

**FINANCIAL INTEGRATION OF NAFTA:
MEASUREMENT AND ANALYSIS OF THE NORTH AMERICAN
FINANCIAL MARKETS CONVERGENCE**

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Abstract

Applying market arbitrage theory on daily data, we measure the empirical financial market convergence of NAFTA's financial markets since 1994. Radar diagram and wavelet multi-resolution analysis (MRA) scalogram movies of the statistical moments of the term interest rate differentials visualize the multidimensional convergence. From the radar movies, we find: 1) a uniform disappearance of the average forward premia; 2) a non-uniform decline of bilateral financial market risk; 3) variation of bilateral financial market pressure measured by skewness; and 4) emergence of uniform market microstructures as measured by vanishing excess-kurtosis. From the MRA movies, we find that the national term structures of interest rates converge, since the stochastic resonance coefficients of the interest rate differentials lose significance: market energy at all frequencies dissipates into "white noise." Testing Ogrimah, Prakash and Rangan's (2009) Lemma, we find that, after 2002, higher financial flow pressure is a necessary condition for lower financial market risk.

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1. Introduction, Literature Review and Research Questions

1.1. Introduction

The motivation for this research is derived from the increasing worldwide interest in monetary integration and monetary union, which first emerged now more than 40 years ago, when the Treaty of Rome of 1957 established the European Union and the Canadian Nobel Prize-winning, Columbia University economist, Robert Mundell (1961) introduced the theory of optimum currency areas.

Canada has demonstrated a long-standing interest in, and has intensely politically debated on, financial integration and monetary cooperation with the U.S. and, possibly, with Mexico. The discussions include a possible shift from the current floating exchange rate regime to a fixed rate regime based on the US dollar, or even the adoption of a common currency union within North America, *e.g.*, the so-called *Amero*. In particular, the implementations of, initially, the Canada-US Free Trade Agreement (CUFTA) since 1989, and of the North America Free Trade Agreement (NAFTA) since 1994, have attracted increasing attention from economists and academic researchers regarding North America's financial integration.

NAFTA's program of the liberalization of North American trade has significantly enhanced trade and investment in North America. NAFTA eliminated the trade barriers, improved the competitive business environment, promoted cross-border goods and service flows, and facilitated capital movements. In consequence, the size of the North American economy more than doubled from US\$7.6 trillion in 1993 to US\$16 trillion in 2007.¹ In actuality, for each member country, NAFTA has opened the financial market, where

¹ The data was obtained from the website http://www.naftanow.org/default_en.asp produced by the governments of Canada, the United States of America, and Mexico.

trading (i.e., arbitrage) has been prompted. Enhance competition of open financial markets of NAFTA lets information technology (IT), or electronic communication technologies become fully functional. The improvement of IT allows traders to instantaneously arbitrage. According to market arbitrage theory, arbitrage by traders, as a forceful factor, can help financial markets converge. Therefore, it is implied that NAFTA is also a significant factor to stimulate financial market convergence in North America.

However, many concerns have also been raised by NAFTA critics, such as the occurrence of “continued high levels of illegal immigration, slow progress on environmental problems, growing income disparities (particularly within Mexico), weak growth in real wages, and trafficking of illegal drugs” (Hufbauer & Schott, 2005, p. 4). Hufbauer and Schott (2005) indicate that some of these problems have significant correlation with the intended economic and financial integration of North America. Consequently, more attention has been attracted towards the convergence of NAFTA in terms of monetary policy, capital and labor movements, and their financial consequences. In other words, 15 years after NAFTA was signed in 1994, political-economic questions regarding financial integration turn now into technical financial-economic questions regarding the measurable progress of financial integration or convergence among NAFTA countries.

Instead of examining all different financial markets, we will concentrate on measuring the financial convergence of the respective interest rate term structures of the NAFTA countries, since any financial integration requires convergence of the cash and Treasury bond markets, which are necessarily followed by the convergence of the valuations in the corporate bond, repo and credit and equity markets, respectively, in a complete financial

integration process. According to Jappelli and Pagano (2008), “to measure the degree of financial integration of a region one needs to compare prices – or rates of return – for comparable securities issued in different areas within it. This generates price-based or return-based measures, such as interest rates differentials, and calls for the analysis of interest rate convergence” (p. 4), as we do in this thesis.

In actuality, Canada, United States and Mexico have demonstrated an overall financial convergence during the past 15 years; even though, the three countries have adopted vastly different monetary policies, associated with their respective floating exchange-rate regimes. This observation we find true, despite the fact that North America is a highly diversified economic region in terms of uneven population density, language differentiation, and relative concentration of transportation into North-South and East-West corridors. On the other hand, convergence of financial markets is reflected by converging term structures, which does not necessarily imply convergence of fiscal and military policies. Different fiscal and military policies can, in actuality, bring the same debt levels, which generate the similar term structure for different states.

In this paper, we analyze the status of financial integration of NAFTA, by dynamically measuring the degree of statistical convergence among its financial markets since 1994, using daily data. The main part of this study focuses on dynamically measuring the statistical differentials between term structures of interest rates, as suggested by financial market arbitrage theory. Foreign exchange (FX) rate arbitrage theory holds that a term forward premium in the bilateral FX markets, which provides a market neutral expectation, is directly expressed in a bilateral term interest rate differential, the so-called swap differential, due to cash and bond, futures and swap, market arbitrage.

The term “interest rate” in this paper represents “nominal interest rate” only. Real interest rates have to be calculated by subtracting inflation rates from nominal interest rates. Since we are using daily data in this research and inflation rates are monthly, the calculated results of real rates cannot be precisely derived.² In addition, FX arbitrage theory suggests us to look at the nominal interest rates (differentials), exchange rates, and forward and spot prices. According to the chart of International Parity Relationships among Exchange Rates, Interest Rates, and Inflation Rates exhibited by Eun, Resnick and Brean (2006, p. 113), the relationships among these three factors represented by International Fisher Effect (IFE), Forward Expectations Parity (FEP), and Interest Rate Parity (IRP) all would better be examined based on higher-frequency data instead of lower-frequency data. To study the convergence of real interest rates would be problematic, since our daily measurements cannot take the longer term Purchasing Power Parity (PPP) into account. Furthermore, as Baele, Ferrando, Hordahl, Krylova, and Monnet (2004) suggest, nominal rates are preferable for yield-based measures to check if the law of one price holds—which is the definition of financial integration.

To visualize the convergence in a very compact fashion, we’ve created radar diagram movies of the first four statistical moments of these nominal term interest rate differentials. We find that the distributions of the term structure differentials are non-stationary: the statistical moments are not constant, but vary over time in a systematic fashion. Furthermore, we applied wavelet multi-resolution analyses (MRA) to corroborate the validity of this dynamic statistical moment analysis of these interest rate differentials. Wavelet multi-resolution analysis - a sort of localized Fourier spectral analysis -

² Since the arbitrage is executed on nominal exchange rate, inflation rate plays a sub-ordinary role, if at all. We did not look, in this thesis, at the International Fisher Effect.

decomposes a time series into a collection of orthogonal basis functions with resonance weights (i.e., localized coefficients of determination) appropriate to the observed raw data series. We have also made the visualizations of these resonance coefficients in scalograms into movies to visualize the dynamic matching of the interest rate term structures, as the term structure differentials over time statistically vanish at all data frequencies, measuring thereby the financial convergence in a non-stationary means and variance sense.

We do not conduct the coefficient of variation test in the context of the measurement of the North American financial market convergence, since its usefulness is limited or non-existent when the mean of interest rate differential is approaching zero. The coefficient of variation is a statistical representation of the dispersion of a probability distribution around the mean. It is defined as the ratio of the standard deviation to the expected return (mean). A lower coefficient of variation indicates a higher mean with less volatility (risk) and vice versa. This test is most useful for variables with positive values and only defined for non-zero mean. However, in our case, the average of the interest rate differentials between NAFTA countries, theoretically, could be zero, especially between Canada and the U.S. at most times. In fact, when the mean of interest rate differential is near zero, the value of coefficient of variation is approaching infinity, so that, the test of the coefficient of variation loses its validity.

Instead, Obrimah, Prakash, and Rangan's (2009) Lemma is applied and empirically tested to better understand the relationship between the higher statistical moments (in particular, between variance or "financial risk" and skewness or "financial pressure") of the selected interest rate differential distributions.

The results of this study reveal measurable evidence about the current condition of financial integration of North America. It also provides some valuable and constructive insights into how NAFTA has encouraged the three partner countries to progress towards financial integration and towards a single currency area and whether, eventually, the whole of North America can become an optimum currency area. For example, it appears that the global stock market crash of October 2008 intervened in the convergence process and brought such convergence to a temporary halt, but that further progress thereafter was quickly resumed so that the NAFTA convergence was not thrown off course.

1.2. Literature Review

1.2.1 Optimum Currency Areas. Since the Canadian, Nobel Prize-winning, Columbia University economist Robert Mundell (1961) introduced the theory of optimum currency areas, interest in monetary integration or monetary union has steadily increased in the financial literature. Many articles have explained the emergence of the Eurozone³ in terms of Mundell's theory of optimum currency areas. Indeed, the European Monetary Union (EMU), as a realized forerunner of a monetary union, may have established possible lessons and examples for monetary integration. However, Mundell (2002) does not consider Europe the best model for other areas, such as the ASEAN countries, which are now considering closer monetary integration or even monetary union. The NAFTA region is generally compared with Europe, although the optimum currency area of the United States of America alone was already established in 1865 and functioned as the existing model for the formulation of Mundell's (1961) theory.

³ "Eurozone" is also known as "Euroland". The term of Euroland is referred as the group of 11 member countries of the European Union, which adopted a single currency of Euro from 1999. Since the euro area expanded to include 16 member countries, this economic and monetary union (EMU) of 16 European Union member countries has been officially defined as "Eurozone".

“The creation of a single currency area brings great welfare gains to the financial markets by drastically increasing capital mobility, in addition to the welfare gains already achieved by the preceding economic union which increased the mobility of goods and services, and facilitated intra-European trade” (Los, 2000, p.210). Therefore, the birth of Euro in 1999 has generated new interest in North America monetary integration and in technical questions like “Can the whole of North America become an optimum currency area” and how does financial convergence proceed with flexible exchange rates, if at all?

1.2.2 NAFTA. The introduction of the Canadian – US Free Trade Area (CUFTA) in 1989 and NAFTA in 1994 caused a major leap towards closer economic relations in North America. However, did this free trade area (FTA) stimulate the formation of a monetary union in North America? Similarly as in Eurozone, NAFTA is not an optimum currency area, since labor does not move freely among these countries (Salvatore, 2006). The borders of the three countries Canada, the USA and Mexico are still closed, or at least controlled by visa access, legal immigration restrictions, etc. Even Canada does not satisfy all the requirements for an optimum currency area with the United States (Arndt, 2002). Mexico and the U.S. “clearly” do not meet the usual criteria for a currency area (FitzGerald, 2000). Salvatore (2006) also indicates that “with NAFTA not being an optimum currency area, there is little need and benefit for Canada and Mexico to unilaterally dollarize” (p.135).

1.2.3 Canada’s Perspective on Monetary Integration of North America. For practical purposes, the Canadian debate centers on the pros and cons of monetary union (Arndt, 2002) and the problem of sovereignty (Mundell, 2002). According to Arndt (2002), the potential contributions to market efficiency by lowering transaction costs and to imported

price stability, by pegging to a low-inflation country, make the idea of monetary union attractive.

Meanwhile, partial or complete loss of seigniorage earnings, diminution or loss of macro-economic policy independence, and the cost of the loss of exchange rate flexibility are the major shortcomings of a monetary union. This issue of sovereignty has been extensively discussed. Monetary sovereignty is a dominant political restriction for a nation to give up a particular currency of its own (Mundell, 2002). Therefore, agreement on monetary policy among the NAFTA countries is a prerequisite for an optimum currency area with one currency. But is financial market convergence among the NAFTA partners possible with some disagreement among the monetary authorities? This paper will demonstrate the affirmative answer to this question.

1.2.4 Canadian Opponents and Proponents of Monetary Union. Controversial opinions for and against North American monetary union have existed since the idea of monetary union was first proposed. Some Canadian opponents of monetary union, such as Laidler and Robson (2002, 2008), Murray (2000, 2002), and Helleiner (2003, 2004, 2006a, 2006b) consider the case for floating rates as the best alternative under current circumstances. “Monetary and policy integration is feasible within NAFTA. However, a common currency, or even a pegged exchange rate system, is not desirable without a significantly greater degree of labor market integration than currently exists” (Laidler, 2006, p.1). In contrast to Laidler’s (2006) argument, our argument is that labor market integration is not essential for a currency union per se, only for an optimum currency union, as demonstrated by the difference between the Eurozone and the United States per se. Earlier Laidler and Robson (2002) had already indicated that the country’s current

monetary regime—a floating exchange rate, inflation targets, and domestic accountability of policymakers—would still offer the most attractive option.

Murray (2002) examined the available data and obtained the result that “The Canadian dollar continues to be used as the principal unit of account, medium of exchange, and store of value within Canada, and there is no indication that dollarization is likely to take hold in the foreseeable future” (p. 35). The foreign exchange markets apparently provide sufficient hedging opportunities for exporters and importers alike. But a fixed exchange rate is financially less risky than a flexible one. For example, under a currency union, liquid capital would still have flown from Toronto to New York in October 2008, but without the concomitant Canadian dollar collapse of 20% versus the US dollar. Of course, by the Spring of 2010, this sudden collapse in the value of the Canadian dollar versus the US dollar is almost wholly reversed, since capital has gradually flowed back from the USA to Canada in the two years since that collapse.

Some of Canada’s most distinguished economists are proponents of monetary union, such as Courchene and Harris (1999, 2000), and Grubel (1999, 2000, 2006). They argue that, from the Canadian persuasive perspective, Canada’s floating exchange rate has not served the country’s economic interest well (Courchene & Harris, 1999) and the solution could be to work toward establishing a North American currency union (Courchene & Harris, 2000). In 1999, Grubel even proposed a common currency for North America—the so-called *Amero*. The case for monetary union would develop more comparative advantages, trade and, consequently, higher economic growth (Grubel, 2000). Following Europe’s example, a monetary union could bring substantial (hundreds of billions per year)

reductions in transactions costs and exchange risk premiums on interest rates (Grubel, 2006).

1.2.5 Canada's Exchange-Rate Regime. Obviously, Canada's flexible exchange rate has not been completely free-floating and may have been actively used for inflation targeting and balance of payments purposes by Canada's central bank. Although many economists have criticized this policy, the government may still manage the exchange rate to bolster the deficient international competitiveness of Canadian firms (Helleiner, 2006b).

