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'Nothing spreads like fear' - from the movie 'Contagion'(2011)

Abstract

The global financial crisis in recent times has created a deep appreciation for the strong connectivity between the world economies. First regarded as a domestic shock, the subprime mortgage crisis in the United States ultimately created intense ripple effects across the borders, leading to the understanding that there are mechanisms in place between economies that can transmit a domestic crisis internationally. Loss of confidence in securitized products based on the real assets market led to a crippling breakdown in the financial market, creating economic and financial instability. Having differentiated the term contagion, with that of spillover and interdependence, an attempt was made to identify the contagious effects of the crisis in the U.S. on financial markets of the G8 countries and Norway. Both stock markets and government bond markets in the economies show comovement during the financial crisis of 2007-2008, with volatility in asset returns increasing. Tests for contagion using cross-market correlation showed that while contagious effects are visible with regard to stock markets, it was less evident in the government bonds markets.

Acknowledgment

An accumulation of three years worth knowledge, effort, determination and hard work is represented in this thesis report. It is the final and frankly, the ultimate, end product of the master's program. And it was not by any means achieved alone.

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SECTION ONE: INTRODUCTION

1.1 Prologue

Crises or shocks have plagued the financial systems of individual countries and the global market as a whole for decades. In their bestselling publication 'This Time is Different', authors Carmen Reinhart and Kenneth Rogoff provide an extensive study of financial crises dating back to nearly 800 years; their target - to show that 'we have been there before'. Most often, a shock occurs in a specific market or a group of market for many reasons like increase in asset prices, changes in interest rates, currency devaluation, etc. Due globalization having brought the world closer, shocks that were thought to be country specific (or crises in one region) have been followed by crises in other countries or regions. Such financial crises has had an impact on countries that are geographically distant, structurally different economies and those who do not share significant economic links such as trade. Therefore, it is evident that there are certain mechanisms in place that transmit or propagate a domestic shock internationally.

In the summer of 2007 came a global financial crisis that was unprecedented in terms of scale and severity. It proved to be the worst global financial meltdown to occur after the World War II, with the 1929 stock market crash leading to the Great depression being the most severe so far. Financial systems lost billions of dollars in value and the social impact was equally intense due to loss of personal wealth caused by unemployment, decline in value of personal assets and loss of savings and investments. Unlike most of the crises, the financial crisis of 2007-2008 affected millions of people around the globe either directly or indirectly.

The media frenzy during this crisis was intense as well, with everyone trying to make sense of the mayhem. A multitude of technical jargon was thrown around by the media, and words like 'global financial crisis', 'spillover', 'securitization', 'sub-prime mortgage', and more interestingly *'contagion'* were made popular. Contagion is a term one commonly associates with the field of medicine and epidemiology. When applying the definition of medical contagion to a financial context, financial contagion can be clarified as the spreading of financial illness from one entity to another through a particular channel of transmission. Academics have specifically differentiated 'contagion' with the term 'spillover', and proceeded to introduce new technical terms such as *interdependence*.

This thesis is organized in the following manner. The first section of the report gives an introduction to the thesis topic 'Financial Contagion during the financial crisis 2007-2008' and the motivation behind it. A formal presentation of the purpose or objective behind the thesis is made in this section, along with the limitations associated with the study.

A prologue to financial crises is laid out in section two, where some of the most significant financial crises in the twentieth century are described.

Section three provides a comprehensive explanation of the two main sub-topics stemming from the thesis topic; 'contagion' and 'financial crisis of 2007-2008'. In subsection one, a literature review of contagion is carried out, where the term is defined using different points of view. Theories of contagion are then discussed, to indentify how shocks are propagated from the market of origin to other different markets. Methods of measuring contagion gives an overture to the measurement procedure selected for the thesis quantitative analysis. Subsection two gives a comprehensive account of the financial crisis of 2007/2008, since it is the specific event under investigation for evidence of contagion. The background to the crisis, factors that triggered it and a timeline of the crisis are recounted in the section.

In Section four, the specific approach to the problem is discussed in detail. First, there is a description about the theoretical model used to identify if contagion has taken place during the recent financial crisis. The test for contagion using the cross-market correlation between asset returns is the measurement method highlighted in the model. An extensive description of the methodology in statistical analysis is laid out, followed by some statistical tests carried out during the regression analysis.

Section five presents the results of the quantitative analysis where the test for contagion is carried out using stock market returns. It first explains the data and the sample being used for the quantitative analysis of contagion in the stock markets. Afterwards, results are presented in the order of different techniques adopted to measure contagion.

Section six applies the theoretical model to the government bond market, to investigate whether contagion took place in this market during the financial crisis of 2007-2008. A short description about the specific market, data and the sample is given before the results of the statistical analysis are presented at the end.

The final section provides inference and implications of the results, together with a conclusion and a discussion on further extensions and possible other application.

1.2 Motivation

The motivation for the thesis has its roots in the two classes undertaken during the second and third semesters of the masters program. The class of 'Investments' gave the very first introduction to the study of financial crises, where the students were made aware that it is dynamic and upcoming area of study. As part of the curriculum, a graded project was carried out on the impact of the recent financial crisis on two countries and whether economic indicators influence the probability of a potential crisis. In the next semester, the subject 'Market Risk' carried us further into the study of extreme events, where many statistical models of measuring and predicting such events were explained in details. A project similar to the one earlier introduced the students to the concepts of bubbles and how they can be measured and predicted. The concept of contagion was discussed briefly and therefore an interest was created to study this phenomenon in more detail.

1.3 Purpose of the Study

The overall purpose of the study is to identify whether financial contagion took place during the financial crisis of 2007-2008. A more specific formulation of this purpose of the thesis is : to evaluate if financial contagion occurred in the stock markets and the government bond markets of the G8 countries (consisting of Canada, France, Germany, Italy, Japan, Russia, United Kingdom and the United States) and Norway during the recent global financial crisis of 2007-2008.

Based on the main purpose of the thesis, some of the more precise objectives are; to define and understand the many aspects of contagion, to study how contagion can be transmitted, to identify how the financial crisis in concern was triggered or what exactly was the catalyst of the crisis, to evaluate how market volatility affects the correlation coefficient calculation and how it can influence the conclusions drawn from the measurement (if there is an incorrect inference of contagion) and finally, to identify if an adjustment to the bias will give a more consistent result.

1.4 Significance of the Study

There are several aspects of the thesis that add value or contribute to the significance of the study. Though many studies have been conducted on contagious effect of the financial crisis of 2007-2008, this particular study measures contagion in two different markets, namely the stock market and the government bond market. A unique dataset including the members of the G8 together with Norway is used to differentiate the thesis from other studies. The methodology has explored several alternative ways of modeling and analyzing the market data to evaluate the effect of heteroskedastic bias on cross-market correlation coefficient. An attempt is also made to link the results of the data analysis to the actual events that took place within the countries in the sample during the defined period of crisis.

1.5 Limitations

The most fundamental limitations to the thesis stem from the theoretical structure which is obtained from the paper 'No Contagion, Only Interdependence: Measuring Stock Market Comovements', by economists Kristin Forbes and Roberto Rigobon(October 2002). Insufficient details about the actual statistical analysis conducted by the authors have limited the thesis in its ability to produce a similar analysis. Description of the data analysis process, along with the tools and methods used, was strongly inadequate and vague. Therefore, many independent assumption have been made with regard to the methods applied, filtering techniques as well as in order to interpret the results. It should be also be noted that the two assumptions of no endogeneity and no omitted variables in the theoretical model can be challenged. If these two assumption become invalid, the method of testing for contagion using an adjusted correlation coefficient can be invalidated. Limitations can occur due to missing data, errors in calculations and statistical inferences all which a natural part of any thesis or research paper. A severe time restriction has also resulted in a relatively lesser number of analyses and scenarios.

SECTION TWO: FINANCIAL CRISES

2.1 What is a Financial Crisis?

As a prelude to defining a financial crisis, the importance of a well-functioning financial system in an economy need to be identified. Financial institutions play a unique and vital role within the economy, because they act as intermediaries between parties that need to borrow and parties willing to lend or invest. An effective financial system results in a healthy economy, where funds are transferred in an optimum manner to economic agents who have feasible investment opportunities. Thereby, a financial crisis or a financial crash prevents the financial system from functioning smoothly and efficiently.

According to Acharya (et.al. 2009), a financial crisis is a phenomenon caused by systematic risk. Systematic risk is where the financial system and financial models applied become unstable. It can also be viewed as a widespread failure of financial institutions or the freezing up of capital markets that can substantially reduce the supply of capital to the real economy. Such a situation is harmful to all market participants because the investors suffer substantial losses and there is a decline in level of confidence over the soundness of the financial system as well as financial assets.

A concrete definition of a financial crisis is given by Mishkin(1992), where he states that it is *'a disruption to financial markets in which adverse selection and moral hazard problem become much worse, so that financial markets are unable to efficiently channel funds to those who have the most productive investment opportunities*.' He lays out five primary factors that cause a financial crisis; an increase in interest rates, stock market declines, increase in uncertainty, bank panics and unanticipated declines in aggregate price levels.

Using a more expansionary approach to categorizing shocks to the financial market , Carmen Reinhart and Kenneth Rogoff in their book 'This time is different'(2009), have identified different types of crises based on two broad thresholds. Crises defined by quantitative thresholds are Inflation crisis, Currency crashes and currency debasement, while crises defined by events are banking crises, external debt crises and domestic debt crisis[1].

[1] A short description of crises defined by events is given in Appendix I

An *inflation crisis*, often known as 'Hyperinflation', is a situation where a certain market or country experiences a high and virtually accelerating level of inflation. Such a situation causes a rapid increase in cost of goods and supply of money in the economy. Rienhart and Rogoff use an annual inflation rate of 20 percent or higher to term an incident of hyperinflation to qualify as a 'crisis'. A *currency crisis* is where the currency used in one market becomes unstable by losing value. Such a devaluation normally occurs when there is a balance-of-payment deficit or when there is heavy speculation within the market about the ability of a government in backing their currency. An annual depreciation of 15 percent or more against the U.S: dollar (or any other relevant anchor currency such as U.K. pound or the euro) is termed to be a currency crisis by the two authors. They also highlight another crisis known as *'Currency debasement'*, which occurred during an era in which the principal means of exchanges was metallic coins. Even though it is not important in modern times, it was nonetheless an integral part in the study of the history of financial crises through two centuries. The first type of currency debasement is benchmarked as a 5 percent reduction or more in the metallic content of coins. The second type of crisis under currency debasement is a situation of currency 'reforms' or conversions, where a new currency replaces a much-depreciated earlier currency in circulation. It is relevant to the present time and examples are presented from Brazil, China and Zimbabwe to highlight such crises of currency debasement.

Reinhart and Rogoff provide a large number of examples and data from nearly 800 in the history to highlight how every financial crisis appears unique at the beginning. But once a closer look is taken, it is easy to identify nearly every crisis has certain fundamental triggers or factors, recurring in different ways.

2.2 History of Financial Crises

This section discusses five of the most significant financial crises during the last century , starting with the 1929 'Great First Contraction'. The most recent global financial recession of 2007-2008, which is identified as the 'Second Great Contraction' (Reinhart & Rogoff, 2009) will be discussed in length in Section three of the thesis.

2.2.1 The 1929 U.S. Stock Market Crash

The stock market crash of 1929 became known as a very powerful and significant financial crisis in the U.S. history. The severity was not only due to the Dow Jones Industrial Average losing 90% of its value between its record high close of 381.2 on September 3, 1929, and its subsequent bottom of 41.22 on July 8, 1932 (Amadeo, 2013). But the crash of 1929, also known as 'Black Tuesday' was the event that pulled America as well as many other regions into the Great Depression, from which it took America nearly 10 years to recover.

After the World War I ended in 1918, the United States experienced the 'roaring twenties' where the economy was fueled by industrialization and popularization of new technologies. Interest rates were kept low to promote investment. Spurred by the bull market, investors purchased shares aggressively, with the notion that stock market can only go up. Purchasing shares on margin became popular, and investors flocked to the market with mortgages taken out on homes and life-savings.

In 1929, the Federal Reserve increased interest rates and the market entered in to a bear state. Panic selling began to occur when investors realized that inflated prices were just based on speculation, not based on fundamental economic strength of companies. Margin investors went bankrupt almost instantly when the stock market crashed in October 28 and 29. By the end of the 1929 stock market crash, a staggering $16 billion worth of market capitalization had been lost from NYSE stocks(Colombo, 'The Stock Market Crash of 1929'). Making matters worse, most of the banks have invested their retailer deposits in the stock market. As a result of the market crash, people lost their savings and the banks had to declare bankruptcy. With the financial system in disarray and millions of dollars worth of money lost, the Great Depression followed the economic crisis, where nearly 1/3 of the American population was forced to live under the poverty line.

2.2.2 The 1987 Stock Market Crash

On October 19, 1987, the global stock market, along with the associated futures and options markets, crashed. This day became known as 'Black Monday', because the event had swift and severe repercussions, and also it revealed the weakness of the actual trading systems and how they can be strain under extreme conditions.

During the period before the crash, equity markets in the U.S. were posting strong gains, with new investors such as hedge funds entering the stock markets. But the months leading up to the crisis saw the global interest rates increasing and the U.S facing a growing trade deficit and a decline in the dollar value. A bullish stock market fueled by low interest rates, hostile takeovers, leveraged buyouts and merger mania, was attracting many investors. On top of that, financial markets were experiencing an increase in the use of 'program trading' strategies where computers and computer models were used in trading, stock market analysis, etc. Investors were popularly using a program strategy of 'portfolio insurance', where stock index futures were used to cushion equity portfolios against broad stock market declines.

Between October 14 and 16, several events in U.S. caused anxiety among investors, resulting in a decline in the equity markets. With rising interest rates, many institutional money managers were trying to hedge their portfolios at the same time. There was a movement from stocks to relatively safer bonds, with market decline further augmented by some technical factors.

By Monday morning on the 19th of October (termed as Black Monday), the stock index futures market was besieged with billions of dollars of sell orders within minutes. It caused an immediate crash in both futures and stock markets. A mass hysterical selling of shares brought on by unreliable information and irrational behavior of investors' overwhelmed the stock markets as well. The Dow Jones Industrial Average fell 508 points, which is 22.6% [2], S&P 500, and Wilshire 5000 declined between 18 and 23 percent on the day amid deteriorating trading conditions and the S&P 500 futures contract declined by 29 percent. The crash of 1987 was the day that the USA stock markets experienced the single largest drop in history, though it did not cause a recession or hamper economic development

[2] Browning, E.S. (2007-10-15). "Exorcising Ghosts of Octobers Past". *The Wall Street Journal* (Dow Jones & Company).

2.2.3 The 1994 Mexican Peso Crisis

During the early 1990s, Mexico was recovering from a decade filled with economic shocks such as 1982 debt crisis and the 1986 collapse of oil prices. Inflation was low and foreign investment has started to flood back in to the economy, with the central bank accumulating billions of dollars' worth reserves.

But the current account deficit of Mexico was on a rise; it has ballooned from $6 billion in 1989 to more than $20 billion in 1992 and 1993 (Whitt, 1996). Observers were worried that the Mexican currency peso was becoming overvalued, which can cause a reduction of exports alongside an increase in imports, ultimately leading to a trade deficit crisis. The country had a crawling peg exchange rate system, where government intervention kept the exchange rate within a narrow target band. Mexico's rate of inflation was becoming consistently higher than the sum of inflation rate of USA and rate of currency depreciation. This resulted in the real exchange rate increasing; making imports from USA cheaper and further contributing to the contributing to the current account deficit.

The political environment in Mexico started to become unstable due to various events such as political assassinations, rebellions and other key political figures stepping down from government positions. Stock markets declined after such events, and fears of political instability set of widespread alarms in the financial market. Crisis of confidence affected the banking system and made it difficult for the government of Mexico to roll over some of their debts. By the end of 1994, Mexico's reserves have eroded from £29 billion to $6 and the government intervened heavily to maintain the level of economic activity.

The series of internal political shocks, coupled with an external shock of rising U.S. interest rates, prompted Mexico to announce the devaluation of the peso on December 20, 1994. The government announced that it was abandoning the exchange rate target bank and allowing the peso to float. The peso plunged to new lows, where by December 27 the exchange rate was 5.7 pesos per dollar, a decline of nearly 40% in dollar terms, and further declining to 8 pesos per dollar in mid-1995. Interest rates soared, companies operating with dollars went bankrupt resulting in employee layoffs, and the government was unable to secure funding through credit markets. Many foreign investors abandoned ship and Mexico was plunged in to a serious economic crisis.

2.2.4 The 1997 Asian Crisis

The period before the 1997 Asian crisis saw the South East Asian countries enjoying unprecedented economic growth. Exports have increased in double-digit rates in Thailand, Malaysia, Singapore and Hong Kong. The nature of these exports had also shifted in recent years from basic materials and products such as textiles to complex and increasingly high technology products, such as automobiles, semi-conductors, and consumer electronics[3]. Investment was booming with capital flowing in to these market, but there was also high level of heavily leveraged investment.

One trigger for the crisis proved to be the decline in the semi-conductors industry in Korea, where excess capacity was becoming evident, with the prices plunging and the firms unable to repay their debts taken to finance the excess capacity. At the same time, a previous boom in the Bangkok property market was deteriorating. These events were being played out in other markets where the heavy investment in industrial assets and property was causing serious problems with regard to repaying loans taken out in US Dollars. While the export markets were still maintaining good levels, imports of capital and retails goods have been increasing even faster. Several East Asian nations were left with dangerous current account deficits.

In 1997, the stock market in Thailand began to decline and a speculative attack was adding pressure to the Thai baht. The country bowed to the inevitable and devalued the Thai baht to float freely against the US Dollar in July 1997. At first, it was considered as a domestic or a localized crisis. But the events in Thailand prompted investors to reassess and test the robustness of currency pegs and financial systems in the region. A domino effect was soon in place, with Malaysia and Philippine following suit with currency depreciations. By the fall of 1997, the crisis has spread to South Korea, Hong Kong and China. In the year after collapse of the baht peg, the value of the most affected East Asian currencies fell 35-83% against the U.S. dollar (measured in dollars per unit of the Asian currency), and the most serious stock declines were as great as 40-60%[4]. Ultimately, IMF and later the World Bank stepped in to provide rescue funding to Thailand, Indonesia (where the crisis reached extreme heights economically, socially and politically) and South Korea.

[3] Charles W.L. Hill 'The Asian Financial Crisis' (University of Washington)
[4] Ramon Moreno 'What Caused East Asia's Financial Crisis'(August 7, 1998) Economic Letter, Federal Reserve Bank of San Francisco

But the crisis was not contained within the region and soon Japan was facing difficulties and uncertainty when a top brokerage firm and one of the top 10 Japanese banks went bankrupt, spreading fears of default and crisis. Stock markets declined in U.S. and other major markets. In June 1998, Russian stock market crashed, with the financial system stretched to the breaking point. U.S. and IMF pledged support, but the impact of economic troubles in Russia reverberated throughout Latin America. Likewise, the sequence of events starting with a foreign currency crisis, ultimately ended up spilling over to the global markets.

2.2.5 The Dotcom Crash of 2000

The dotcom bubble is a speculative bubble related to the shares of internet companies and is also known as internet bubble or Information Technology bubble. The 1990's saw the accessibility and user-friendliness of personal computer expanding. It was fast becoming a useful business tool, where various specialized applications were helping users to engage in a wide variety of business activities such as tax preparing to word processing. U.S. companies started to focus more on computer software development, which had high profit margins as opposed to hardware development.

The shares of software companies became strong performers in the 1990s, with the enthusiasm generated promoting many startups. Venture capitalists eventually entered the industry by proving funding and facilitating public issue of shares for those up-and-coming startup IT companies. Buoyed by a healthy economic environment of low interest rates and inflation rates, the boom in the internet and software industry drove the U.S. stock markets to new height (the technology-dominated NASDAQ rose from 1000 to over 5000 points during the period 1995-2000) . At the peak of the dot-com bubble in 1999, it was said that a new millionaire was created every 60 seconds in Silicon Valley (Colombo, The Dot-com Bubble, 2012)

But the lack of concrete business plans and moreover, a lack of proper flow of earnings, was putting a strain on the bubble. In the year 2000, investors started to realize that most of the growth in the technology industry was brought on by speculation and 'fad-investment' rather than based on solid returns and sustainable expansion. The NASDAQ fell significantly and the share prices of most 'dotcom' companies reduced to virtually nothing. With many firms being liquidated, IT professionals were left without jobs and with worthless stock options.

SECTION THREE: KEY SEGMENTS

The main title or the fundamental question studied in the thesis is whether financial contagion took place during the financial crisis of 2007-2008. Before venturing in to the various aspects of the method and process of measuring for contagion, a closer look is taken of the two key points stemming from the topic; contagion and the financial crisis of 2007-2008. The following sections provides a comprehensive study of the two aspects in order to get a better understanding of the thesis.

