

$$h_t = \alpha + \beta(\varepsilon_t)^2. \tag{15}$$

In the specification of DGPs, we use the common factor z_t to capture systemic risk which impacts upon asset returns with a loading of $a_i, i = 1,2$. This could represent a global liquidity shock, a change in investors' risk preferences, or any factor common to both markets. The idiosyncratic factors $u_{i,t}, i = 1,2$ capture unique aspects to each return, and impact upon asset returns with a loading of $b_i, i = 1,2$. In a stable period, the idiosyncratic factors represent potentially diversifiable non-systemic risk. In the special case where $a_1 = a_2 = 0$, the markets are driven entirely by their respective idiosyncratic factors[8]

3.2.2 Data-generating processes for a crisis period

The DGP for a crisis period is an extension of the DGP for the stable period in (11)-(15) by allowing for increases in asset-return volatility resulting from an additional propagation mechanism caused by contagion. Later, this DGP for the crisis period is further extended to allow for structural breaks in the idiosyncratic factors. To distinguish it from the stable period, returns in the crisis period are denoted as $y_{i,t}, i = 1,2$. The DGP during the crisis period is specified as

$$y_{1,t} = a_1 z_t + b_1 u_{1,t}, \tag{16}$$

$$y_{2,t} = a_2 z_t + b_2 u_{2,t} + \lambda b_1 u_{1,t}, \tag{17}$$

where z_t is specified as in (13), and (14). Contagion is defined as shocks originating in country 1, $b_1 u_{1,t} = y_{1,t} - b_1 z_t$, which impact upon the asset returns of country 2, over and above the contribution of the systematic factor $a_2 z_t$ and the country's idiosyncratic factor $b_2 u_{2,t}$. The strength of contagion is determined by the parameter λ. $\lambda = 0$ represents no contagion and is used to examine the size properties of the test statistic. The values of $\lambda > 0$ are used to examine the power properties of the test statistic.

3.2.3 Analysis of the covariance structure

The design in our Monte Carlo simulations can capture some of the key empirical features of financial crises. To highlight these properties, we consider the variance-covariance matrices of the two

[8]The assumption that the idiosyncratic factors are identically distributed can be relaxed by including autocorrelation and conditional volatility in the form of GARCH; see, for example, Bekaert, Harvey, and Ng (2005).

sample periods: the stable period and the crisis period, respectively. Based on the independence assumption of the common factor and idiosyncratic factor, the variance-covariance matrix during the stable period is obtained as

$$Cov(x_{1t}, x_{2t}) = \begin{bmatrix} a_1^2 + b_1^2 & a_1 a_2 \\ a_1 a_2 & a_2^2 + b_2^2 \end{bmatrix}. \tag{18}$$

Similarly, the variance-covariance matrix during the crisis period is

$$Cov(y_{1t}, y_{2t}) = \begin{bmatrix} a_1^2 r^2 + b_1^2 & a_1 a_2 r^2 + \lambda b_1^2 \\ a_1 a_2 r^2 + \lambda b_1^2 & a_2^2 r^2 + b_2^2 + r^2 b_1^2 \end{bmatrix}. \tag{19}$$

The increase in volatility in the country that was the source of the crisis is obtained directly:

$$r_1 = \frac{Var(y_{1,t})}{Var(x_{1,t})} - 1 = \frac{a_1^2(r^2-1)}{a_1^2 + b_1^2}. \tag{20}$$

When there is no structural break ($r = 1$), there is no increase in volatility in the country that was the source of the crisis. In this case, any increase in the volatility of y_{2t} (asset returns) in country 2 is only the result of contagion ($\lambda > 0$). The increase in volatility in country 2 is given by

$$r_2 = \frac{Var(y_{2,t})}{Var(x_{2,t})} - 1 = \frac{a_2^2(r^2-1) + \lambda^2 b_1^2}{a_2^2 + b_2^2}. \tag{21}$$

This expression indicates that volatility can increase for two reasons: an increase in volatility in the systemic factor $a_2^2(r^2-1) + \lambda^2 b_1^2$ and an increase in volatility arising from contagion $\lambda^2 b_1^2$.

3.2.4 Experimental design

The DGPs used in the Monte Carlo experiments are based on the equations (9)-(15). The crisis period is characterized by contagion from $y_{1,t}$ to $y_{2,t}$. The crisis period allows for structural breaks in the idiosyncratic factor of $y_{1,t}$. We consider two scenarios for the transmission of financial contagion. One is the linear transmission mechanism of financial contagion, and the other is the non-linear. For both scenarios, we consider three cases.

We assume that during stable periods,

$$x_{1,t} = 0.6z_t + 0.3u_{1,t}, \tag{22}$$

$$x_{2,t} = 0.2z_t + 0.4u_{2,t}. \tag{23}$$

For the linear transmission mechanism of financial contagion, during the crisis period, the DGPs are specified as follows:

$$y_{1,t} = 0.6z_t + 0.3u_{1,t}, \tag{24}$$

$$y_{2,t} = 0.2z_t + 0.4u_{2,t} + \lambda(0.3u_{1,t}). \tag{25}$$

However, for the non-linear transmission mechanism of financial contagion, during the crisis period, the DGPs are specified as follows:

$$y_{1,t} = 0.6z_t + 0.3u_{1,t}, \tag{26}$$

$$y_{2,t} = 0.2z_t + 0.4u_{2,t} + \lambda(0.3u_{1,t})^2 sign(0.3u_{1,t}), \tag{27}$$

where $sign(.)$ is the sign function

$$sign(x) \equiv \begin{cases} 1 & \text{if } x > 0 \\ 0 & \text{if } x = 0 \\ -1 & \text{if } x < 0. \end{cases}$$

We assume that there are structural breaks in the idiosyncratic factor of $y_{1,t}$. To examine the performance of our test when there is contagion, we allow the shocks to follow three distributions, and for the following cases 1-3, the parameters in common factor z_t are chosen as $(\rho, \alpha, \beta) = (0.5, 0.25, 0.4)$. Forbes and Rigobon (2002) use a uniform distribution to show how heteroskedasticity can bias cross-market correlation coefficients. In case 1, we follow Forbes and Rigobon and use a uniform distribution as an idiosyncratic shock. In case 2, a normal distribution is used to model the distribution of an idiosyncratic shock. To capture the possibility of fat tails in a market return distribution, we use a t-distribution to model an idiosyncratic shock. In case 4, we use an ARCH model to model the distribution of an idiosyncratic shock.

Case 1. For the stable period, $u_{1,t}$ and $u_{2,t}$ are uniformly distributed between -1 and 1; i.e., $u_{1,t} = Uniform(-1,1)$, and $u_{2,t} = Uniform(-1,1)$. For the crisis period, $u_{1,t}$ is uniformly distributed between -10 and 10; i.e., $u_{1,t} = Uniform(-10,10)$, and $u_{2,t} = Uniform(-1,1)$. The strength of contagion is set at $\lambda = 0, 0.01, 0.1, 0.2$. $\lambda = 0$ is used to examine the size properties of our test, while $\lambda = 0.01, 0.1, 0.2$ are used to examine the power properties of our test.

Case 2. For the stable period, $u_{1,t}$ and $u_{2,t}$ are normally distributed with mean 0 and variance 1; i.e., $u_{1,t} = N(0,1)$ and $u_{2,t} = N(0,1)$. For the crisis period, $u_{1,t} = N(0,3)$, and $u_{2,t} = N(0,1)$.

Case 3. For the stable period, $u_{1,t}$ and $u_{2,t}$ have t-distributions; i.e., $u_{1,t} = t(3)$, and $u_{2,t} = t(3)$. For the crisis period, $u_{1,t} = t(1)$, and $u_{2,t} = t(3)$.