Theoretically, the occasional intervention of Canadian monetary authorities invalidates the mechanism of a truly free-floating exchange rate regime and the theory of free-market anarchism (Rothbard, 2005). But the evidence shows that the interventions in the Canadian dollar market are very rare and more supportive to eliminate occasional "gapping" in the Canadian dollar rate, caused by temporary illiquidity or one-sidedness of the market, than as a specific trade promotion tool.

1.2.6 Historical Background of Measuring Financial Integration. The idea of measuring the level of financial integration is not new. We find that various methodologies have been used to determine the degree of financial integration in different financial markets. Some theoretical methodologies have been developed to identify the longer term relationship between financial integration and business cycle volatility (Mendoza, 1994). For example, using a macroeconomic approach, Brouwer (1997) adopted interest parity conditions as indicators of financial integration in East Asia by using standard regressions, co-integration analysis and error decompositions on domestic and foreign interest rates. Another methodology adapted in the financial integration literature is β -convergence, which is an econometric approach developed from longer term economic growth theories

and measures if markets tend to converge by investigating the deviations from the benchmark (Baele et al., 2004; Durlauf & Quah, 1999). All these macro-economic approaches are forms of comparative – static analyses and not of dynamic analysis, as we use in this thesis.

1.2.7 Critique of Static Unit Root “Regression Analysis” to Demonstrate Convergence. Most empirical studies have used static “regression analysis” to examine the integration of different financial markets in North America during various time periods. For example, the null hypothesis of financial integration in North America from January 1984 to December 2003 was rejected by CAPM- and APT-based regression analysis (Beaulieu, Khalaf, & Gagnon, 2006). The Mexican stock market has been increasing its efficiency in recent years and its dynamic behavior has become more like the U.S. and Canadian stock markets, based on static regression analysis (Coronel-Brizio, Hernandez-Montoya, Huerta-Quintanilla, & Rodriguez-Achach, 2007). The degree of stock market integration is demonstrated to be higher at the end of the complete period than at its beginning by examining the North American equity market, the local Mexican equity market and the peso dollar exchange rate over the 1991-2002 period on the basis of regression analysis (Adler & Qi, 2003).

In contrast, the conflicting conclusion - that the passage of NAFTA has not resulted in a greater integration of the North American stock markets - has been derived also by using regression analysis to compute a unit root test (Ewing, Payne, & Sowell, 1999), showing no interest rate convergence towards an integration root smaller than unity. Had that integration root been statistically significantly less than one, this would have, perhaps, indicated asymptotic market convergence, but still not demonstrated actual convergence.

Los (1999, 2001, 2006) shows evidence, theoretically and empirically, that static regression analysis to establish such unit roots (i.e., lack of asymptotic convergence) is scientifically incomplete and highly biased, since it is based on a necessarily prejudiced presentation of an incomplete set of unidirectional orthogonal projection results. To identify the value of the root beyond reasonable doubt, at least two such orthogonal projections must be shown, and not one, by producing both the original regression and its reversed regression. Consequently, most of the published results regarding financial convergence are not scientifically trustworthy, since they do not provide the complete range of identification results of the root's value. Moreover, they are based on static ("snapshot") integration analysis and not on dynamic (asymptotic) stability or convergence analysis as in this thesis.

Furthermore, in our opinion it does not make much sense to look at the convergence of the three North-American stock markets, for the following reasons:

1. The indices of the stock markets in the three North-American countries represent different portfolios of a large number of various stocks. So, when one compares the rates of change of each of these indices, one compares apples and oranges. Why would these differently composed portfolios (e.g. Dow Jones Industrial Average, S&P TSX Composite, and IPC) with different number of stocks moment-wise (expected return, risk, skewness and kurtosis) converge?
2. Even if the indices of these stock markets would represent the same number of stocks, the analysis would require that the stocks would be the same, i.e., they would have to be cross-listed in all three stock markets. This is clearly not the case.

3. For an analysis of “stock market” convergence one would have to look at the convergence of each stock cross-listed in each of the three countries and the dimensionality of the problem would be exacerbated by the large numbers of stocks to be compared.

A country’s macro equity market is a portfolio of all of a country’s micro equity markets in aggregate. Each micro equity market is a market for a specific equity share. Each country has a different macro equity market, consisting of a different portfolio with different capitalizations for each of its micro equity markets. Therefore, comparing countries’ macro equity markets would be comparing apples and oranges. One would have to compare the micro equity market for each cross-listed share to ascertain micro-equity market convergence (Schwartz, 2010). In this thesis, we do not analyze such incomparable convergence, but we look at the convergence of the complete term structures of the three Treasury markets, so that we compare apples with apples and oranges with oranges: term interest rates are directly comparable by each term.

1.3. Research Problem Statement

Thus far, statistical measurements of financial integration of North America have not been done dynamically and, in particular, not by looking at complete sets of distributional term structures, as we propose and demonstrate in this paper. Most of the studies have concentrated on the consequence of NAFTA, economic integration within North America, or policymaking regarding a North America Monetary Union. But there has been no research to actually dynamically measure and visualize the progress of statistical convergence among the North American financial markets as a consequence of the NAFTA since 1994.

Even though points of controversy towards monetary and financial integration are still hotly debated, mostly from political perspectives, the interest of this paper does not reside in proposing for or opposing against financial integration of North America. The objective of this paper is to fill the gap in factual financial research by, for the first time, dynamically measuring and visualizing how the multidimensional North American financial markets have converged over time since NAFTA came into effect.

1.4. Research Questions

This thesis seeks to make some contribution to the measurement and analysis of how the North American financial markets actually have converged since 1994. This paper sets out to answer the following two major research questions.

1. Is there financial convergence among the NAFTA member countries and in what sense: certainly or statistically? How can we measure it dynamically, so that we can answer the question how much convergence there has taken place since 1994 and how far monetary integration has still to go before we can ascertain that the North American financial markets are completely converged?
2. How can we dynamically visualize such measurable convergence of the multidimensional – multi-term financial markets in a very compact and persuasive fashion, if it exists at all?

2. Data, Financial Theory and Methodology

2.1 Data

All data are obtained from a single reliable and accessible source—Thomson Reuters DataStream. To measure the convergence over time of the respective North American financial markets, we use daily data (weekdays), to allow for unique interventions and special singular daily events. The data consist of very short-term interest rates (overnight interbank rates), Treasury bill rates (with maturities at 1, 3, 6 and 12 months), and benchmark bond yields (with maturities at 3, 5 and 10 years). These data are commonly used in the interbank, cash and bond markets. Most of the historical data set starts on the 1st of January 1994 and ends at the end of April 2009. And most of them cover the entirely 15-year period since NAFTA came into force in 1994 and includes 3,998 observations for each term interest rate series, for each of the three countries.

In actuality, the complete term structures of interest rates are only available since 2002. The U.S. Treasury Department began to sell 4-week Treasury bill on July 31st, 2001. Moreover, as informed by Banco de Mexico, the long part of the yield curve in Mexico is relatively recent. The extension of the yield curve started as follows: 3-year in January 2000, 5-year in May 2000, and 10-year in July 2001. So the most consistent financial market information for Mexico can only be obtained from 2003 on, after 2002.

Nevertheless, the unavailability of these term structures before 2002 is not a shortcoming of the study, since we observe how that introduction of complete term structures has actually led to better, more efficient and effective financial market convergence, since it has expanded the set of available hedging terms for the exporters and importers.

Daily spot FX rates of Canadian dollar per U.S. dollar (CAD\$/US\$) and Mexico Peso per U.S. dollar (MXN Peso/US\$) are also used to corroborate the validity of the dynamic moment analysis and wavelet multi-resolution scalogram analysis (dynamic matching) of term interest rate differentials, since all foreign exchange (FX) trading is a form of pair trading, or swapping. When the countries' respective pair of term interest rates converges, the expected forward premium vanishes as the forwards equalize to the dynamic spot price. That does not necessarily imply a fixed exchange rate, since the interest rate differential is stochastic or "statistical," but, by continuous market arbitrage, it eliminates the possibility for systematic FX speculation in the bilateral FX markets.

So, one can have dynamic statistical convergence, without convergence to one fixed spot rate. This is the same as a heat-seeking missile converging on a dynamically evading (piloted) target: the two objects converge by minimizing the statistically distance between the two via a learning or feedback rule, although still following very dynamic and essentially unpredictable flight paths. Furthermore, fluctuation in exchange rate can be reflected by the non-stationary variation in risk of interest rate differential. That is why we adopt FX Market Arbitrage Theory.

2.2 Financial Arbitrage Theory

According to FX Market Arbitrage Theory (Eun & Resnick, 2006), exporters and importers need forward prices to cover (i.e., "fix" the future prices used for) the estimation of their future revenues and expenses. These forward prices provide objective market-neutral forecasts, since they are generated by the market processes of all arbitraging (i.e., trading) participants in the FX markets. The arbitrage formula used is the following trading identity:

The forward (Canadian dollar/US dollar) FX rate at the current time (zero) for the future term T is:

$$F_{0,T}^{\text{CAD}/\$} = X_0^{\text{CAD}/\$} e^{(r^{\text{CAD}} - r^{\$})T},$$

where $X_0^{\text{CAD}/\$}$ = spot FX rate, r^k = the Tth term interest rate for the kth currency (e.g., for the Canadian dollar or CAD).

Then, after logarithmic transformation and division of both sides by the maturity term T, we can get that the time-normalized, logarithmic forward term premium ratio $F_{0,T}^{\text{CAD}/\$} / X_0^{\text{CAD}/\$}$, which is equal to the term interest rate differential, also known as swap differential:

$$\ln[F_{0,T}^{\text{CAD}/\$} / X_0^{\text{CAD}/\$}] / T = [\ln F_{0,T}^{\text{CAD}/\$} - \ln X_0^{\text{CAD}/\$}] / T = r^{\text{CAD}} - r^{\$}$$

Thus, FX market arbitrage theory suggests to look at the (daily) differentials of two national term structures of interest rates, whereby by “term structure” is meant the whole set of daily time series of interest rates for all available maturity terms T. The terms structures of Canada, the U.S. and Mexico are plotted over time as Figures 1, 2 and 3, respectively, in Appendix A. All four variables, including $F_{0,T}^{\text{CAD}/\$}$, $X_0^{\text{CAD}/\$}$, r^{CAD} , and $r^{\$}$, are indexed by daily time t.

2.3 Methodology

2.3.1 Dynamic Moment Analysis. To measure the financial convergence of the financial markets of NAFTA member countries, we apply dynamic moment analysis of the interest rate differentials between Canada and the U.S. and between Mexico and the U.S., respectively. The U.S. interest rate term structure is used as a base, so that $r^{\text{CAD}} - r^{\$}$ and $r^{\text{MXN}} - r^{\$}$ are the two relevant interest rate differentials.

There are eight financial market measurements for each country: the overnight interest

rate, the 1-month treasury-bill rate, 3-month treasury-bill rate, 6-month treasury-bill rate, 12-month (1-year) treasury-bill rate, 3-year benchmark bond yield, 5-year benchmark bond yield and 10-year benchmark bond yield. We compute differentials for each of the eight interest rates between Canada versus U.S., and Mexico versus U.S. The daily time series of the 1-month, 1-year and 10-year interest rate differentials between Canada and the U.S. and Mexico and the U.S., respectively are graphed in the following Figures 1-6.

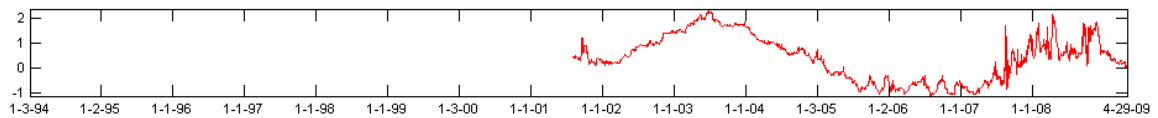


FIGURE 1
1-Month Treasury Bill Interest Rate Differential between Canada and the U.S.

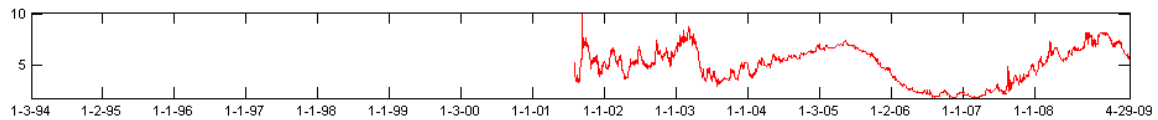


FIGURE 2
1-Month Treasury Bill Interest Rate Differential between Mexico and the U.S.

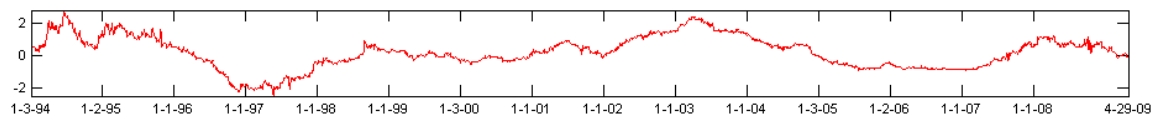


FIGURE 3
1-Year Treasury Bill Interest Rate Differential between Canada and the U.S.

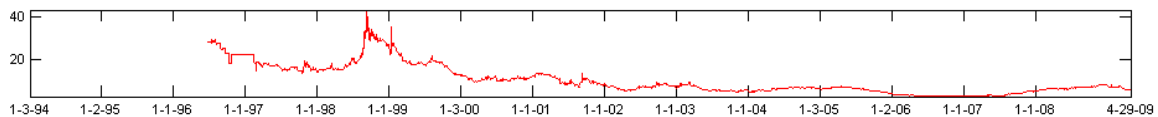


FIGURE 4
1-Year Treasury Bill Interest Rate Differential between Mexico and the U.S.

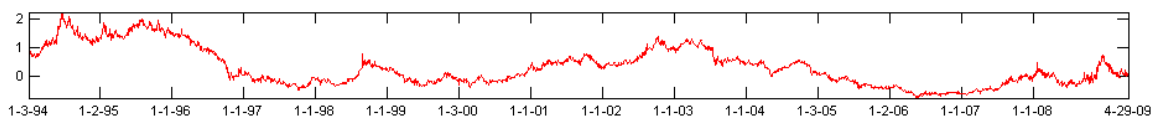


FIGURE 5
10-Year Benchmark Bond Interest Rate Differential between Canada and the U.S.

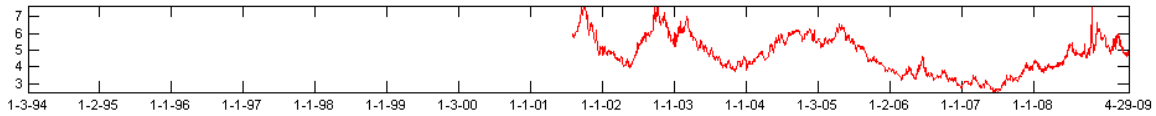


FIGURE 6
10-Year Benchmark Bond Interest Rate Differential between Mexico and the U.S.