3.1. Contagion: A Literature Review

In recent times, shocks or crises that were thought to be country specific, has had an impact on countries that are geographically distant and structurally different economies. There are instances were transmission of a financial crisis has taken places between markets that have no significant linkages through any channels. A good example for such a situation is the considerable effect of the 1998 Russian 'Ruble Crisis' on the economy of Brazil. These two countries were very different in geographic location and economic structures, and did not appear to share any direct linkages through channels like trade. But soon after the Russian ruble was devalued in 1998, the Brazilian stock market fell by over 50 percent. This is an indication that there are various channels or methods through which shocks can be propagated from one market to another. The question remains, does the above example qualify as contagion?

3.1.1 What is Contagion

The word 'contagion' is unanimous with the field of medicine, where it is said to be ' the transmission of a disease by direct or indirect contact' (www.merriam-webster.com). A more general definition of contagion from the same source is that it is 'an influence that spreads rapidly'. The same term is being more and more used in the financial context as well, and *financial contagion* has become a much discussed area of study. When perusing the various theoretical literature on this subject, it is evident that a surge of interest in contagion occurred in 1990's. This particular decade has seen many severe financial and currency crises, such as the Exchange Rate Mechanism attacks of 1992, the Mexico peso collapse of 1994, the East Asian crisis of 1997, the Russian collapse of 1998 and the Brazilian devaluation of 1999. But the East Asian crisis is often cited as a global shock that spurred policymakers and economists to conduct intense research in identification and analysis of the causes and effects of financial contagion.

3.1.2. Definitions of financial contagion

A basic definition of the term is given as **'the likelihood that significant economic changes in one country will spread to other countries'**[5]. Kristin Forbes and Roberto Rigobon in their article 'No Contagion, Only Interdependence' (October 2002) defines contagion as *'a significant increase in cross-market linkages after a shock to one country (or group of countries)'*. It is the degree to which asset prices or financial flows move together across markets after a turbulent period (after a financial shock) relative to the similar comovement in tranquil times. Cross-market linkages are the different ways in which different markets or economies are linked together. One example would be trade, which is a *real* cross-market linkage. These linkages can be measured by different statistics such as correlation in asset returns, the probability of speculative attack or the transmission of shocks or volatility.

Dornbusch, Park, & Claessens (August 2000) define contagion as *' the spread of market disturbances - mostly on the downside - from one country to the other, a process observed through comovement in exchange rates, stock prices, sovereign spreads and capital flows'*. And according to Reinhart, Kaminsky, & Vegh (2003) in their article 'The unholy trinity of

[5] www.investopedia.com

financial contagion', this term is defined as *'an episode in which there are significant immediate effects in a number of countries following an event - that is, when the consequences are fast and furious and evolve over a matter of hours or days'*. They further elaborate that only 'excess comovement' in financial and economic variables across countries in response to a common shock will constitute contagion. A separation is made between the terms contagion and *spillover*, the latter being identified as a situation where the initial international reaction to the news of a crisis will be muted, but gradual and protracted effects can emerge to cumulatively create major economic consequences.

Even though significant research has been done, still there is no consensus among all economists on a universally accepted definition of contagion. Some argue that if a shock is transmitted from one country to another, it will constitute contagion even if there is no significant increase in cross-market relationships. Others dispute the fact that contagion can be defined based on simple tests of changes in cross-market linkages. It is their opinion that it is necessary to identify exactly how a shock is propagated across markets, and only certain transmission mechanisms constitute contagion; irrespective of its magnitude.

Many academic papers related to contagion has often cited the works of Kristin Forbes and Roberto Rigobon. This thesis itself will be using the definition and theoretical model laid out by the two economists, which makes it important to look further into their work. In 'Measuring Contagion' (Forbes & Rigobon, 2001), they introduce the term 'shift-contagions' instead of 'contagion' to differentiate their definition from other existing conceptions of the term. The term simply clarifies that contagion arises from a shift in cross-market linkages but avoids specifying *how* this shift occurs. The impact of the devaluation of Russian ruble on the Brazilian stock market and the impact of a stock market crash in the U.S. on the markets of Canada are the two example used to simplify their definition of contagion.

When a crisis in one country is transmitted to another country, even without a significant change in cross-market relationships, some may argue that it constitutes contagion. But Forbes and Rigobon counter-argues that if two markets show a high degree of comovement during periods of stability, an increase in that relationship or the correlation between two markets *after* a crisis in one market does not alone result in contagion. If the increase in cross-market linkages is not *significant*, it is an instance high 'interdependence' between the two markets and not shift-contagion. According to the above classification, the decline in the stock

markets of Brazil after the Russian ruble crisis can be identified as contagion. Since U.S. and Canada have a high level of trade and other linkages between them (indicating that the two markets are highly correlated in all states of the world), the decline in Canadian stock markets due to a U.S. market crash cannot be easily identified as contagion. One need to look at the significance of the changes in cross-market linkages in order to determine whether it constitutes contagion or not.

The definition 'contagion is a significant increase in cross-market linkages after a shock to a single or group of countries' has empirical usefulness. This definition easily translates into a simple test of contagion, which is to test whether the cross-market correlations change significantly after a shock. Forbes and Rigobon have further identified three main advantages of using the same definition in proving their research. The fist advantage is related to international diversification. Under the expectation that most economic disturbances are idiosyncratic, thus markets around the globe display relatively low correlation, international diversification is deemed to reduces portfolio risk and increases expected returns. Therefore, testing for contagion through correlation of assets markets can be a clear test of effectiveness of the international diversification strategy. The second advantage is in its use in evaluating the role and potential effectiveness of international institutions and bailout funds. The final advantage is that provides a useful method of distinguishing between explanations of how shocks are transmitted across markets.

3.1.3. Theories of Contagion

There are various theories as to how contagion can occur, or more specifically, how shock are propagated internationally. These theories are broadly categorized in to two groups; crisis-contingent theories and non-crisis-contingent theories (Forbes & Rigobon, 2001). *Crisis-contingent theories* explain why transmission mechanisms change during a crisis and therefore why cross-market linkages increase after a shock to one entity. The crisis causes a structural shift, so that shocks are transmitted via a channel that does not exist in stable period. Evidence of shift-contagion is supported in these theories. *Non-crisis contingent theories* assume that transmission mechanisms remains constant during a crisis as well as a non-crisis period, and therefore cross-market linkages do not increase after a shock. This group of theories emphasize on spillovers that results from the normal interdependence among market economies. Interdependence means that shocks of either global or local in

nature are propagated across countries through their real and financial linkages, and such high comovement would not normally constitute contagion. Therefore, these theories of contagion provide evidence against contagion.

Crisis-Contingent Theories

Under the crisis contingent theories, there are three broad mechanisms of international propagation of shocks;

- Multiple equilibria
- Endogenous liquidity
- Political economy

Multiple equilibria occurs when the channel of transmission is *investor psychology*, where propagation of a shock is driven by the investors' expectations or beliefs, rather than by any real linkages. In other words, when a crisis rams one economy, investors change their expectations (which can also be triggered by a memory of past crises) and therefore transmits the shock through propagation mechanisms that does not exit during stable periods. Accordingly, contagion is said to transpire when a crisis in one economy causes the second economy to move from a good equilibrium to a bad one, characterized by a devaluation, a drop in asset prices, capital outflows, or debt default. Investors re-compute their priors on variables such as debt default, causing a downward movement in assets prices. This change in the prices of the second economy (relative to the change in the price of the first) is exacerbated during the shift of equilibriums.

Endogenous liquidity theories of contagion can be identified as a portfolio re-composition. This channel only occurs after the initial shock to one market and is not present during periods of stability. A crisis in one economy can reduce the liquidity of market participants, which can force them to re-compose their portfolios and sell assets in other countries to continue operations in the said economy. In the same manner, if the liquidity shock is large enough, a crisis in one market could increase the degree of credit rationing and force investors to sell their holdings of assets in countries not affected by the initial crisis. It is important to understand that imperfect information or information asymmetries lead to an increased correlation of asset prices as well. If a financial crisis occurs in one country and it reflects and reveals weak fundamentals, investors may rationally conclude that similarly situated countries are also likely to face such problem. Therefore, uninformed investors are unable to distinguish

between a liquidity shock and a bad signal and thereby charge a premium where informed investors are the net sellers. As a result, informed investors can be hit by liquidity shocks that force them to sell their holdings. The high comovement between the asset prices that follows can lead to a situation of shock propagation through channels that did not exists previously.

The final transmission mechanisms under this group of theories is *political contagion*. It is where contagion arise through political economies that have a greater impact in exchange rate regimes. For an example, one research studies the European devaluation of 1992 and 1998 and develops a model that assumes that central bank presidents are under pressure to maintain their countries' fixed exchange rates. When one country decides to abandon its peg, this reduces the political costs to other countries of abandoning their respective pegs, which increases the likelihood of these countries switching exchange rate regimes (Dornbusch, Park, & Claessens, 2000).

Rational or irrational behaviour of the investors and the incentive scheme for individual financial agents can cause contagion through channel that did not exist during periods of stability. Also, countries whose financial assets are widely traded in global markets and whose domestic financial markets are more liquid may be more vulnerable to financial contagion.

Non-Crisis-Contingent theories

Internationally propagated shocks that do not generate shift-contagion is grouped under non-crisis-contingent theories. These transmission mechanisms or channels can be divided into four broad channels ; trade and financial linkages, policy coordination, country re-evaluation and random aggregate shocks.

Local shocks in one country can affect the economic fundamentals of other countries through trade links and currency devaluations. For an example, any major trading partner of a country in which a financial crisis has induced a sharp currency depreciation, could experience declining asset prices and large capital outflows. Or they could become the target of a speculative attack as investors anticipate a decline in exports to the crisis country and hence a deterioration in the trade account. Consistent with their 'unholy trinity of contagion' proposition, Reinhart (et.al) highlights that financial linkages such as cross-border capital flows and common creditors (including the role of commercial banks in spreading an initial shock) are prominent in the theoretical explanation of contagion. Dorndusch (et.al) also

highlights financial links, namely where economic integration between markets involves both trade and financial links. Thus, a financial crisis in one country can lead to direct financial effects, including reductions in trade credits, foreign direct investment and other capital flows abroad.

Policy coordination is the second transmission mechanism under discussion, and it creates a link between countries in a way that one country's response to an economic shock forces another country to follow suit. For an example, a trade agreement might include a clause in which lax monetary policy in one country can force other member countries to raise trade barriers.

Country re-evaluation or learning explains the fact that investors may apply the lessons learned after a shock in one country, to other countries with similar macroeconomic structures and policies. For an example, if a country with a weak banking system is discovered to be vulnerable to a currency crisis, investors could reevaluate the strength of the banking system in other countries and adjust their expected probabilities of a crisis accordingly.

Finally, it is suggested that *random aggregate or global shocks* could simultaneously affect the fundamentals of several economies. Studies have identified various global shocks that can trigger market adjustments in an international context. A common global cause, such as major economic shifts in industrial countries, a rise in the international interest rates and changing commodity prices as well as demand for commodities, can trigger crises in other economies. These can lead to comovement in assets prices or capital flows directly after the shock.

The transmission channels described above are the 'real' linkages between markets, and it is assumed that after an initial shock, these mechanisms do not change significantly. If there is a large (but not significantly large) cross-market correlation after a shock, it is only a continuation of the linkages that existed before the crisis, not contagion.

Reinhart (et. al 2003) identifies three key elements - an abrupt reversal in capital inflows, surprise announcements and a leveraged common creditors - is the 'unholy trinity' that distinguishes cases of contagion occurring across borders, to those not qualifying as contagion. They further emphasize that financial linkages and investor behaviour figure most prominently in the theoretical explanation of contagion.

3.1.4. Measurement of Contagion

According to Forbes and Rigobon (2001), the empirical literature that tests if contagion exists is more elaborate than the theoretical literate available on the subject. Four different approaches have been identified to measure the transmission of shocks and test for contagion; analysis of cross-market correlation coefficients, GARCH frameworks, cointegration and probit models.

The test of contagion based on the cross-market correlation is a simple and straightforward measure. It estimates how two markets move together during periods of stability as well as turbulence. First, the correlation coefficient is calculated for the two markets under consideration for a relatively stable period. Then it is tested if the same correlation has significantly increased after one market experience a shock or crisis. If there is a significant increase of the correlation coefficient, it is taken as an indication that the transmission mechanisms between the two markets have strengthened, resulting in contagion.

In the second method, test of contagion is carried out using a ARCH (Autoregressive Conditional Heteroskedasticity) or GARCH (Generalized Autoregressive Conditional Heteroskedasticity) framework to estimate the variance-covariance transmission mechanism across countries. This approach estimates spillovers in volatility - that is, cross-market movements in asset prices. Most of the studies using various versions of these frameworks has found that market volatility is transmitted between countries. But they do not explicitly test if this propagation changes significantly after a shock, constituting contagion.

Test of contagion through cointegration analyses for changes in the co-integrating vector between markets over long periods of time. The focus is on the long run relationship between markets instead of short-run changes after a shock. Downsides of using this method can be that focusing on long-term periods can cause the tests to miss brief periods of contagion. Also, some economists have performed these tests assuming that the real linkages between the markets remain constant over the entire period. If it is shown that co-integrating relationship increased over time, contagion would be identified, whereas it might only be a permanent sift in cross-market linkages.

The final approach to testing contagion attempts to directly measure how different factors affect a country's vulnerability to financial crises. It uses simplifying assumptions and exogenous events to identify a model and directly measure changes in the propagation mechanism. The research involves estimating the probability of a crisis conditional on information on the occurrence of crisis elsewhere, taking into account fundamentals or similarities. Dornbusch(et.al) has given en example in his article on a research conducted by Eichengreen, Rose, and Wyplosz (1996). They have used a binary-probit model and a panel of quarterly macroeconomic and political data covering 20 industrial economies from 1959 through 1993, show that the probability of a domestic currency crisis increases with a speculative attack on a currency elsewhere and that contagion is more likely to spread through trade linkages than through macroeconomic similarities (Dornbusch, Park, & Claessens, 2000).

3.2 The Second Great Contraction of 2007-2008

A financial recession or a financial crisis often has its grassroots in different economic and political factors moving together. In the global financial recession of 2007-2008, a domestic crisis in United States of America burst open a floodgate to the discrepancies in the global financial system. The financial crisis was triggered in the first quarter of 2006, when a gradual downturn began in the housing market of U.S. Even though this event was the most visible in the global crisis that unfolded, it proved to be only the tip of the iceberg. A complicated financial structure with cross-border linkages became the silent but the most lethal vehicle through which the crisis became propagated to every single aspect of the financial systems around the globe.

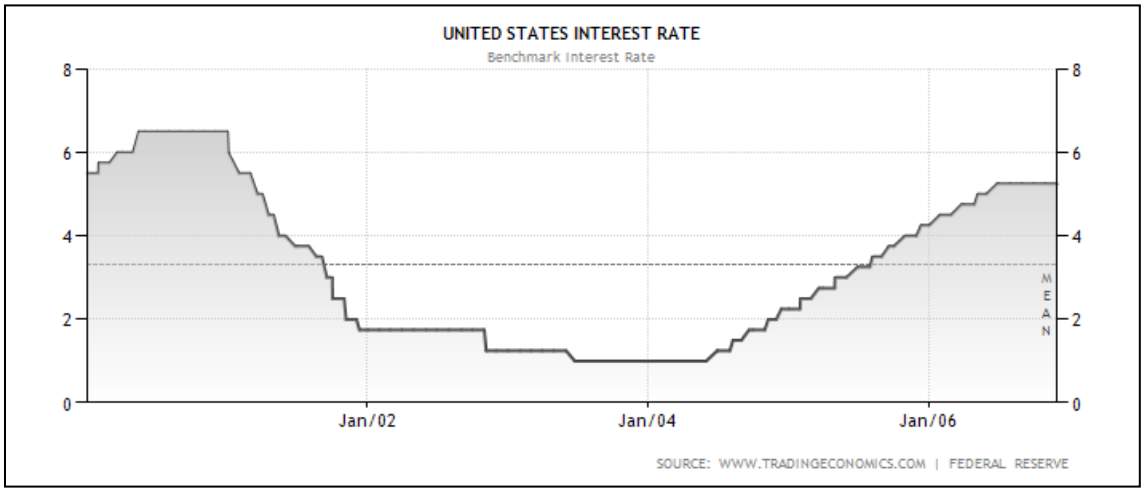
3.2.1 Background to the crisis

Monetary excess due to lax monetary policy

Following the burst of the Internet Bubble of 2000, US Federal Reserve was determined to revive the economy and to prevent price deflation similar to Japan in 1990's. They adopted a lax interest rate policy, where interest rates were record low levels(Figure 1). During the same time, a global imbalance was in creation. New capitalist societies were growing in China, India and Eastern Europe and they were emerging as fast developing invest and savings oriented nations. Countries like USA, Western Europe and Australia were consumer-oriented, promoting spending and debt. Capital flowed in to these markets from investment driven markets, making available a flood of excess funds. The availability of large capital inflows from abroad facilitated the low-interest environment in the U.S. economy. But it also resulted in a fundamental mispricing in capital markets, with implications of low credit spreads, a false belief low volatility and inflated risky assets. Even though interest rates were purposely kept at a minimum, it did not directly lead to an increase in inflation of goods and services prices. Rather, these years became a continuation of The Great Moderation[6], and this persistent macro-economic stability led many to believe that macro-economic risks had been significantly reduced.

[6] 'The Great Moderation' is a period of low volatility in macroeconomics , mainly in output and inflation, in USA and other major industrial countries. It is common consensus that the Great Moderation started in the 1980s and ended in 2007.

Figure 1: United States Benchmark Interest Rates from the period 2000-2006



Source: www.tradingeconomics.com

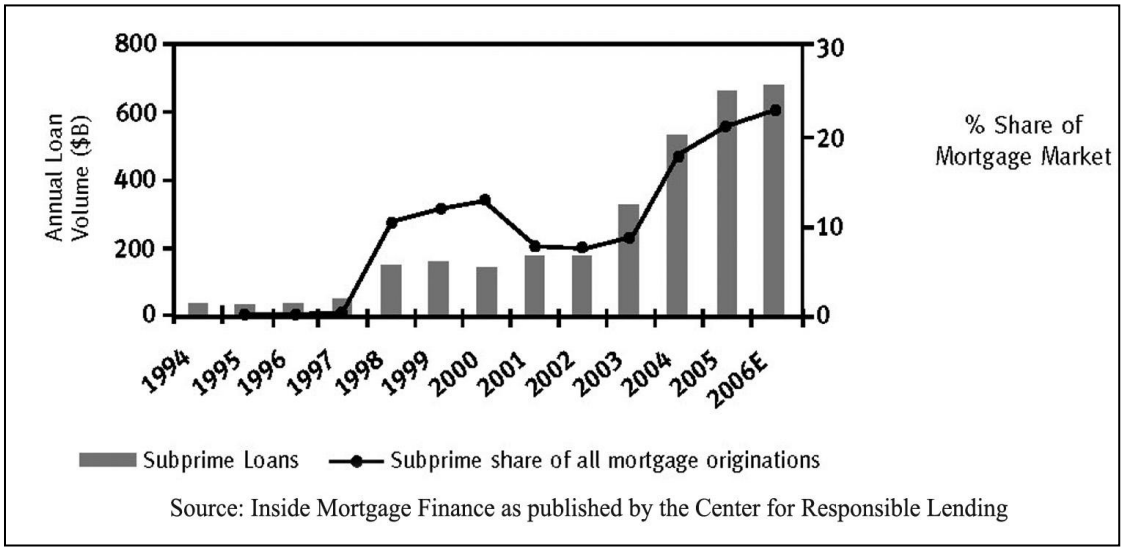
Leading up to a housing bubble[7]

Monetary excess created by lax monetary policies made high levels of funds or credit available in markets, mainly in forms of mortgage, consumer and corporate loans. Lending institutions like banks and financing corporations feasted on the flood of funds. With interest rates were at a ground-level, these institutions were compelled to increase the number of loans granted in order to add to yield. Cheap credit was obtainable to consumers since banks and mortgage brokers offered teaser rates, no-documentation mortgages, piggyback mortgages (a combination of two mortgages that eliminates the need for a down payment) and NINJA ('No Income No Job or Assets) loans. New financial products offered the elimination/removal of the credit risk from banks' balance sheets (discussed in more detail later). This gave little incentive for banks to carry out stringent background checks to assess the credit worthiness of the borrower. Sub-prime lending[8] became a major part of the overall mortgage finance market, where sub-prime loans grew from $35 billion on 1994 to $650 billion in 2007 (Tashman, May 2007)

[7] In his working paper 'The financial crisis and the policy responses: an empirical analysis of what went wrong' , prominent economist John B. Taylor discloses he had found empirical evidence that the lax monetary policy during 2001-2003 was the main cause of the housing boom and the subsequent crash.