Case 4. The common factor is assumed as $z_t \sim N(0,1)$. For the stable period, $u_{1t} = \sqrt{h_t}\varepsilon_t, \varepsilon_t \sim N(0,1), h_t = 0.25 + 0.4(u_{1t})^2$, and $u_{2t} = 0.5u_{2,t-1} + \varepsilon_t, \varepsilon_t \sim N(0,1)$. For the crisis period, $u_{1t} = \sqrt{h_t}\varepsilon_t, \varepsilon_t \sim N(0,1), h_t = 5(0.25 + 0.4(u_{1t})^2)$, and $u_{2t} = 0.5u_{2,t-1} + \varepsilon_t, \varepsilon_t \sim N(0,1)$.

Throughout the experiment, we simulate 1,000 data sets of the random sample at daily frequency. The sample sizes for the stable periods are set as $n = 250$ and $n = 500$, respectively, which correspond to about one and two years of daily data. The sample sizes for the crisis period are set as $m = 30$, and $m = 60$, respectively, which correspond to about one and two months of daily data.

Tables 1 and 2 report the estimated sizes and powers of our test when the financial contagion is transmitted by a linear transmission mechanism. Table 1 shows the results for when the stable period is longer than the crisis period, while Table 2 shows the results for when the crisis period is longer than the stable period. For comparison, under the same simulation designs, the simulation results of FR's test (2002) are also reported in Table 1 and Table 2. The size performance of our test is based on simulating the model under the null hypothesis of no contagion by setting $\lambda = 0$. We consider the empirical rejection rates using the asymptotic critical value, -1.65, at the 5 per cent level.

It is clear that, under the same simulation setting, FR's test yields low sizes. FR's test is consistently undersized for all experiments, with the test not rejecting the null of no contagion often enough. The result that FR's test is undersized is consistent with much of the empirical literature, which finds little evidence of contagion when using this test.

Since contagion is assumed to transfer from country 1 ($y_{1,t}$) to country 2 ($y_{2,t}$) during the crisis period, the power of the test should increase as the λ increases. Our test has good power in detecting financial contagion. For a given contagion, the estimated power of our test always increases rapidly with respect to the strength of the financial contagion (λ) for all three cases. For example, when the strength of contagion λ increases from 0.01 to 0.1, the power of our test (in case 1) increases from 13.1 per cent to 99.4 per cent. In contrast, the estimated power of FR's test is zero when $\lambda = 0.01, 0.1$. Overall, for cases 1 to 4, FR's test exhibits quite low power, suggesting that their test tends not to find evidence of contagion when it does exist, which in turn indicates that the strong empirical evidence of "no contagion, only interdependece" obtained by FR's test is potentially spurious.

Tables 3 and 4 report the simulation results when the financial crisis is transformed by a non-linear function ($\lambda(0.3u_{1,t})^2 sign(0.3u_{1,t})$). Our test has reasonable size performance for all four cases in Table 3. The estimated size for case 4 in Table 4 underestimates the nominal size. In contrast, FR's test still shows quite a low size. A possible reason for the low size is the arbitrary and unrealistic restrictions on the variance of country-specific shocks in FR's test. Our test is more powerful than FR's test for all cases.

4 Empirical Evidence of International Financial Contagion Effects in the Canadian Banking System

As noted earlier, financial crises can be transmitted either through channels that exist only in crisis periods (unstable linkages; i.e., financial contagion exists) or through channels that exist in both crisis and stable periods (stable linkages; i.e., financial contagion does not exist). From the policy perspective of preserving financial stability, it is important to discriminate between these two alternative transmission mechanisms. Since banks play a central role in the payments system, the financing of investment and growth, and the credit creation process, we use our test to examine whether there are contagion effects to the Canadian banking system from recent international financial crises, including the 1987 U.S. stock market crash, the 1994 Mexican peso crisis, the 1997 East Asian crisis, and the ongoing 2007 subprime crisis. The stock returns of Canadian banks are used to measure the banks's vulnerability to a financial crisis.

As in Forbes (2001), and Hartmann, Straetmans, and de Vries (2005), a stock return is chosen as an indicator to investigate whether there exists contagion for several reasons. First, since stock returns are measured at a much high frequency, they can more accurately pinpoint the effects of a specific crisis and are available for a large sample of countries. Second, since stock returns incorporate the immediate impact of a crisis as well as its expected longer-term effects, stock returns should capture the total impact of a crisis on a particular country. Third, the choice of bank stock prices for measuring banking system risk is also motivated by Merton's (1974) option-theoretic framework toward default. This approach has played an important role in risk analysis.

We use daily data on the stock prices of Canada's six largest commercial banks[9] and on the stock market indexes of six Asian countries (Hong Kong, Indonesia, Korea, Malaysia, Phillippines,

[9]The six largest commercial banks by asset size (the big six) are the Bank of Montreal (BMO), CIBC, National Bank (NAT), RBC Financial Group (RBC), Scotiabank (BNS), and TD Bank Financial Group (TD).

and Thailand), G-7 countries, and four Latin American countries (Mexico, Argentina, Brazil, and Chile). The stock price returns and stock market indexes are constructed by 100 times the difference in the log of the stock prices and indexes. All data are from Datastream.

4.1 Contagion from the 1987 U.S. stock market crash

For the first empirical analysis of our test, we consider the financial crisis caused by the 1987 U.S. stock market crash, which has been extensively discussed over the past decade. However, the empirical evidence of contagion remains mixed. For example, King and Wadhwani(1990) test for an increase in stock market correlation between the United States, the United Kingdom, and Japan, and find that cross-market correlations increased significantly after the U.S. stock market crash of 1987. Using a heteroskedasticity-adjusted test, Forbes and Rigobon (2002) show that little evidence of contagion can be found for the 1987 crisis.

Following Forbes and Rigobon (2002), we define the crisis period as 17 October 1987 (the date the crash began) through 4 December 1987, and define the stable period as 1 January 1986 through 16 October 1987. The asymptotic critical value at the 5 per cent level is -1.645. Any test statistic less than this critical value indicates contagion, while any test statistic greater than or equal to this value indicates no contagion. Table 5 reports estimated Kendall's tau correlation coefficients for both the stable and crisis periods, test statistics from our contagion test, and our results.

Several conclusions can be drawn from Table 5. First, our test shows that there is a significant increase in the linkages from the U.S. stock market to each of the Candian big six banks during the crisis period, indicating that there is strong evidence of contagion from this crisis to each of the big six banks. Also, the linkages between U.S. and Canadian stock markets increased significantly, suggesting that contagion occurred in the Canadian stock market. Prior to the crisis in the U.S. stock market, even though returns were not tightly correlated with the stock market returns in

France, Germany, Italy, Japan, the United Kingdom, Hong Kong, Korea, and Malaysia (in fact, there was a negative relationship with Malaysia), the sharp increases in co-movements with these countries after the crisis provides sufficient evidence that they experienced financial contagion from the 1987 U.S. stock market crash. Overall, our test indicates that, after the crash in the U.S. stock market, contagion occurred in the Candian big six banks, as well as in France, Germany, Italy, Japan, the United Kingdom, Hong Kong, Korea, and Malaysia.[10]

Table 6 reports the empirical results of FR's test. In contrast with our results, FR's heteroskedasticity-adjusted test indicates that the correlations between the U.S. stock market and Canadian banks, with the exception of CIBC, decreased, suggesting that these banks did not experience financial contagion from the U.S. stock market crash. In the crisis period, though we observe increases in correlations between the United States and several countries, with the exception of Canada, and Hong Kong, none of these increases were significant enough to support a conclusion that contagion effects occurred in these countries. Based on the fact that FR's test is built on arbitrary assumptions on the variance of the country-specific noise in the market in which the crisis originates, and the empirical findings from our test, we strongly question the empirical results of FR's test.

4.2 Contagion from the 1994 Mexican peso crisis

In December 1994, the Mexican government suffered a balance-of-payments crisis, which led to a devaluation of the peso and a precipitous decline in the Mexican stock market. This crisis generated fears that contagion could quickly lead to crises in other emerging markets, especially in the rest of Latin America. Following the literature, we define the crisis period in the Mexican market as lasting from 19 December 1994 (the day the exchange rate regime was abandoned) through 31 December 1994. The stable period is defined as 1 January 1993 through 18 December 1994.