Next, the monthly four distributional moments (mean, variance, skewness and excess kurtosis) are computed for all available interest rate differentials. Financial convergence of NAFTA is a multi-dimensional statistical process. Therefore, statistical measures of the shapes of the statistical distributions, like the higher-order statistical moments, will be powerful tools to investigate the market conditions in North America.

Based on this dynamic moment analysis, we can observe whether all four moments of the term interest rate differentials converges to zero.

- 1st Moment: if the monthly mean of the differential converges to zero, average interest rate levels equalize: the average forward premia vanish and the FX rates converge on average. However, this does not imply that the FX rates are constant. It only means that the forward premium has only disappeared on average and that, on average, the best forward prediction of the FX rate, at any future term, is the dynamic spot rate, i.e., the best prediction of next month's currency rate is this month's average value. Another way of phrasing this is that the swap differential converges on average to zero, i.e., toward the zero mean of "white noise." But this allows, in principle, still large variation around the mean. Thus, we look also at the variance.
- 2nd Moment: if the variance of the rate differential converges on average to zero, the volatility (or "market risk" or "energy") of the FX rate differential vanishes. We'll observe that it never reaches perfectly zero, since FX risk may become small, but it never

disappears in the forward markets. It thus becomes “white noise” energy, i.e., constant undifferentiated “background noise” energy, because of hundreds of thousands of “noise” traders, who take very small temporary positions in the currency markets and reverse those positions quickly, giving rise to continuous reversions to the mean zero interest rate differential “noise.” But variance is a symmetric measure and the distributions of interest rate differentials are not symmetric. Thus, we look also at the skewness.

- 3rd Moment: skewness of differential converges to zero. For example: if the skewness is positive, then there is market pressure for the CAD to depreciate versus the US dollar and if the skewness is negative, there is market pressure for the CAD to appreciate versus the U.S. dollar. This market pressure can emerge from a change in the structural composition of the varying trading positions. Thus, we look at kurtosis.
- 4th Moment: excess kurtosis of differential converges to zero. This means that the: micro-structural market composition converges to neutrality. Our financial interpretation of the measured excess kurtosis in the interest rate differentials is the following (and we emphasize that this is a very important measure for FX traders and regulators to monitor on a continuing basis):
 - Zero-excess kurtosis: the micro-structural market composition is normal, there is a normal balance between a group of speculators and many hedgers, and normal backwardation is expected.
 - Negative excess or platy-kurtosis: a more uniform micro-structural market composition exists; there is no differentiation between speculators and hedgers; there exists neither backwardation nor cotango. The result is that the market is directionless and the interest rate differentials show undifferentiated, almost uniform, statistical dispersion.

- Positive excess or leptokurtosis: a clearly differentiated micro-structural market composition exists with few speculative, large premium traders combined with a large number of small hedgers (*e.g.*, small day traders); and substantial backwardation or contango exists. Extreme positions are taken by speculators, in combination with a very large number of small daily positions by small hedgers or “noise traders.” The market is tightly controlled by a few direction setters and sharp changes in the market pricing can occur.

For a mathematical standard of statistical comparison, compare the following figures of theoretical (symmetric) distributions with different degrees of excess kurtosis, obtained from <http://en.wikipedia.org/wiki/Kurtosis>. Figure 7 has a regular probability scale on the vertical axis and Figure 8 has a logarithmic probability scale on the vertical axis. Most empirical term interest rate distributions show positive excess kurtosis, or leptokurtosis and consequently show some apparent direction and trading structure.

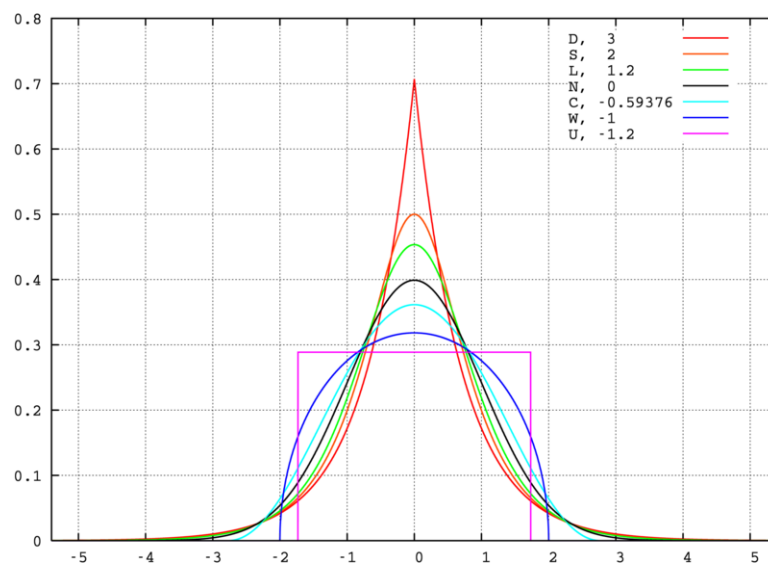


FIGURE 7

Plot of Several Symmetric Unimodal Probability Densities with Unit Variance (Wikipedia, 2009a).
4

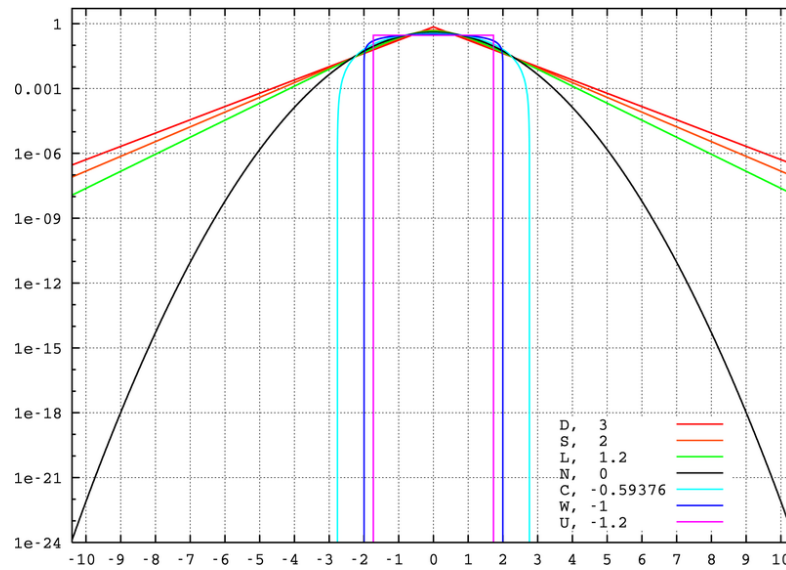


FIGURE 8
Logscale Plot of Several Symmetric Unimodal Probability Densities with Unit Variance (Wikipedia, 2009b).⁵

In addition, the following explanation for both Figure 7 and 8 is provided by Wikipedia (2009a, 2009b):

- D: Laplace distribution, a.k.a. double exponential distribution, red curve (two straight lines in the log-scale plot), excess kurtosis = 3
- S: hyperbolic secant distribution, orange curve, excess kurtosis = 2
- L: logistic distribution, green curve, excess kurtosis = 1.2
- N: normal distribution, black curve (inverted parabola in the log-scale plot), excess kurtosis = 0
- C: raised cosine distribution, cyan curve, excess kurtosis = -0.593762...
- W: Wigner semicircle distribution, blue curve, excess kurtosis = -1
- U: uniform distribution, magenta curve (shown for clarity as a rectangle in both images), excess kurtosis = -1.2.

The Bernoulli distribution (not featured in these graphs) is the most platykurtotic distribution of all, with probability $p = (1-p) = \frac{1}{2}$. For which the kurtosis is -2. For example, a Bernoulli distribution is generated by counting the number of times one obtains "heads"

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when flipping a theoretical coin once, a coin toss. In such a market, one can just as well flip a fair coin to decide on the direction for the next day.

Interestingly, there is no upper limit to the degree of excess positive kurtosis or leptokurtosis and thus also not on the degree of statistical control of a dynamic FX market. In the limit there is a perfect control, i.e., a pegged or “fixed” exchange rate that can be reset at a different value at will by politicians. For example, compare the political determination of the value of the (no longer existing) East German Mark versus the West German mark at the time of the German Unification, or the monetary integration of East Germany with West Germany, in 1990.

2.3.2 Radar Diagram Movies. Another objective of this paper is to dynamically visualize the actual, empirical financial convergence of NAFTA in a very compact fashion. First, we create dynamic moment radar charts with eight term interest rate dimensions of the bilateral interest rate differentials between Canada and the U.S. and between Mexico and the U.S., and have the eight measurements shown at the same time (with each measurement as a direction) for every monthly statistical moment (based on the daily observations).

All dynamic moment radar diagrams have been made into movies, where time progresses on a monthly basis. Thus, we compress measured time by a factor of about 30x for visual compactness, since daily time takes too long to monitor *ex post*. However, in practice these measures could be computed and monitored in real-time using Kalman and higher-order filters.

In Appendix B we’ve collected all radar diagram movies of the term structures of the three NAFTA partners: Canada, U.S. and Mexico (Movies 1 – 8). With the radar diagram

movies, dynamical measurement of the degree of statistical convergence can be visually demonstrated, by monitoring how the North American financial markets statistically converge over time⁶. One can either look at the radar diagram movies of the moments of the terms structures of the three NAFTA partners (Movies 1 – 4 provide all four moment diagram movies, respectively, in Appendix B), or, as is preferred, by looking at the radar diagram movies of the interest rate differentials (Movies 5 – 8 provide those four moment diagram movies, respectively, in Appendix B). These digital movies are all available online and Appendix B provides the online links.

2.3.3 Wavelet Multi-Resolution Scalogram Movies: Dynamic Matching. We use wavelet multi-resolution scalogram movies to visualize the dynamic statistical matching of the bilateral term interest rates in another, less aggregated, fashion, which better lends itself for the detection of irregular phenomena in the FX markets. Using wavelet multi-resolution analytic scalograms, we can corroborate the validity of the dynamic moment analysis of the term interest rate differentials between Canada and Mexico versus the U.S., respectively, and investigate the singular event dates, which we have extracted from the radar diagram movies (cf. Appendix C).

With wavelet multi-resolution analysis (MRA), we have transformed the original financial market term interest rate differential signals into resonance coefficients, as first suggested by Los (2001), and later demonstrated in Los (2003) for both FX and stock markets. These resonance coefficients are actually conventional coefficients of determination of the correlation of a segment of the series of observations with a particular corresponding time-scale segment on the wavelet grid generated by the so-called

⁶ This can be realized, of course, in real-time, when real-time data would be streaming in. So, this thesis provides a vivid example of what can be done with visualization of the dynamics of arbitraging FX markets.

Daubechies wavelet with six moments, or wavelet db6, again as suggested by Los (2003).

Since the average wavelet on the grid has zero value, all the energy of the investigated empirical time series is then expressed into these resonance coefficients at various time-scales. These resonance coefficients are colorized according to their fractional value between zero and one in the scalograms, so that one can detect time-frequency areas of high correlation and high energy or volatility (cf. Appendix C). For our case, the less differentiated-colorized structure one observes at a time scale (i.e., inverse of frequency scale), the more the interest rate differential converges at that particular time scale. Thus the scalogram shows the financial market convergence progressing simultaneously at various time-scales.

The scalograms cover daily data over the 3,998-day period with the 1-64 (3 months) scale. We decompose the wavelet figures generated by the Wavelet Toolbox software of MatLab, and then build the elements of the original signals, scalograms and selected coefficients lines into digital movies to conduct the dynamic Wavelet Multi-resolution Analysis (MRA) to monitor the dynamic statistical convergence in an energy fashion.

2.4 Theoretical Test: Obrimah, Prakash and Rangan's Lemma (2009)

In this paper, we also conduct a statistical test based on Obrimah, Prakash and Rangan's Lemma (2009). This Lemma was developed by Obrimah et al. (2009) in the context of venture capital return distributions. With this model, they show that "preference for lower variance risk can be associated with preference for higher skewness in [venture capital market] returns whenever a generous condition governing relations between the first, second, and third moments holds" (Obrimah et al., 2009, p. 10).

Obrimah et al.'s Lemma (2009):

$\text{Var}(r_A) \leq \text{Var}(r_B)$ implies $\text{Skew}(r_A) \geq \text{Skew}(r_B)$,

if the condition, $|E(r_A^3) - E(r_B^3)| \leq 3r_B [\text{Var}(r_B) - \text{Var}(r_A)]$ is satisfied.

Thus if this particular condition holds (and it usually does), then, if the variance of rate of return of asset A is smaller or equal than that of the rate of return of asset B, the skewness of the distribution of asset A's return is equal or larger than the skewness of the distribution of asset B's return.

A bit further translated from statistical into financial terms, we now make the following statement: when we observe a less volatile (risky) return stream, it is implied that we are observing higher financial pressure with a more definite direction. Therefore, more definite capital flow direction and financial pressure is necessary for the existence of relatively less market risk, under a flexible exchange rate system. Keep in mind, of course, that such financial pressure can abruptly change, when the market microstructure is very non-neutral and the lepto-kurtosis of the statistical distribution of interest rate differentials is very high.

Our objective of using this Lemma to test the empirical data series of daily interest rate differentials is to investigate the structure of respective bilateral financial markets and provide a means to better understand the relationship between the higher statistical moments (variance and skewness) of selected interest rate differential distributions. In addition, we also aim at testing the ability of the model to characterize the bilateral financial markets and their bilateral capital flows in North America.

This model is developed with a framework where the variance (risk) of random variable B is higher than the variance (risk) of random variable A. Once the condition is satisfied, it is implied that the differences in returns are determined by differences in the

higher moments of the return distribution. To conduct our test with respect to the model, we adopt the same framework and make several restrictive (and, perhaps, somewhat unrealistic) assumptions:

1. FX rates (CAD/USD and Mexico Peso/USD) are completely free-floating. These markets are (almost) friction-less: all explicit trading transaction costs can be minimized to the greatest degree, or even eliminated.
2. The financial market conditions in these NAFTA countries are converging and becoming very similar.
3. The bilateral financial markets in North America can be characterized by variance and skewness only.
4. $\text{Var}(r_B) = \text{Var}(r_A) + \text{Var}(\varepsilon) = \text{Var}(r_A) + E(\varepsilon^2)$ since $E[\varepsilon|r_A] = 0$, there is no conditionality or relationship between the rate of return of asset A and its noise. But the return on asset B has a larger volatility or risk than the return on asset A
5. $E[r_B] > 0$ and $E(\varepsilon^2) \geq 0$, i.e., the mean of asset return B is positive and the noise variance of asset return A is zero or positive. There is no constancy of return (or, in our case, of interest rates. They are freely determined market rates).