[8] Sub-prime lending is where loans are granted to borrowers who have lower-than-average credit rating. The upfront and continuing cost of these types of loans are higher than that of prime lending.

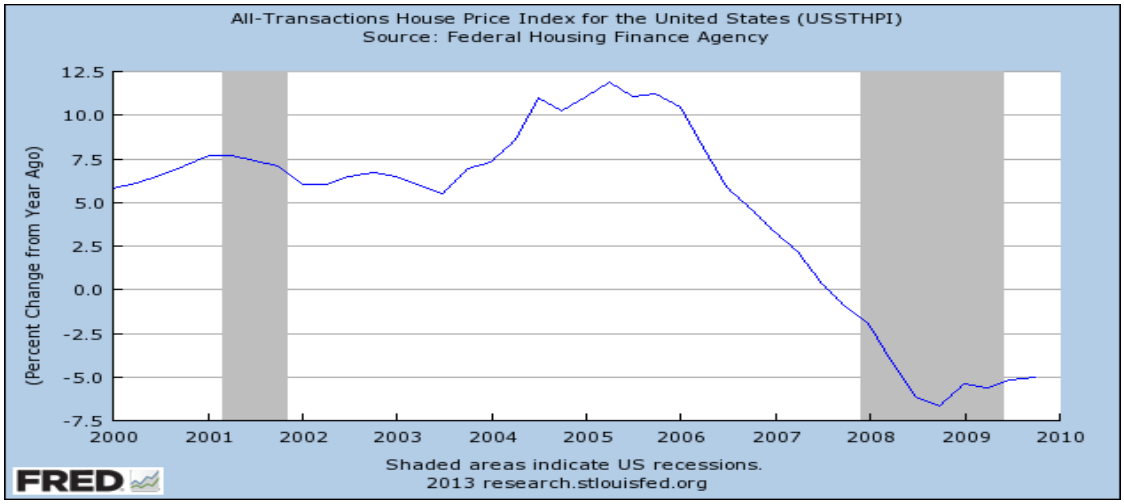
Figure 2: Subprime mortgage market growth and Share of Total Mortgage Market



Source : Tashman, (May 2007)

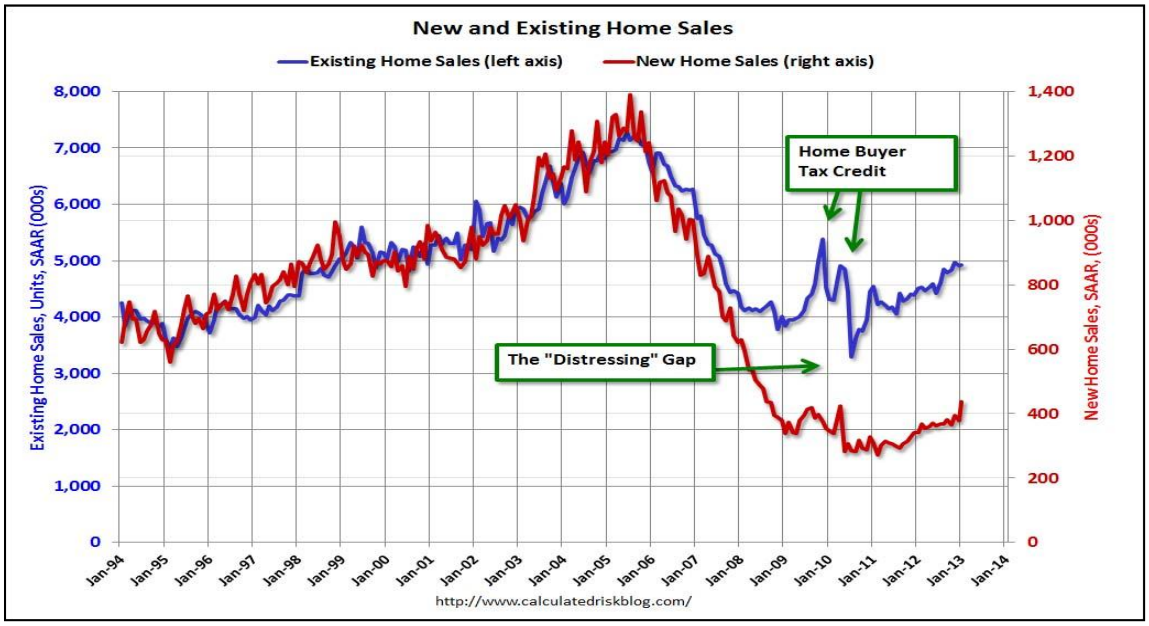
The combination of cheap credit and low lending standards resulted in a housing frenzy. All mortgages were granted under the premise that housing prices can only increase and a borrower can always refinance a loan using the increased value of the house. A large number of American homeowners took out second mortgages on their houses and new buyers flocked in to the real estate market. House prices soared and new home sales increased, which is evident from the graphs shown in Figure 03 and 04 below.

Figure 3: U.S. Housing Price Index



Source : Federal Reserve Economic Data(Federal Reserve Bank of St.Louis)

Figure 4: New and Existing Home Sales (Period 1994 - 2014)



Source: www.calculatedriskblog.com

The New Finance Structure and Securitization

For the last decade, financial markets have seen innovations like never before, with new forms of securitization and usage of derivatives being the most popular. It also saw changes in the banking strategies, originating from U.S.A and subsequently spreading to Europe and other markets. The traditional banking model operated in such a way that the specific bank who originates the loan, will hold it in their balance sheets until the loan has been repaid. It created an element of long term risk (from default)to the financial institution and tied up capital and other resources as well. This system was then replaced by an "Originate and Distribute" model, in which loans are originated (for example residential mortgages), pooled, 'tranched' and distributed via *securitization* to other financial investors.

Securitization is a process of transforming illiquid assets like real estate in to a security. To further elaborate, banks would typically create 'structured' products, often referred to as *collateralized debt obligations* or CDOs (Figure 05 gives a basic understanding of selected terminology). Once the banks formed diversified portfolios, consisting of such products , they were 'sliced' or divided into different 'tranches'. Each tranche comes attached with its risks and benefits, where the 'super senior tranche' is known to be the safest tranche and 'equity tranche' is known as 'toxic waste' since it is the last in the payment pecking order. Each tranche is constructed to ensure a specific rating (E.g. AAA rating to the top tranche). These tranches

were then sold to financial and non-financial investors, having varying appetites for risk. Banks managed to de-intermediate assets off their banks' balance sheets, even though in real terms, many of the securitized assets were held by conduits or 'special purpose vehicles' established and controlled by those very banks.

There was a substantial rise in popularity of securitized products or structured derivatives, since such financial engineering allowed banks to sell off mortgages and to release resources to provide more loans. It opened up the financial markets to investors and facilitated more loan to homeowners, where securitization ensured lower mortgage rates and lower interest rates on corporate and other types of loans. With banks facing only the 'pipeline risk' of holding loans for a couple of months, the lending standards became more lenient. Very little precaution was taken during the process of screening applications and monitoring loans, resulting in more and more credit being extended to those with subprime credit standings. Again, such a situation contributed to an unsustainable increase in assets prices, namely the housing bubble.

Figure 5 : Explanation of technical terms

Collateralized Debt Obligations (CDOs) is an investment-grade security is backed by a diversified portfolio of mortgages, other types of loans (e.g. auto loans), corporate bonds and other assets like credit card receivables. Collateralized Debt Obligation are similar in structure to Collateralized Mortgage Obligations(CMO) and Collateralized Bond Obligations(CBO). CDOs are generally called asset-backed commercial papers if the portfolio or package consists of corporate debt and mortgage-backed securities if the loans are mortgages.

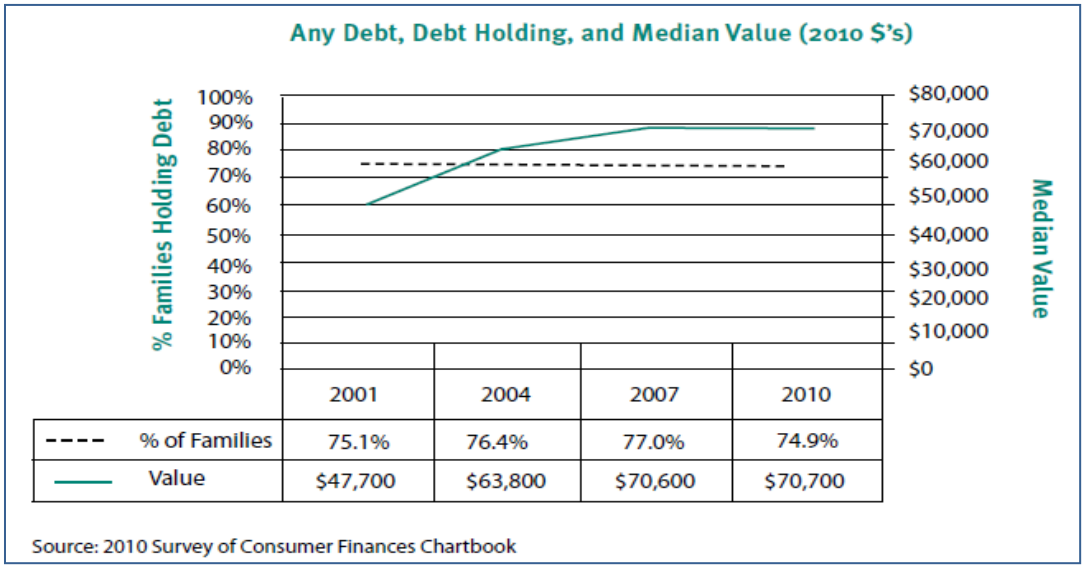
Mortgage Backed Securities are based on both prime mortgages and subprime mortgages and they can be secured by adjustable-rate mortgages or fixed rate mortgages. **Prime mortgages** are high quality mortgages made out to borrowers with high credit ratings and low default risk. They are eligible for purchase or securitization in the secondary mortgage market. **Subprime mortgages** are mortgages that are made out to borrowers who have low credit rating, meaning such borrowers are deemed to have a higher-than-average risk of defaulting on their loan. Lending institutions generally charge a higher interest rate as compared to prime mortgages, in order to compensate for the higher risk they themselves must bear. Investors in MBSs bear the risk of default on the original loan as well as the fluctuations of the interest rates.

3.2.2 Causes to the crisis

Increase in mortgage defaults

In the consumer driven economy of United States, individuals and corporate entities were enjoying the endless liquidity available at low rates and minimum responsibility. Figure 06 gives an indication how household debt has during the last decade.

Figure 6: U.S. Household Debt Holdings and Values, 2001 to 2010



Source: Report by Centre for Responsible Lending (U.S. - December 2012)

Consumer debt as a fraction of house value has increased dramatically, from 56% in 1985 to 68% in 2005 to 89% in late 2008 (Acharya & Richardson, 2009), all indicating that individual leverage was at a very high level. In 2005 and 2006, interest rates began to climb steadily back to more normal levels, which is actually a market correction. Housing prices began to falter, which is again a correction to the over-pricing or over-valuation of the real assets(namely real estate). The substantial downturn in the housing market left the homeowners with mortgages that were essentially worthless. Since homes are the primary asset for most households, this led to a severe loss of household wealth. Highly leveraged homeowners found that they were unable to repay the mortgages when their introductory low-level interest rates were reverted to regular rate. Most affected were those with insufficient credit strength, aka. subprime mortgage owners. Therefore, subprime mortgage defaults began to increased at the beginning of year 2007.

Pitfalls of the new system

In the face of a collapsed housing market, structured financial products and securitization began to lose its glittery image. When the probability of defaults increase, the likelihood of significant credit losses on the tranches into which original mortgages have been sliced, will rise as well. This means that the credit risk on the senior tranches increases, often exponentially when housing market declines and interest rates increase. Since the subprime mortgage market was hit the hardest during the housing bubble burst, the lower tranches of CDOs and CMOs also began to suffer heavy losses. Most of the lower tranches were held by hedge funds, and also the process of securitization allowed hedge funds , money market and pension funds to indirectly hold assets that was previously prevented by regulatory requirements. With the subprime mortgage defaults leading to a loss of vale in their investments, most of the hedge funds in the U.S. losing millions of dollars.

In the meantime, banks were faced with a *liquidity crisis*. Traditionally, commercial banks financed long term assets or long term loans with short-term deposits or on the basis of retail deposits. This maturity mismatch left the commercial banks exposed to funding liquidity risk , and a similar vulnerability was seen from the balance sheets of investment banks. Banks were forced to rely more and more on short-term repurchase agreements or 'repos', and such a reliance on overnight financing required that the investment banks roll over a large part of their funding on a daily basis. Dramatic decline in liquidity made the banking systems in developed worlds more vulnerable to decline in asset values and defaults.

The rating agencies invariably contributed to the growth of a financial crisis. Credit agencies primarily rate the credit default risk of the assets to which they grant the particular rating. This was misinterpreted to mean that the rating covered market and liquidity risk as well. Structured products received more favourable ratings due to the fact that the assessment parameters of the agencies did not encompass the overall picture. Also, they collected a higher fee for structured products. Combined with over-optimistic forecasts based on historically low mortgage default and delinquency rates, investors were led to believe that they are holding virtually risk-free tranches with high yields.

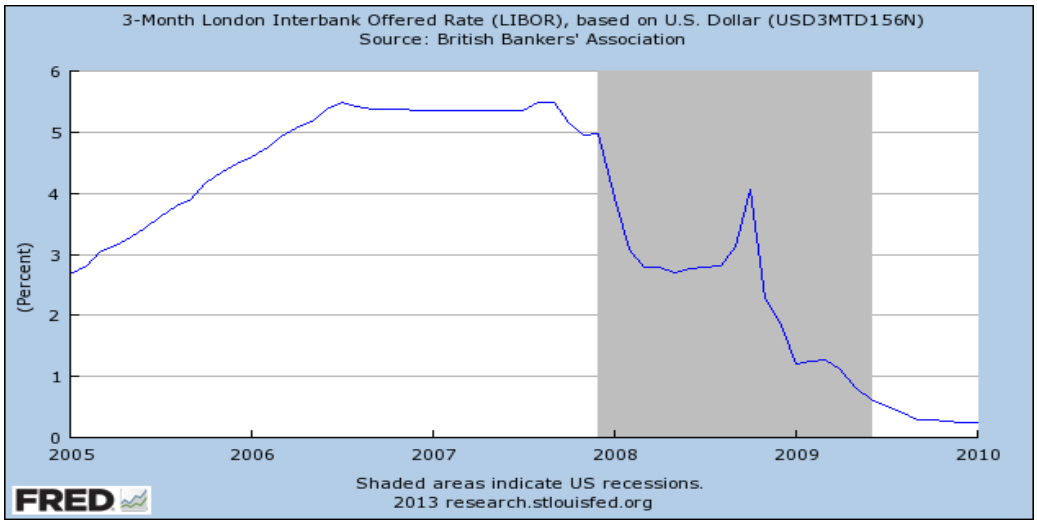
3.2.3 Unfolding of the crisis

Summer of 2007 saw U.S. home loan lenders reporting declines in earnings, with New Century Financial declared bankruptcy, the second largest subprime lender in U.S. along with American Home Mortgage Investment Corp. declaring bankruptcy. Rating agencies Moody's, Standard & Poor's and Fitch began to downgrade the credit ratings of tranches across U.S. subprime deals. This pushed down the prices of mortgage-related products and continued to unnerve the credit markets. One critical point in this unfolding calamity was the collapse of two highly leveraged hedge funds managed by Bear Stearns in June 20, 2007. These two hedge funds were heavily invested in subprime asset-backed securities. The falling prices of collateralized debt obligations saw the lenders of these fund demanding more collateral, with Merrill Lynch (one the fund's main creditors) seizing their assets. Finally, Bear Stearns injected $3.2 billion worth of loans in to the fund to prevent more panic and fire sales.

By this time, the crisis was slowly but surely spilling over the borders of the U.S. to other developed countries. In July 2007, a small bank in Germany, IKB, became the first European victim to the shock. Its conduit was unable to roll over asset-backed commercial paper and to provide the promised line. In the same time, the market for short term asset-backed commercial paper began to dry up, signaling that money market participants are becoming reluctant to lend to each other. Banks depend on the repo market, the federal funds and the interbank market in addition to short-term asset-backed commercial paper to fund themselves. Then came the announcement that tipped the scale; French bank BNP Paribas has frozen redemptions for three investments funds, citing its inability to value structured product. This caused the interbank markets to freeze up on August 9, 2007, causing the very first 'liquidity wave' . It resulted in the perceived default and liquidity risks of banks to rise significantly, driving up the LIBOR (Figure 45).

The financial turmoil continued throughout 2007, punctured by margin calls, fire sales, downgrades, subprime lenders going bankrupt and quantitative hedge funds suffering losses in millions of dollars due to their exposure to subprime mortgage-backed securities. The Federal Reserve stepped in to mitigate the liquidity crunch by reducing the discount rate and injected funds to failing banks. Various sovereign wealth funds have invested a total of more than $38 billion in equity from November 2007 until mid-January 2008 in major U.S. banks (Brunnermeier, 2008)

Figure 7: LIBOR for the period 2005 - 2010



Source : Federal Reserve Economic Data(Federal Reserve Bank of St.Louis)

2008 was not spared the crashing waves of the financial crisis, highlighted by the run on Bear Stearns, the fifth largest investment bank in U.S. and the subsequent rescue of it. They were heavily leveraged and exposed significantly to the subprime mortgage market. But since the company had more than 150 million trades spread across various counterparties, they were considered to be 'too interconnected' to be allowed to fail suddenly. The run on Bear Stearns on March 10, 2008 ended with the government of U.S.A intervening, by guaranteeing a total of $29 million for JP Morgan to purchase the troubled investment bank.

Mortgage delinquency rates continued to grow in the following months, and in September 2008 Lehman Brothers, the fourth largest investment bank in USA, collapsed. This event proved to be a critical turning point of the great recession, because banks lost faith in the value of securitization tied to the United States real estate market. The collapse of Lehman Brothers came as a great shock because there was an implied assurance in the market that the government will always save crucial financial institutions from falling. But when the Treasury and Federal Reserve o decided not to act as a guarantor in a bid takeover of Lehman Brothers, the market realized that no bank is 'too-big-to-fall'. In September 2008, Lehman Brothers declared bankruptcy, causing widespread panic in the entire financial intermediation system. Prime brokerage firms connected to Lehman Brothers, especially that in U.K. went bankrupt, and led to massive losses across many hedge funds. In the wake of this event, inter-bank markets froze and stock markets reacted strongly around the globe.

Throughout the year 2008 and early 2009, the Federal Reserve of U.S. and the governments of other major markets announced various controls and facilities to regain market stability. Fund availability for private and public firms as well as local and state governments was curtailed. Government institutions who have invested in asset-based securities faced loss of wealth similar to individuals and corporate. The ongoing European Sovereign Debt Crisis, popularly known as the 'Eurozone Crisis', has its beginnings in the great financial crisis of 2007-2008. A majority of businesses around the world revealed financial difficulties, and resulted in thousands of employees being made redundant. The economic, social and political impact of this crisis are immeasurable and very much present to this date. Complex and intense interconnectivity of the global financial system was the main channel of transmission of the domestic crisis in U.S. to the rest of the world.

As a closing note, it should be noted that the Second Great Recession or Contraction of the world economy continues beyond the events stated above. But the boundaries of the thesis is identifying the event which is the clear catalyst for the shock in the selected market. Therefore, the leading causes as well as the most important happenings of the crisis were identified and discussed.

SECTION FOUR: METHOD OF QUANTITATIVE ANALYSIS

In any quantitative study, especially one using statistical modeling, it is important to clearly identify how boundaries of the specific problem have been defined, what is the theoretical foundation on which the study is based upon and what kind of a procedure has been followed to carry out the study. The main purpose or the main problem of the thesis has already been defined as 'was there financial contagion during the financial crisis of 2007-2008?'

An important pre-requisition for a solid investigation of contagion is to clearly identify the catalyst for the crisis. The reason is that the specific identification of the market in which the crisis is triggered, or the market where a domestic crisis was first triggered and then transmitted internationally, is an essential part of the statistical analysis. From the analysis of the financial crisis of 2007-2008 in Section three, it is clear that the event that triggered the shock is the subprime mortgage crisis in United States. Therefore, the thesis will focus on whether there are contagious effect from market volatility in the U.S to the countries of the chosen sample.

The theoretical model used to evaluate whether contagion occurred between the U.S. and each of the other countries in the sample, was extracted from a research papers published by Kristin Forbes and Roberto Rigobon (2002). These two economists follow a specific definition of contagion which facilitates the use of cross-market correlation in order to measure or to test for contagion. Since standard correlation measurement is influenced by volatility in market returns, it can provide inaccurate evidence of contagion. Therefore, an adjustment is made to the conditional correlation, which removes or corrects the volatility of returns stemming from the market in which the crisis is generated.