[10]Since many of the smaller stock markets were not in existence during the crisis, we focus on the 10 largest stock markets.

Table 7 reports our empirical results. The co-movements between Canadian banks and the Mexican stock market are low during the stable period and decrease during the crisis period, suggesting that the co-movements between Canadian banks and the Mexican stock market fell during the period of financial crisis. Specifically, the linkages between RBC and TD are negative during the crisis period, indicating that these two banks showed discordance with this financial crisis. Overall, the empirical results of our test reveal that the crisis did not cause contagion in Canadian banking system.

Cross-market linkages between Mexico and other countries in the Latin American region increased sharply during the crisis period. This is a prerequisite for contagion to occur. Our test shows that the increases were significant, suggesting that Argentia, Brazil, and Chile experienced financial contagion from the Mexican stock market crisis of December 1994. The linkages between Mexico and East Asian countries were weakly related during the stable period, while becoming negatively linked during the crisis period, indicating that the financial crisis was not transmitted to the East Asian countries.

Even though the Mexican stock market had positive linkages with Canada, the United States, and Italy during both the crisis and stable periods, the linkages became weaker during the crisis period. Clearly, no financial contagion occurred from the Mexican market to the United States, Canada, and Italy. The Mexican stock market displayed negative linkages with France, Germany, Japan, and the United Kingdom. Contagion did not occur from the Mexican market to these countries.

Overall, the empirical results reveal clear evidence that the 1994 Mexican peso crisis is characterized by a regional pattern; i.e., the contagious effects of this crisis were limited to the Latin American region. The empirical results of FR's test are reported in Table 8; they indicate that there is no evidence of contagion occurring from Mexico to any other country, including the Canadian banking system.

4.3 Contagion from the 1997 East Asian Crisis

We next consider the East Asian crisis of 1997. The difficulty in testing for contagion during this period is that no single event acts as a clear catalyst for this crisis. For example, the Thai market declined sharply in June, the Indonesian market fell in August, and the Hong Kong market crashed in mid-October. Following Forbes and Rigobon (2002), we focus on testing for contagion from Hong Kong to the rest of the world during the volatile period directly after the Hong Kong crash. The October decline in the Hong Kong market is used as the base for our contagion test. The crisis period is therefore defined as one month starting on 17 October 1997 (the start of the visible Hong Kong stock market crash), and the stable period as 1 January 1996 through 16 October 1997.

Table 9 reports the empirical results of our test. The linkages between Hong Kong and Canadian banks during the crisis period are larger than those during the stable period. CIBC, BMO, NAT, and TD display significant increases in co-movements with the Hong Kong stock market, indicating that the four banks suffer financial contagion from this crisis. Even though we can observe increases in co-movements between Hong Kong stock market and BNS and RBC, these increases are not significant, indicating that no contagion occurred to BNS and RBC from this financial crisis.

Cross-market linkages between Hong Kong and most countries increased during the crisis period. In particular, the significant increases in co-movements with most of the East Asian countries, with the exception of Thailand, provide evidence of contagion to these countries. During the stable period, Hong Kong stock market had weak linkages with Latin American countries and G-7 countries, but during the crisis period the linkages with these countries increased significantly, suggesting that contagion occurred from Hong Kong to these countries. In contrast, Table 10 reports the empirical results of FR's test. Only one coefficient (for Italy) increases significantly during the crisis period. In fact, FR's adjusted correlations show that the correlations for the crisis period are lower than those of the stable period.

4.4 Contagion from the ongoing 2007 subprime crisis

The ongoing subprime crisis began in mid-2007. On 15 August 2007, the Dow Jones Industrial Average dropped below 13,000 and the S&P 500 crossed into negative territory for that year. Similar drops occurred in virtually every market in the world. Little empirical work has been undertaken on the ongoing subprime crisis, except for Dungey et al. (2007), who focus on the second moments of the crisis by examining a factor structure. Following Dungey et al., we define the stable period as 2 January 2007 through 31 July 2007. The crisis period is first defined as the three months starting 1 August 2007. We then extend that crisis period by changing its end date from 1 November 1 2007 to 23 September 2008, to examine the persistency of the crisis.

Table 11 reports the empirical results of our test for the three months starting 1 August 2007. Table 11 shows that Canadian banks experienced sharp increases in co-movements with the U.S. stock market following the ongoing subprime crisis. Indeed, these increases are significant even at 1 per cent significant level (the asymptotic critical value at 1 per cent is -2.33), suggesting that there was financial contagion from the ongoing 2007 subprime crisis to Canadian banks during the period of crisis (three months starting on 1 August 2007). On average, the test statistic value in the case of the ongoing subprime crisis is -7.552, which is lower than in the case of the 1987 U.S. stock market crash and the 1997 East Asian crisis by 28.21 per cent and 84.33 per cent, respectively, implying that the intensity of the 2007 subprime crisis is stronger.

However, in comparison with the 1987 U.S. stock market crash and the 1997 East Asian financial crisis, there is much less evidence of contagion from the 2007 U.S. subprime crisis in Asian countries. Financial contagion occurred only in Korea's stock market, whereas the cross-market linkages between the U.S. stock market and other Asian countries even decline during the crisis period. There are two possible explanations for this reduction in contagion during the ongoing subprime crisis. First, investors retrenched from these markets after the series of crises since 1987, causing significant changes in the countries' international financial structures. In particular, commercial banks substantially reduced their volume of short-term loans to these markets, reducing the risks from banks withdrawing their credit during future crises. Second, these markets undertook reforms to improve their economic fundamentals, thereby reducing their vulnerability to a crisis.

The cross-market linkages between the U.S. stock market and G-7 countries, with the exception of France, have increased significantly during the ongoing 2007 subprime crisis, suggesting that there has been financial contagion in these countries from the 2007 U.S. subprime crisis. The empirical results show that contagion has occurred in Brazil, Chile, and Mexico, while there is no evidence of contagion in Argentina. Table 12 reports the empirical results of FR's test, which suggests that there is no evidence of contagion from the ongoing U.S. subprime crisis to any other country, including the Canadian banking system.

To further examine the persistent contagion impact on the Canadian banking system, we prolong the crisis period by changing the end date from 1 November 2007 to 23 September 2008. Figure 1 and Figure 2 report the empirical results of our test and FR's test, respectively. Figure 1 shows that our test statistic values are always below the critical value of -1.645, providing solid evidence that Canadian banks increase significantly in co-movements with the U.S. stock market when the end date of crisis period changes from 1 November 2007 to 23 September 2008. This indicates that Canadian banks have been experiencing contagion from the ongoing 2007 subprime crisis. Figure 2 shows that as usual, FR's test could not provide empirical evidence of contagion to Canadian banks from this crisis.

5 Conclusion

This paper proposes a non-parametric method to test financial contagion. The Monte Carlo simulation results suggest that the overall performance of the test is satisfactory. The test is applied to investigate contagion from a variety of recent financial crises to the Canadian banking system. The empirical results reveal that there existed financial contagion to the Canadian banking system from the 1987 U.S. stock market crash, the 1997 East Asian crisis, and the ongoing 2007 subprime crisis, while the 1994 Mexican peso crisis did not have a contagious impact on the Canadian banking system. During the period of the subprime crisis, the average test statistic value is -7.552, which is lower than in the case of the 1987 U.S. stock market crash and the 1997 East Asian crisis by 28.21 per cent and 84.33 per cent, respectively, implying that the intensity of the 2007 subprime crisis is stronger. We also find strong evidence that the ongoing 2007 subprime crisis has more persistent impacts on the Canadian banking system.