Therefore, we let r_A denote the interest rate differential between Canada and the U.S.; r_B denote the interest rate differentials between Mexico and the U.S.; $E[r_A]$ and $E[r_B]$ denote the mean of rate of return series r_A and r_B respectively.

In this test, we will show the relation between 2nd and 3rd statistical moments (variance and skewness, respectively) of interest rate differentials among NAFTA countries, and find out how the micro-market structures are characterized in terms of these higher statistical moments. On the other hand, our findings will add value for international investors who

pursue risk aversion and seek lower risk or variance and/or skewness preference and seek a more definite capital return direction.

3. Results and Discussion

3.1 Some Salient Observations

Our analysis of the data has produced the following salient observations in accordance with our two dynamic visualization approaches and test of the relationship between the second and third statistical moments:

1. The financial markets of Canada, United States and Mexico have demonstrated an increasing tendency to financial convergence over time, in a statistical (distributional) sense.
2. However, the yield curve of Mexico shows several large deviations from the yield curves of Canada and U.S., *e.g.*, during Mexico's first and second float in 1994-95 and the Brazilian Stock Market Crisis in September 1998.
3. Moreover, interest rates with longer maturities show higher degrees of statistical convergence than shorter-term rates, while shorter term rates show more volatility (market risk) for all three countries.
4. Based on the wavelet multi-resolution scalograms of the interest rate differentials, we observe that some events in the FX markets are seasonal, *i.e.*, they occur regularly on a weekly and monthly basis, because of institutional actions, *e.g.*, bill auctions, bond auctions, etc.
5. To conduct a more effective dynamic analysis and interpretation, we generated movies of radar diagrams and of wavelet multi-resolution analysis (MRA), since communicating visually, *e.g.*, by way of a movie, is six times more effective than communicating with words alone (US Department of Labor, 1996).

3.2 Radar Diagram Movies

3.2.1. Means and Variances Risk of the Interest Rate Differentials between Canada and Mexico vs. U.S. Figures 9 and 10 are static snapshots of the dynamic movies of November, 2002 and July 2007, respectively. Comparing Figure 10 with Figure 9 we see that the means of the bilateral interest rate differentials have been converging to zero in those five years. This is even more visible, when one observes Movie 5 in Appendix B. We find that, the financial markets in Canada and U.S. demonstrated an earlier and faster mutual convergence than those in Mexico and the U.S. immediately after the conclusion of NAFTA in 1994. However, the U.S. and Mexican financial markets have been converging faster since about 2002, i.e., after the 9/11 terrorist attack and the beginning of the war in Iraq.

This overall convergence is indicated by the gradual disappearance of the average forward premia in those markets for all maturity terms, so that possible time arbitrage in these bilateral FX markets is gradually eliminated.

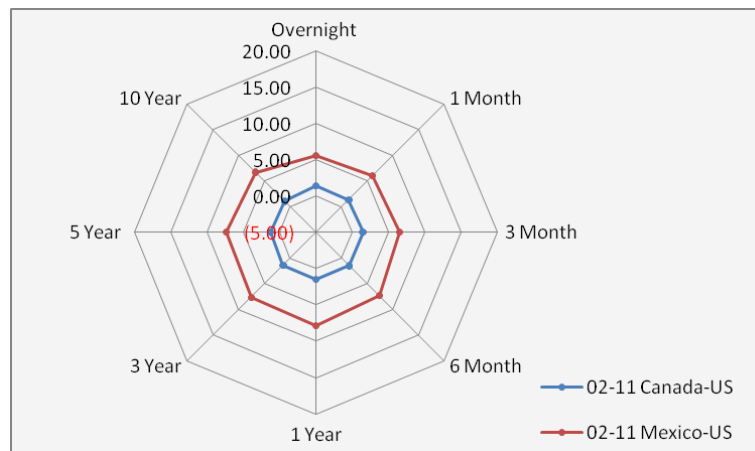


FIGURE 9
Monthly Mean of Interest Rate Differentials, November 2002

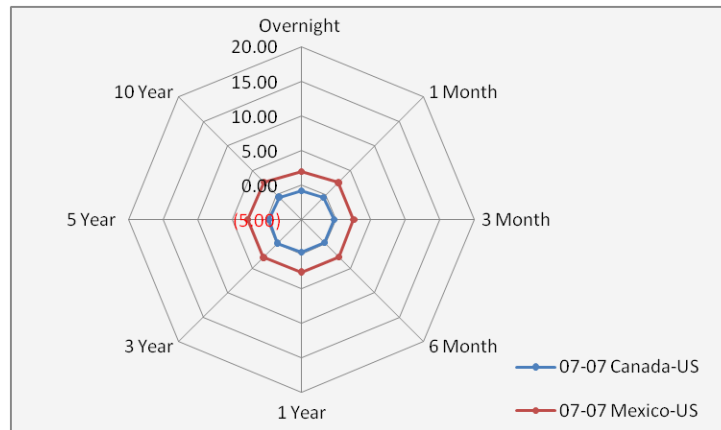


FIGURE 10
Monthly Mean of Interest Rate Differentials, July 2007

Figures 11 and 12 show similar comparative snapshots of the variance (risk) of the bilateral differentials in November 2002 and July 2007, respectively, and again more dynamically in Movie 6 of Appendix B. The bilateral FX risk has been declining in a non-consecutive fashion because of the irregular interventions in the financial markets by the governments and other powerful financial institutions.

The variance of the interest rate differentials between Mexico and U.S. show very high values from 1994 until 1996, in particular in the overnight rates, due to Mexico's first and second free float of its exchange rate with the U.S., respectively. Then, after 2002, the variance of the interest rate differential between Mexico and U.S. started to decrease in value substantially at all maturities, except, of course, in the August –October 2008 period of the Global Financial Crisis.

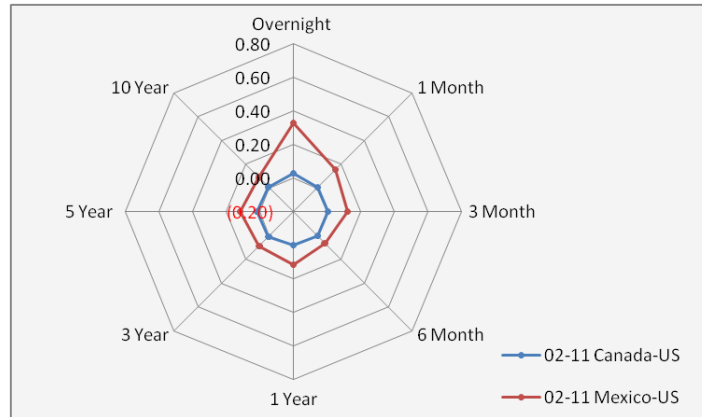


FIGURE 11
Monthly Variance of Interest Rate Differentials, November 2002

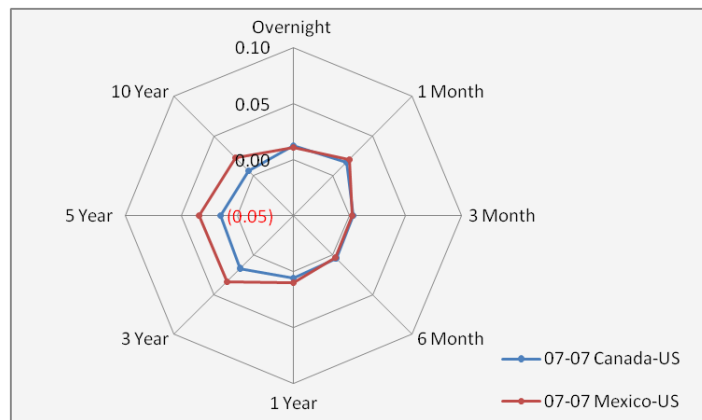


FIGURE 12
Monthly Variance of Interest Rate Differentials, July 2007

The following Table 1 shows a historical record of some major disturbances in the global financial markets that affected also the bilateral financial relationships among the three NAFTA countries since the NAFTA accord of 1994.

TABLE 1
Exceptional Events

Periods	Events
12/20/94-05/03/95	Mexico's first free float of exchange rate
10/16/95-09/09/98	Mexico's second free float of exchange rate
07/02/97-12/31/98	Asian Financial Crisis
08/17/98-12/31/99	The Russian Stock Market Crisis
09/10/98-12/31/00	The Brazilian Stock Market Crisis
12/19/01-12/31/02	Argentina Economic Crisis
07/30/02-12/31/02	South American Economic Crisis
03/13/07-09/14/08	The U.S. Subprime Industry Collapse
09/15/08-10/31/09	Global Financial Crisis

3.2.2 Skewness (*Financial Pressure*) Risk between Canada and Mexico vs. U.S. In our investigation of the statistical convergence of the North American financial markets we include the analysis of the third and fourth moments, respectively the skewness and excess kurtosis, of the bilateral interest rate differentials. “A probability distribution may be symmetric or asymmetric around its mean. A popular measure for the asymmetry of a distribution is called its skewness” (Rachev, Menn, & Fabozzi, 2005, p. 48). By incorporating the skewness, we are able to measure the degree of financial market pressure for CAD or Mexico Peso to appreciate or depreciate versus the USD as the basis currency.

Skewness is a crucial measurement in FX market investments. If people buy and sell assets across international boundaries at no cost and assets had the same degree of risk (i.e., variance risk, skewness risk and excess kurtosis risk), or the difference in the risk of investing in the two countries is constant, then interest rate levels should be equalized. We find that the empirical interest rate differentials between the NAFTA countries are clearly indicative of the existence of skewness risk, i.e., the variability of the skewness, since we observe that skewness switches from positive to negative and vice versa. In other words,,

the financial market pressures are clearly not constant and switch dynamically and in a fairly unpredictable fashion over time.

The skewness of the distributions of these interest rate differentials switches around the mean, which implies that the pressures based on the new-information-based expectations of respective currency depreciation or appreciation vary over time for flexible foreign exchange rate regimes. However, the degree of such variation of skewness (skewness risk) has been decreasing over the past 15 years. Moreover, this skewness of interest rate differentials (varying market pressures on respective FX rate) shows also overall tendency to converge to zero, but again in a non-uniform fashion.

For example, the comparison between the two static snapshots (Figure 13 and 14) of the skewness of the interest rate differentials at all available maturities of November 2002 and July 2007 show actually a temporary increase in such skewness, and thus in financial pressure, over that five year period. But Movie 7 in Appendix B still dynamically demonstrates the overall convergence of the skewness and thus the reduction of financial market pressure since 1994.

Thus, skewness indicates the relative financial pressure in an FX market: a positive skewness indicates that the currency (CAD or Peso) is expected to depreciate versus the US dollar in the future, since there is a statistical tendency towards more positive interest rate differentials at the particular maturities (representing positively sloped forward curves or “cotango” versus the U.S. dollar); and a negative skewness that the particular currency is expected to appreciate versus the US dollar, since there is a statistical tendency towards more negative interest rate differentials at the particular maturities (representing negatively sloped forward curves or “normal backwardation” versus the U.S. dollar).

According to the radar diagram Movie 7, the distribution of interest rate differentials between Mexico and United States is always more skewed, and shows therefore more financial market pressure, than that between Canada and United States, at least prior to 2002. There are two major reasons: 1) the liquidity of the Mexican financial market is relatively small compared to that of the other two NAFTA countries causing illiquidity problems (i.e., narrowness of the capital flow channel) at the Mexican side, and 2) differences of market structures in these three countries provide different levels of market expectations (i.e., differences in investment potential) for the corresponding currency. The Canadian expectations are more similar to the American expectations than the Mexican expectations.

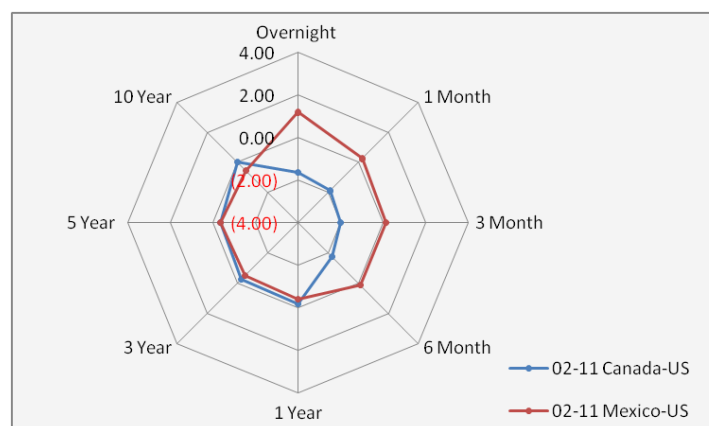


FIGURE 13
Monthly Skewness of Interest Rate Differentials, November 2002

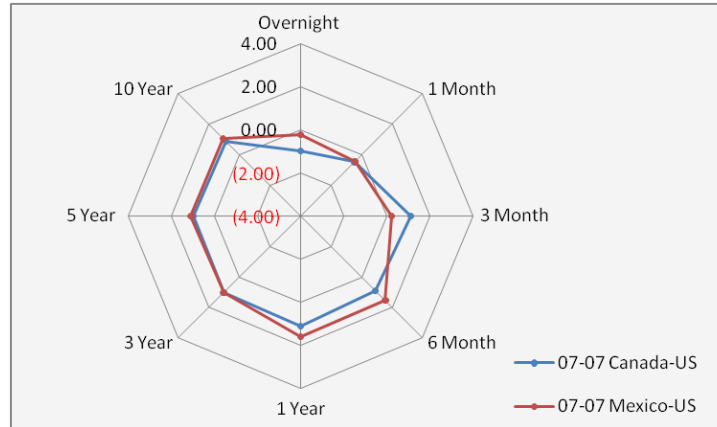


FIGURE 14
Monthly Skewness of Interest Rate Differentials, July 2007

The results of Movie 7 also lead us to conclude that:

- 1) immediately after each exceptional event (cf. Table 1), the interest rate differentials show more skewed distributions and thus more financial market pressure. It means that there is more market expectation for CAD and Mexico Peso to depreciate or appreciate;
- 2) the skewness of overnight short-term interest rate differentials demonstrates more extreme values than the other term interest rates, especially when exceptional events take place. In contrast, the skewness of the medium and longer term maturity, 5- and 10-year, interest rate differentials shows more convergence to zero over time. In other words, the extensions of the medium term and longer term bond swaps expressed in those forward rates or interest rate differentials at long-term end show more convergence among NAFTA countries than at the shorter maturities, where there is more difference of expectations and of investment potential. The longer maturities show more convergence of expectations than the shorter maturities.