This section describes the theoretical model that is utilized to test for contagion, and how it will be applied to two different types of asset returns; stock returns and government bond returns. A description of the exact procedure followed or the exact methods used to measure contagion in the markets is laid out under 'Methodology'. The last part provides a details to the various pre-and post estimation tests performed on the data, especially focused towards vector autoregression model.

4.1 Theoretical Model

Foundation for the quantitative analysis is the model presented by two economists attached to the Massachusetts Institute of Technology, Kristin J. Forbes and Roberto Rigobon. Their paper 'No Contagion, Only interdependence; Measuring Stock Market Comovements' published in The Journal of Finance (Vol.LVII,No.5;October 2002) examines whether actual contagion has taken place in three significant financial crises during the last three decades. This section will discuss the findings of the article, along with the model extracted from it to be used in this thesis.

As laid out in Section One, Forbes and Rigobon utilize *'a significant increase in cross-market linkages after a shock to one country (or a group of countries)*' as the definition of contagion. There are certain empirical advantages in using such a definition, because it helps to narrow the area of study and focus it on a simple test for contagion. Out of different methods of measuring cross-market linkages, emphasis here is to test for contagion by evaluating the correlation in asset returns.

When there is a shock in one market, the cross-market linkages can increase and it can easily be identified as contagion. But it is important to look deeper into the relationship that exists between the two countries. If the two countries or two markets display a high degree of comovement during the relatively stable time period, an increase in cross-market linkages after a shock can just be a continuation of the same high level of relationship (refer the example of U.S. and Canada, pg. 21). Forbes and Rigobon use the term *'interdependence'* describe the situation of an increase in cross-market correlations after a shock between two market that have strong linkages in *all* states of the world.

The general method of testing for contagion using correlation is to first estimate the cross-market correlation during the stable period and then compare it to the same estimate *after* a shock in one market. Afterwards, it is tested if the increase in correlation coefficients are significant. If the increase is significant, it is taken as an indication that the transmission mechanisms between the two markets have increased and therefore contagion has occurred. Few example are given for the various studies that have utilized this method, and most of them have found evidence of contagion in connection with several major crises.

The two authors argue that using the standard method of estimating the cross-market correlation is biased, giving an inaccurate interpretation of contagion. The standard definition of correlation, which is the Pearson's Correlation coefficient, is given below;

$$\boldsymbol{\rho} = \frac{\boldsymbol{covarinace_{x,y}}}{\boldsymbol{\sigma_x \sigma_y}} \qquad \text{(Equation 01)}$$

where $\boldsymbol{x}$ represents the returns of the market in which the crisis or shock is triggered and $\boldsymbol{y}$ represents the returns from the second market under consideration. This equation can be also be written as;

$$\boldsymbol{\rho} = \boldsymbol{\beta}\frac{\boldsymbol{\sigma_x}}{\boldsymbol{\sigma_y}} \qquad \text{(Equation 02)}$$

Using examples, the equations above are used to show how the correlation coefficient(ρ) is *conditional* on the variance (or the standard deviation σ) of market returns; specifically that of the market in which the shock is generated. As a result, the standard or the *conditional cross-market correlation* increases when the market volatility increases, even though the actual linkages (represented by β in Equation 02) stays constant. This volatility in market return is identified as the *heteroskedasticity bias*, which renders the correlation coefficient inaccurate and biased upwards. An increase in cross-market correlation can be due to a strengthening of cross-market linkages and /or due to market volatility. Therefore, in order to properly interpret whether there is actual contagion , cross-market correlations must first be adjusted for the heteroskedasticity in market returns.

The correction of the bias using the factor of δ, is one of the most important aspects of the theoretical framework discussed in the paper. It is simply the relative increase in the variance of market returns *x* from the stable period to the period after a crisis, noted as;

$$\delta = \frac{\text{variance}_{\text{x}}^{\text{crisis}}}{\text{varaince}_{\text{x}}^{\text{stable}}} - 1 \qquad \text{(Equation 03)}$$

Using formal proof for justification, Forbes and Rigobon provides a formula for the conditional correlation as ;

$$\rho * = \rho\sqrt{\frac{1+\delta}{1+\delta\rho^2}} \qquad \text{(Equation 04)}$$

where ρ* is the conditional correlation coefficient and ρ is the unconditional correlation coefficient.

A simple algebraic rearrangement of equations 03 and 04 yields the unconditional correlation coefficient to be written as;

$$\rho = \frac{\rho^*}{\sqrt{1+\delta[1-(\rho^*)^2]}} \qquad \text{(Equation 05)}$$

Applying the models or the equations presented above, Forbes and Rigobon carry out tests for contagion on three major financial crises. From the data derived from stock markets of a wide sample of countries, they study the 1997 Asian Crisis, 1994 Mexican devaluation and the 1987 U.S. market crash. Both the conditional and unconditional correlation coefficients are calculated for each crisis and it is tested if the increase in correlations after a shock is significant by using a one-sided t-test. It is found that while applying the conditional correlation, many countries show evidence of contagion; and after correcting for the bias of market volatility, hardly any evidence of contagion was shown.

The quantification and adjustment for the heteroskedasticity bias has its validation based on two assumptions; absence of omitted variables and no endogeneity between markets. In other words, it is assumed that there are no exogenous global shocks and there aren't any exogenous feedback from stock market *y* to stock market *x*. As discussed under the literature review on contagion, random or aggregate global shocks like a contraction in the international supply of capital or a decline of global demand for commodities, can cause cross-market correlation between markets to increase after an economic shock. Therefore, such a change to the fundamental linkages between countries are assumed to be non-existent. Further analysis of impact of relaxing these two assumptions is presented in the article under discussion.

An important requirement in carrying out tests for contagion using the above theoretical model is that certain criteria for validation or *near identification* has to be fulfilled. First, it should be possible to clearly identify from which country the shock has been generated. In other words, which country has triggered the shift in market volatility. Secondly, the shift or the increase in market volatility should be large. And finally, the relevant country or the crisis country should be included as one market in the estimation of correlations.

4.2 Approach to the Problem

The main problem of the thesis, as laid out in Section one, is to identify whether contagion occurred during the financial crisis of 2007-2008. To be more specific, the study will concentrate whether contagion occurred in the stock market and government bonds market during the financial crisis. Theoretical model explained above will be applied to both markets, and thereby the adopted measurement method of contagion is the cross-market correlation in stock market returns and government bond market returns.

First, it is important to ascertain whether three prerequisites for the validation of the model, or the near identification criteria can be fulfilled. The most important requirement is a clear identification of the market/country in which the shock was generated or the crisis began. From the details in Section Three, it is fairly obvious that the subprime mortgage crisis in the U.S. was the catalyst of the financial crisis of 2007-2008. Therefore, the United States is defined as the market in which the crisis was triggered, and contributed towards market volatility. The second criteria is that the shift in market volatility should be substantial. This fact can be observed in most of the datasets, which will be discussed in coming sections. The final requirement is crisis country should be included as an integral part of the correlation calculations. It means that the thesis will evaluate the contagious effects from the U.S. to each of the countries in the selected sample.

The approach to the problem have several steps. First, the conditional(standard) correlation coefficient is estimated for each pair of countries in the sample as per Equation 01. The U.S. will be the fixed element in every single pair of countries evaluated. Correlation is estimated between returns for the specific market(stock or government bonds), for each pair of countries, for three specified periods. A test of significance is then carried out on each of the cross-market correlation coefficients to evaluate if the change in correlations between the periods (as specified in the hypothesis) is significant. If it is, there is evidence of contagion.

An assessment is then carried out on the heteroskedastic bias, created by the volatility in returns within the markets of the U.S. Having estimated the adjustment factor for this bias using Equation 03, the unconditional cross-market correlation is calculated in the same procedure as the conditional correlation. A test of significance is carried out in order to determine if contagion has taken place.

4.3 Methodology Of Statistical Analysis

Different techniques or methods have been chosen to implement the above approach, which are: a vector autoregression (VAR) method, a simple bivariate analysis and a multiple variable regression or analysis. With regard to application in the stock market, all three techniques are used, while in the government bonds market, a bivariate analysis is not carried out.

4.3.1 VAR Analysis

The vector autoregression (VAR) method has more emphasis in the quantitative analysis. Considering that it is a model which became more popular in the last three decades, special attention has been given to explore many elements connected to a VAR analysis.

According to the methodology adopted by Forbes and Rigobon, a VAR analysis is carried out to obtain a variance-covariance matrix. Afterwards, this matrix is used to calculate the cross-market correlation coefficients between each pair of countries for the three different time periods. The same technique is adopted in this quantitative study, where a regression based analysis of the data is performed using a VAR (vector autoregression) framework. It was elected to have five lags within the regression and therefore all the lagged values of the market returns in U.S. and the other country in a pair are considered as the regressors. VAR is performed for *each dataset* (where U.S. is the fixed element in each pair) for *each of the three periods* (stable, crisis and full) specified in the following sections. A *variance-covariance matrix* is then derived from each of the regressions, and this matrix provides the variance of each coefficient estimate (of each regressor) and the covariance between them.

These parameters are then used to calculate the conditional cross-market correlations, the adjustment factor and then the unconditional cross-market correlation. Since market volatility is caused by the crisis generated in the U.S., the adjustment factor (Equation 03) or the correction to the standard correlation coefficient is estimated using the variance of returns in the U.S stock/government bond market. It is important to remember that the correlation is calculated between the *coefficients* of each regressors and not for each variable directly. An inference is drawn about the behaviour of the variables through the interactions and the standard error of the coefficient estimates.

Once cross-market correlations (both conditional and unconditional) are calculated, each one of them are tested for significance. The hypothesis formulated to test for significance is to compare the correlation coefficient during the crisis period with that of the full period. More specifically, the test hypothesis is;

$$H_0 : \rho > \rho_t^h$$

$$H_1 : \rho \leq \rho_t^h$$

If the z-statistic is higher in absolute value to the critical value of 1.65 at 5% significant level, the null hypothesis is rejected and it is considered as statistical evidence that contagion have taken place.

Treatment of interest rates

Interest rates have been included in the above regression in order to control for aggregate shocks in the market as well as any monetary policy coordination. Even though it is not by far a perfect measure, interest rates can be used as a reasonable proxy to any global shifts in real economic variables and/or policies that affect stock market performance. Therefore, the three-month interbank rates for each pair of countries has been utilized as exogenous variables[9] in a VAR analysis(E.g. in the analysis between U.K. and U.S., interbank interest rates of these two countries are included in the regression as exogenous variables). The possibility of including interest rates as endogenous variables was considered. But a trial analysis rendered the VAR estimations complicated and the results did not deviate significantly from those obtained by including interest rates as exogenous variable.

Tools needed for the quantitative analysis

Given the magnitude of data as well as the requirement to run vector autoregression analyses for several pairs of countries for different time periods, it was a formidable task to carry out individual regressions. Data was gathered, transformed and mined using the Excel software, but it was not a sufficient tool to run advanced regressions such as VAR. Therefore, it became a necessity to learn the basic operations of the statistical software program STATA. The command-based statistical software was utilized to carry out VAR analysis as well as the bivariate and multiple regressor analysis. Pre- and post-estimation tests which are discussed in length later in this section were also performed using STATA.

[9] An exogenous variable is independent from the states of the other variables in the model.

4.3.2 Bivariate and multiple regression models

As a control measurement or for sensitivity testing, a simple bivariate analysis was also carried out to test for contagion using cross-market correlation. Unlike the VAR analysis, the variance will be observed for each variable and the covariance between the variables are used to arrive at the correlation. The equation;

$$\boldsymbol{Y_t = \alpha + X_t + u_t}$$

is used, where X_t or the independent variable is U.S. stock market returns while Y_t or the dependent variable is the stock market returns in the other country in a specific pair of countries. Similar to the VAR analysis, the conditional and unconditional correlation coefficients (for each pair of countries and for each of the three periods) were calculated and subsequently tested for significance using the z-statistic.

With regard to the analysis carried out in the stock markets, the bivariate equation is then extended to include all the lagged values of the two variables as predictors. This multiple regressor model is essentially the first part of the VAR equation, only with the analysis using the covariance between the variables themselves instead of the coefficient estimates of the variables. Such an analysis was carried out to ascertain there will be a significant impact on the test results. The similar procedure as the bivariate analysis is carried out, sans the extensive pre-and-post estimation tests in the VAR model.

A similar multiple regression analysis is carried out on the government bond market, with the bonds returns in the second country as the dependent variable, and bond returns in the U.S. as well as the three-months interbank lending rates(for both countries in a pair) are taken to be the independent variables. Conditional and unconditional correlations are separately estimated and tested for significance to determine whether contagion has taken place in the government bonds market.

Hypothesis testing

As mentioned above, the simple calculation of cross-market correlations and observation of its increase after a shock is insufficient when determining whether contagion has occurred. Once a crisis is generated in one market, the asset returns react to such a situation, obvious through market volatility. When the variance of returns increase so does the correlation coefficient between the two markets under consideration. What constitutes contagion is a 'significant' increase between cross-market linkages when a crisis occurs.

The test hypothesis to test for significance is;

$H_0 : \rho > \rho_t^h$

$H_1 : \rho \leq \rho_t^h$

where ρ is the correlation coefficient during the full period, and ρ_t^h is the correlation figure during the crisis period. An application of the simple one sided t-test was problematic and therefore it was necessary to formulate a method to quantify this 'significance'. Thus, the Fisher's Z-transformation is used to compare two correlation coefficients and to determine the significance level. This method converts the standard Pearson's correlation coefficient in to a normally distributed variable 'z'.

$$\text{z-statistic} = \frac{z_0 - z_1}{\sigma_{z0} - \sigma_{z1}}$$

where z_0 and z_1 are the transformed values of the two correlation coefficients using the Fisher z-transformation method. For an example, z_0 is estimated using the equation ;

$$z_0 = \frac{1}{2} ln \frac{1+\rho}{1-\rho}$$

where it has a known standard error of;

$$\sigma(z_0) = \sqrt{\frac{1}{n_0 - 3}}$$

and n_0 is the number of observations in related correlation calculation. The one -sided z-statistic is then compared with the critical value of the 5% significance level which is 1.65.

4.4 Key Concepts

Vector Autoregression

Vector autoregression (VAR) was first introduced to economics by the econometrician and macro-economist Christopher Sims in 1980. This model of analysis proved to be one of the most successful, flexible and easy to use models of multivariate time series analysis. It is a natural extension of the univariate autoregressive model to dynamic multivariate time series. VARs is successfully used for forecasting as well as for analyzing causal relationships among economic and financial time series variables. There are three types of VARs; reduced-form VARs, recursive VARs and structural VARs (SVAR).

A vector autoregression with two time series variables, Y_t and X_t consists of two equations: In one, the dependent variable is Y_t and in the other equations, the dependent variable is X_t. The regressors in both equations are lagged values of both variables. A VAR extends the univariate autoregression to a 'vector' of time series variables. When the number of lags in each of the equations is the same and is equal to p, the system of equations is called a VAR(p). For an example, in the case of two time series variables Y_t and X_t, with two lagged values for each variable, the VAR(2) consists of the two equations;

$$\boldsymbol{Y_t = \beta_{10} + \beta_{11}Y_{t-1} + \beta_{12}Y_{t-2} + \gamma_{11}X_{t-1} + \gamma_{12}X_{t-2} + u_{1t}}$$

$$\boldsymbol{X_t = \beta_{20} + \beta_{21}Y_{t-1} + \beta_{22}Y_{t-2} + \gamma_{21}X_{t-1} + \gamma_{22}X_{t-2} + u_{2t}}$$

where the β's and the γ's are unknown coefficients and the u_{1t} and u_{2t} are error terms. As an illustration, considering the pair of countries U.S. and U.K., X_t would be the stock market return in U.S. while Y_t is the returns in U.K

The coefficients of a VAR are obtained by estimating each equation by the OLS (Ordinary Least Squares) method. Under the VAR assumptions, the OLS estimators are consistent and have a normal distribution in large samples. Accordingly, statistical inferences are normal and hypothesis testing including joint hypotheses that involve restrictions across multiple equations, is possible. It is important to ensure that the variables in the analysis are plausibly related to one another, because too many variables having unjustifiable relationships can introduce estimation errors without any predictive content. In the same way, using an appropriate lag length is important for a VAR to be stable and consistent.

Variance-covariance matrix

A variance-covariance matrix (also known as covariance matrix or a dispersion matrix) is a matrix whose element in the i, j position is the covariance between the i th and j th elements of a random vector (that is, of a vector of random variables). In a simple definition, covariance measures the degree to which two variables change or vary together. If the covariance of two random variables (E.g. Xi, Xj) are considered, it can be mathematically represented as ;

$cov(X_i, X_j) = E[(X_i - \mu_i)(X_j - \mu_j)]$

where μ_i is the expected value of X_i and μ_j is the expected value of X_j. This relationship can be further generalized in to a multivariate situation and for estimated coefficients in a regression analysis. In such a variance-covariance matrix, the variance of each parameter estimate (i.e. each $\hat{\beta}$) as well as the covariance between each coefficient is explicitly represented using a matrix notation. The diagonal of the matrix shows the variance of the coefficients estimates, which is the square of the standard errors. The matrix written as;

$$cov(\hat{\beta}) = \begin{vmatrix} var(\hat{\beta}_1) & cov(\hat{\beta}_1, \hat{\beta}_2) & \dots & cov(\hat{\beta}_1, \hat{\beta}_k) \\ cov(\hat{\beta}_2, \hat{\beta}_1) & var(\hat{\beta}_2) & \dots & cov(\hat{\beta}_2, \hat{\beta}_k) \\ \dots & \dots & \dots & \dots \\ cov(\hat{\beta}_k, \hat{\beta}_1) & cov(\hat{\beta}_k, \hat{\beta}_2) & \dots & var(\hat{\beta}_k) \end{vmatrix}$$

is essentially the covariance or variance-covariance matrix.

Heteroskedasticity

In statistics, heteroskedasticity arises when the standard deviations of a variable, monitored over a specific amount of time, are non-constant. Under the presence of heteroskedasticity, OLS estimators remain unbiased. But the standard error and the coefficient variance of the OLS estimators (variance of the coefficients) will be biased. In assets prices such as in stocks and bonds, conditional heteroskedasticity is visible, indicating that market volatility(giving rise to non-constant variances) causes the correlation coefficient to be bias.

4. 5 Pre-and-Post Estimation Tests

Tests described in this subsection were performed to ensure stationarity of data, to assess ways of filtering data as well as any exclusion of results and many other stability factors. Performance of these tests has largely attempted to ensure that the results derived from vector autoregression method were subject to rigorous validation and to prevent any statistical shortcomings.

4.5.1 Data transformation and testing for unit root

In the analysis of time series data, it is important to investigate the stationarity of the data. A strict definition of stationarity is that it is a stochastic process whose joint probability distribution does not change when shifted in time, displaying a constant mean and variance in addition. Since the practical application of this definition is difficult, a 'weaker' definition of stationarity is adopted when time series data is used for empirical studies.

It is important to identify if the data or the regressors of the regression contains a stochastic trend, since a stochastic trend indicates **a unit root** is present in the data. This can cause the ordinary-least squares(OLS) estimators the t-statistic to have a nonstandard distribution. Therefore, a unit root test using an autoregressive model is carried out to assess whether the time series variable is non-stationary. One of the well known unit root test is the **augmented Dickey-Fuller (ADF) test**, used for larger and more complicated sets of time series models as opposed to the **Dickey-Fuller test**. The null hypothesis of a unit root presence is tested, and it will be rejected if the negative ADF test statistic is more negative compared to different levels of confidence.

Since it is important that the time series data used in a vector autoregression analysis be stationary, the data used in the quantitative study has been transformed to the first difference of the returns' natural logarithm. Afterwards, the **augmented Dickey-Fuller (ADF) test** was run for every single data set to ensure there is no unit root in the data and that it is stationary. Figure 08 displays the unit root test conducted for the (transformed) stock market returns in United Kingdom for the full period under consideration. Since the test statistic is negative 19.278 and much lower than the statistics in the main three levels of significance, the null hypothesis of a unit root can be rejected and the data can deemed to be stationary.