Table 1: Percentage Rejections of the H_0 and Contagion=$\lambda(0.3u_{1,t})(n>m)$

	$CT_{n,m}$				FR's test			
	$\lambda=0$	$\lambda=0.01$	$\lambda=0.1$	$\lambda=0.2$	$\lambda=0$	$\lambda=0.01$	$\lambda=0.1$	$\lambda=0.2$
				$n=250$	$m=30$			
Case 1	0.061	0.131	0.994	1.000	0.000	0.000	0.000	0.182
Case 2	0.055	0.235	0.913	1.000	0.000	0.020	0.091	0.473
Case 3	0.072	0.252	0.764	0.948	0.022	0.051	0.287	0.508
Case 4	0.079	0.104	0.294	0.591	0.000	0.000	0.000	0.051
				$n=500$	$m=60$			
Case 1	0.057	0.172	1.000	1.000	0.000	0.000	0.000	0.193
Case 2	0.060	0.279	0.983	1.000	0.000	0.010	0.121	0.703
Case 3	0.062	0.376	0.818	0.981	0.029	0.091	0.354	0.772
Case 4	0.035	0.087	0.301	0.670	0.000	0.000	0.000	0.091

The table reports the estimated size and power of the contagion test $CT_{n,m}$, and Forbes and Rigobon's test (FR's test). The nominal size of the tests is set at 5% based on the asymptotic distribution. The data-generating process (DGP) for the stable period is designed as: $x_{1,t}=0.6w_t+0.3u_{1,t}$, where $w_t=0.5w_{t-1}+\varepsilon_t$,and $\varepsilon_t=\sqrt{h_t}.v_t, h_t=1+0.5(\varepsilon_{t-1})^2$ $+0.4h_{t-1}, v_t=N(0,1)$. The DGP for the crisis period is designed as: $y_{1,t}=0.6w_t+0.3u_{1,t}, y_{2,t}=0.2w_t+0.4u_{2,t}+\lambda(0.3u_{1t})$. Case 1: for the stable period, $u_{1,t}$ and $u_{2,t}$ are uniformly distributed. For the crisis period, $u_{1,t}$ is uniformly distributed between -10 and 10, and $u_{2,t}$ is uniformly distributed between -1 and 1. Case 2: For the stable period, $u_{1,t}=N(0,1)$ and $u_{2,t}=N(0,1)$. For the crisis period, $u_{1,t}=N(0,3)$ and $u_{2,t}=N(0,1)$. Case 3: for the stable period, $u_{1,t}=t(3)$, $u_{2,t}=t(3)$. For the crisis period, $u_{1,t}=t(1)$ and $u_{2,t}=t(3)$.
Case 4: The common factor $z_t=N(0,1)$. For stable period, $u_{1,t}=\sqrt{h_t}\varepsilon_t, \varepsilon_t=N(0,1)$, and $h_t=0.25+0.4(u_{1,t})^2)$. For the crisis period, $u_{1,t}=\sqrt{h_t}\varepsilon_t, \varepsilon_t=N(0,1), h_t=5(0.25+0.4(u_{1,t})^2)$, and $u_{2,t}=0.5u_{2,t-1}+\varepsilon_t, \varepsilon_t=N(0,1)$.

Table 2: Percentage Rejections of the H_0 and Contagion=$\lambda(0.3u_{1,t})(n<m)$

	$CT_{n,m}$				FR's test			
	$\lambda=0$	$\lambda=0.01$	$\lambda=0.1$	$\lambda=0.2$	$\lambda=0$	$\lambda=0.01$	$\lambda=0.1$	$\lambda=0.2$
				$n=120$	$m=250$			
Case 1	0.032	0.074	0.999	1.000	0.000	0.000	0.000	0.000
Case 2	0.049	0.086	0.903	1.000	0.000	0.000	0.000	0.000
Case 3	0.076	0.148	0.742	0.955	0.000	0.000	0.003	0.014
Case 4	0.031	0.047	0.185	0.534	0.000	0.000	0.000	0.011
				$n=250$	$m=250$			
Case 1	0.009	0.044	1.000	1.000	0.000	0.000	0.000	0.000
Case 2	0.042	0.101	0.981	1.000	0.000	0.000	0.000	0.000
Case 3	0.035	0.105	0.887	0.998	0.000	0.002	0.013	0.481
Case 4	0.013	0.044	0.201	0.586	0.000	0.000	0.000	0.000

The table reports the estimated size and power of the contagion test $CT_{n,m}$, and Forbes and Rigobon's test (FR's test). The nominal size of the tests is set at 5% based on the asymptotic distribution. The data-generating process (DGP) for the stable period is designed as: $x_{1,t}=0.6w_t+0.3u_{1,t}$, where $w_t=0.5w_{t-1}+\varepsilon_t$, and $\varepsilon_t=\sqrt{h_t}.v_t, h_t=1+0.5(\varepsilon_{t-1})^2$ $+0.4h_{t-1}, v_t=N(0,1)$. The DGP for the crisis period is designed as: $y_{1,t}=0.6w_t+0.3u_{1,t}, y_{2,t}=$ $0.2w_t+0.4u_{2,t}+\lambda(0.3u_{1t})$. Case 1: for the stable period, $u_{1,t}$ and $u_{2,t}$ are uniformly distributed. For the crisis period, $u_{1,t}$ is uniformly distributed between -10 and 10, and $u_{2,t}$ is uniformly distributed between -1 and 1. Case 2: For the stable period, $u_{1,t}=N(0,1)$ and $u_{2,t}=N(0,1)$. For the crisis period, $u_{1,t}=N(0,3)$ and $u_{2,t}=N(0,1)$. Case 3: for the stable period, $u_{1,t}=t(3)$, $u_{2,t}=t(3)$. For the crisis period, $u_{1,t}=t(1)$ and $u_{2,t}=t(3)$.
Case 4: The common factor $z_t=N(0,1)$. For stable period, $u_{1,t}=\sqrt{h_t}\varepsilon_t, \varepsilon_t=N(0,1)$,and $h_t=0.25+0.4(u_{1,t})^2)$. For the crisis period, $u_{1,t}=\sqrt{h_t}\varepsilon_t, \varepsilon_t=N(0,1), h_t=5(0.25+0.4(u_{1,t})^2)$, and $u_{2,t}=0.5u_{2,t-1}+\varepsilon_t, \varepsilon_t=N(0,1)$.

Table 3: Percentage Rejections of the H_0 and Contagion=$\lambda(0.3u_{1,t})^2 sign(0.3u_{1,t})(n > m)$

	$CT_{n,m}$				FR's test			
	$\lambda = 0$	$\lambda = 0.001$	$\lambda = 0.01$	$\lambda = 0.05$	$\lambda = 0$	$\lambda = 0.001$	$\lambda = 0.01$	$\lambda = 0.05$
				$n = 250$	$m = 30$			
Case 1	0.063	0.284	1.000	1.000	0.000	0.000	0.189	0.875
Case 2	0.067	0.312	1.000	1.000	0.000	0.011	0.439	0.945
Case 3	0.060	0.467	0.845	1.000	0.026	0.151	0.347	0.731
Case 4	0.070	0.073	0.361	0.965	0.000	0.010	0.031	0.763
				$n = 500$	$m = 60$			
Case 1	0.054	0.297	1.000	1.000	0.000	0.000	0.228	0.986
Case 2	0.071	0.327	1.000	1.000	0.000	0.013	0.557	0.972
Case 3	0.069	0.507	0.912	1.000	0.020	0.217	0.406	0.845
Case 4	0.064	0.071	0.450	1.000	0.000	0.013	0.027	0.921

The table reports the estimated size and power of the contagion test ($CT_{n,m}$), and Forbes and Rigobon's test (FR's test). The nominal size of the tests is set at 5% based on the asymptotic distribution. The data-generating process (DGP) for the noncrisis period is designed as: $x_{1,t} = 0.6w_t + 0.3u_{1,t}$, where $w_t = 0.5w_{t-1} + \varepsilon_t$,and $\varepsilon_t = \sqrt{h_t}.v_t, h_t = 1 + 0.5(\varepsilon_{t-1})^2$ $+0.4h_{t-1}, v_t = N(0,1)$. The DGP for the crisis period is designed as: $y_{1,t} = 0.6w_t + 0.3u_{1,t}, y_{2,t} = 0.2w_t + 0.4u_{2,t} + \lambda(0.3u_{1t})^2 sign(0.3u_{1,t})$. Case 1: for the stable period, $u_{1,t}$ and $u_{2,t}$ are uniformly distributed. For the crisis period, $u_{1,t}$ is uniformly distributed between -10 and 10, and $u_{2,t}$ is uniformly distributed between -1 and 1. Case 2: For the stable period, $u_{1,t} = N(0,1)$ and for the crisis period $u_{1,t} = N(0,3)$, and $u_{2,t} = N(0,1)$. Case 3: for the stable period, $u_{1,t} = t(3)$, Case 4: The common factor $z_t = N(0,1)$. For stable period, $u_{1,t} = \sqrt{h_t}\varepsilon_t, \varepsilon_t = N(0,1)$,and $h_t = 0.25 + 0.4(u_{1,t})^2)$. For the crisis period, $u_{1,t} = \sqrt{h_t}\varepsilon_t, \varepsilon_t = N(0,1), h_t = 5(0.25 + 0.4(u_{1,t})^2)$, and $u_{2,t} = 0.5u_{2,t-1} + \varepsilon_t, \varepsilon_t = N(0,1)$.