3.2.3. Kurtosis (Market Micro-structural Differentiation) Risk between Canada and

Mexico vs. U.S. According to the observed varying values of excess kurtosis, trading in those bilateral financial markets performs very differently in exceptional periods of time, but is approaching a similar degree of normal (neutral) micro-structural composition in the long run - in particular the degrees of freedom of trading depending on the composition and numbers of trading. For example, the bid-ask spread, which is stochastically looking for the discovery of the informed FX price, is for a large part determined in intra-dealer quote-driven markets, like FX and Treasury markets, by the number of dealers divided in two large groups of “bullish” and “bearish” traders (Handa, Schwartz, & Tiwari, 2003).

The comparative snapshot of the kurtosis of the interest rate differentials in Figure 15 and 16 respectively, show not much variation in excess kurtosis between November 2002 and July 2007, with only slightly positive excess kurtosis in the 2-5 month maturity range in November 2002. However, Movie 8 of Appendix B clearly demonstrates that such excess kurtosis is also far from static, that such excess kurtosis can change rather rapidly and that, therefore, there is also considerable kurtosis risk in NAFTA’s FX markets. This variation of excess kurtosis, or kurtosis risk, indicates that the micro-structural composition of the trading groups can rapidly change in the FX markets, in particular in recent years, when FX markets have become globally accessible to internet-based day traders. The composition of “bulls and bears” can rapidly change in the economic, financial, political and strategic commodities, rumor-filled FX markets. “Flights to safety” are only easily arranged in very liquid markets, as, perhaps, they should, since such arrangements allow for much greater market liquidity.

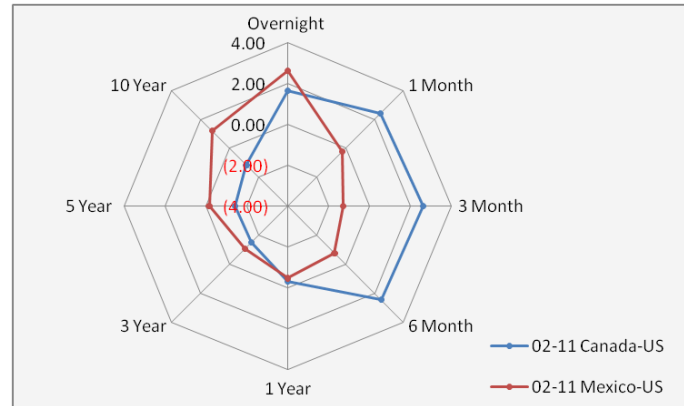


FIGURE 15
Monthly Excess Kurtosis of Interest Rate Differentials, November 2002

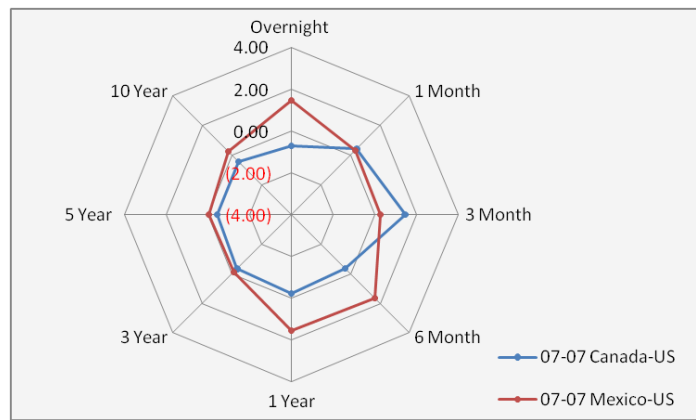


FIGURE 16
Monthly Excess Kurtosis of Interest Rate Differentials, July 2007

Based on the monthly statistical values of interest rate differentials, both bilateral financial markets exhibit negative excess kurtosis (platy-kurtosis) at most times, which indicates the overall amorphousness of the FX markets, with lower than normal probability of extreme values and less than normal mean-reversion of trading positions. Moreover, the degree of this platy-kurtosis falls into a range between 0 and -2, meaning that the degree of the monthly excess kurtosis of these north American FX markets is located between that of a normal distribution and of a Bernouilli distribution (i.e., distribution associated with the continuous tossing of a fair coin).

In these bilateral financial markets, platy-kurtosis indicates that there is not a specific group of hedgers or speculators trading the FX risk between them. There is, apparently, an undifferentiated crowd of liquidity traders, trading over a wide range of term positions, with very little informed price formation. No observable differentiation between hedgers and speculators is present, and neither longer-term consistent one-directional backwardation nor contango exists in the NAFTA FX markets most of the time over the last 15 years, as we already observed in the preceding subsection about skewness risk.

At some exceptional periods, however, the data exhibit very high values of excess kurtosis with strong peaks near the mean, and with heavy tails, indicating severely decreased market liquidity. Thus, with high positive excess or leptokurtosis, and extreme position and trading values are prevalent. During these exceptional periods, the micro-structural market composition is suddenly clearly differentiated: with few speculators (i.e., the extreme interest rate differentials) who take market risk and a large number of small hedgers (with very small interest rate differentials around the zero means) who want to get rid of market risk. A large number of noise traders, or small hedgers, aggregate and then transfer the majority of the market risk to the few large speculators. This has now become the market micro-structural dynamics of global FX market risk arbitrage.

For example, in July 2006, according to Table 2, most values of the excess kurtosis of the interest rate differentials were extremely high, at all maturities, with most positive excess kurtosis at the Mexican border. Interestingly at the Canadian border, there was some platy-kurtosis at the 3-month maturity and very low leptokurtosis at the 5-year maturity. But for this particular case we do know what caused the sudden extreme position-taking.

TABLE 2
Excess Kurtosis of Interest Rate Differentials in July 2006

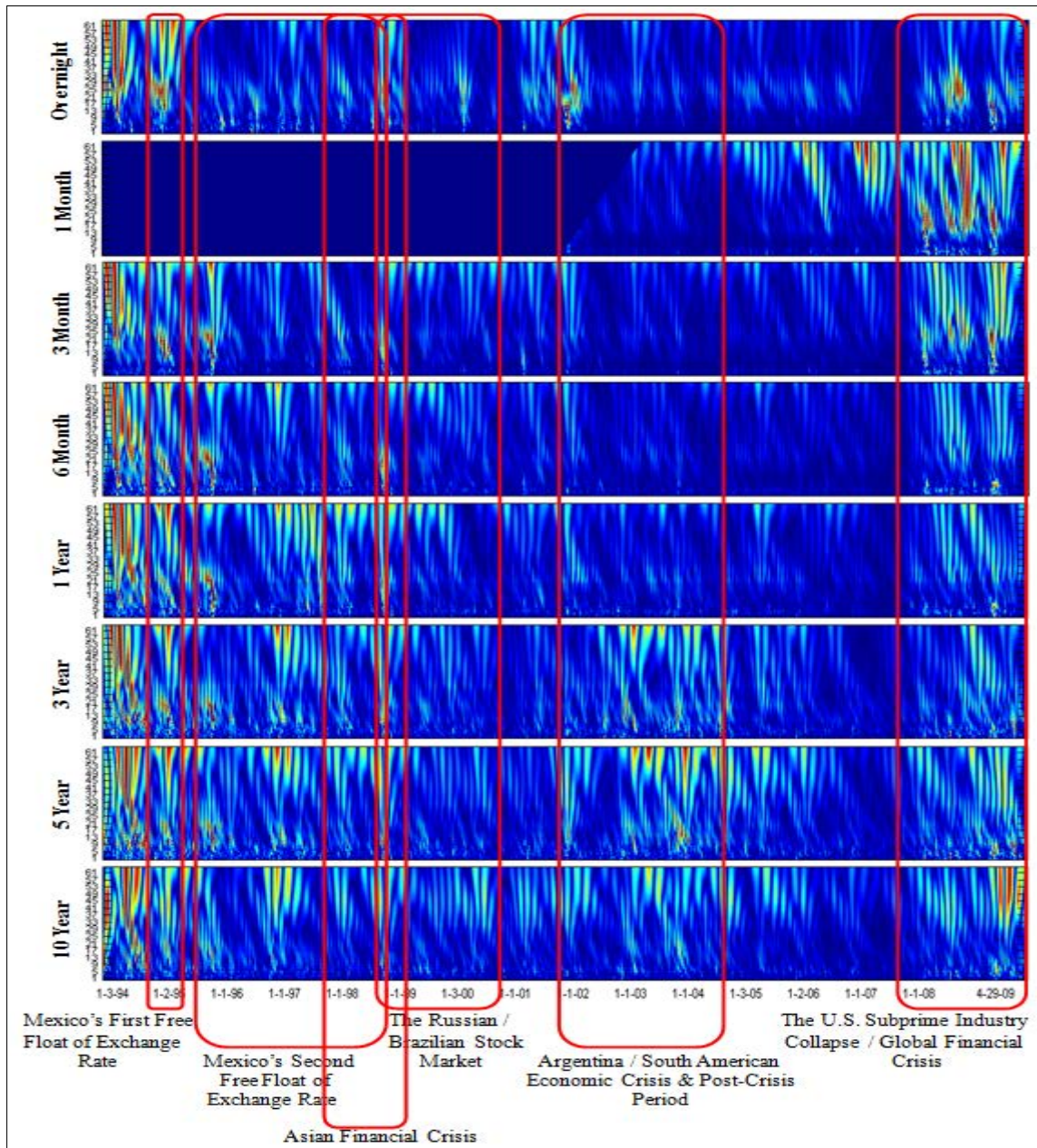
	Overnight	1 Mth	3 Mth	6 Mth	1 Yr	3 Yr	5 Yr	10 Yr
Canada-US	11.73	14.37	-0.62	21.84	21.81	6.14	1.36	16.81
Mexico-US	20.50	18.36	21.15	21.61	21.25	21.13	21.41	21.60

In this case, the high excess kurtosis was caused by the tightening of the Federal, in particular the ramping up of the Federal Funds Rate. The U.S. raised the Fed funds rate (its control rate) significantly to 5.25% at the end of June 2006. This contributed to an increase in the adjustable rate mortgage rates, which created significant difficulties for homeowners. The Federal Reserve aimed to deflate the (regionally very localized!) U.S. housing bubble by adopting a tighter monetary policy and higher interest rates, which led, eventually, to the prime-rate mortgage crisis. As a result of the Fed's action, the micro structure of financial markets in North America shifted accordingly, with very few speculators and a high number of intra-day liquidity and noise trading at all maturities.

3.3 Wavelet Multi-resolution Scalogram Movies

Using wavelet MRA, we observe in a different, but confirming fashion, that interest rates among the NAFTA countries have established an overall statistical convergence at all maturity terms, since the resonance coefficients of the interest rate series show increasingly less colorized structures (brightly red-yellow-green colorized events) over time. The high-energy (high-risk) singular micro-structural market events tend to quickly dissipate

into very low energy (low risk) “white noise” (i.e., dark blue in the pictures)⁷. For example, the Interest Rate Differential between Canada and US, and Mexico and US respectively, as showing in the following Figures 17 and 18, demonstrate the resonance coefficients since

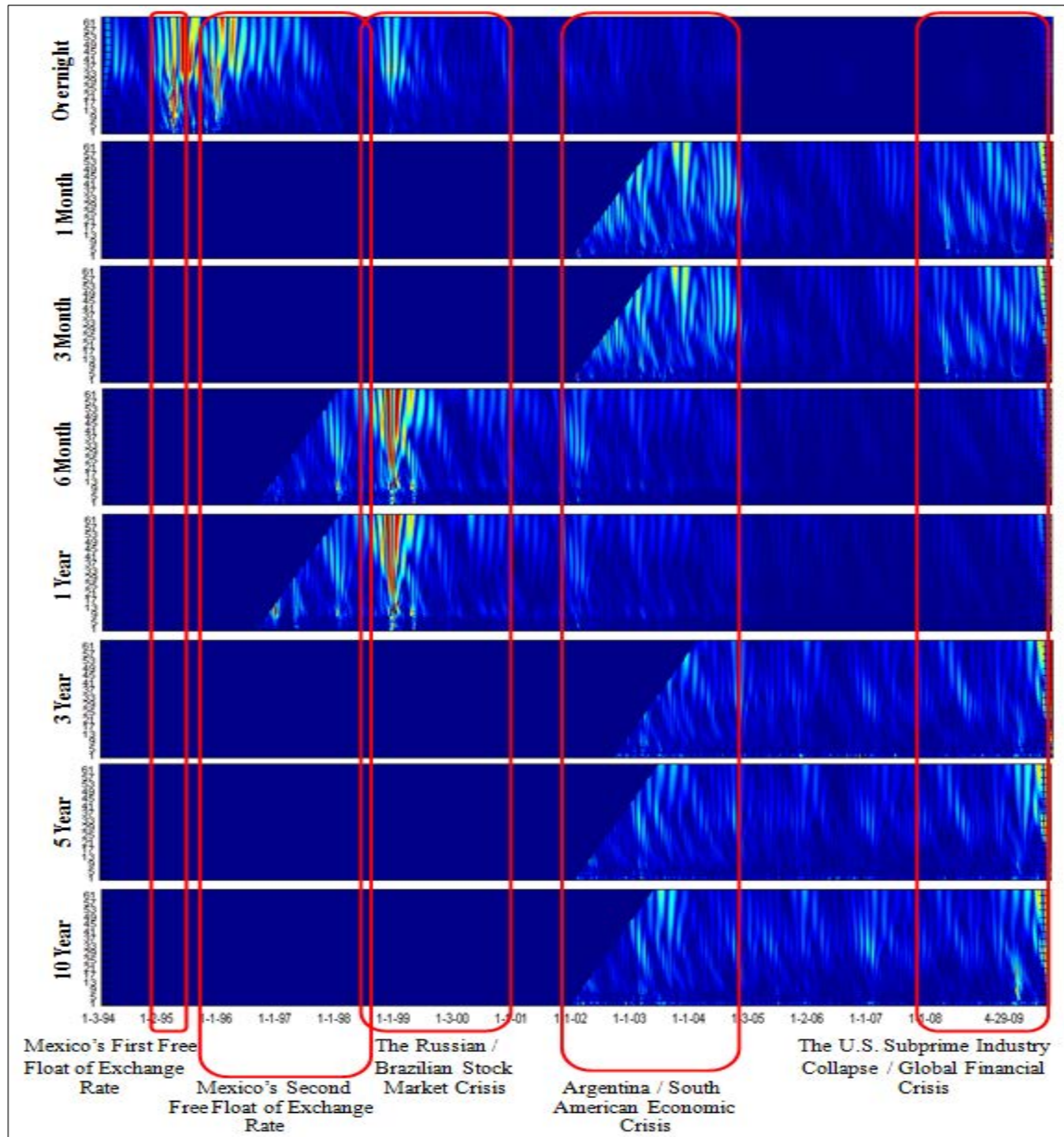


1994 through April 2009. The truly singular events (i.e., major discontinuities) in the NAFTA FX markets are visible by colorization in red at all dyadic scales, from daily

⁷ White noise is observed when all wavelet MRA resonance coefficients are equal and insignificant in value.

through 64 business days (cf. Table 1 for these Exceptional Events).