Figure 8 : The Augmented Dickey Full test for the stock market returns of U.K. (Period 1 January 2005 to 31 March 2009)

```
. dfuller fdLNrUK, trend lags(10)

Augmented Dickey-Fuller test for unit root         Number of obs   =      1539

                                 ---------- Interpolated Dickey-Fuller ----------
                 Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)           -19.278           -3.960            -3.410            -3.120
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0000
```

4.5.2 Selection of the appropriate lag length

A vital step in conducting a VAR analysis is that the regression has an appropriate number of lags. A lagged value is simply a later point of time in a time series; if *t* is the present date, then the lag of one would be *t-1*,which would be yesterday. Too many lags can increase estimation uncertainty, while too little can affect the estimation accuracy due to valuable information being lost. There are various tests used to identify the number of lags, most of which are included in the STATA software. According to the magnitude of data, a recommendation of the lag number is given using approaches such as;

- the log of the likelihood function**(LL)**
- A likelihood-ratio test statistic followed by it degrees of freedom and p-value **(LR, df and p)**
- Four information criteria tests of **FPE**(Akaike's final prediction error), **AIC** (Akaike's information criterion), **HQIC** (Hannan and Quinn's information criterion) and **SBIC** (Schwarz's Bayesian information criterion)

Figure 09 shows appropriate lag length selected by the different methods or tests. The test was performed on the (transformed) stock market returns in United Kingdom for the full period under consideration. A star('*') indicates the recommended number of lags according to the magnitude of data.

Figure 9: Lag selection test for the VAR analysis between stock market returns of U.K. and U.S. (Period 1 January 2005 to 31 March 2009)

```
. varsoc fdrUK fdrUSA, maxlag(15) exog(fdintUSA fdintUK)

   Selection-order criteria
   Sample:  1/17/2005 - 3/31/2009                  Number of obs      =      1535
```

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	10117.5				6.5e-09	-13.1745	-13.1668	-13.1537
1	10299	363.04	4	0.000	5.2e-09	-13.4058	-13.3929	-13.3711
2	10645.9	693.89	4	0.000	3.3e-09	-13.8527	-13.8346	-13.804
3	10730.7	169.53	4	0.000	3.0e-09	-13.9579	-13.9346	-13.8953
4	10959	456.66	4	0.000	2.2e-09	-14.2502	-14.2217	-14.1737
5	10981.6	45.133	4	0.000	2.2e-09	-14.2744	-14.2407	-14.184
6	11066	168.88	4	0.000	2.0e-09	-14.3792	-14.3404	-14.2749
7	11113.1	94.142	4	0.000	1.8e-09	-14.4353	-14.3913	-14.3171
8	11169.8	113.31	4	0.000	1.7e-09	-14.5039	-14.4548	-14.3718
9	11216	92.438	4	0.000	1.6e-09	-14.5589	-14.5046	-14.4129
10	11252.7	73.388	4	0.000	1.6e-09	-14.6015	-14.542	-14.4416
11	11264.2	22.968	4	0.000	1.5e-09	-14.6113	-14.5466	-14.4375
12	11288.8	49.283	4	0.000	1.5e-09	-14.6382	-14.5683	-14.4504
13	11301.2	24.871	4	0.000	1.5e-09	-14.6492	-14.5741	-14.4475
14	11344.5	86.603*	4	0.000	1.4e-09*	-14.7004*	-14.6202*	-14.4848*
15	11347.9	6.6616	4	0.155	1.4e-09	-14.6995	-14.6141	-14.47

```
   Endogenous:  fdrUK fdrUSA
    Exogenous:  fdintUSA fdintUK  _cons
```

The results from the tests indicate that the most appropriate number of lags to be included in the vector autoregression is 14 or more. Such a high number of lag can render the regression analysis too complicated and cause a high estimation error. Since lags are used control for serial correlation and control for any variation in trading patterns during a five day trading week, it was ultimately decided to use *five lags* for each variable in the VAR method as well as the multiple regression analysis (for stock markets).

4.5.3 Granger Causality Test

The sheer amount of quantitative analysis from the VAR was overwhelming and it became a necessity to explore possible ways to exclude certain results and to filter the data. One way was to apply the Granger causality test on the regressors and to find out if the variables Granger cause one another other. The Granger causality test is the test of a null hypothesis that the coefficients on all the values of a variable (E.g. x_{t-1} , $x_{t-2,\ldots}$ x_{t-k}) are zero. This null hypothesis implies that these regressors have no predictive content for Y_t beyond that contained in the other regressors (Stock & Watson, 2007).

Certain empirical research use 'Granger causality' to show the result of exclusion tests in a bivariate VAR (e.g. returns of U.S. and returns of Canada) or a multivariate VAR (taking into account all the lagged values of variables defined in the regression. But it should not be used in isolation, more qualitative information or facts should be used in connection with the test to interpret the results (Becketti, 2013).

Figure 10 below shows the results of the Granger causality test , performed on the dataset containing stock market returns from U.S. and the U.K for the full time period. It is tested whether the returns in the U.S. 'Granger causes' returns in the U.K. and vice versa. The p-value shown in the last column can be compared with a significance level of 1%, 5% or 10%.

Figure 10: Granger Causality test for the VAR analysis between stock market returns of U.K. and U.S. (Period 1 January 2005 to 31 March 2009)

```
. vargranger

   Granger causality Wald tests
```

Equation	Excluded	chi2	df	Prob > chi2
fdrUK	fdrUSA	193.95	5	0.000
fdrUK	ALL	193.95	5	0.000
fdrUSA	fdrUK	43.594	5	0.000
fdrUSA	ALL	43.594	5	0.000

It is obvious that the p-value is considerably significant between both causality assumptions, meaning each variable has a certain causality on each other . Therefore this method cannot be justifiably used to filter the number of observation generated from the regression analysis. Therefore, assumption of no endogeneity as stated in the theoretical model is enforced, meaning that there is no feedback from market *y* to market *x*. Given the size and structure of the U.S. economy, it is safe to assume that impact of the market activities of U.S on other countries is much larger compared to the impact from those markets to the U.S. economy.

SECTION FIVE: APPLICATION TO THE STOCK MARKET

Section five provides the details of the quantitative study carried out in order to asses if contagion occurred in the stock markets of sample countries, stemming from the crisis in the U.S. economy. The sample selection and the data used for the statistical analysis are laid out before moving on to the results obtained when testing for contagion in stock market returns.

5.1 The Sample

Even though the financial crisis of 2007-2008 has had an impact on practically every market around the world, it was chosen to narrow the data analysis to a sample of nine countries; the G8 countries and Norway. Considering that the country in which the crisis originated is one member of the G8, it was interesting to see how the crisis would affect its main trade partners.

The G8 or the 'Group of Eight' is an international forum consisting of the world's wealthiest countries. It is made up of the heads of governments from Canada, France, Germany, Italy, Japan, the Russian Federation, the United Kingdom and the United States. At its inception in 1975, the group's original countries consisted of France, Germany, Italy, Japan, United Kingdom and the United States. These countries were later joined by Canada in 1976 and Russia in 1998. The European Union is also represented at meetings by both the president of the European Commission and the leader of the country that has European Union presidency.

U.S. and the European Union members of G8

Before the subprime mortgage crisis, the United States was an active investor in the global share market, where investors held more than $5 million in foreign assets. Their largest investment market was the United Kingdom (accounting for nearly 18 percent of the UK stock capitalization) followed by Germany (15%) and France (12%) (Shirai, 2009). Meanwhile, United Kingdom and Europe were the most active foreign investors when it came to the U.S. stock market as well as the debt securities market. For an example, UK was in the forefront holding $421 billion worth stocks in U.S. as of June 2007. Compared to Asian investors, most of the European investors were risk-takers, investing heavily in corporate and asset-backed securities in the U.S. financial market.

Cross-border banking has also expanded over time , with banks having claims in other banks and its affiliated banks operating abroad as well as in non-bank institutions through loans, corporate bonds, ABs, MBS and CDOs. Banks with American nationality were heavily involved in international banking activity by establishing branches and subsidiaries in the UK and other European markets.

With a background of such intense connectivity between the U.S. and the European G8 members, the impact of the subprime mortgage crisis had an obviously strong repercussions within the group of countries. Many banks saw the immediate deterioration of their assets, resulting in a fast impairment of their capital. For an example, IKB Deutsche Industriebank AG ('IKB) in Germany, who provides credit to small and medium sized companies, became the first European bank to declare financial trouble in July 2007. In 9 August 2007, BNP Paribas, France's largest bank, halted redemptions on three investment funds that held assets backed by U.S. subprime mortgage debt. Overnight interest rates in Europe increased as a direct consequence. The European Central Bank immediately responded with the largest short-term liquidity injection in its 9 year history, with €94.8 billion ($130 billion at the time) worth of overnight repos. And then Northern Rock, the United Kingdom's fifth-largest mortgage lender, fell victim to the first bank run in the United Kingdom in September 2007, even though Bank of England provided liquidity support. Bank write-downs and bankruptcy threatened the financial systems in U.K and European countries due to their exposure to the structured credit assets or structured financial products like asset-backed securities.

U.S. and Japan

Nearly 12% of Japan's stock capitalization consists of U.S. financial products, even though the Japanese investors prefer to follow a relatively conservative role, with more investment in secure low-risk assets offered by the U.S financial market. With regard to banking activities, general data shows that the banks of Japan were not significantly involved in the global intermediation of funds. Therefore, Japan suffered relatively less bank write-downs and loss of financial value compared to its European counterparts in the G8 forum. Factors such as a large pool of household savings(opposed to U.S.'s consumer driven households), dominancy of commercial banks over other financial institutions like investment banks, caution about foreign investment and the absence of a major real estate bubble dampened an acute level of repercussions from the U.S. subprime mortgage crisis.

U.S. and Russia

Russia is not integrated in to the global financial system as the other members of the G8 group. When the crisis began in U.S., the oil-rich nation was confident that they will not be severely affected as most of the other industrialized and developed countries. With a hefty $560 billion in reserves, a GDP of 7 percent during the previous years and a stable Russian ruble, the country did not feel immediate effects of the subprime mortgage crisis in U.S. But a significant drop in world oil prices proved to be a that was the main factor that sent Russian stock markets plunging in 2008. The commodities markets, dominated by automation and metal started to feel the effects of reduced global demand once the financial crisis became more severe. Construction and retails firms were suffering due to their exposure in the credit market. Two major banks were taken over by state-run institutions, which put a heavy stress on the national Stabilization Fund. Still, Russia did not necessarily suffer similar consequences like it's G8 counterparts, thanks to a strong oil production sector and market deregulation to maintain some stability. But it is not by any means a statement that the old World Super power escaped unscathed.

U.S. and Canada

Due to the close geographical proximity between the United States and Canada, they enjoy a healthy relationship through trade and financial links. Canada currently stands as the number one country with whom U.S. trades, with an year to date as at April 20013 trade volume amounting to US$ 209 billion[10]. Therefore it is natural that the domestic crisis in the subprime mortgage market in U.S. is transmitted to Canada through various channels. Recession came relatively late to Canada but nonetheless, it's impact was significant with the credit defaults, unemployment, decline in manufacturing sectors and exports as well as a fall in the GDP. Unlike its European counterparts, Canada seems to be in a better position to weather the storm with a strong banking system, an effective policy response and a relative low debt/GDP ratio (Campbell, 2009).

[10] www.census.gov/foreign-trade/top/dst/current/balance

U.S. and Norway

Although Norway is neither a member in the G8 nor the European Union, it is associated to the group through the membership in European Economic Area. This Scandinavian country was intriguing to many economists over the relatively modest impact the international financial crisis has had on the country's economy.

Before the period of global financial turmoil, Norway experienced a period of economic stability and healthy activity. Low interest rates and low levels of inflation encouraged spending and housing sales were in the rise with the availability of low cost credit. This eventually led to a drastic increase in real estate prices, resulting in a bubble in the real assets sector. A fall of more than 14 percent was recorded between August 2007 to December 2008, until it's recovery in 2009[11]. The stock market bore the brunt of the crisis transmission, with the price index collapsing by nearly 64 percent in six months from May 22nd till November 20th 2008. Even though these events took place, Norway managed to act quickly by implementing a countercyclical policy such as increasing demand through interest rate cuts and expanding the fiscal stimulus. A close regulation of the banking sector, controlling of unemployment and a substantial sovereign fund consisting of oil industry revenue all contributed towards Norway being heralded as the only western industrialized country to survive the financial crisis of 2008 generally unharmed.

[11] Extracted from the discussion paper 'A Chronology of Financial Crises for Norway' by Ola Honningdal Grytten and Arngrim Hunnes (Business School, Department of Economics, May 2010)

5.2. The Data

In order to carry out the quantitative analysis for contagion in the stock market., data for Canada, France, Germany, Italy, Japan, Norway, Russia, U.K. and the U.S. is collected from Datastream. Table 01 shows the stock market index considered for each country.

Table 1: Stock market indices for data extraction

COUNTRY	INDEX	DATASTREAM CODE
Canada	S&P/TSX Composite Index	TTOCOMP(PI)
France	CAC 40 Index	FRCAC40(PI)
Germany	DAX 30 Index	DAXINDX(PI)
Italy	FTSE MIB Index	FTSEMIB(PI)
Japan	Nikkei 225 Index	JAPDOWA(PI)
Norway	OSE All Share Index	OSLOASH
Russia	RTS Index	RSRTSIN(PI)
United Kingdom	FTSE 100 Index	FTSE100(PI)
United States	S&P 500 Composite Index	S&PCOMP(PI)

Data is obtained in a non-synchronized manner, using the closing market price of each index[12]. The daily returns are estimated using the US Dollar value of each stock market index and the stock market's rate of return in country i in day t is calculated as;

$$R_{i,t} = \ln (P_{i,t} / P_{i,t-1})$$

Many economic (time series) data exhibits trends, meaning it tends to grow over the long run, while the standard deviations of many time series is approximately proportional to its level. However, the log of a time series grows linearly and therefore the log of the standard deviation is approximately constant. As explained by the previous section, transforming data into first *difference of the natural logarithm for each variable* greatly reduced the trends and made the data stationary. Furthermore, a two-day moving average is calculated for the

[12] A working paper by Mardi Dungey and Abdullah Yalama (May 2010) tests for contagion based on a non-synchronized dataset of closing market prices and a synchronized dataset for which market prices are extracted on a specific point of time. They find that changing from the non-synchronized to synchronized data does not greatly affect the conclusions of the testing methodology by Forbes and Rigobon.

transformed data to control for the fact that markets in different countries are open during different hours as well as non trading days such as weekends and public holidays[13].

For the quantitative study of the crisis based on cross market correlation, it was necessary to identify the period in which markets showed relatively constant activity. Afterwards, it was important to demarcate the period in which the crisis first began and created volatility in the markets. From timeline of the crisis analysed earlier, it was determined that the period between 1 January 2005 and 30 March 2009 will be the full time period for which data will be gathered. As highlighted in Section 3.2 , the crisis in U.S. first comes to head in June 2007 with the collapse of two highly leveraged hedge funds managed by Bear Stearns. Soon afterwards, the money market dried up in August 2007 creating a liquidity crisis in the global market. Another critical point was the Lehman brother collapse in September 2008, which was often cited as *the event* that sent the financial markets declining. Stock markets show a significant dip during the latter part of 2008 but show a recovery during the first quarter of 2009.

From the events, it is identified that the stable period is to be from 1 January 2005 to 31 May 2007, while the period from 1 June 2007 to 31 March 2009 will be the period of turmoil in the markets(Refer the volatility peaks in the graph from Figure 08). In order to carry out cross-market correlation, daily stock market returns are calculated for each of the three periods defined above (i.e. stable, crisis, full), for each of the eight sets of countries (E.g. US and Canada, US and France, etc.)

Figure 11: S&P 500 Volatility Index for the period 1 January 2005 to 31 March 2009

source: www.yhoo.com/finance

[13] Herewith, the term 'returns' will refer to the transformed data

5.3. Results

5.3.1. Correlation calculation using VAR(5)method

In order to assess if there are contagious effects from the U.S. stock market returns volatility to other stock market in the sample, the first attempt is to use a VAR(5) method. A variance-covariance matrix was generated for each pair of countries (the U.S. is the fixed element in every pair) for each one of the periods (stable, crisis, full). Using the information from the matrix, the cross-correlations (as per the standard definition) between each coefficient estimate was calculated. A sample correlation matrix that has been estimated using a variance -covariance matrix is given in Appendix III.

Filtering of the 351 estimates of correlation coefficients (per matrix) obtained is done by applying the assumption of endogeneity (refer section 4.5.3). The regression where market return *x* is considered the dependent variable will be omitted, and therefore all correlation coefficients related with that particular regression will not be considered for the final analysis (From the matrix attached in Appendix III, the data omitted has been highlighted in gray).

From those selected, cross-market correlations between own lags (E.g. correlation between first lag and second lag of UK returns) were omitted. It is because the focus of the data analysis in is essentially on the correlation between returns of two countries, not within each country. A simple average of all the selected lagged values is adopted to obtain the single parameter figures (E.g. variance of market return *x* and market return *y*) and the single conditional correlation coefficient between each pair of countries for each different period. The variance of each coefficient estimate is calculated as the square of standard error and a simple average is taken of all the lagged values' standard error figures.

Finally, the Fisher's 'z' transformation test for significance is applied for each figure of correlation coefficient and compared with the critical value of 1.65 to ascertain whether there was contagion or not. It should be emphasized again that all the calculations using this model has been done using the parameters of *coefficient estimates* of the regressors. An inference is drawn from the relationship between these beta coefficients as to how the actual variables or the market returns behave.

These steps are first followed in the calculation of conditional cross-market correlations for each of the three periods described. Table 02 displays the results of this initial VAR model application for the sample data on stock market returns.

Table 2: **Test for contagion in stock markets: VAR(5) model**
Conditional cross-market correlation coefficients and variance for the U.S. and each country in the sample is reported. 'C' indicates contagion and 'N' indicates no contagion

Country	Stable		Turmoil		Full		*z-stat*	*C or N*
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
United States	0.00396		0.00305		0.00140			
Canada	0.00158	-0.22	0.00289	-0.30	0.00118	-0.29	-0.33	N
France	0.00147	-0.29	0.00228	-0.37	0.00095	-0.36	-0.29	N
Germany	0.00150	-0.29	0.00240	-0.35	0.00100	-0.34	-0.24	N
Italy	0.00145	-0.27	0.00209	-0.32	0.00089	-0.31	-0.08	N
Japan	0.00112	-0.11	0.00130	-0.15	0.00059	-0.14	-0.28	N
Norway	0.00121	-0.15	0.00184	-0.24	0.00077	-0.23	-0.36	N
Russia	0.00116	-0.10	0.00165	-0.18	0.00070	-0.17	-0.32	N
United Kingdom	0.00139	-0.28	0.00235	-0.38	0.00097	-0.36	-0.32	N

Several observations can be seen from the table above. France, Germany and the United Kingdom are highly correlated with the U.S. during the relatively stable period. This is not surprising since these countries share close trade and financial links, with each country being a powerful market in the global financial system. Lowest correlation with the U.S. stock market is displayed by Japan and Russia, with correlation coefficients of 0.11 and 0.10 respectively. Yet again, it is a clear inference for the actual relations between the countries, since both Japan and Russia have relatively conventional/restricted financial structures and linkages with U.S. economy when compared to the other countries in the sample.

Another observation is that the conditional correlation coefficients for each country, along with the variances of returns, increases directly after the shock in the U.S. market. For an example, the variance of return in Canada increases by 84% from the stable period to crisis period. This increase in correlation is a pre-requisite for contagion, which is exhibited by every country in the sample.

The final and important observation is that once the test of significance is carried out for the increase in cross-market conditional correlations, it is not a statistically significant change to be judged as contagion. All the z-statistics are well below the one-sided critical value of 1.65

at 5% significant value. Therefore, the clear result is that after testing the conditional cross-market correlation, there is no evidence of contagion in any of the pairs of countries.

As mentioned in several places, a key concept of the theoretical model is that the standard correlation coefficient is inaccurate and biased due to heteroskedasticity in market returns. More specifically, the relative increase in variance of market returns of the country in which the crisis is triggered, cause the corresponding conditional correlation to be biased upwards. It means that the increase in correlation coefficients after the manifestation of a shock can simply be caused by an increase in market volatility, and such a situation does not qualify as contagion.

A correction to the bias is estimated for each correlation coefficient, leading to the calculation of the *unconditional cross-market correlation*. Table 03 displays the results for the calculated unconditional correlation coefficients as well as the significance of each increase between periods.

Table 3: **Test for contagion in stock market: VAR(5) model**
Unconditional cross-market correlation coefficients and variance for the U.S. and each country in the sample is reported. 'C' indicates contagion and 'N' indicates no contagion

Country	Stable		Turmoil		Full		*z-stat*	*C or N*
	σ^2	ρ	σ^2	P	σ^2	ρ		
United States	0.00396		0.00305		0.00140			
Canada	0.00158	-0.22	0.00289	-0.39	0.00118	-0.29	-2.41	C
France	0.00147	-0.29	0.00228	-0.47	0.00095	-0.36	-2.90	C
Germany	0.00150	-0.29	0.00240	-0.45	0.00100	-0.34	-2.71	C
Italy	0.00145	-0.27	0.00209	-0.40	0.00089	-0.31	-2.26	C
Japan	0.00112	-0.11	0.00130	-0.20	0.00059	-0.14	-1.28	N
Norway	0.00121	-0.15	0.00184	-0.31	0.00077	-0.23	-1.98	C
Russia	0.00116	-0.10	0.00165	-0.23	0.00070	-0.17	-1.50	N
United Kingdom	0.00139	-0.28	0.00235	-0.48	0.00097	-0.36	-3.01	C

The observations from the table above show a drastic change when compared to the previous calculations. For one matter, after the bias for heteroskedasticity (or the impact of market volatility generated by the U.S.) has been corrected, the crisis period *unconditional* correlation has actually *increased* when compared to the same figure under conditional correlation calculations. Therefore, the change in the correlation coefficient from the stable to crisis

period has become more pronounced. After the z-statistic is calculated using the Fisher's z transformation method, it is compared with the critical value of 1.65.