Table 4: Percentage Rejections of the H_0 and Contagion=$\lambda(0.3u_{1,t})^2 sign(0.3u_{1,t})(n<m)$

	$CT_{n,m}$				FR's Test			
	$\lambda=0$	$\lambda=0.001$	$\lambda=0.01$	$\lambda=0.05$	$\lambda=0$	$\lambda=0.001$	$\lambda=0.01$	$\lambda=0.05$
				$n=120$	$m=250$			
Case 1	0.027	0.164	1.000	1.000	0.000	0.000	0.000	0.000
Case 2	0.051	0.153	1.000	1.000	0.000	0.000	0.000	0.000
Case 3	0.067	0.323	0.902	1.000	0.003	0.035	0.042	0.073
Case 4	0.012	0.025	0.237	1.000	0.000	0.000	0.000	0.512
				$n=250$	$m=250$			
Case 1	0.012	0.186	1.000	1.000	0.000	0.000	0.000	0.000
Case 2	0.037	0.196	1.000	1.000	0.000	0.013	0.000	0.000
Case 3	0.071	0.473	0.977	1.000	0.000	0.033	0.047	0.049
Case 4	0.005	0.017	0.267	1.000	0.000	0.000	0.000	0.853

The table reports the estimated size and power of the contagion test ($CT_{n,m}$), and Forbes and Rigobon's test (FR's test). The nominal size of the tests is set at 5% based on the asymptotic distribution. The data-generating process (DGP) for the stable period is designed as: $x_{1,t} = 0.6w_t + 0.3u_{1,t}$, where $w_t = 0.5w_{t-1} + \varepsilon_t$,and $\varepsilon_t = \sqrt{h_t}.v_t, h_t = 1 + 0.5(\varepsilon_{t-1})^2$ $+0.4h_{t-1}, v_t = N(0,1)$. The DGP for the crisis period is designed as: $y_{1,t} = 0.6w_t + 0.3u_{1,t}, y_{2,t} = 0.2w_t + 0.4u_{2,t} + \lambda(0.3u_{1t})^2 sign(0.3u_{1,t})$. Case 1: for the noncrisis period, $u_{1,t}$ and $u_{2,t}$ are uniformly distributed. For the crisis period, $u_{1,t}$ is uniformly distributed between -10 and 10, and $u_{2,t}$ is uniformly distributed between -1 and 1. Case 2: For the stable period, $u_{1,t} = N(0,1)$ and for the crisis period $u_{1,t} = N(0,3)$, and $u_{2,t} = N(0,1)$. Case 3: for the stable period, $u_{1,t} = t(3)$, Case 4: The common factor $z_t = N(0,1)$. For stable period, $u_{1,t} = \sqrt{h_t}\varepsilon_t, \varepsilon_t = N(0,1)$,and $h_t = 0.25 + 0.4(u_{1,t})^2)$. For the crisis period, $u_{1,t} = \sqrt{h_t}\varepsilon_t, \varepsilon_t = N(0,1), h_t = 5(0.25 + 0.4(u_{1,t})^2)$, and $u_{2,t} = 0.5u_{2,t-1} + \varepsilon_t, \varepsilon_t = N(0,1)$.

Table 5: 1987 U.S. Stock Market Crash

	Stable period		Crisis period			
	$\hat{\rho}_{xy}$	σ_τ	$\hat{\rho}^h_{xy}$	σ_τ	$CT_{n,m}$	Result
CIBC	0.135	0.032	0.401	0.122	−8.272	C
BMO	0.165	0.031	0.228	0.132	−2.051	C
NAT	0.159	0.030	0.463	0.119	−9.997	C
BNS	0.160	0.031	0.292	0.124	−4.322	C
RBC	0.162	0.033	0.247	0.133	−2.668	C
TD	0.145	0.032	0.401	0.131	−8.033	C
Canada	0.385	0.027	0.656	0.103	−10.008	C
France	0.096	0.050	0.510	0.093	−8.274	C
Germany	0.052	0.048	0.362	0.126	−6.349	C
Italy	0.078	0.049	0.215	0.153	−2.799	C
Japan	0.092	0.028	0.438	0.122	−12.25	C
U.K.	0.139	0.046	0.550	0.116	−9.035	C
Hong Kong	0.024	0.032	0.081	0.129	−1.759	C
Korea	0.027	0.030	0.142	0.168	−3.849	C
Malaysia	−0.019	0.032	0.472	0.136	−15.445	C

This table reports the values of the $CT_{n,m}$ test statistics to detect the contagion from the 1987 U.S. stock market crash to the Canadian big six bank, Canada, France, Germany, Italy, Japan, and United Kindom. The estimations of concordance before and after the crisis are also reported. The stable period is defined as 1 January 1986 through 16 October 1987. The crisis period is defined as one month starting on 17 October 1987 through 4 December 1987. “C” in the final column indicates that the contagion test ($CT_{n,m}$) is greater than the critical value and that therefore contagion occurred. “N” in the final column indicates that no contagion occurred.

Table 6: 1987 U.S. Stock Market Crash

	Stable period		Crisis period			
	ρ	σ	ρ_{ad}	σ	FR's Test	Result
CIBC	0.131	2.863	0.276	3.371	−2.269	C
BMO	0.222	1.281	0.106	2.161	1.993	N
NAT	0.279	1.418	0.207	4.504	1.220	N
BNS	0.286	1.564	0.136	3.015	2.607	N
RBC	0.169	1.778	0.084	3.415	1.515	N
TD	0.247	1.392	0.163	3.065	1.443	N
Canada	0.600	0.681	0.273	3.598	6.003	N
France	0.110	1.114	0.196	3.815	−1.044	N
Germany	0.040	1.214	0.133	3.503	−1.135	N
Italy	0.074	1.029	0.120	2.649	−0.571	N
Japan	0.201	1.053	0.043	3.689	0.967	N
UK	0.180	0.819	0.189	3.667	−0.105	N
Hong Kong	0.041	1.113	−0.001	7.450	0.722	N
Korea	0.003	1.323	0.026	1.815	−0.3971	N
Malaysia	0.019	1.441	0.176	5.246	−2.942	C

This table reports the values of FR test statistics to detect the contagion from the 1987 U.S. stock market crash to the Canadian big six bank, Canada, France, Germany, Italy, Japan, and United Kindom. The estimations of concordance before and after the crisis are also reported. The stable period is defined as 1 January 1986 through 16 October 1987. The crisis period is defined as one month starting on 17 October 1987 through 4 December 1987. "C" in the final column indicates that the FR's test is greater than the critical value and that therefore contagion occurred. "N" in the final column indicates that no contagion occurred.