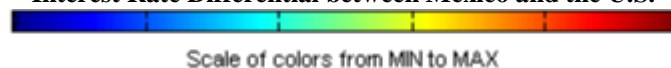
FIGURE 17



Interest Rate Differential between Canada and the U.S.

FIGURE 18

Interest Rate Differential between Mexico and the U.S.



To match the term interest rate differentials and visualize the statistical convergence of the North American financial markets in a more dynamic fashion, we transformed also

these wavelet multi-resolution scalograms into digital movies in Appendix C. Figure 19 is an example of captured image from the beginning of the wavelet MRA digital movie of Overnight Interest Rate Differential between Canada and United States (Movie 1 in Appendix C). All of the Wavelet digital movies can be accessed from the links in Appendix C.

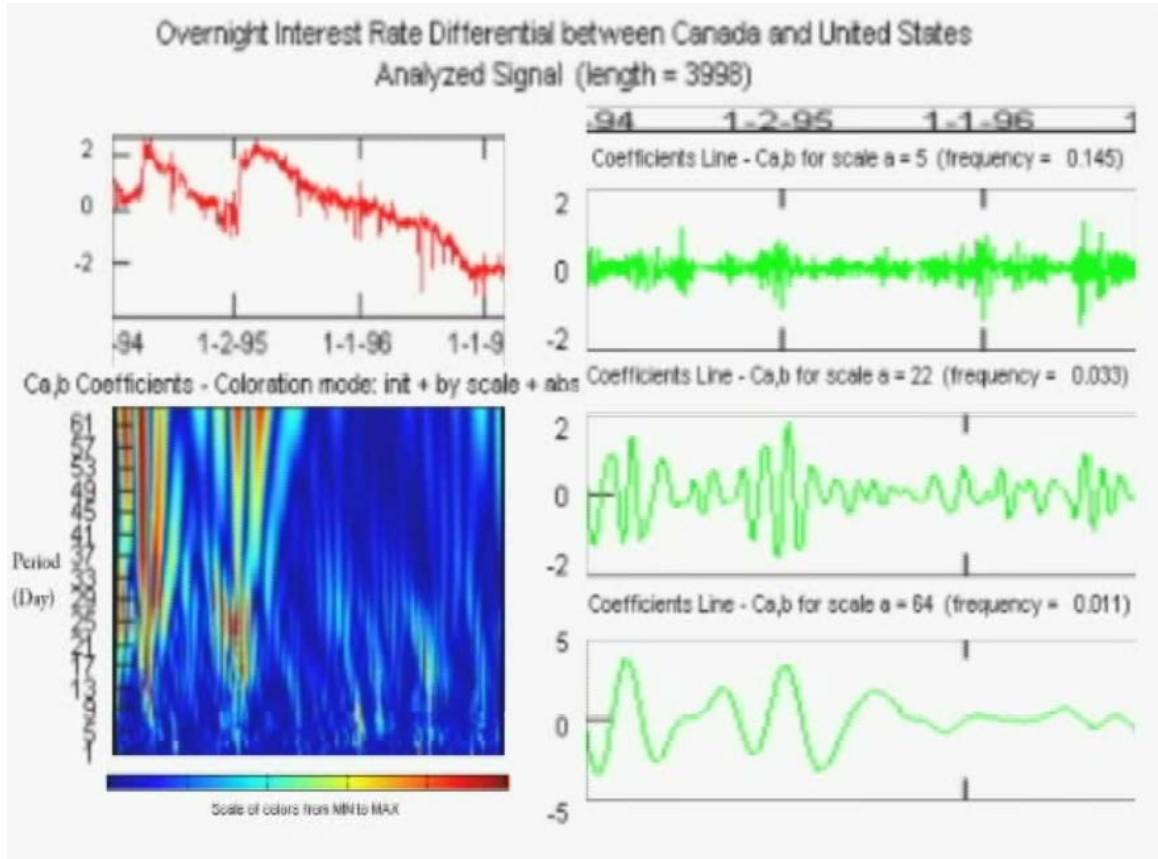


FIGURE 19

Wavelet MRA of Overnight Interest Rate Differential between Canada and the United States.

Note: The top left is the original signal of daily interest rate differentials; the bottom left is the wavelet scalogram; the right side exhibits the coefficients lines with work-day time scales, as follows: $a = 5$ (1 week), 22 (1 month) and 64 (3 month) respectively.

In Figure 19, the original signal (3,998 daily observations of overnight interest rate differentials between Canada and U.S.) is plotted at the top left. The Daubechies Wavelet with six moments, or wavelet db6, is used for the wavelet MRA and the resulting colorized resonance coefficients are shown at the bottom left. At the right side, coefficients lines are

extracted with different frequencies from high to low, as indicated by the number of days in the time horizon—5, 22 and 64 business days (1 week, 1 month and 3 months). The same methodology and composition is used for all the wavelet digital movies in Appendix C.

Considering the scalograms, the number of singularities is increasing in both bilateral financial markets when the interest rate differentials represent longer maturity terms. *E.g.*, more dark-blue area can be observed on the overnight interest rate differential than on the 10 year differentials. Less colorized structure is observed on the shorter term interest rate differentials. In other words, despite the higher volatility of the short term interest rate differentials, perhaps surprisingly, one can observe more converges of the interest rate differentials for the short-term maturities than for the longer-term maturities.

From the Movies 1, 3, 5, 7, 9, 11, 13 and 15 in Appendix C, we observe that the less colorized structure — dark blue area -- becomes more prevalent at the greatest point during the period between the end of 2006 and the beginning of 2007. Thus, the interest rate differentials between Canada and U.S. approach the greatest convergence at this time scale, which is consistent with the result that we obtain based on the radar diagram movies. For the interest rate differential between Mexico and U.S., the singularities dissipate into “white noise” at the greatest level during the years, 2004-2008.

The most significant singularities (brightly red-yellow-green colorized events) reflected on the scalograms of interest rate differentials between Canada and U.S. are majorly caused by the official formation of NAFTA in 1994, by the Asian Financial Crisis in 1997, the Brazilian Stock Market Crisis in 1998, and the Global Financial Crisis in 2008 (cf. Table 1 for these Exceptional Events). For the bilateral financial market between Mexico and U.S., we observe the effects of Mexico’s first free float of exchange rate in

1994, second free float in 1995, the Brazilian Stock Market Crisis in 1998, '01 the Argentina Economic Crisis in 2001 and the Global Financial Crisis of 2008.⁸

From the coefficient lines with frequencies from high to low for all interest rate differentials, we also observe overall financial convergence of NAFTA during the past 15-year period, since variations become smaller and smaller along all coefficients lines. Variations of coefficients perform differently when scales and frequencies are different. With $a = 5$ and frequency = 0.145 (5 business day or 1 week), the coefficient line shows smaller but more frequent variations. This coefficient line also indicates that activities occupied frequently on a weekly basis prior to 2002. With $a = 22$ and frequency = 0.033 (22 business days or 1 month), variations become more significant, while more bright colors are shown on the monthly level on the scalograms. Coefficients line with $a = 64$ and frequency = 0.011 (64 business days or 3 months) demonstrates bigger-range, but smoother variations. Unlike high frequency coefficients line, exceptional events are not obvious on the low frequency horizons.

3.4 Test Results of Obrimah, Prakash, and Rangan's Lemma (2009)

Given our observation that the statistical distributions of the interest rate differentials between Canada and Mexico versus U.S. are highly skewed over time, we find that the proposition of Obrimah et al. (2009) is appropriately applicable for the bilateral financial markets in North America after 2002. We find that the lower variance risk of interest rate differentials can be consistently associated with higher skewness (i.e., higher financial pressure), when the condition satisfies a regularity relationship between the first, second and third moments. In the FX markets, more skewness of interest rate differential indicates

⁸ Sub-periods of these exceptional financial-economic events are listed in Table 1.

more financial market pressure for CAD or Mexico Peso to appreciate or depreciate versus the USD, according to Financial Arbitrage Theory.

We formulated the testable proposition that if one FX premium (CAD/USD or Mexico Peso/USD) or interest rate differential shows less variance, i.e., is less risky, than the other, there exist more financial market pressures for positive skewness for the first FX premium than for the second and thus for more potential change of the first FX rate versus the US dollar than for the second. In other words, the FX premium with the least variance or market risk, is the most likely to change versus the US dollar, because it is usually associated with more financial pressure to change versus the US dollar.

Application of the proposition to the bilateral financial markets with data series of daily interest rate differentials is straightforward: if one series of interest rate differentials shows less variance (i.e., less risky) than the other interest rate differential series, then the other, more risky is usually less skewed shows thus lower financial pressure to change.

The actual direction of the FX change depends on the sign of the means of the respective distributions. A positive mean of the interest rate differential indicates an average tendency towards contango versus the US dollar and thus to depreciate versus the US dollar. A negative mean of the interest rate differential indicates an average tendency towards normal backwardation versus the US dollar and thus to appreciate versus the US dollar. A positive skewness only indicates that there is financial pressure to move the existing mean further up. A negative skewness indicates that there is financial pressure to move the existing mean down.

We have applied the proposition to the data set starting from 1994 to 2009 with 3,998 observations for each interest rate differential series. The regularity condition is satisfied

for all time periods. However, our observations are not always consistent with the testable proposition, as shown in Table 3. *Inter alia*, the conclusion clearly depends on the maturity term of the forward premium (i.e., maturity term of the interest rate differential). For the whole data series (1994-2009), the Lemma holds empirically true for the longer term – 3, 5 and 10 year – maturities, but is refuted for the shorter – from overnight to 1 year – maturities, with the exception of the 1 month maturity, for which it also holds true.

TABLE 3
Data Set of Interest Rate Differential Starting From 1994

Overnight			1 Month		
	Variance	Skewness		Variance	Skewness
Canada-US	1.30	-0.13	Canada-US	0.81	0.05
Mexico-US	126.15	2.46	Mexico-US	2.98	-0.25
3 Month			6 Month		
	Variance	Skewness		Variance	Skewness
Canada-US	1.10	-0.17	Canada-US	1.02	-0.06
Mexico-US	47.38	1.46	Mexico-US	47.83	1.34
1 Year			3 Year		
	Variance	Skewness		Variance	Skewness
Canada-US	0.95	-0.13	Canada-US	0.69	0.17
Mexico-US	48.74	1.26	Mexico-US	2.17	0.03
5 Year			10 Year		
	Variance	Skewness		Variance	Skewness
Canada-US	0.51	0.36	Canada-US	0.43	0.72
Mexico-US	1.99	0.28	Mexico-US	1.27	0.13

But we also find that the testable proposition holds empirically true from 2002 on for all term maturities. When we test the proposition of the Lemma against the data set starting in 2002, it does empirically hold true, as can be seen in Tables 4 and 5. Tables 4 and 5 exhibit the values of variance and skewness of eight term interest rate differentials, where the data start from 2002 and 2005 respectively.

TABLE 4
Data Set of Interest Rate Differential Starting from 2002

Overnight			1 Month		
	Variance	Skewness		Variance	Skewness
Canada-US	1.07	-0.02	Canada-US	0.85	0.05
Mexico-US	3.49	-0.18	Mexico-US	3.06	-0.25
3 Month			6 Month		
	Variance	Skewness		Variance	Skewness
Canada-US	0.83	0.08	Canada-US	0.83	0.13
Mexico-US	2.98	-0.30	Mexico-US	2.84	-0.38
1 Year			3 Year		
	Variance	Skewness		Variance	Skewness
Canada-US	0.82	0.19	Canada-US	0.64	0.23
Mexico-US	2.90	-0.33	Mexico-US	2.17	0.03
5 Year			10 Year		
	Variance	Skewness		Variance	Skewness
Canada-US	0.43	0.31	Canada-US	0.28	0.40
Mexico-US	1.67	0.04	Mexico-US	1.18	0.13

TABLE 5
Data Set of Interest Rate Differential Starting from 2005

Overnight			1 Month		
	Variance	Skewness		Variance	Skewness
Canada-US	0.81	0.79	Canada-US	0.58	0.68
Mexico-US	4.61	0.11	Mexico-US	4.14	-0.01
3 Month			6 Month		
	Variance	Skewness		Variance	Skewness
Canada-US	0.51	0.66	Canada-US	0.46	0.58
Mexico-US	3.95	0.04	Mexico-US	3.42	0.07
1 Year			3 Year		
	Variance	Skewness		Variance	Skewness
Canada-US	0.43	0.56	Canada-US	0.35	0.57
Mexico-US	3.10	0.06	Mexico-US	1.90	0.17
5 Year			10 Year		
	Variance	Skewness		Variance	Skewness
Canada-US	0.18	0.49	Canada-US	0.09	0.52
Mexico-US	1.55	0.27	Mexico-US	1.04	0.41

Interestingly, the proposition appears to be stronger when time progresses. (i.e., the closer we are to the present day, the more the markets are converging to each other.) The pre-2002 period involves clearly too many exceptional events (cf. Table 1) and distorts the

empirical truth of the proposition, since the exceptional event singularities (cf. Table 1) are distorting the regular shape of the statistical distributions of the interest rate differentials or forward premia at particular times or in short periods.

In Table 4 and 5, it is obvious that the variances of interest rate differential between Mexico and U.S. are all greater than that between Canada and U.S. It is indicative that the interest rate differential between Mexico and U.S. is more volatile than that between Canada and U.S. Also, the distribution of interest rate differentials between Canada and U.S. is always more skewed towards the positive direction, indicative for the regular upward financial pressure towards contango, i.e., depreciation of the Canadian dollar versus the US dollar, in particular in the 2002-2005 period.

Our results show that the bilateral market between Mexico and U.S. always stochastically dominates by its greater variance (more FX market risk). Before 2002, there was more market pressure for Mexico Peso versus USD to depreciate; while after 2002, more market pressure for CAD versus USD to depreciate is observed. Therefore, we think that our testable proposition based on Obrimah et al.'s (2009) Lemma is more appropriate for the converging bilateral financial markets of NAFTA after 2002, when all three term structures were completed and fully matched at all terms.

The test result is consistent with what we observed from radar diagram movies that after 2002, the financial markets of NAFTA started to show substantial uniform convergence. In the 1994-2003 periods there were too many singularities, i.e., exceptional events, which disrupted the uniformity of the dynamic North American financial market convergence.

4. Conclusion

Based on our radar diagram movies of converging statistical moments of term interest rate differentials and wavelet multi-resolution scalogram movies used to visualize the dynamic stochastic matching or convergence of the term interest rate differentials, we have observed an actual fairly uniform financial convergence during the past 15 years among the three NAFTA countries. This convergence was only occasionally and temporarily disrupted by exceptional events. We have monitored and analyzed the North American financial markets based on daily interest rate differentials since 1994 using daily data. We have also identified some factors which have led to the financial market divergence of NAFTA during the exceptional time periods.