The test for significance gives the verdict of contagion in all countries, *except* for Japan and Russia. This point can be justified in some way according to the brief qualitative analysis of the sample countries in Section 5.1. Japan and Russia were able to contain the more devastating effects of the global financial crisis which was generated by the Subprime mortgage crisis in the U.S. and the fact that these two countries have different financial and political structure would have attributed to it. In comparison, United Kingdom who has very close financial ties with the U.S. seemed to have been severely affected, according to the highly significant z-statistic. Therefore, the estimation of the unconditional cross-market correlation using the vector autoregression framework, goes on to find evidence of contagion during the recent global financial meltdown. This is even after the correlation factor has been adjusted for the heteroskedasticity in market returns.

5.3.1.1.Using significant coefficients in the VAR model

In a regression analysis, a general assessment of the importance of each variable in the regression is done using the p-value of the coefficient estimates. If it is less than 0.01, 0.05 or even 0.10, then the coefficient is said to be significant, indicating that the inclusion of the relevant variable can improve the overall regression[14]. Applying the same concept to the VAR analysis, a simple change was made to the estimation technique. Instead of taking an average of *all* the lagged values when estimating variances and covariance, the significant coefficients (of the regression) were identified and an average is taken between those selected lagged values, and their parameters such as variance and covariance. Therefore, the correlation coefficient is estimated using data only from the significant coefficients, not all the coefficients. Other than this minor change, all other filtering assumptions are held constant. Table 04 displays the results of calculating the conditional correlation using the average from significant coefficients instead of the average of all the coefficients under analysis.

[14] A sample regression analysis using VAR(5) method is attached in Appendix IV.

Table 4: **Test for contagion in stock market: VAR(5) model with significant coefficients**
Conditional cross-market correlation coefficients and variance for the U.S. and each country in the sample is reported. 'C' indicates contagion and 'N' indicates no contagion

Country	Stable		Turmoil		Full		*z-stat*	*C or N*
	σ^2	ρ	σ^2	P	σ^2	ρ		
United States	0.00406		0.00313		0.00143			
Canada	0.00142	-0.16	0.00295	-0.32	0.00120	-0.31	-0.35	N
France	0.00151	-0.31	0.00237	-0.40	0.00099	-0.38	-0.32	N
Germany	0.00154	-0.31	0.00247	-0.36	0.00103	-0.36	-0.00	N
Italy	0.00148	-0.29	0.00190	-0.31	0.00081	-0.30	-0.09	N
Japan	0.00115	-0.11	0.00136	-0.19	0.00061	-0.18	-0.34	N
Norway	0.00110	-0.15	0.00163	-0.17	0.00071	-0.23	1.28	N
Russia	0.00105	-0.08	0.00152	-0.12	0.00072	-0.15	0.60	N
United Kingdom	0.00143	-0.30	0.00246	-0.41	0.00101	-0.39	-0.35	N

Similar to the initial analysis, UK, France and Germany shows the highest cross-market correlation during both stable and crisis periods, with Japan and Russia having the lowest during the period of relative stability. The cross-market correlations as per the standard definition ,does not display any drastic changes, though there *are* difference, when comparing these findings with that of the previous VAR estimations. For an example, the crisis period correlation in France using average of all regressors is 0.37. The same figure using the average of the significant regressors has increase to 0.40. With regard to Norway, the correlation using the simple average is 0.24 while the comparable figure using the averages of significant regressors yields 0.17. But, yet again the test for significance for the change in conditional cross-market correlation does *not* show positive results of contagion.

The heteroskedastic bias created by market volatility is quantified using the variance of market returns *x*. The variance of the significant coefficient estimates are used to calculate the adjustment factor and then the conditional correlation is corrected to arrive at the unconditional correlation coefficient.

Table 5: Test for contagion in stock market: VAR(5) analysis with significant coefficients
Unconditional cross-market correlation coefficients and variance for the U.S. and each country in the sample is reported. 'C' indicates contagion and 'N' indicates no contagion

Country	Stable		Turmoil		Full		*z-stat*	*C or N*
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
United States	0.00406		0.00313		0.00143			
Canada	0.00142	-0.16	0.00295	-0.36	0.00120	-0.31	-1.31	N
France	0.00151	-0.31	0.00237	-0.44	0.00099	-0.38	-1.49	N
Germany	0.00154	-0.31	0.00247	-0.41	0.00103	-0.36	-1.08	N
Italy	0.00148	-0.29	0.00190	-0.34	0.00081	-0.30	-1.00	N
Japan	0.00115	-0.11	0.00136	-0.22	0.00061	-0.18	-0.92	N
Norway	0.00110	-0.15	0.00163	-0.20	0.00071	-0.23	0.77	N
Russia	0.00105	-0.08	0.00152	-0.13	0.00072	-0.15	0.25	N
United Kingdom	0.00143	-0.30	0.00246	-0.45	0.00101	-0.39	-1.56	N

From the table shown above, it can be observed that adjusting for market volatility actually increases the cross-market correlation directly after a crisis. The same phenomenon was observed in the previous calculations under the VAR framework. An interesting fact is that the absolute value of all the z-statistics have increased, except for Norway and Russia. But this increase is not substantial enough indicate contagion between the market returns of the U.S. and each of the other countries.

5.3.1.2.Summary of VAR results

Through the VAR(5) analysis, inferences were drawn about the regressors using the coefficient estimates, their parameters and relationships. Two types of estimation techniques, using the average between all the coefficient estimates and the average of the significant coefficient estimates were applied. Both techniques gave no statistical evidence for contagion as per the standard conditional correlation calculations. Only the technique where the average of all coefficient estimates was considered, gave statistical evidence that contagion occurred in six countries out of the sample. Selecting the significant coefficients still gave the verdict of no contagion for all the countries, even though the absolute value of z-statistics were considerably higher in all countries except Norway and Russia.

A certain debatable point raised by the VAR(5) model is that the variance of stock market returns in the U.S. shows a *downturn* directly after the shock is manifested in the market. This causes the unconditional cross-market correlation during the crisis period to be higher than the corresponding figure under conditional correlation calculations, whereas it should have been lowers according to the calculations of Forbes and Rigobon.

Such a situation is quite unusual as the general tendency it that the returns (time series data) deviates significantly away from the mean when there is turbulence in the market. The one reason for such an anomaly can be due to an estimation discrepancy, since the variance of U.S. returns fluctuated according to the different dataset as per the estimation method. A certain amount of conflict can be caused due to drawing an inference from the standard error of each coefficient estimate, instead of the variance between the actual returns,

5.3.2 Correlation calculation using a bivariate model

Due to some inconsistencies seen in the VAR method, a further investigation of data was carried out using a different framework. A simple bivariate analysis is performed using the returns in United States stock market as the independent variable and the returns from the other country as the dependent variable. The correlation calculated is between the variables themselves, instead of using the beta coefficient parameters as per the VAR framework. Since there are no lagged values to be considered, the calculation of the conditional or the standard correlation coefficient is straightforward. The following tables showcase the results, along with the z-statistics to assess the significance of the shift in correlation coefficients.

Table 6: Test for contagion in stock market: Bivariate analysis
Conditional cross-market correlation coefficients and variance for the U.S. and each country in the sample is reported. 'C' indicates contagion and 'N' indicates no contagion

Country	Stable		Turmoil		Full		*z-stat*	*C or N*
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00001		0.00018		0.00008			
Canada	0.00003	0.50	0.00024	0.68	0.00012	0.66	0.93	N
France	0.00003	0.43	0.00023	0.55	0.00011	0.53	0.48	N
Germany	0.00003	0.43	0.00019	0.58	0.00010	0.55	0.75	N
Italy	0.00003	0.38	0.00022	0.49	0.00011	0.48	0.39	N
Japan	0.00005	0.04	0.00017	-0.03	0.00010	-0.02	-0.27	N
Norway	0.00008	0.18	0.00036	0.44	0.00020	0.39	1.15	N
Russia	0.00009	0.15	0.00039	0.25	0.00022	0.22	0.46	N
United Kingdom	0.00002	0.38	0.00021	0.55	0.00010	0.53	0.58	N

From the table it can be seen that the standard correlation between Canada, France, Germany and United Kingdom is high during the period of relative stability in stock markets. Japan has the lowest correlation with the stock markets in the U.S. at 0.04. The variance of returns in all the countries increase after a shock , U.S reporting an increase of more than 11 times, U.K by 8.5 times and Italy by 7.26 times. As a result, the correlation coefficient have increased as well, except in Japan. Correlation between Japan and the United States actually *decrease* by 181%, indicating that the crisis generated in the US Subprime mortgage market did not immediately create downturn in the Japanese stock markets. The fluctuations in correlation estimates are not sufficient enough to validate contagion, since the null hypothesis cannot be rejected at the 5% significant level.

It should be kept in mind that an increase in correlation can be due only to market volatility, and such an event foes not constitute contagion. Therefore, the bias created by market volatility should be removed for a better analysis. An adjustment factor denoting the relative increase in activity within the market where the shock is generated, is used to recalculate the correlation coefficient. Table 07 presents the corrected, unconditional correlation between countries as well the test for significance.

Table 7: Test for contagion in stock market: Bivariate analysis
Unconditional cross-market correlation coefficients and variance for the U.S. and each country in the sample is reported. 'C' indicates contagion and 'N' indicates no contagion

Country	Stable		Turmoil		Full		*z-stat*	*C or N*
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00001		0.00018		0.00008			
Canada	0.00003	0.50	0.00024	0.26	0.00012	0.66	-11.34	C
France	0.00003	0.43	0.00023	0.18	0.00011	0.53	-8.74	C
Germany	0.00003	0.43	0.00019	0.20	0.00010	0.55	-9.12	C
Italy	0.00003	0.38	0.00022	0.16	0.00011	0.48	-7.74	C
Japan	0.00005	0.04	0.00017	-0.01	0.00010	-0.02	0.24	N
Norway	0.00008	0.18	0.00036	0.14	0.00020	0.39	-5.95	C
Russia	0.00009	0.15	0.00039	0.07	0.00022	0.22	-3.38	C
United Kingdom	0.00002	0.38	0.00021	0.18	0.00010	0.53	-8.65	C

Recalculation of the correlations after correcting for the heteroskedasticity bias show very strong results. The one sided z-statistic is high for every single pair of countries, except between Japan and the U.S., inferring that the recent financial crisis has a significant enough impact to have contagious effects. Again, countries with whom the United States have strong financial links like Canada, Germany and the U.K. show the highest z-statistics with -11.34, -9.12 and -8.65 respectively. The variance of market returns in the United States after the manifestation of a shock was a staggering 11. 22 times more that the variance during periods of relative market stability. Adjusting the crisis correlation estimates for this increase in variances has caused unconditional correlation coefficient for the crisis period to decline drastically, compared to the conditional crisis period correlation estimates. But the correlation between returns for the total period under consideration has remained high, and it has resulted in a high z-statistics between the countries to constitute contagion. Only in the case of Japan is it possible to accept the null hypothesis, because the changes in correlation is not statistically significant. A factual study of the economy of Japan during the period of 2007-2008 indicates that the stocks markets did not show such a drastic reaction as did the G8 counterparts.

5.3.3 Correlation calculation using a multiple regression model

The parameters used in the vector autoregression to estimate correlation factors were standard errors of the coefficient (beta) estimates and the covariance between each coefficient estimate of the lagged values or the regressors. A slightly different analysis of data was performed expanding the simple bivariate model above to include multiple regressors, all of which are the lagged values of returns for each market. Similar to the VAR analysis, five lags are adopted for each country's returns. But instead of the covariance between the coefficient estimates obtained from a regression analysis, the focus is on the covariance between the actual variables or the regressors themselves.

As in the VAR analysis, a simple average of all the lagged values is used to arrive at the covariance between the variables as well as the variance of the variable *x* and variable *y*. Using these parameters, the standard correlation or the conditional correlation coefficient is calculated.

Table 8: Test for contagion in stock market: Multiple regression model
Conditional cross-market correlation coefficients and variance for the U.S. and each country in the sample is reported. 'C' indicates contagion and 'N' indicates no contagion

Country	Stable		Turmoil		Full		*z-stat*	*C or N*
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00001		0.00018		0.00008			
Canada	0.00003	0.033	0.00024	0.035	0.00012	0.034	0.005	N
France	0.00003	0.014	0.00022	0.032	0.00011	0.032	-0.009	N
Germany	0.00003	0.036	0.00019	0.034	0.00010	0.034	-0.001	N
Italy	0.00003	0.033	0.00021	0.029	0.00011	0.030	-0.006	N
Japan	0.00005	0.016	0.00017	0.012	0.00010	0.012	-0.006	N
Norway	0.00008	0.020	0.00036	0.024	0.00020	0.023	0.023	N
Russia	0.00009	0.016	0.00039	0.020	0.00022	0.019	0.021	N
United Kingdom	0.00002	0.033	0.00021	0.033	0.00010	0.033	0.000	N

As it can be seen from Table 08, the variance in stock market returns have increased directly after the crisis. But the correlation coefficients do not show a noticeably increase; moreover, the indicator has actually reduced in France, Germany, Italy and Japan during the crisis period. Therefore, none of the pairs of countries gives results positive towards constituting contagion.

To observe the impact of the heteroskedasticity bias on the correlation estimate, an adjustment factor is estimated using the same technique of simple averages. Table 09 shows the unconditional correlation estimations for the sample selected.

Table 9: Test for contagion in stock market: Multiple regression model
Unconditional cross-market correlation coefficients and variance for the U.S. and each country in the sample is reported. 'C' indicates contagion and 'N' indicates no contagion

Country	Stable		Turmoil		Full		*z-stat*	*C or N*
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00001		0.00018		0.00008			
Canada	0.00003	0.033	0.00024	0.010	0.00012	0.034	-0.527	N
France	0.00003	0.014	0.00022	0.009	0.00011	0.032	-0.495	N
Germany	0.00003	0.036	0.00019	0.010	0.00010	0.034	-0.525	N
Italy	0.00003	0.033	0.00021	0.008	0.00011	0.030	-0.459	N
Japan	0.00005	0.016	0.00017	0.003	0.00010	0.012	-0.190	N
Norway	0.00008	0.020	0.00036	0.007	0.00020	0.023	-0.351	N
Russia	0.00009	0.016	0.00039	0.006	0.00022	0.019	-0.284	N
United Kingdom	0.00002	0.033	0.00021	0.009	0.00010	0.033	-0.505	N

Each of the crisis period correlation reduces once they are corrected for the bias created by market volatility. But comparing the correlation coefficients between the period of crisis and the full period as per the hypothesis, does not show a significant enough change. None of the z-statistics show a figure higher than the critical value at 5% significance level and therefore, no indication of contagion is shown through the analysis of cross-market correlations.

As a control measure, a similar multiple regression analysis was conducted with some minor changes to the methodology. Instead of using the average of all the lagged variables, a regression analysis was carried out in order to identify the most significant variables within the regression. Once they were identified, the covariance between those variables were estimated. Using the corresponding (average) variance of each significant (lagged) variable,

the standard correlation was estimated. Table 10 displays the results obtained through the analysis of conditional correlations using the significant variables.

Table 10: Test for contagion in stock market: Multiple regression model with significant coefficients Conditional cross-market correlation coefficients and variance for the U.S. and each country in the sample is reported. 'C' indicates contagion and 'N' indicates no contagion

Country	Stable		Turmoil		Full		*z-stat*	*C or N*
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00001		0.00018		0.00008			
Canada	0.00003	0.019	0.00024	0.023	0.00012	0.040	-0.362	N
France	0.00003	0.038	0.00022	0.036	0.00011	0.041	-0.114	N
Germany	0.00003	0.038	0.00019	0.037	0.00010	0.037	0.004	N
Italy	0.00003	0.034	0.00021	0.028	0.00011	0.030	-0.031	N
Japan	0.00005	0.022	0.00017	0.012	0.00010	0.012	-0.006	N
Norway	0.00008	0.025	0.00036	0.032	0.00020	0.029	0.057	N
Russia	0.00009	0.068	0.00039	0.011	0.00022	0.027	-0.349	N
United Kingdom	0.00002	0.036	0.00021	0.038	0.00010	0.038	0.007	N

Again there is not one single case which qualifies as contagion. Similar to the calculations based on the previous technique, selection of significant variables does not make an impact on the final results.

The unconditional correlation is estimated next, using the same adjustment factor. From the table 11 in the next page, it can be seen that adjusting for the bias has again resulted in 'no contagion', re-enforcing the fact that the changes in the correlation coefficients is cause by market volatility, not substantial changes between linkages. One point of discussion can be that the volatility in the other market, except U.S., is affecting the cross-market correlation estimates.

Table 11: Test for contagion in stock market: Multiple regression model with significant coefficients Unconditional cross-market correlation coefficients and variance for the U.S. and each country in the sample is reported. 'C' indicates contagion and 'N' indicates no contagion

Country	Stable		Turmoil		Full		*z-stat*	*C or N*
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00001		0.00018		0.00008			
Canada	0.00003	0.019	0.00024	0.007	0.00012	0.040	-0.713	N
France	0.00003	0.038	0.00022	0.010	0.00011	0.041	-0.662	N
Germany	0.00003	0.038	0.00019	0.011	0.00010	0.037	-0.572	N
Italy	0.00003	0.034	0.00021	0.008	0.00011	0.030	-0.466	N
Japan	0.00005	0.022	0.00017	0.003	0.00010	0.012	-0.190	N
Norway	0.00008	0.025	0.00036	0.009	0.00020	0.029	-0.429	N
Russia	0.00009	0.068	0.00039	0.003	0.00022	0.027	-0.517	N
United Kingdom	0.00002	0.036	0.00021	0.011	0.00010	0.038	-0.579	N

5.4 Summary

Results from the test for contagion in stock markets showed certain ambiguity. When estimating the correlation coefficient using the standard definition, none of the three different techniques showed evidence of contagion. Once the heteroskedastic bias has been corrected for and the unconditional correlation is estimated, both the VAR model (using simple averages) as well as the bivariate framework resulted in contagion being identified for most of the countries in the sample. Changing the method to take in to account only significant variables and their coefficients gave a different picture. In the VAR analysis, the tests for significance came close to the critical value at 5% significance level, but it was not sufficient to constitute contagion. In the multiple regressor analysis, there was no significant changes in correlation coefficients either, indicating that there is no evidence of contagion.

Variance of stock market returns show increases in all of the countries after the crisis was generated in the U.S. markets. But it was interesting to observe that when adopting the VAR model, the variance in the U.S. actually shows a decline. Other models in contrast show an increase in market volatility which is a norm.

SECTION SIX: APPLICATION TO BOND MARKETS

The previous section discussed the quantitative analysis carried out in testing for contagion in stock market returns during the financial crisis of 2007-2008. This section is dedicated to observe the behaviour of bond markets during the same crisis and to find if there is evidence of contagion.

Subsection one gives a brief introduction to the bonds markets, with an emphasis on the government bond market. Subsection two provide details on the data and the sample used, whereas the methodology has been already described in the previous sections. The results of the quantitative study is presented in subsection three with a summary discussion.

6.1 What is the Bonds Market?

Bonds are known as a fixed income and relatively low-risk debt securities, used by companies, governments, municipalities and states to raise funds for a broad range of financing purposes. It is one of the three main asset classes after stocks and cash equivalents. Even though the bonds market does not receive the same media coverage and popular attention, it is a market with substantial value. New debt is issued or existing debts are traded in this market, providing much needed long term funding opportunities to private and public expenditures.

When compared to corporate bonds, Government bonds are believed to be considerably low-risk since they are backed by the 'full faith' of the issuing government. These types of bonds are most often issued based on a country's sovereign currency, with the intent of raising finance for various national expenditures. Even though these bonds are deemed to be low risk, they are by far not *risk free* since factors such as country risk, political risk, inflation and interest rate risk can influence the overall risk status of the government bonds. But reserve accumulation and regulatory changes have seen greater cross-border integration of sovereign markets, meaning there is a higher percentage of non-resident investors holding government securities. And there is also a trend that market-based economies such as the U.S. and the U.K. , banks holder a relatively low amount of government bonds in their portfolios. But in bank-based financial systems like those in Europe and Canada, government securities make up a larger share in the banks' asset holding (Andritzky, 2012).