Table 7: 1994 Mexican Peso Crisis

	Stable period		Crisis period			
	$\hat{\rho}_{xy}$	σ_τ	$\hat{\rho}^h_{xy}$	σ_τ	$CT_{n,m}$	Result
CIBC	0.075	0.030	0.008	0.099	2.204	N
BMO	0.091	0.029	0.002	0.113	3.054	N
NAT	0.058	0.028	0.054	0.093	0.132	N
BNS	0.089	0.030	0.007	0.096	2.792	N
RBC	0.116	0.029	−0.002	0.097	4.095	N
TD	0.129	0.030	−0.012	0.104	4.754	N
Canada	0.167	0.029	0.061	0.094	3.622	N
France	0.088	0.030	−0.100	0.104	6.306	N
Germany	0.089	0.028	−0.100	0.115	6.403	N
Italy	0.041	0.031	0.029	0.099	0.348	N
Japan	−0.052	0.030	−0.089	0.115	1.215	N
U.K.	0.145	0.029	−0.025	0.100	5.887	N
U.S.	0.167	0.030	0.051	0.129	3.941	N
Argentina	0.187	0.029	0.496	0.079	−10.605	C
Brazil	0.102	0.031	0.484	0.084	−12.420	C
Chile	0.143	0.030	0.421	0.090	−9.270	C
Hong Kong	0.060	0.031	−0.115	0.102	5.713	N
Indonesia	0.074	0.030	−0.053	0.109	4.158	N
Korea	0.111	0.070	−0.118	0.103	7.736	N
Malaysia	0.075	0.029	−0.069	0.099	4.915	N
Philippines	0.131	0.030	−0.070	0.114	6.709	N

This table reports the values of the $CT_{n,m}$ test statistics to detect the contagion from the 1994 Mexican peso crisis to the Canadian big six banks, the countries of East Asian, Latin America, and G-7. The estimations of concordance before and after the crisis are also reported. The stable period is defined as 1 January 1993 through 18 December 1994. The crisis period is defined as 19 December 1994 through 31 December 1994. "C" in the final column indicates that FR's test is greater than the critical value and that therefore contagion occurred. "N" in the final column indicates that no contagion occurred.

Table 8: 1994 Mexican Peso Crisis

	Stable period		Crisis period			
	ρ	σ	ρ_{ad}	σ	FR's Test	Result
CIBC	0.053	1.127	0.013	1.141	0.908	N
BMO	0.026	1.164	0.006	1.196	2.238	N
NAT	−0.003	1.495	−0.001	1.865	1.346	N
BNS	0.035	1.297	0.008	1.449	1.903	N
RBC	−0.019	1.228	−0.005	1.187	2.669	N
TD	−0.026	1.357	−0.006	1.302	3.006	N
Canada	0.104	0.661	0.025	0.653	4.133	N
France	0.133	0.967	−0.009	0.897	2.505	N
Germany	0.122	1.001	−0.040	0.660	2.857	N
Italy	0.065	1.481	0.012	1.438	0.934	N
Japan	−0.068	1.029	−0.044	1.245	−0.409	N
U.K.	0.221	0.638	−0.004	0.512	4.051	N
U.S.	0.234	0.568	0.032	0.394	3.606	N
Hong Kong	0.090	1.656	−0.012	1.770	1.759	N
Indonesia	0.123	1.493	−0.023	1.656	2.574	N
Korea	0.161	1.141	−0.033	1.501	3.453	N
Malaysia	0.067	1.437	−0.005	1.769	1.273	N
Philippines	0.195	1.612	−0.028	1.914	3.993	N
Argentina	0.303	1.763	0.175	3.504	2.268	N
Brazil	0.177	3.352	0.202	4.304	−0.427	N
Chile	0.233	1.061	0.171	1.926	1.079	N

This table reports the values of FR's test statistics to detect the contagion from the 1994 Mexican peso crisis to the Canadian big six banks, the countries of East Asian, Latin America, and G-7. The cross-market correlation coefficients and standard deviations are also reported. The cross-market correlation coefficients of the crisis period are adjusted from Forbes and Rigobon (2002). The stable period is defined as 1 January 1993 through 18 December 1994. The crisis period is defined as 19 December 1994 through 31 December 1994. "C" in the final column indicates that FR's test is greater than the critical value and that therefore contagion occurred. "N" in the final column indicates that no contagion occurred.

Table 9: Testing for Financial Contagion for the 1997 East Asian Crisis

	Stable period		Crisis period			
	$\hat{\rho}_{xy}$	σ_τ	$\hat{\rho}^h_{xy}$	σ_τ	$CT_{n,m}$	Result
CIBC	0.096	0.033	0.265	0.179	−5.162	C
BMO	0.065	0.031	0.240	0.169	−5.679	C
NAT	0.069	0.031	0.375	0.170	−9.989	C
BNS	0.078	0.031	0.100	0.167	−0.717	N
RBC	0.098	0.030	0.115	0.177	−0.556	N
TD	0.084	0.031	0.160	0.173	−2.447	C
Canada	0.156	0.031	0.331	0.189	−5.576	C
France	0.099	0.032	0.490	0.131	−12.043	C
Germany	0.190	0.033	0.570	0.155	−11.498	C
Italy	0.129	0.031	0.485	0.146	−11.354	C
Japan	0.172	0.03	0.345	0.158	−5.764	C
U.K.	0.154	0.033	0.600	0.124	−13.554	C
U.S.	0.076	0.031	0.225	0.199	−4.788	C
Argentina	0.056	0.032	0.140	0.181	−2.629	C
Brazil	0.070	0.033	0.200	0.185	−3.912	C
Chile	0.034	0.032	0.285	0.173	−7.771	C
Mexico	0.118	0.032	0.295	0.192	−5.475	C
Hong Kong	0.026	0.049	0.159	0.100	−2.708	C
Indonesia	0.167	0.033	0.250	0.168	−2.544	C
Korea	0.061	0.031	0.115	0.188	−1.771	C
Malaysia	0.195	0.032	0.335	0.171	−4.257	C
Philippines	0.135	0.033	0.430	0.163	−8.942	C
Thailand	0.118	0.034	0.015	0.189	3.066	N

This table reports the values of the $CT_{n,m}$ test statistics to detect the contagion from the 1997 East Asian crisis to the Canadian big six banks, the countries of East Asian, Latin American, and the G-7. The estimations of concordance before and after the crisis are also reported. The stable period is defined as 1 January 1996, through 16 October 1997. The crisis period is defined as one month starting on 17 October 1997. "C" in the final column indicates that the contagion test $(CT_{n,m})$ is greater than the critical value and that therefore contagion occurred. "N" in the final column indicates that no contagion occurred.

Table 10: 1997 East Asian Crisis

	Stable period		Crisis period			
	ρ	σ	ρ_{ad}	σ	FR's test	Result
CIBC	0.094	1.289	0.059	2.778	0.548	N
BMO	0.054	1.241	0.049	2.404	0.089	N
NAT	0.055	1.325	0.102	2.514	−0.741	N
BNS	0.089	1.303	0.059	2.345	0.484	N
RBC	0.090	1.232	0.050	1.785	0.643	N
TD	0.069	1.392	0.059	2.309	0.155	N
Canada	0.171	0.581	0.321	1.786	1.696	N
France	0.153	0.957	0.261	2.086	−1.523	N
Germany	0.299	0.898	0.276	2.411	0.330	N
Italy	0.129	1.260	0.253	2.204	−1.776	C
Japan	0.287	0.895	0.136	2.317	2.397	N
U.K.	0.211	0.580	0.286	1.415	−1.047	N
U.S.	0.089	0.806	0.015	2.181	1.179	N
Argentina	0.131	1.377	0.015	5.050	1.881	N
Brazil	0.133	1.660	0.030	6.308	1.667	N
Chile	0.063	0.921	0.098	1.882	−0.540	N
Mexico	0.211	1.307	0.076	5.346	2.187	N
Hong Kong	0.051	1.304	0.003	7.198	0.605	N
Indonesia	0.317	1.876	0.162	4.984	2.439	N
Korea	0.103	1.472	0.035	4.925	1.084	N
Malaysia	0.298	1.569	0.141	3.565	2.495	N
Philippines	0.217	1.726	0.180	3.130	0.563	N
Thailand	0.120	2.548	0.018	6.969	1.641	N

This table reports the values of FR's test statistics to detect the contagion from the 1997 East Asian crisis to the Canadian big six banks, the countries of East Asia, Latin American, and G-7. The cross-market correlation coefficients and standard deviations are also reported. The cross-market correlation coefficients of the crisis period is adjusted from Forbes and Rigobon (2002). The stable period is defined as 1 January 1996, through 16 October 1997. The turmoil period is defined as one month starting on 17 October 1997. "C" in the final column indicates that FR's test is greater than the critical value and that therefore contagion occurred. "N" in the final column indicates that no contagion occurred.