Since 1994, the liberalized trade program of NAFTA has significantly enhanced trade and investment in North America. Along with the improvement of the competitive business environment among partners leading to increased market efficiency, elimination of the trade barriers, promotion of cross-border good and services flows, and facilitation of capital movements, the financial markets in this region have been statistically converging as well. The progress of the convergence is a sign of hinged international market efficiency in the financial market area.

However, while the financial markets of Canada and US achieved a major step towards convergence, we find marked evidence that the yield curve of Mexico shows still large dynamic discrepancies from the yield curves of its NAFTA counterparty countries due to Mexico's first and second float in December 1994 and February 1995, respectively. Also, in 1998, substantial financial market divergence of NAFTA can be observed especially between Mexico and US because of the Russian and Brazilian Stock Market Crises in 1998.

During these major events, the interest rates differentials of all maturities between Canada and the US were comparatively flat and even reversed.

As a volatile emerging financial market, Mexico presented a very different response. Even though NAFTA has made the business environment among the three countries more and more parallel, Mexico's financial market was still less liquid and efficient than the two other North American markets. This made the Mexico's financial market also substantially divergent from Canada and US during the recent September 1998 – February 1999 period. The degree of efficiency of Mexico's financial markets can be examined in detail by looking at the variance (volatility) of its term interest rates.

After 1999, and even more precisely, after 2002, a more uniform financial market convergence of NAFTA is observed. By July 2007, the financial markets of NAFTA had already converged to a very narrow point in the radar diagram of the interest rate differentials at all eight term maturities. Nevertheless, substantial financial market divergence occurred again briefly due to the 2008 Global Stock Market crisis. This global stock market crisis was triggered by the liquidity crunch felt by Wall Street firms, which, consequently, had to sell stock and experienced collectively very rapid asset value declines in October 2008 (Several Wall Street investment houses bled value already in the preceding year leading up to the Global Crisis of 2008). This liquidity crisis also led both the Canadian and Mexican exchange rates to depreciate significantly, when capital was rapidly retracted to Wall Street investment banks in New York City.

We have also observed that monetary policies, financial market liquidity and volatility, market expectations of respective currency depreciation or appreciation, degree of neutral micro-structural composition (degrees of freedom of trading) are all essential factors to

determine the degree of financial market convergence of NAFTA.

In summary, we observe non-consecutive and non-uniform statistical convergence of the North-American bilateral term interest rate structures since 1994 until about 2002, followed by a more uniform convergence thereafter. NAFTA's financial market convergence appears to have become more uniform, when all three countries adopted complete term structures in 2002 and FX arbitrage was effectively facilitated.

But we did not observe the co-integration (i.e., linear co-movement) erroneously reported in the financial literature, because of the faulty projection methodology (of unilateral unit root projections or “regressions”) used. It's a subtle, but very important difference. Would co-integration actually exist, the financial markets in North America would move exactly in tandem and be on their way towards fixed exchange rate, as in the European integration when it adopted to move towards a fixed exchange rate system after 1993 and replacement of its 11 mutually fixed currencies by the Euro on January 1, 1999. This would be a very dangerous and mistaken course for North America, which is better served by the observed statistical convergence and increasing stochastic dominance phenomena. Statistical convergence implies that the markets do not move exactly in tandem, but retain the flexibility of independent movement, in particular of monetary policy, when it is needed for those infrequently, but often drastic, exceptional events.

The fundamental mistake of the 1992 Treaty of Maastricht of the European Union was to insist on exact linear co-integration of the monetary and fiscal policies of its member states to achieve one currency, the Euro. This has led to a monolithic and internally inflexible European market space, without the concomitant labor mobility to make it a liquid optimum currency area. In contrast, the North American NAFTA approach retains

the flexibility of the three North American financial markets relative to each other and allows for their three different fiscal and monetary policy regimes to co-exist, as they converge to create a system of flexibly interrelated financial markets, which do not have to move in tandem (lock-step) to interact.

The consequence is that the North American financial market as a whole is better prepared to withstand the impact of major global crises, like the global stock market crash of October 2008, than the European financial market. NAFTA's bilateral flexible FX rates operate as springs between the economically and financially converging countries. Still, the NAFTA countries are clearly linked. The statistical convergence of the North American financial markets has constructed flexible hinges between its three financial systems, so that they can adjust flexibly to each other via these flexible exchange rates, while the integration of the European financial markets has led to a rigid financial framework with internally fixed exchange rates (because of the one Euro), which cannot adjust to external shocks, because the Eurozone as a whole has to act monolithically.

As the NAFTA system has demonstrated, in a flexible exchange rate regime the drawback of no predictability can effectively be eliminated by institutionalizing well-functioning forward FX markets, by constructing matching debt markets with similar term structures. Meanwhile, liquidity risk is also eliminated because capital can still flow freely among NAFTA countries. Thus, term structures become alike and capital is valued in a similar fashion in all three countries.

The current 2010 crises of the PIGS (Portugal, Italy and Ireland, Greece and Spain) clearly demonstrate that deficiency of that rigid internally fixed FX regime framework without the required labor mobility (which only exists in name in Europe). NAFTA has

similar disparities between its member countries, but does not exhibit the same financial internal stress, although it is also impaired by relative labor market immobility, since it has now well-working, efficient forward FX markets. Thus, the lack of labor mobility can be replaced by complete and efficient forward markets in addition to a flexible spot FX regime.

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APPENDIX A

Term Interest Rate Structure

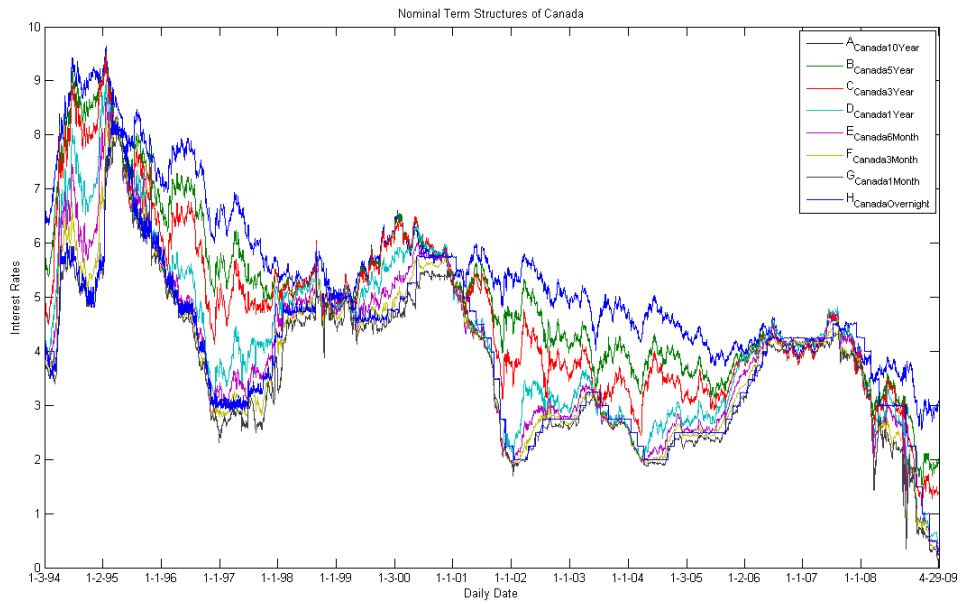


FIGURE 1
Term Structures of Canada

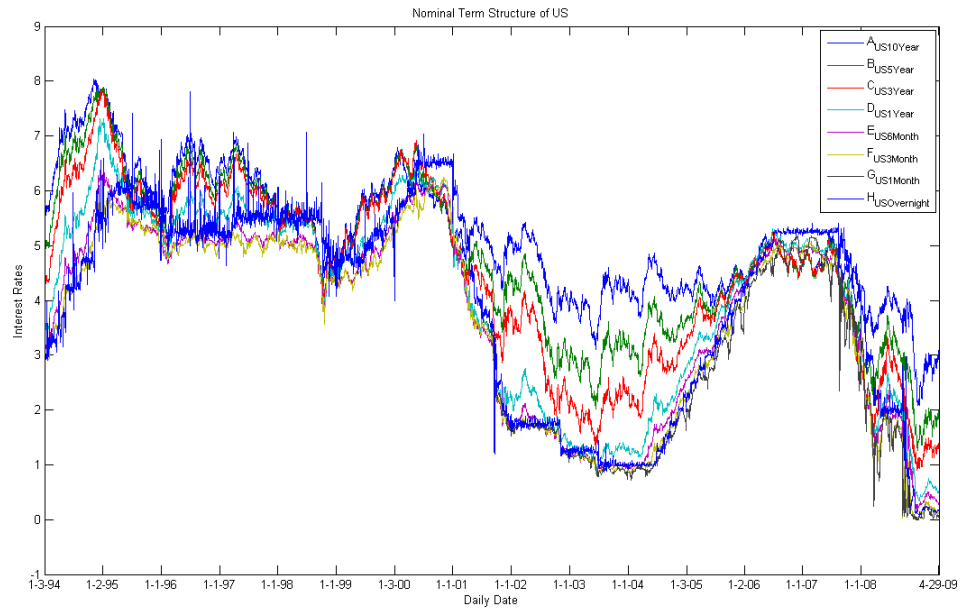


FIGURE 2
Term Structures of the U.S.

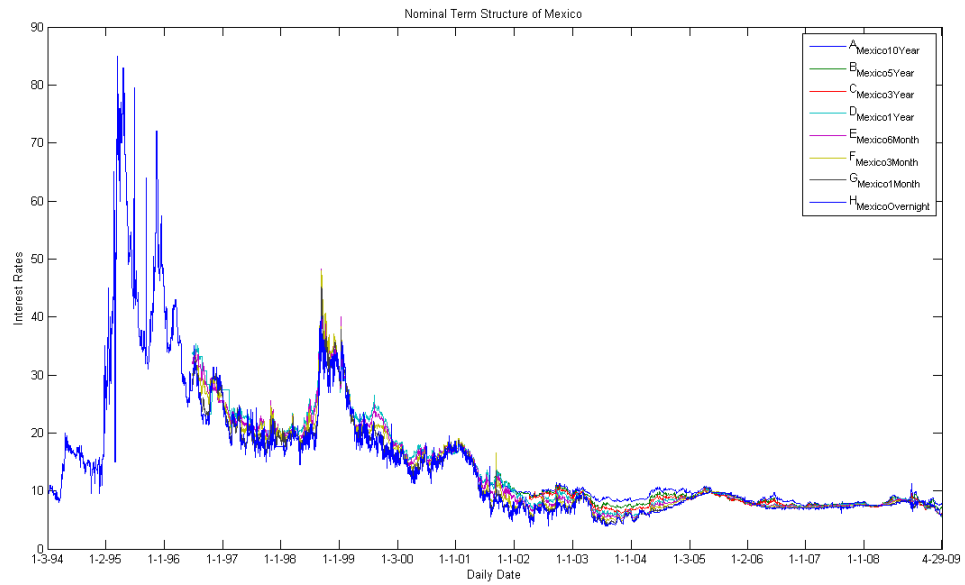


FIGURE 3
Term Structures of Mexico

APPENDIX B

Radar Diagram Movies—Dynamic Moment Analysis

To analyze the status of financial integration of NAFTA since 1994, we generate the radar diagram movies by dynamically measuring the degree of statistical convergence of its financial markets and visualizing the process of statistical convergence in a very compact fashion.

In Movie 1-4, we look at the three individual countries at the same time. We use three different colored curves: blue, red and green represent Canada, the U.S. and Mexico respectively. 8 measurements (the overnight interest rate, the 1 - month treasury-bill rate, 3 - month treasury-bill rate, 6 - month treasury-bill rate, 12 - month treasury-bill rate, 3 year benchmark bond yield, 5 year benchmark bond yield and 10 year benchmark bond yield) shows at the same time for monthly statistical moments (mean, variance, skewness and excess kurtosis) based on the daily observations. Each direction represents one measurement. Time progresses on a monthly basis starting from January 1994 to April 2009.

Movie 1-4 can be accessed online through the following links:

[Movie 1: Radar Diagram Movie of Monthly Mean of Interest Rates of 3 Countries](http://people.uleth.ca/~roy.sun/Video_1_Monthly_Mean_of_Interest_Rates.swf)

(http://people.uleth.ca/~roy.sun/Video_1_Monthly_Mean_of_Interest_Rates.swf)

[Movie 2: Radar Diagram Movie of Monthly Variance of Interest Rates of 3 Countries](http://people.uleth.ca/~roy.sun/Video_2_Monthly_Variance_of_Interest_Rates.swf)

(http://people.uleth.ca/~roy.sun/Video_2_Monthly_Variance_of_Interest_Rates.swf)

[Movie 3: Radar Diagram Movie of Monthly Skewness of Interest Rates of 3 Countries](http://people.uleth.ca/~roy.sun/Video_3_Monthly_Skewness_of_Interest_Rate.swf)

(http://people.uleth.ca/~roy.sun/Video_3_Monthly_Skewness_of_Interest_Rate.swf)

[Movie 4: Radar Diagram Movie of Monthly Kurtosis of Interest Rates of 3 Countries](http://people.uleth.ca/~roy.sun/Video_4_Monthly_Kurtosis_of_Interest_Rates.swf)

(http://people.uleth.ca/~roy.sun/Video_4_Monthly_Kurtosis_of_Interest_Rates.swf)

To make the dynamic moment analysis a more powerful tool and to conduct a better measurement of the degree of statistical convergence of NAFTA, we construct Movie 5-8 by looking at the interest rate differentials between Canada and the U.S., and between Mexico and the U.S., according to FX Market Arbitrage Theory. Hence, these movies show only two different colored curves: blue and red represent interest rate differentials between Canada and the U.S., and between Mexico and the U.S., respectively. In Movies 5-8, in a similar fashion as in the first four movies, eight term measurements show at the same time for each of the four monthly statistical moments. For the compactness of timely monitoring, time progresses on a monthly basis in these movies.

Some term interest rate data is not available for the early years. Only after 2002 the term structures in all three countries were complete. So, complete circles of all three countries are shown only after April 2002. In all of these four movies, we set the minimum scale with different negative values instead of “0” because, in this way, we can have a better observation on how the two curves perform when they approach the value of zero.

Movie 5 shows the monthly mean of interest rate differentials, where scale is ranged from -5.00 to 20.00 in percentage. We set the maximum scale to 20 percent because Mexico adopted very high interest rates from 1994 to 1999. Its high interest rate values cause the interest rate differential between Mexico and the U.S. to be fairly large correspondingly. That is why the red curve even goes out of the range during the period between 1994 and 1999.