Government bonds are often in high demand directly after a shock in the stock markets, because the investors prefer to switch to the securities which have a generally consistent income and duration as well as priority over equity holders. Such a situation was evident during the financial crisis in 2007-2008, where many financial institutions including central banks invested heavily in government debt. With the following recession and government bailouts, most governments found themselves in deep need for cash and thus ended up issuing a high amount of government bonds. But many foreign government debt holders pulled out of the market, creating a deep crisis in the bonds market. Repercussions were intense, especially in the Eurozone countries. Most European countries found themselves submerged in rising debt, and crippling downgrading of credit ratings on most of the government bonds created a rippling effects throughout the region. With the risk factor having increased many folds, governments were forced to issue bonds with high rates of returns. All of these events eventually led to a severe sovereign debt crisis in the Eurozone starting in 2008.

6.2 The Data and the Sample

Data to be used for quantitative study of contagion in the government bonds market is obtained through DATASTREAM[15]. The application has specially formulated government bond indices for most countries, where government bonds of varying maturity periods are considered. The focus was on the relatively long-term period and it was decided to utilize data obtained from 10-year benchmark (Datastream) Government bonds indices.

The total return of the bonds are calculated as;

$$IV_n = IV_0 \times (1+TRR_n)$$

where:
IV_n = closing index value on day n
IV_0 = closing index value on prior day end
TRR_n = total return on day n

All the bond index values are in US dollar and has been transformed to the first difference of the natural logarithm with a two-day moving average.

[15] Datastream by Thomson Reuters is an integrated application providing a wide range of global financial data.

It was decided to keep the time period constant to evaluate whether the government bonds market was affected during the same period as the stock market during the financial crisis of 2007-2008. The time period when the Sovereign Debt Crisis in the Eurozone would have shown more volatility, but for the purpose of the thesis, the period between 1 January 2005 and 31 March 2009 is considered as the full period. It is subsequently divided in to two groups where relatively stable activity is shown from 1 January 2005 to 31 May 2007 and the rest of the time period is specified as the 'crisis' period.

The sample consists of the members of G8 as well as Norway, similar to stock market analysis. But reliable and comparable data was not available for Russia and has therefore has been excluded from the sample of countries. The analysis is performed between the U.S, Canada, France, Germany, Italy, Japan, Norway and U.K.

6.3 Results

6.3.1 Correlation calculation using VAR(5)method

A VAR(5) is first used to filter the data and obtain a variance-covariance matrix between the coefficient estimates, for each set of countries for all three specified periods. From the parameters of coefficient estimates (i.e. variance, covariance) derived from the matrix, the correlation coefficients are calculated. The methodology and techniques are similar to those applied for stock market analysis.

A simple average of the parameters (of all the relevant lagged values) is estimated to arrive at the single conditional cross-market correlation value for each pair of countries. Table 12 displayed in the next page shows the results obtained from the calculation of conditional correlation between the U.S. and each of the other countries in the sample.

Table 12: Test for contagion in Government Bonds market: VAR(5) model
Conditional cross-market correlation coefficients and variance for the U.S. and each country in the sample is reported. 'C' indicates contagion and 'N' indicates no contagion

Country	Stable		Turmoil		Full		*z-stat*	*C or N*
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00483		0.00309		0.00160			
Canada	0.00134	-0.15	0.00152	-0.07	0.00067	-0.09	0.41	N
France	0.00135	-0.17	0.00163	-0.14	0.00071	-0.15	0.23	N
Germany	0.00135	-0.17	0.00164	-0.15	0.00071	-0.16	0.16	N
Italy	0.00135	-0.17	0.00159	-0.13	0.00070	-0.14	0.31	N
Japan	0.00120	-0.14	0.00174	-0.19	0.00073	-0.18	-0.25	N
Norway	0.00119	-0.08	0.00157	-0.02	0.00067	-0.04	0.40	N
United Kingdom	0.00136	-0.19	0.00152	-0.08	0.00067	-0.11	0.60	N

It can be observed that while the variance of bond returns increase in all the countries, the average variance in the U.S. actually reduces by 36%. Again it should be highlighted here that the variance in U.S. government bond returns changes for each dataset analysis. It is due to the fact that the variance is calculated as the square of standard error of each coefficient estimate from the regression. For each separate dataset, the variance in bond returns in the U.S. show a reduction between the stable period and the crisis period.

The significance test applied to the conditional cross-market correlation in the government bonds market does not give any indication that contagion has occurred. There are no significant changes between the correlation coefficients between the periods, which is evident from the numbers itself. A point of interest here is that the conditional correlation during the crisis period has not increased; rather it has *reduced* for all the countries, except for Japan. The government bonds market in Japan shows the highest volatility, with a 45% increase in the variance of returns as well as the highest level of cross-market correlations from all the countries in the sample.

Since the correlation coefficient above is conditional on market volatility, a correction is made to remove the effects of such volatility. The unconditional correlation is estimated next to observe if the correction of bias will give different outcome.

Table 13: Test for contagion in Government Bonds market: VAR(5) model
Unconditional cross-market correlation coefficients and variance for the U.S. and each country in the sample is reported. 'C' indicates contagion and 'N' indicates no contagion

Country	Stable		Turmoil		Full		*z-stat*	*C or N*
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00483		0.00309		0.00160			
Canada	0.00134	-0.15	0.00152	-0.09	0.00067	-0.09	0.02	N
France	0.00135	-0.17	0.00163	-0.18	0.00071	-0.15	-0.53	N
Germany	0.00135	-0.17	0.00164	-0.19	0.00071	-0.16	-0.66	N
Italy	0.00135	-0.17	0.00159	-0.16	0.00070	-0.14	-0.39	N
Japan	0.00120	-0.14	0.00174	-0.24	0.00073	-0.18	-1.29	N
Norway	0.00119	-0.08	0.00157	-0.02	0.00067	-0.04	0.30	N
United Kingdom	0.00136	-0.19	0.00152	-0.10	0.00067	-0.11	0.18	N

It can be seen that after adjusting for heteroskedasticity, the results further reinforce the fact that there is no evidence of contagion. It can be an indication that the period specified does not show any major fluctuations in the government bonds market, unlike in the stock market. But it should also be noted that the test for significance between the correlation coefficients in Japan shows a considerably high number when compared to the conditional correlation estimate.

6.3.2 Correlation calculation using a multiple regression model

A further analysis is carried out using a multiple variable model without any lags. In this scenario, three months interbank interest rates of the U.S. and other countries' have been included as regressors in the equation. Similar to previous tests, the conditional as well as the unconditional cross-market correlations is calculated and then tested for significance. Even though interest rates have been included as independent variables, correlation is calculated only between the two bond market returns.

Table 14: Test for contagion in Government Bonds market: Multiple regression model
Conditional cross-market correlation coefficients and variance for the U.S. and each country in the sample is reported. 'C' indicates contagion and 'N' indicates no contagion

Country	Stable		Turmoil		Full		*z-stat*	*C or N*
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00000		0.00002		0.00001			
Canada	0.00001	0.38	0.00003	0.13	0.00002	0.20	-1.43	N
France	0.00001	0.40	0.00003	0.21	0.00002	0.26	-1.16	N
Germany	0.00001	0.40	0.00003	0.23	0.00002	0.27	-1.02	N
Italy	0.00001	0.40	0.00003	0.15	0.00002	0.22	-1.49	N
Japan	0.00001	0.18	0.00003	0.38	0.00002	0.33	1.36	N
Norway	0.00002	0.20	0.00005	-0.10	0.00003	-0.03	-1.56	N
United Kingdom	0.00001	0.36	0.00003	0.13	0.00002	0.19	-1.38	N

The table above shows that the conditional cross-market correlations between the U.S. and Japan and Norway are the lowest, while rest of the countries has a high correlation during the stable period. An interesting observation is that even though the variance of bond returns shows a minimal increase from the stable period to crisis period, the correlation coefficient has reduced in all the countries, except Japan. It is again an indication that Japan has had close linkages with the government bonds market in U.S. when the crisis was taking place. The z-statistic for almost all the countries are high, even though it does not exceed the critical value at 5% significance value.

Table 15: Test for contagion in Government Bonds market: Multiple regression model
Unconditional cross-market correlation coefficients and variance for the U.S. and each country in the sample is reported. 'C' indicates contagion and 'N' indicates no contagion

Country	Stable		Turmoil		Full		*z-stat*	*C or N*
	σ^2	P	σ^2	ρ	σ^2	ρ		
USA	0.00000		0.00002		0.00001			
Canada	0.00001	0.38	0.00003	0.06	0.00002	0.20	-2.97	C
France	0.00001	0.40	0.00003	0.10	0.00002	0.26	-3.61	C
Germany	0.00001	0.40	0.00003	0.11	0.00002	0.27	-3.74	C
Italy	0.00001	0.40	0.00003	0.07	0.00002	0.22	-3.24	C
Japan	0.00001	0.18	0.00003	0.19	0.00002	0.33	-3.25	C
Norway	0.00002	0.20	0.00005	-0.04	0.00003	-0.03	-0.42	N
United Kingdom	0.00001	0.36	0.00003	0.06	0.00002	0.19	-2.90	C

In order to assess the impact of market volatility on the correlation estimates, the unconditional correlation coefficient was calculated and the results are shown in Table 15 (previous page). Adjusting for the heteroskedasticity bias has drastically reduced the correlation estimated during the crisis period, as compared to the same figure under conditional correlation estimation. Therefore, the change in correlation is significant at the 5% significant level, indicating that cross-market linkages have strengthened enough to cause contagion in all the countries of the sample, except between the U.S. and Norway.

6.3.3 Summary of results

Unlike the VAR(5) test applied to the stock market, use of the same method has not found evidence of contagion once the unconditional correlation coefficient was estimated. The only highlight is that the z-statistic with related to the U.S.-Japan pair of countries indicate an increase. It can be due to the fact that Japan was more inclined towards investing in safe government securities, and therefore was more exposed to the government debt market.

A multiple variable model without any lags displayed significant change correlations, indicated by higher than 1.65 z-statistics to all the countries except in Norway. An interesting observation is that the standard cross-market correlation coefficient under both methods does not indicate a significant enough change to constitute contagion.

SECTION SEVEN: CONCLUSION, CAVEATS AND EXTENSIONS

The thesis has centered around the key question of whether financial contagion has taken place during the financial crisis of 2007-2008. Having narrowed down the quantitative analysis to the stock markets and government bond markets of the G8 countries and Norway, a test for contagion is carried out using the cross-market correlation coefficient between asset returns. The period defined for the analysis is a span of more than four years, during which the crisis began and reached a peak.

As per the article on which the theoretical model is based on, Forbes and Rigobon argue that the standard correlation calculation is inaccurate when testing for contagion. Since the coefficient is conditional on market volatility, it is biased upwards when a crisis increases the volatility of market returns. They propose an adjustment to this heteroskedastic bias and use it to formulate a corrected correlation coefficient named as 'unconditional correlation coefficient'. By analyzing the stock market returns during three selected financial crises of selected countries, they emphasize that while the standard correlation estimation gives a higher indication of contagion, the adjusted correlation reveals limited results of contagion. The key idea behind this is that an increase on cross-market correlation can be due to only an increase in market volatility and thereby does not constitute actual contagion. In order to find out if the cross-market correlations have changed significantly after a shock to one market, the increase in variance of returns (market volatility) should be removed.

In applying the framework to the stock market returns, a VAR(5) model, a simple bivariate analysis and a multiple regression model were adopted. With regard to the quantitative study carried out on the stock markets, the overall results can be seen as mixed or somewhat inconclusive. When the conditional correlation was estimated, all three techniques demonstrated that significance tests yielded the result of no contagion in all instances. But once the market volatility was corrected for and the unconditional correlation was estimated, the VAR(5) model and the bivariate model showed some indication of contagious effects from the U.S. to the European countries and Canada. Even though Norway was a country hailed to have weathered the financial crisis of 2007-2008 in a better manner, the stock market is seen to have been vulnerable to the activities abroad. Russia and Japan had the least tendency to show evidence for contagion, and this fact can be justified using information from the description of the sample. Inevitably, the stock markets of each country reacted to the

crisis spilling from the U.S. and the transmission mechanisms at that instance would have primarily been investor behavior. Stock markets are very sensitive to the information asymmetries, and therefore rational or irrational decision of the investors in the face of certain events cause many market to move together. Given the scale and impact of the subprime mortgage crisis in the U.S., it is difficult to proclaim that it is only market volatility stemming from the U.S. that is causing the increase in cross-market correlations. Market volatility in each of the other markets have been equally strong, indicating that some form of fundamental changes have taken place with regard to cross-market linkages.

The multiple regression model, where parameters such as variance, covariance are between the lagged values themselves came up with insignificant z-statistics with regard to the test for contagion. Only a slight increase in the significance test is recorded between the conditional correlations and the unconditional correlations.

It is difficult to draw a concrete conclusions from the results on contagion occurring in the stock markets. The VAR model has certain elements that can be estimated different or even interpreted in a different manner. To what length inferences can be drawn by the analysis using coefficient estimates and their parameters are arguable. Unlike the analysis carried out by Forbes and Rigobon, the time period utilized in this study is much longer, especially the period of crisis. For such a lengthy period of time, there is a vast amount of data leaving room for estimation error. As it was shown by the lag selection test, the most appropriate number of lags should be more than 10 whereas the methodology uses only five lags in its estimations. This simple point creates an discrepancy between the statistically appropriate methods and the subjective use of certain measurement.

Another inconsistency encountered in the VAR(5) model was that the variance of stock market returns in U.S. shows a relative decrease, instead of the expected increase. This leads to a question as to whether there is an actual requirements for the heteroskedastic bias to be corrected. It might be an estimation error, but the fact that contagious effects can stem from other markets cannot be ignored as well. Since the unconditional correlation in the VAR model indicates contagion, a shift in variance of returns in other countries might have a counter-effect causing the significance shift in correlations between the defined periods.

Given that the VAR model using lagged values have certain disparities, a more consistent and relatively safe model to follow would be the bivariate analysis. This method indicated that all countries in the sample, except Japan are experiencing contagious effects from the U.S. stock market. Even though there might not be problems regard to an appropriate lag length or shortcomings in drawing inferences from regression coefficients estimates, this model cannot be incorporated with the effects of interest rates, and also the predictive value of previous market returns cannot be utilized.

With regard to the government bonds market, application of the VAR(5) model shows that no significant changes in the correlations have occurred during the crisis. Therefore, there is no financial contagion during the financial crisis in the particular market. In sharp contrast, a multiple variable model, which includes bond market returns (without lagged values) and interest rates of the two countries under consideration, indicate that contagion has occurred in all the countries in the sample except for Norway. Due to difficulty in obtaining reliable information, it was difficult to link this finding with the actual events that would have taken place during the crisis. It was noted that the correlation factors have reduced from the stable period to crisis period when applying both methods, even though the variance has increased. Therefore, it is obvious there are other factors influencing the cross-market correlation coefficient.

Taking all the factors given above in to consideration, a generalized conclusion can be made that the financial crisis of 2007-2008 had some form of contagious effect on the stock markets in the G8 countries and Norway. Japan was identified by two methods to be the market in which contagion did not occur and Russia was included in one method. The volatility on the other markets seemed to have contributed to this facts as well. In connection with the government bonds market, there is not concrete evidence of contagion occurring.

Caveats and Possible Extensions

The definition of contagion used in the thesis is somewhat restricted, even though it provides a straightforward framework to carry out empirical studies. It mentions that contagion is a significant increase in cross-market linkages after a shock in one or group of markets. Such a definition facilitates the utilization of correlation between asset returns to test for contagion, but it does not provide a definition for the actual linkages between the countries. Meaning, this definition avoids differentiating and measuring the various transmission mechanisms. While it makes the statistical analysis relatively straightforward, the narrow definition can be limiting when interpreting the results obtained from the quantitative study.

A key concept in the theoretical model is that since the correlation estimations traditionally finds evidence of contagion because it is conditional on market volatility, and biased upwards when there is high comovement in the market after a crisis. The adjustment factor for this bias is based on two assumption of no endogeneity and no omitted variables. The assumption of endogeneity has especially been enforced in filtering the data in VAR model. If any of the dataset find evidence that there is feedback from the market *y* to market *x*, the correction of the bias will be invalid.

Treatment of interest rates in the government bonds market can be challenged since they are much more important in connection to valuing bonds rather than stock market. The option of including other economic indicators such as the Gross Domestic Produces, the exchanges rate, etc. would have made the regression less limited.

The hypothesis tested by the framework is comparing the correlation coefficient in the crisis period with that of the full period. Correction for the bias is performed on the correlation during the crisis period and effectively, the stable and full period correlation coefficients will remain constant (same as the value as conditional correlation). But it should be pointed out that the full period includes the period in which a shock was generated causing the market returns to increase. A point of debate is raised as to why the full period correlation is not adjusted for the volatility in market returns as well. A robust test is attached in the Appendix to evaluate whether a test for significance using the hypothesis constructed by correlation during the stable period and the crisis period, instead of full period and crisis period correlation display drastic differences.

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Appendix

Appendix I : Definition of financial crises by Events (Reinhart and Rogoff : 'This Time is Different')

Appendix II : Stock Market volatility during the financial crisis

Appendix III: Correlation matrix for VAR analysis of stock market returns of U.S. and U.K.

Appendix IV: VAR regression analysis for stock market returns of U.S. and U.K.

Appendix V: Robust test using stabe period correlation and crisis period correlation

Appendix I : Definition of financial crises by Events (Reinhart and Rogoff : 'This Time is Different')

Table A2. Defining Crises by Events: A Summary

Type of Crisis	Definition and/or Criteria	Comments
Banking crisis Type I: systemic/severe Type II: financial distress/ milder	We mark a banking crisis by two types of events: (1) bank runs that lead to the closure, merging, or takeover by the public sector of one or more financial institutions; and (2) if there are no runs, the closure, merging, takeover, or large-scale government assistance of an important financial institution (or group of institutions), that marks the start of a string of similar outcomes for other financial institutions.	This approach to dating the beginning of a banking crisis is not without drawbacks. It could date a crisis too late, because the financial problems usually begin well before a bank is finally closed or merged; it could also date a crisis too early, because the worst part of a crisis may come later. Unlike the external debt crises (see below), which have well-defined closure dates, it is often difficult or impossible to accurately pinpoint the year in which a crisis ended.
Debt crises: External	A sovereign default is defined as the failure to meet a principal or interest payment on the due date (or within the specified grace period). The episodes also include instances where rescheduled debt is ultimately extinguished in terms less favorable than the original obligation.	While the time of default is accurately classified as a crisis year there are a large number of cases where the final resolution with the creditors (if it ever did take place) seems interminable. Fort his reason we also work with a crisis dummy that only picks up the first year.
Debt crisis: Domestic	The definition given above for external debt applies. In addition, domestic debt crises have involved the freezing of bank deposits and or forcible conversions of such deposits from dollars to local currency.	There is at best some partial documentation of recent defaults on domestic debt provided by Standard and Poors. Historically, it is very difficult to date these episodes and in many cases (like banking crises) it is impossible to ascertain the date of the final resolution.