Table 11: Testing for Financial Contagion for the Ongoing 2007 Subprime Crisis

	Stable period		Crisis period			
	$\hat{\rho}_{xy}$	σ_τ	$\hat{\rho}^h_{xy}$	σ_τ	$CT_{n,m}$	Result
CIBC	0.186	0.034	0.377	0.113	−5.582	C
BMO	0.194	0.033	0.563	0.107	−10.166	C
NAT	0.152	0.036	0.406	0.135	−7.049	C
BNS	0.202	0.032	0.389	0.112	−5.687	C
RBC	0.187	0.034	0.510	0.108	−9.542	C
TD	0.181	0.035	0.439	0.101	−7.286	C
Canada	0.419	0.029	0.710	0.085	−10.207	C
France	0.073	0.033	−0.110	0.133	5.502	N
Germany	0.325	0.032	0.484	0.120	−5.030	C
Italy	0.332	0.033	0.463	0.120	−3.982	C
Japan	0.331	0.033	0.436	0.126	−3.163	C
U.K.	0.314	0.032	0.465	0.116	−4.769	C
Argentina	0.398	0.028	0.344	0.109	0.182	N
Brazil	0.456	0.028	0.542	0.092	−3.151	C
Chile	0.534	0.025	0.614	0.069	−2.548	C
Mexico	0.401	0.029	0.525	0.102	−3.813	C
Hong Kong	0.122	0.001	0.058	0.003	1.862	C
Indonesia	0.102	0.001	−0.058	0.007	1.035	N
Korea	0.106	0.001	0.142	0.006	−2.647	C
Malaysia	0.021	0.001	−0.054	0.008	2.160	N
Philippines	−0.03	0.001	−0.200	0.006	5.105	N
Thailand	0.104	0.001	0.040	0.007	1.846	N

This table reports the values of the $CT_{n,m}$ test statistics to detect the contagion from the ongoing 2007 subprime crisis to the Canadian big six banks, the countries of East Asia, Latin American, and G-7. The estimations of concordance before and after the crisis are also reported. The stable period is defined as 1 January 2007, through 31 July 2007. The crisis period is defined as three months starting on 1 August 2007. "C" in the final column indicates that the contagion test $(CT_{n,m})$ test is greater than the critical value and therefore contagion occurred. "N" in the final column indicates that no contagion occurred.

Table 12: Testing for Financial Contagion for the 2007 Subprime Crisis

	Stable period		Crisis period			
	ρ	σ	ρ_{ad}	σ	FR's Test	Result
CIBC	0.295	0.816	0.294	1.827	0.011	N
BMO	0.335	0.807	0.431	1.385	−1.055	N
NAT	0.299	0.870	0.353	1.501	−0.564	N
BNS	0.298	0.872	0.279	1.160	0.200	N
RBC	0.346	0.905	0.406	1.344	−0.658	N
TD	0.352	0.817	0.354	1.427	−0.019	N
Canada	0.662	0.803	0.511	1.215	1.612	N
France	0.119	1.084	−0.125	2.004	2.229	N
Germany	0.509	0.792	0.232	2.008	2.651	N
Italy	0.534	0.909	0.257	1.783	2.658	N
Japan	0.534	0.966	0.290	1.166	2.351	N
U.K.	0.507	0.813	0.223	1.569	2.703	N
Argentina	0.336	1.693	0.247	1.654	0.919	N
Brazil	0.699	1.337	0.493	1.677	2.561	N
Chile	0.751	1.494	0.468	2.111	3.480	N
Mexico	0.633	1.378	0.379	2.302	2.902	N
Hong Kong	0.162	0.966	0.032	2.350	1.985	N
Indonesia	0.157	1.107	−0.032	1.906	2.145	N
Korea	0.084	1.591	0.102	1.579	−0.203	N
Malaysia	0.111	0.729	−0.073	1.230	2.083	N
Philippines	0.001	1.318	−0.098	2.198	1.199	N
Thailand	0.150	0.977	0.008	1.949	1.605	N

This table reports the values of FR's test statistics to detect the contagion from the ongoing 2007 subprime crisis to the Canadian big six banks, the countries of East Asia, Latin American, and the G-7. The cross-market correlation coefficients and standard deviations are also reported. The cross-market correlation coefficients of the crisis period is adjusted from Forbes and Rigobon (2002). The stable period is defined as 1 January 2007, through 31 July 1997. The crisis period is defined as three months starting on 1 August 2007. "C" in the final column indicates that the FR's test is grater than the critical value and that therefore contagion occurred. "N" in the final column indicates that no contagion occurred.

Figure 1: Contagion from the Ongoing 2007 Subprime Crisis (Statistic value of $CT_{n,m}$)