This movie demonstrates a stronger overall convergence between Canada and the U.S. during the past 15 years since the blue curve always takes small moves around the convergence value of “0.00”. As we discussed in Section 2.3.1, “if the monthly mean of the differential converges to zero, average interest rate levels equalize, average forward premia vanish and FX rates converge on average.” Even though, the red curve always bears a distance from “0”, especially at the beginning; we can still observe that the monthly mean of interest rate differential between Mexico and the U.S. is converging to zero.

In general, both bilateral financial markets have obtained progress towards financial convergence, except for several exceptional periods: Mexico’s first and second free float of exchange rate in 1994 and 1995, and the Russian and Brazilian stock market crises in 1998, respectively.

Movie 6 shows the monthly variance of interest rate differentials. We set the scale range from -0.20 to 0.80 before February 2004, and after this, we adjust the scale range from -0.05 to 0.10 because the volatility of interest rate differential between Mexico and the U.S. has reduced substantially since Feb 2004. This adjustment is already indicative of the financial integration among NAFTA member countries because of the risk deduction in bilateral financial markets.

Prior to Feb 2004, the blue curve converges to zero most of the time and its performance is comparatively stable, meaning that the bilateral financial market in Canada and the U.S. are far less risky than that in Mexico. Therefore, financial convergence between Canada and the U.S. can be easily observed.

After Feb 2004, the volatility of interest rate differential between Mexico and the U.S. starts to converge towards zero and the interest rate differentials become stabilized. However, during the period of 07’ U.S. Subprime Industry Collapse, both curves, especially their shorter term interest rate ends, fluctuate substantially. During the Global Financial Crisis of 2008, these curves take frequent big moves. Except for these periods, we can still observe an overall financial convergence among NAFTA countries, since both interest rate differentials are converging to zero in a non-uniform fashion.

In Movie 7, the monthly skewness of interest rate differentials is demonstrated with a scale ranged from -4.00 to 4.00. The skewness of distribution of these interest rate differentials varies around the mean. We can observe that the degree of the variation of skewness has been decreasing in the past 15 years. In other words, skewness risk, i.e., the risk of substantially varying financial pressures, has diminished in the past 15 years.

Moreover, this skewness of interest rate differentials shows also an overall tendency to converge to zero in a non-uniform fashion. Prior to 2001, we can observe many more and greater extreme values. As we see on this movie, after 2001, both the blue and red curves exhibit smaller variations from “0”, except for May-November 2002, July 2006, December 2006-July 2007, and September-December 2009. These are the sub-periods of South American Economic Crisis in 2002, the leap of Federal Fund Rate in 2006, the U.S. Subprime Industry Collapse in 2007, and Global Financial Crisis in 2008, respectively.

From Movie 7, we can observe that the distribution of interest rate differentials between Mexico and the U.S. is always more skewed than that between Canada and the U.S. Thus there is always more financial pressure on the Mexican Peso/US\$ rate than on the CAD/US\$ rate, because Mexico’s liquidity channel is so much more narrow, its scale for capitalization so much smaller.

Both of the overnight short-term interest rate differentials demonstrate more extreme values than the other term interest rates. In particular, when some major disturbances in the global financial markets take place, these overnight short-term rate differentials possess vastly more skewed distributions. In contrast, the skewness of the medium and long term maturity, 5- and 10-year, interest rate differentials always take comparatively smaller fluctuations around “0”, meaning that the medium and long term interest rates show more convergence among NAFTA countries than the shorter term rates.

Movie 8 is the radar diagram movie of monthly excess kurtosis of interest rate differentials. Scale range is from -4.00 to 4.00. This movie shows that the excess kurtosis of interest rate differentials always changes rapidly. Moreover, both bilateral financial markets exhibit negative excess or platy-kurtosis at most time, and the degree of this platy-kurtosis falls into a range between 0 and -2.

When some major financial disturbances occur (cf. the earlier Table 1), we can observe that, data sets demonstrate very high values of excess kurtosis with strong peaks near the mean, and with heavy tails. Hence, during these periods, with high positive excess kurtosis (lepto-kurtosis), extreme values are prevalent. In particular, in July 2006, after the U.S. raised the Fed funds rate significantly to 5.25%, the excess kurtosis of interest rate differentials exhibit extremely high values, at all maturities, with most excess kurtosis at the Mexican side. However, at the Canadian side, there was some platy-kurtosis at the 3-month maturity and low lepto-kurtosis at the 5-year maturity.

Based on this movie, our observations are that trading in those bilateral financial markets performs very differently in exceptional periods of time, but that it is approaching similar degrees of neutral market composition in the non-exceptional periods.

Movie 5-8 can be accessed online through the following links:

[Movie 5: Radar Diagram Movie of Monthly Mean of Interest Rate Differentials](http://people.uleth.ca/~roy.sun/Video_5_Monthly_Mean_of_Interest_Rate_Differentials_between_Canada_and_Mexico_against_US.swf)

(http://people.uleth.ca/~roy.sun/Video_5_Monthly_Mean_of_Interest_Rate_Differentials_between_Canada_and_Mexico_against_US.swf)

[Movie 6: Radar Diagram Movie of Monthly Variance of Interest Rate Differentials](#)

(http://people.uleth.ca/~roy.sun/Video_6_Monthly_Variance_of_Interest_Rate_Differentials_between_Canada_and_Mexico_against_US.swf)

[Movie 7: Radar Diagram Movie of Monthly Skewness of Interest Rate Differentials](#)

(http://people.uleth.ca/~roy.sun/Video_7_Monthly_Skewness_of_Interest_Rate_Differentials_between_Canada_and_Mexico_against_US.swf)

[Movie 8: Radar Diagram Movie of Monthly Kurtosis of Interest Rate Differentials](#)

(http://people.uleth.ca/~roy.sun/Video_8_Monthly_Kurtosis_of_Interest_Rate_Differentials_between_Canada_and_Mexico_against_US.swf)

APPENDIX C

Wavelet Multiresolution Scalogram Movies—Wavelet Multiresolution Analysis

We use wavelet multi-resolution scalogram movies to visualize the dynamic statistical matching or convergence of the bilateral term interest rates. With wavelet multi-resolution analysis, we transform the original financial market term interest rate differential signals into resonance coefficients (i.e., bilateral coefficients of determination), which are colorized according to their fractional value between zero and one in the scalograms. The less differentiated-colorized structure (in our case, dark blue) we observe at a time scale, the more the interest rate differential converges at that particular time scale correspondingly.

We have constructed 16 wavelet scalogram movies and they can also be accessed online through the links at the end of this section.

The original signal in each movie consists of 3,998 daily observations of bilateral interest rate differentials. The Daubechies Wavelet with six moments, or wavelet db6, is used for the wavelet MRA. Each movie is comprised of three sections: the original signals, scalograms and selected coefficients lines. These coefficients lines with different frequencies are ranked from high to low, as indicated by the number of days in the time horizon—5, 22 and 64 business days (1 week, 1 month and 3 months).

Using scalograms, we observe that interest rates among the NAFTA countries have established an overall statistical convergence at all maturities. In all of these movies, the resonance coefficients of the interest rate differentials demonstrate less and less colorized structures over time; moreover, the high-energy singular market events, which are colorized in red at all dyadic scales from daily through 64 business days, tend to quickly dissipate into “white noise”, which is colorized in dark blue in this color set-up of the wavelet MRA Toolbox of MATLAB® (Version 12.0).

From these scalograms, we also find that the number of singularities increases in both bilateral financial markets when longer maturity terms are presented. Particularly in the movies, we can discover more dark-blue areas at the short-term maturities than that at longer-term maturities. The more dark-blue areas we can detect in the scalogram, the more convergence we can observe on that particular bilateral term interest rate differential.

Based on the scalogram movies, we also detect that, perhaps surprisingly, more singular events take place in the bilateral financial market between Canada and the U.S. than between Mexico and the U.S., since we observe more singularities (brightly red-yellow-green colorized events) in the Canada-US bilateral financial market at all term interest rate maturities. These small singularities, in particular in the overnight rates, often correspond to central bank interventions.

Additionally, the most significant singularities taking place in the two bilateral markets are associated with major financial disturbances. From the movies of interest rate

differential between Canada and the U.S., we can see how the official formation of NAFTA in 1994, 1997 Asian Financial Crisis, 1998 Brazilian/Russian Stock Market Crisis, and 2008 Global Financial Crisis clearly affect this bilateral market. For the bilateral financial market between Mexico and U.S., we observe the effects of Mexico's first free float of exchange rate in 1994, second free float in 1995, 1998 Brazilian Stock Market Crisis, 2001 Argentina Economic Crisis and 2008 Global Financial Crisis. Unlike the Canada-US bilateral financial market, whose disturbances are majorly from the global circumstance, the Mexico-US market has its major disturbances from regional financial markets. Furthermore, the 2008 Global Financial Crisis produced much less effect on the financial market between Mexico and the U.S. than that between Canada and the U.S. Perhaps, because the Wall Street investment banks had better opportunity to retract liquidity from Canada than from Mexico by easily swapping Canada dollar bonds for U.S. dollar bonds.

We adopt coefficients lines with three different frequencies from high to low to investigate the volatility or risk in these bilateral financial markets. Based on the movies, we discover that the variation of all coefficients lines become smaller and smaller over time, which indicates that the volatility or risk has decreased also in a non-uniform fashion in all bilateral interest rate markets.

The variations of coefficients perform differently when scales and frequencies change. We observe smaller but more frequent variations on the high-frequency coefficients lines, which are located at the top of our diagrams. Variations become more significant when frequency decreases, *e.g.* on the coefficients lines in the middle with $\alpha=22$ and frequency = 0.033. Coefficients lines at the bottom with the lowest frequency, demonstrate bigger-range but more smooth variations. In addition, on the high frequency horizon, exceptional market events can be easily seen.

Based upon the movies of term interest rate differential between Canada and the U.S., we can observe strong convergence on all term interest rate maturities only during the period between the end of 2006 and the beginning of 2007. During this time scale, the less colorized structure — the dark blue area-- becomes significant at the greatest point. However, the brightly red-yellow-green colorized singular events accumulate again when 2008 Global Financial Crisis takes place. In actuality, we observe most singularities only in the early years immediately after the NAFTA Agreement was concluded in 1994. They tend to dissipate into “white noise” eventually. This uniform convergence result is consistent with what we obtained earlier from the radar diagram movies.

Compared with that between Canada and the U.S., strong convergence in the bilateral financial market between Mexico and the U.S., exhibits a longer time scale from the end of 2004 to the beginning of 2008. During this period of time, the singularities in the bilateral interest rate market dissipate into “white noise” at the greatest level. From these movies, the longer time-scaled dark blue area becomes visible from the end of 2004 to the beginning of 2008.

In general, we observe a non-uniform statistical convergence of the North American bilateral term interest rate structures since 1994, based on the wavelet scalogram movies, with a more uniform convergence since 2002, which is in accordance with the results produced by the radar diagram movies of the first four statistical moments.

Wavelet Multi-resolution Scalogram Movies can be accessed via the following links:

[Movie 1: Overnight Interest Rate Differential between Canada and United States](http://people.uleth.ca/~roy.sun/Overnight_Canada_vs_US.swf)

(http://people.uleth.ca/~roy.sun/Overnight_Canada_vs_US.swf)

[Movie 2: Overnight Interest Rate Differential between Mexico and United States](http://people.uleth.ca/~roy.sun/Overnight_Mexico_vs_US.swf)

(http://people.uleth.ca/~roy.sun/Overnight_Mexico_vs_US.swf)

[Movie 3: 1 Month Treasury Bill Rate Differential between Canada and United States](http://people.uleth.ca/~roy.sun/1_Month_Canada.swf)

(http://people.uleth.ca/~roy.sun/1_Month_Canada.swf)

[Movie 4: 1 Month Treasury Bill Rate Differential between Mexico and United States](http://people.uleth.ca/~roy.sun/1_Month_Mexico.swf)

(http://people.uleth.ca/~roy.sun/1_Month_Mexico.swf)

[Movie 5: 3 Month Treasury Bill Rate Differential between Canada and United States](http://people.uleth.ca/~roy.sun/3_Month_Canada.swf)

(http://people.uleth.ca/~roy.sun/3_Month_Canada.swf)

[Movie 6: 3 Month Treasury Bill Rate Differential between Mexico and United States](http://people.uleth.ca/~roy.sun/3_Month_Mexico.swf)

(http://people.uleth.ca/~roy.sun/3_Month_Mexico.swf)

[Movie 7: 6 Month Treasury Bill Rate Differential between Canada and United States](http://people.uleth.ca/~roy.sun/6_Month_Canada.swf)

(http://people.uleth.ca/~roy.sun/6_Month_Canada.swf)

[Movie 8: 6 Month Treasury Bill Rate Differential between Mexico and United States](http://people.uleth.ca/~roy.sun/6_Month_Mexico.swf)

(http://people.uleth.ca/~roy.sun/6_Month_Mexico.swf)

[Movie 9: 1 Year Treasury Bill Rate Differential between Canada and United States](http://people.uleth.ca/~roy.sun/1_Year_Canada.swf)

(http://people.uleth.ca/~roy.sun/1_Year_Canada.swf)

[Movie 10: 1 Year Treasury Bill Rate Differential between Mexico and United States](http://people.uleth.ca/~roy.sun/1_Year_Mexico.swf)

(http://people.uleth.ca/~roy.sun/1_Year_Mexico.swf)

[Movie 11: 3 Year Benchmark Bond Rate Differential between Canada and United States](http://people.uleth.ca/~roy.sun/3_Year_Canada.swf)

(http://people.uleth.ca/~roy.sun/3_Year_Canada.swf)

[Movie 12: 3 Year Benchmark Bond Rate Differential between Mexico and United States](http://people.uleth.ca/~roy.sun/3_Year_Mexico.swf)

(http://people.uleth.ca/~roy.sun/3_Year_Mexico.swf)

[Movie 13: 5 Year Benchmark Bond Rate Differential between Canada and United States](http://people.uleth.ca/~roy.sun/5_Year_Canada.swf)

(http://people.uleth.ca/~roy.sun/5_Year_Canada.swf)

[Movie 14: 5 Year Benchmark Bond Rate Differential between Mexico and United States](http://people.uleth.ca/~roy.sun/5_Year_Mexico.swf)

(http://people.uleth.ca/~roy.sun/5_Year_Mexico.swf)

[Movie 15: 10 Year Benchmark Bond Rate Differential between Canada and United States](http://people.uleth.ca/~roy.sun/10_Year_Canada.swf)

(http://people.uleth.ca/~roy.sun/10_Year_Canada.swf)

[Movie 16: 10 Year Benchmark Bond Rate Differential between Mexico and United States](http://people.uleth.ca/~roy.sun/10_Year_Mexico.swf)

(http://people.uleth.ca/~roy.sun/10_Year_Mexico.swf)