Appendix II : Stock Market volatility during the financial crisis

S&P 500: Movement of Stock Market Index in the U.S. (Period 1 January 2005 to 31 March 2009)

S&P/TSX Composite Index : Movement of Stock Market Index in Canada (Period 1 January 2005 to 31 March 2009)

CAC 40: Movement of Stock Market Index in France (Period 1 January 2005 to 31 March 2009)

DAX : Movement of Stock Market Index in Germany (Period 1 January 2005 to 31 March 2009)

NIKKEI 225: Movement of Stock Market Index in Japan (Period 1 January 2005 to 31 March 2009)

FTSE MIB: Movement of Stock Market Index in Italy (Period 1 January 2005 to 31 March 2009)

RTSI INDEX: Movement of Stock Market Index in Russia (Period 1 January 2005 to 31 March 2009)

FTSE 100: Movement of Stock Market Index in U.K. (Period 1 January 2005 to 31 March 2009)

	fdrUK													**fdrUSA**											
	L.	L2.	L3.	L4.	L5.	L.	L2.	L3.	L4.	L5.				L.	L2.	L3.	L4.	L5.	L.	L2.	L3.	L4.	L5.			
	fdrUK	fdrUK	fdrUK	fdrUK	fdrUK	fdrUSA	fdrUSA	fdrUSA	fdrUSA	fdrUSA	fdintUK	fdintUSA	_cons	fdrUK	fdrUK	fdrUK	fdrUK	fdrUK	fdrUSA	fdrUSA	fdrUSA	fdrUSA	fdrUSA	fdintUK	fdintUSA	_cons
fdrUK																										
L.fdrUK	1.00																									
L2.fdrUK	0.25	1.00																								
L3.fdrUK	0.56	0.30	1.00																							
L4.fdrUK	0.17	0.52	0.30	1.00																						
L5.fdrUK	0.30	0.15	0.54	0.23	1.00																					
L.fdrUSA	-0.41	-0.14	-0.23	-0.07	-0.11	1.00																				
L2.fdrUSA	-0.37	-0.45	-0.25	-0.23	-0.06	0.19	1.00																			
L3.fdrUSA	-0.29	-0.38	-0.45	-0.26	-0.24	0.57	0.24	1.00																		
L4.fdrUSA	-0.25	-0.28	-0.37	-0.45	-0.12	0.12	0.53	0.25	1.00																	
L5.fdrUSA	-0.19	-0.25	-0.29	-0.37	-0.42	0.34	0.13	0.60	0.20	1.00																
fdintUK	0.04	0.02	0.01	0.05	0.02	-0.03	-0.04	-0.05	-0.07	-0.02	1.00															
fdintUSA	-0.03	0.00	0.00	-0.05	-0.02	0.03	0.03	0.05	0.08	0.02	-0.98	1.00														
_cons	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.01	-0.01	1.00													
fdrUSA																										
L.fdrUK	0.41	0.10	0.23	0.07	0.12	-0.17	-0.15	-0.12	-0.10	-0.08	0.02	-0.01	0.00	1.00												
L2.fdrUK	0.10	0.41	0.12	0.21	0.06	-0.06	-0.18	-0.15	-0.11	-0.10	0.01	0.00	0.00	0.25	1.00											
L3.fdrUK	0.23	0.12	0.41	0.12	0.22	-0.09	-0.10	-0.18	-0.15	-0.12	0.00	0.00	0.00	0.56	0.30	1.00										
L4.fdrUK	0.07	0.21	0.12	0.41	0.09	-0.03	-0.09	-0.10	-0.18	-0.15	0.02	-0.02	0.00	0.17	0.52	0.30	1.00									
L5.fdrUK	0.12	0.06	0.22	0.09	0.41	-0.05	-0.02	-0.10	-0.05	-0.17	0.01	-0.01	0.00	0.30	0.15	0.54	0.23	1.00								
L.fdrUSA	-0.17	-0.06	-0.09	-0.03	-0.05	0.41	0.08	0.23	0.05	0.14	-0.01	0.01	0.00	-0.41	-0.14	-0.23	-0.07	-0.11	1.00							
L2.fdrUSA	-0.15	-0.18	-0.10	-0.09	-0.02	0.08	0.41	0.10	0.22	0.05	-0.01	0.01	0.00	-0.37	-0.45	-0.25	-0.23	-0.06	0.19	1.00						
L3.fdrUSA	-0.12	-0.15	-0.18	-0.10	-0.10	0.23	0.10	0.41	0.10	0.24	-0.02	0.02	0.00	-0.29	-0.38	-0.45	-0.26	-0.24	0.57	0.24	1.00					
L4.fdrUSA	-0.10	-0.11	-0.15	-0.18	-0.05	0.05	0.22	0.10	0.41	0.08	-0.03	0.03	0.00	-0.25	-0.28	-0.37	-0.45	-0.12	0.12	0.53	0.25	1.00				
L5.fdrUSA	-0.08	-0.10	-0.12	-0.15	-0.17	0.14	0.05	0.24	0.08	0.41	-0.01	0.01	0.00	-0.19	-0.25	-0.29	-0.37	-0.42	0.34	0.13	0.60	0.20	1.00			
fdintUK	0.02	0.01	0.00	0.02	0.01	-0.01	-0.01	-0.02	-0.03	-0.01	0.41	-0.40	0.00	0.04	0.02	0.01	0.05	0.02	-0.03	-0.04	-0.05	-0.07	-0.02	1.00		
fdintUSA	-0.01	0.00	0.00	-0.02	-0.01	0.01	0.01	0.02	0.03	0.01	-0.40	0.41	0.00	-0.03	0.00	0.00	-0.05	-0.02	0.03	0.03	0.05	0.08	0.02	-0.98	1.00	
_cons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.01	-0.01	1.00

Appendix IV: VAR analysis for stock market returns of U.S. and U.K.

```
Vector autoregression

Sample:  1/7/2005 - 5/31/2007                   No. of obs      =       875
Log likelihood =  7534.956                      AIC             = -17.16333
FPE            =  1.21e-10                      HQIC            = -17.10906
Det(Sigma_ml)  =  1.14e-10                      SBIC            = -17.02146

Equation           Parms      RMSE     R-sq      chi2     P>chi2
------------------------------------------------------------------
fdrUK                 13     .003778   0.3733   521.3116   0.0000
fdrUSA                13     .003133   0.3282   427.5352   0.0000
------------------------------------------------------------------

------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
fdrUK        |
       fdrUK |
         L1. |  -.2290329   .0367712    -6.23   0.000    -.3011031   -.1569628
         L2. |  -.6712158   .0361647   -18.56   0.000    -.7420972   -.6003344
         L3. |  -.1633195   .0421983    -3.87   0.000    -.2460267   -.0806124
         L4. |  -.3228026   .0359862    -8.97   0.000    -.3933343   -.2522709
         L5. |    .015942   .0348576     0.46   0.647    -.0523777    .0842616
             |
      fdrUSA |
         L1. |    .480833    .044532    10.80   0.000      .393552     .568114
         L2. |   .1149205   .0451208     2.55   0.011     .0264854    .2033555
         L3. |   .3970833   .0545784     7.28   0.000     .2901116     .504055
         L4. |    .101241   .0452415     2.24   0.025     .0125694    .1899126
         L5. |   .1513452   .0470528     3.22   0.001     .0591234    .2435671
             |
    fdintUSA |   .0086496   .0401561     0.22   0.829     -.070055    .0873542
     fdintUK |  -.0069285   .0379894    -0.18   0.855    -.0813864    .0675294
       _cons |   2.82e-06   .0001268     0.02   0.982    -.0002456    .0002513
-------------+----------------------------------------------------------------
fdrUSA       |
       fdrUK |
         L1. |   .0423867   .0304996     1.39   0.165    -.0173915    .1021648
         L2. |   .0033482   .0299966     0.11   0.911     -.055444    .0621403
         L3. |   .0203505   .0350011     0.58   0.561    -.0482504    .0889515
         L4. |  -.0084765   .0298485    -0.28   0.776    -.0669786    .0500255
         L5. |   .0306783   .0289124     1.06   0.289     -.025989    .0873456
             |
      fdrUSA |
         L1. |  -.0446333   .0369368    -1.21   0.227     -.117028    .0277614
         L2. |  -.6657496   .0374251   -17.79   0.000    -.7391015   -.5923977
         L3. |   -.017087   .0452697    -0.38   0.706     -.105814    .0716401
         L4. |  -.3348099   .0375252    -8.92   0.000    -.4083581   -.2612618
         L5. |   .0112819   .0390277     0.29   0.773    -.0652109    .0877748
             |
    fdintUSA |  -.0226506   .0333073    -0.68   0.496    -.0879317    .0426304
     fdintUK |   .0247417   .0315101     0.79   0.432     -.037017    .0865003
       _cons |   .0000137   .0001051     0.13   0.897    -.0001924    .0002197
------------------------------------------------------------------------------

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Appendix V: Robust test for contagion comparing the stable period correlation and crisis period correlation

A robust test is carried out to identify whether changing the test hypothesis would have a significant impact the results of contagion.

APPLICATION TO STOCK MARKET

Test of Contagion using bivariate analysis

Conditional cross-market correlation

Country	Stable		Turmoil		Full		*z-stat*	C/N
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00001		0.00018		0.00008			
Canada	0.00003	0.499	0.00024	0.681	0.00012	0.658	5.51	C
France	0.00003	0.426	0.00023	0.546	0.00011	0.530	3.07	C
Germany	0.00003	0.431	0.00019	0.577	0.00010	0.553	3.82	C
Italy	0.00003	0.379	0.00022	0.491	0.00011	0.477	2.71	C
Japan	0.00005	0.041	0.00017	-0.033	0.00010	-0.020	-1.44	N
Norway	0.00008	0.177	0.00036	0.436	0.00020	0.392	5.61	C
Russia	0.00009	0.146	0.00039	0.245	0.00022	0.225	2.01	C
United Kingdom	0.00002	0.375	0.00021	0.547	0.00010	0.527	4.27	C

Unconditional cross-market correlation

Country	Stable		Turmoil		Full		*z-stat*	C/N
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00001		0.00018		0.00008			
Canada	0.00003	0.499	0.00024	0.257	0.00012	0.658	-5.55	C
France	0.00003	0.426	0.00023	0.183	0.00011	0.530	-5.24	C
Germany	0.00003	0.431	0.00019	0.198	0.00010	0.553	-5.08	C
Italy	0.00003	0.379	0.00022	0.159	0.00011	0.477	-4.63	C
Japan	0.00005	0.041	0.00017	-0.009	0.00010	-0.020	-0.98	N
Norway	0.00008	0.177	0.00036	0.137	0.00020	0.392	-0.79	N
Russia	0.00009	0.146	0.00039	0.072	0.00022	0.225	-1.45	N
United Kingdom	0.00002	0.375	0.00021	0.184	0.00010	0.527	-4.06	C

These results confirm that there are certain contagious effects between U.S. and the other markets of the sample. Even though conditional correlation calculations indicate contagion in all countries, other than Japan, adjusting for the bias of market volatility, it is revealed that contagion did not occur in Norway and Russia as previously shown.

Test of Contagion using multiple regression model

Conditional cross-market correlation

Country	Stable		Turmoil		Full		*z-stat*	C/N
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00001		0.00018		0.00008			
Canada	0.00003	0.033	0.00024	0.035	0.00012	0.034	0.02	N
France	0.00003	0.014	0.00022	0.032	0.00011	0.032	0.34	N
Germany	0.00003	0.036	0.00019	0.034	0.00010	0.034	-0.05	N
Italy	0.00003	0.033	0.00021	0.029	0.00011	0.030	-0.06	N
Japan	0.00005	0.016	0.00017	0.012	0.00010	0.012	-0.08	N
Norway	0.00008	0.020	0.00036	0.024	0.00020	0.023	0.09	N
Russia	0.00009	0.016	0.00039	0.020	0.00022	0.019	0.07	N
United Kingdom	0.00002	0.033	0.00021	0.033	0.00010	0.033	-0.01	N

Unconditional cross-market correlation

Country	Stable		Turmoil		Full		*z-stat*	C/N
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00001		0.00018		0.00008			
Canada	0.00003	0.033	0.00024	0.010	0.00012	0.034	-0.46	N
France	0.00003	0.014	0.00022	0.009	0.00011	0.032	-0.10	N
Germany	0.00003	0.036	0.00019	0.010	0.00010	0.034	-0.52	N
Italy	0.00003	0.033	0.00021	0.008	0.00011	0.030	-0.47	N
Japan	0.00005	0.016	0.00017	0.003	0.00010	0.012	-0.24	N
Norway	0.00008	0.020	0.00036	0.007	0.00020	0.023	-0.25	N
Russia	0.00009	0.016	0.00039	0.006	0.00022	0.019	-0.21	N
United Kingdom	0.00002	0.033	0.00021	0.009	0.00010	0.033	-0.46	N

Conditional cross-market correlation: Multiple regression model with significant coefficients

Country	Stable		Turmoil		Full		*z-stat*	C/N
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00001		0.00018		0.00008			
Canada	0.00003	0.019	0.00024	0.023	0.00012	0.040	0.07	N
France	0.00003	0.038	0.00022	0.036	0.00011	0.041	-0.04	N
Germany	0.00003	0.038	0.00019	0.037	0.00010	0.037	-0.01	N
Italy	0.00003	0.034	0.00021	0.028	0.00011	0.030	-0.11	N
Japan	0.00005	0.022	0.00017	0.012	0.00010	0.012	-0.20	N
Norway	0.00008	0.025	0.00036	0.032	0.00020	0.029	0.12	N
Russia	0.00009	0.068	0.00039	0.011	0.00022	0.027	-1.11	N
United Kingdom	0.00002	0.036	0.00021	0.038	0.00010	0.038	0.05	N

Unconditional cross-market correlation: Multiple regression model with significant coefficients

Country	Stable		Turmoil		Full		*z-stat*	C/N
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00001		0.00018		0.00008			
Canada	0.00003	0.019	0.00024	0.007	0.00012	0.040	-0.25	N
France	0.00003	0.038	0.00022	0.010	0.00011	0.041	-0.54	N
Germany	0.00003	0.038	0.00019	0.011	0.00010	0.037	-0.53	N
Italy	0.00003	0.034	0.00021	0.008	0.00011	0.030	-0.50	N
Japan	0.00005	0.022	0.00017	0.003	0.00010	0.012	-0.36	N
Norway	0.00008	0.025	0.00036	0.009	0.00020	0.029	-0.32	N
Russia	0.00009	0.068	0.00039	0.003	0.00022	0.027	-1.26	N
United Kingdom	0.00002	0.036	0.00021	0.011	0.00010	0.038	-0.48	N

As reflected by the hypothesis comparing correlation of the full period and the crisis period, all estimations using the multiple regression model indicates that contagion has not occurred between the markets.

Test of Contagion using VAR(5) model

Conditional cross-market correlation: VAR model

Country	Stable		Turmoil		Full		*z-stat*	C/N
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00396		0.00305		0.00140			
Canada	0.00158	-0.222	0.00289	-0.304	0.00118	-0.290	-1.71	C
France	0.00147	-0.292	0.00228	-0.369	0.00095	-0.358	-1.69	C
Germany	0.00150	-0.291	0.00240	-0.353	0.00100	-0.343	-1.35	N
Italy	0.00145	-0.275	0.00209	-0.317	0.00089	-0.314	-0.90	N
Japan	0.00112	-0.109	0.00130	-0.155	0.00059	-0.142	-0.91	N
Norway	0.00121	-0.150	0.00184	-0.243	0.00077	-0.227	-1.88	C
Russia	0.00116	-0.100	0.00165	-0.180	0.00070	-0.165	-1.58	N
United Kingdom	0.00139	-0.276	0.00235	-0.377	0.00097	-0.364	-2.21	C

Unconditional cross-market correlation: VAR model

Country	Stable		Turmoil		Full		*z-stat*	C/N
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00396		0.00305		0.00140			
Canada	0.00158	-0.222	0.00289	-0.389	0.00118	-0.290	-3.58	C
France	0.00147	-0.292	0.00228	-0.469	0.00095	-0.358	-4.04	C
Germany	0.00150	-0.291	0.00240	-0.449	0.00100	-0.343	-3.57	C
Italy	0.00145	-0.275	0.00209	-0.405	0.00089	-0.314	-2.86	C
Japan	0.00112	-0.109	0.00130	-0.200	0.00059	-0.142	-1.82	C
Norway	0.00121	-0.150	0.00184	-0.312	0.00077	-0.227	-3.34	C
Russia	0.00116	-0.100	0.00165	-0.232	0.00070	-0.165	-2.64	C
United Kingdom	0.00139	-0.276	0.00235	-0.479	0.00097	-0.364	-4.63	C

Conditional cross-market correlation: VAR model with significant coefficients

Country	Stable		Turmoil		Full		*z-stat*	C/N
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00406		0.00313		0.00143			
Canada	0.00142	-0.077	0.00295	-0.323	0.00120	-0.308	-4.98	C
France	0.00151	-0.310	0.00237	-0.397	0.00099	-0.384	-1.92	C
Germany	0.00154	-0.308	0.00247	-0.364	0.00103	-0.364	-1.24	N
Italy	0.00148	-0.290	0.00190	-0.307	0.00081	-0.303	-0.36	N
Japan	0.00115	-0.115	0.00136	-0.193	0.00061	-0.177	-1.55	N
Norway	0.00110	-0.153	0.00163	-0.172	0.00071	-0.230	-0.39	N
Russia	0.00105	-0.079	0.00152	-0.118	0.00072	-0.145	-0.77	N
United Kingdom	0.00143	-0.298	0.00246	-0.408	0.00101	-0.395	-2.46	C

Unconditional cross-market correlation: VAR model with significant coefficients

Country	Stable		Turmoil		Full		*z-stat*	C/N
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00406		0.00313		0.00143			
Canada	0.00142	-0.077	0.00295	-0.362	0.00120	-0.308	-5.85	C
France	0.00151	-0.310	0.00237	-0.442	0.00099	-0.384	-2.98	C
Germany	0.00154	-0.308	0.00247	-0.407	0.00103	-0.364	-2.21	C
Italy	0.00148	-0.290	0.00190	-0.344	0.00081	-0.303	-1.18	N
Japan	0.00115	-0.115	0.00136	-0.218	0.00061	-0.177	-2.07	C
Norway	0.00110	-0.153	0.00163	-0.195	0.00071	-0.230	-0.85	N
Russia	0.00105	-0.079	0.00152	-0.134	0.00072	-0.145	-1.08	N
United Kingdom	0.00143	-0.298	0.00246	-0.454	0.00101	-0.395	-3.54	C

The VAR analysis shows that most of the countries have experienced contagion in all estimations, with the exception of Norway and Russia in almost all the cases.

GOVERNMENT BONDS MARKET

Test of Contagion using VAR(5) model

Conditional cross-market correlation: VAR model

Country	Stable		Turmoil		Full		*z-stat*	C/N
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00483		0.00309		0.00160			
Canada	0.00134	-0.146	0.00152	-0.073	0.00067	-0.092	1.43	N
France	0.00135	-0.173	0.00163	-0.141	0.00071	-0.151	0.64	N
Germany	0.00135	-0.174	0.00164	-0.152	0.00071	-0.160	0.42	N
Italy	0.00135	-0.172	0.00159	-0.129	0.00070	-0.143	0.86	N
Japan	0.00120	-0.145	0.00174	-0.193	0.00073	-0.182	-0.97	N
Norway	0.00119	-0.077	0.00157	-0.018	0.00067	-0.036	1.15	N
United Kingdom	0.00136	-0.190	0.00152	-0.079	0.00067	-0.107	2.20	C

Unconditional cross-market correlation: VAR model

Country	Stable		Turmoil		Full		*z-stat*	C/N
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00483		0.00309		0.00160			
Canada	0.00134	-0.146	0.00152	-0.091	0.00067	-0.092	1.08	N
France	0.00135	-0.173	0.00163	-0.175	0.00071	-0.151	-0.04	N
Germany	0.00135	-0.174	0.00164	-0.189	0.00071	-0.160	-0.31	N
Italy	0.00135	-0.172	0.00159	-0.160	0.00070	-0.143	0.24	N
Japan	0.00120	-0.145	0.00174	-0.239	0.00073	-0.182	-1.91	C
Norway	0.00119	-0.077	0.00157	-0.023	0.00067	-0.036	1.07	N
United Kingdom	0.00136	-0.190	0.00152	-0.098	0.00067	-0.107	1.82	C

In the government bonds market, Japan and United Kingdom shows that contagion has occurred, which is evident from the significant changes in the correlation between the U.S. and Japan.

Test of Contagion using multiple regression model

Conditional cross-market correlation: Multiple regression model

Country	Stable		Turmoil		Full		*z-stat*	C/N
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00000		0.00002		0.00001			
Canada	0.00001	0.383	0.00003	0.131	0.00002	0.196	-5.30	C
France	0.00001	0.400	0.00003	0.207	0.00002	0.258	-4.14	C
Germany	0.00001	0.400	0.00003	0.230	0.00002	0.274	-3.69	C
Italy	0.00001	0.398	0.00003	0.149	0.00002	0.216	-5.28	C
Japan	0.00001	0.180	0.00003	0.381	0.00002	0.326	4.28	C
Norway	0.00002	0.201	0.00005	-0.098	0.00003	-0.026	-5.87	C
United Kingdom	0.00001	0.360	0.00003	0.129	0.00002	0.192	-4.81	C

Unconditional cross-market correlation: Multiple regression model

Country	Stable		Turmoil		Full		*z-stat*	C/N
	σ^2	ρ	σ^2	ρ	σ^2	ρ		
USA	0.00000		0.00002		0.00001			
Canada	0.00001	0.383	0.00003	0.060	0.00002	0.196	-6.68	C
France	0.00001	0.400	0.00003	0.097	0.00002	0.258	-6.34	C
Germany	0.00001	0.400	0.00003	0.108	0.00002	0.274	-6.14	C
Italy	0.00001	0.398	0.00003	0.069	0.00002	0.216	-6.86	C
Japan	0.00001	0.180	0.00003	0.186	0.00002	0.326	0.13	N
Norway	0.00002	0.201	0.00005	-0.045	0.00003	-0.026	-4.84	C
United Kingdom	0.00001	0.360	0.00003	0.060	0.00002	0.192	-6.18	C

The results from the multiple regression model is drastically different, where all the countries except for Japan is seen to experience contagion.