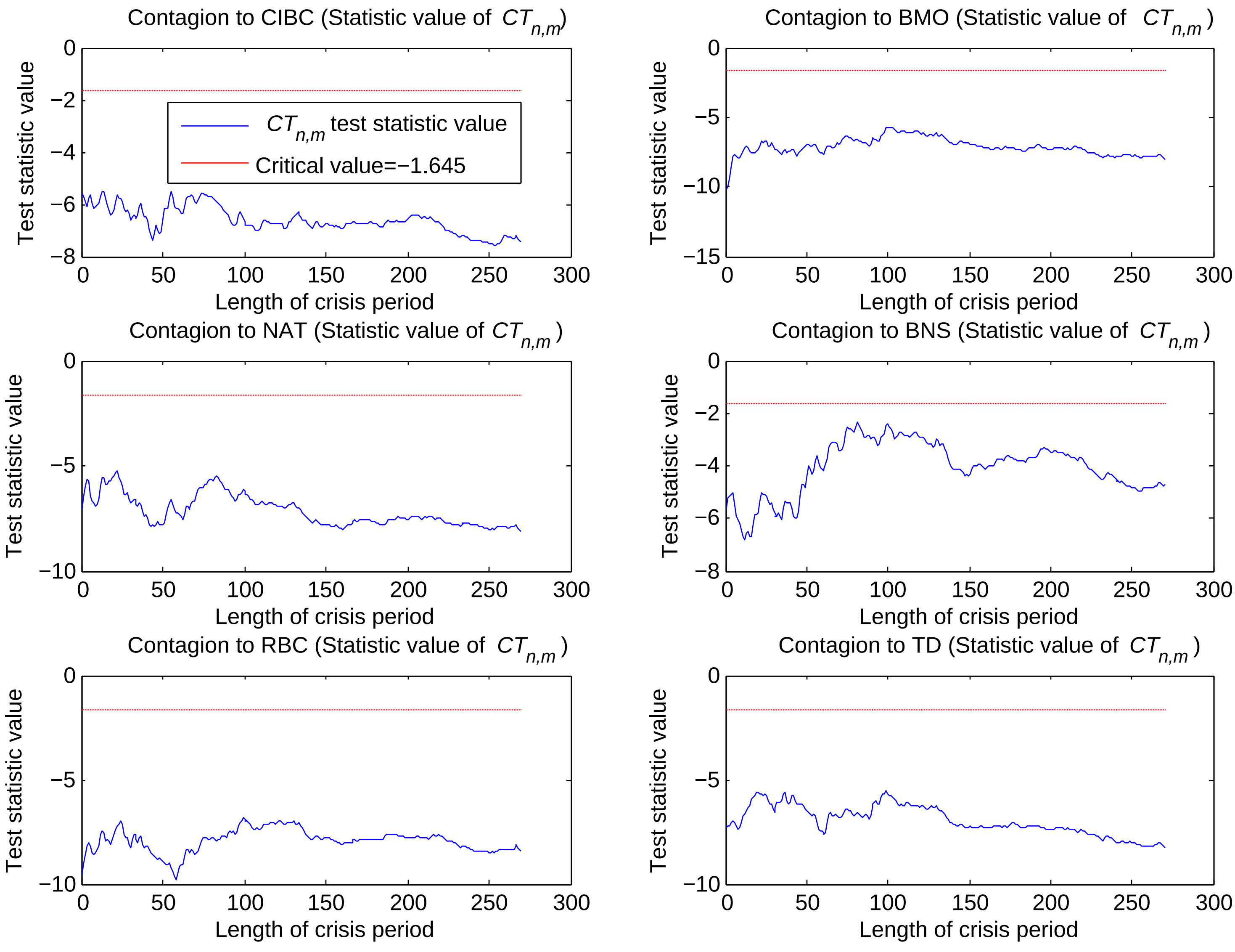
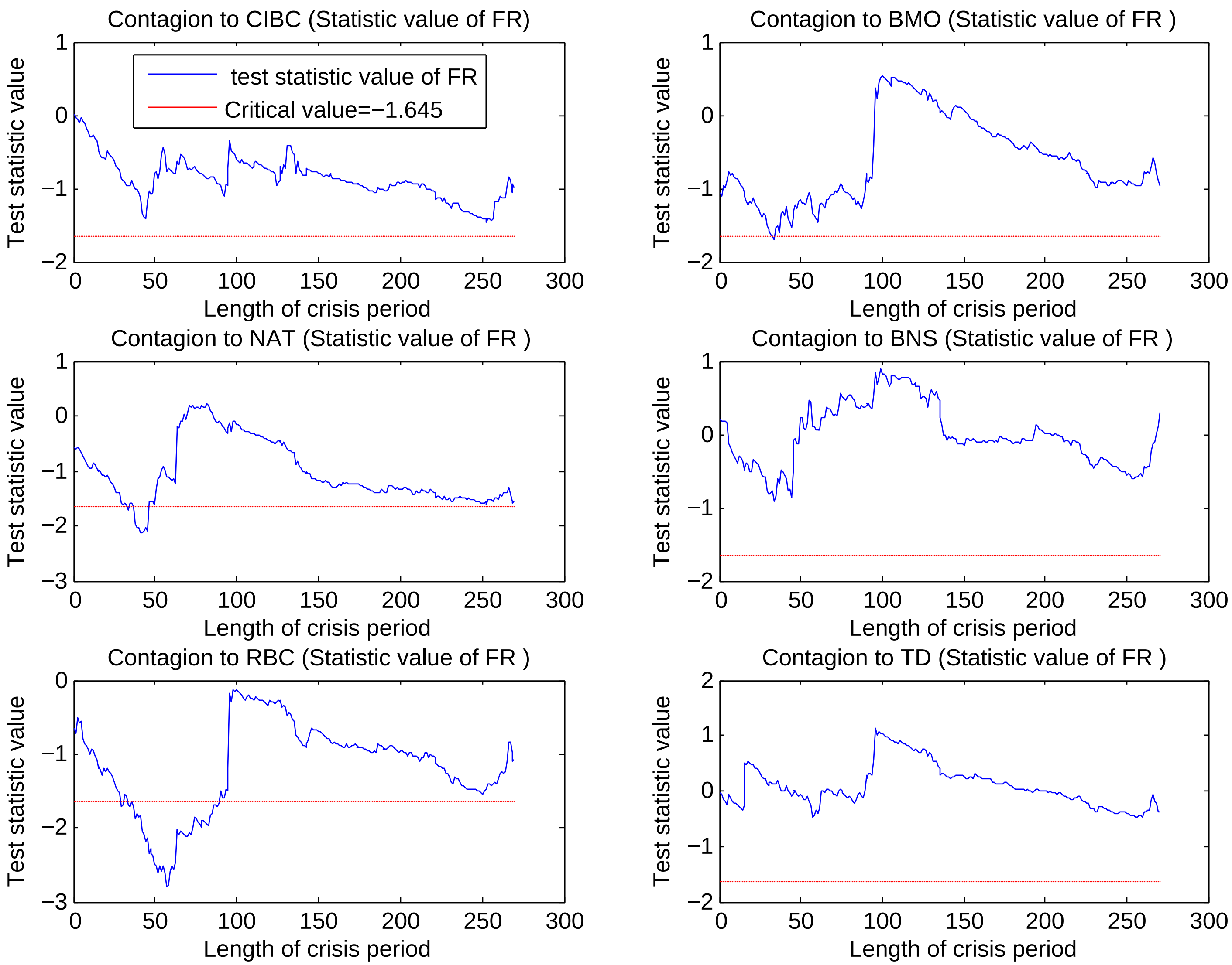


Figure 2: Contagion from the Ongoing 2007 U.S. Subprime Crisis (Statistic value of FR)



References

Baig, T. and I. Goldfajn. 1998. "Financial market contagion in the Asian crisis." *International Monetary Fund, Working Paper No. 155.*

Barberis, N., A. Shleifer, and J. Wurgler. 2005. "Comovement," *Journal of Financial Economics 75(2): 283-317.*

Bekaert, G., C.R., Harvey, and A. Ng. 2005. "Market integration and contagion," *Journal of Business 78 (1):39-69.*

Calvo, S. and C. Reinhart. 1996. " Capital flows to Latin America: Is there evidence of contagion effects? *Private Capital Flows to Emerging Markets After the Mexican Crisis, 151-84, edited by G.A.Calvo, M. Goldstein, and E. Hochreiter. Washington, DC: Institute for International Economics.*

Cherubini, U., E. Luciano, and W. Vecchiato. 2004. *Copula Methods in Finance. Hoboken, NJ: John Wiley and Sons.*

Dornbusch, R., Y. C. Park, and S. Claessens. 2000. "Contagion: Understanding how it spreads." *World Bank Research Observer 15 (2): 177-97.*

Dungey, M., R. Fry, B. Gonzalez-Hermosillo, and V.L. Martin. 2005. "Empirical modelling of contagion: a review of methodologies." *Quantitative Finance 5 (1): 9-24.*

Dungey, M., R. Fry, B. Gonzalez-Hermosillo, V. L. Martin, and C. Tang. 2007. "Are financial crises alike?" Paper presented at the Federal Reserve Bank of Atlanta conference on Financial Market Integration and Its Implications. November.

Forbes, K. 2001. "Are trade linkages important determinants of country vulnerability to crises?" National Bureau of Economic Research, Working Paper No. 8194.

Forbes, K. and R. Rigobon. 2002. "No contagion, only interdependence: measuring stock market comovements.” *Journal of Finance 57 (5): 2223-61.*

Gravelle, T., M. Kichian, and J. Morley. 2006. “Detecting shift-contagion in currency and bond markets.” *Journal of International Economics 68(2): 409-23.*

Hamao, Y., R. Masulis, and V. Ng. 1990. “Correlations in price changes and volatility across international stock markets.” *Review of Financial Studies 3 (2): 281-307.*

Hartmann, P., S. Straetmans, and C. de Vries. 2005. “Banking system stability: a cross-Atlantic perspective.” *European Central Bank Working Paper No.527.*

Hartmann, P., S. Straetmans, and C. G. de Vries. 2004. “Asset market linkages in crisis periods” *The Review of Economics and Statistics 86 (1): 313-26.*

Hollander, M. and D. A. Wolfe. 1999. “Nonparametric statistical methods.” Second edition, New York: John Wiley and Sons.

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

Merton, R. C. 1974. “On the pricing of corporate debt: the risk structure of interest rates.” *Journal of Finance 29 (2): 449-70.*

Rodriguez, J.C. 2007. “Measuring financial contagion: a copula approach.” *Journal of Empirical Finance 14 (3): 401-23.*

Yang, J., C. Hsiao, Q. Li, and Z. Wang. 2006. “The emerging market crisis and stock market linkages: further evidence.” *Journal of Applied Econometrics 21 (6): 727-44.*