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Financial Market Contagion: A standard factor model approach

Empirical evidence for the 2007-2009 Financial Crisis

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Preface and Acknowledgements

This paper is my Master thesis for the conclusion of the Master program Economics & Business, specialization Financial Economics, at the Erasmus University Rotterdam. My interest in financial economics started during the Bachelor program Economics & Business Economics. This interest developed further during my Master, where I followed seminars in Risk Management and Advanced Money, Credit & Banking. In particular, the subject of financial contagion caught my attention. The recent financial crisis again showed the importance of studying this area of financial economics.

I would firstly like to thank my supervisor, Willem Verschoor, professor of finance and the director of the Department of Business Economics at the Erasmus School of Economics. He accompanied me in the whole writing process and provided me with all the advice I needed. I could clearly see his affinity with the subject and could benefit from his extraordinary experience with research in the area of financial economics. Moreover, he gave me a lot of flexibility and really inspired me to get the best out of myself.

I also want to thank my friends and family for the support and motivation they gave me during the period of doing this thesis. In special, thanks to Jos, Marti, Tibor, and Bojan van Wissen and Sanne van der Meer for their contributions.

Please enjoy reading this paper as much as I did writing it!

Falco van Wissen, 27 January 2013

Abstract

Firstly, this paper explores the theory behind fundamental causes and international transmission mechanisms of financial contagion. I define contagion as a structural break in the linear transmission mechanism of financial shocks. The causes of financial contagion can be found in macro-economic changes as well in changing behavior of financial agents. Secondly, this paper builds on a standard factor model of stock market returns to test for contagion in the 2007-2009 financial crisis. I find strong evidence of contagion for 15 countries out of a sample of 16.

JEL classification: G10, F30, C10, G15, F65
Keywords: contagion, globalization, financial crisis, factor model, correlation analysis

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1. Introduction

The recent global financial crisis of 2007-2009 showed how vulnerable the nowadays international financial architecture is to negative shocks to a single market. The US subprime mortgage crisis, which started with the bursting of the housing bubble in the summer of 2007, quickly spread around the world resulting in a global liquidity and solvability crisis. This heated up the ongoing debate regarding the propagation mechanisms of foreign shocks. See for example the recent published book on international financial contagion edited by Kolb (2011).

Because of the nowadays more liberalized international capital markets, financial crises spread more easily across markets and even affect economies with strong fundamentals. This process of international capital market liberalization facilitates a greater flow of funds to markets around the world (Candelon, Hecq, and Verschoor (2005)). World-wide financial deregulation allows banks and domestic corporations to finance domestic investments more easily with foreign capital. On the one hand, this allows financial agents to diversify their portfolios more in order to reduce the risk exposures of their assets. It also creates new (international) markets for domestic investments, which are not bound by national savings anymore. The problem is that the liberalization process also leads to a higher risk of financial instability. Because of the higher level of financial interdependencies across markets, shocks can much easier spread across markets which make economies more vulnerable to financial crises via contagion effects.

This process of global liberalization might be an explanation for why, if true, crises have grown increasingly severe in their impact on affected countries than was the case in the past, which was questioned by Kamin (1999). Candelon, Hecq, and Verschoor (2005) namely state that it is a common belief that the Asian financial crisis, that started with the devaluation of the Thai baht in July 1997, is more virulent in its impact on affected economies than previous crises. I think nowadays one can say that the financial crisis of 2007-2009 was at least as virulent and even more devastating.

One must be very careful in defining contagion. Namely, the transmission of shocks from one country to another does not always have to be contagious. Take the US and Canada for example. Those countries are located in the same geographical region, have many similarities in terms of market structure and history, and have strong direct linkages through trade and finance. Because of these strong connections, both in tranquil and crisis times, it is not surprisingly that large negative shocks in the US are quickly passed on to Canada and vice versa. If the transmission of shocks due to these cross-market linkages do not significantly differ from those in tranquil times, this should not be considered as contagion. On the other hand, many people agree that the 1998 devaluation of the Russian ruble affected the Brazilian stock market due to contagion. These two markets are located in separate geographic regions, have different market structures and have virtually no direct linkages through trade or financial channels. During more tranquil periods, shocks to the Russian economy hardly affect the Brazilian economy. This may indicate that the cross-market linkages between the two markets are stronger in crisis times than in tranquil times and so the transmission of the 1998 crisis from Russia to Brazil was due to contagion. This paper assumes that for contagion to occur, the observed pattern of comovements in asset prices must be too strong (or too weak) relative to what can be predicted conditional on a constant mechanism of international transmission.

Therefore, in this paper financial contagion is defined as 'a structural break in the linear transmission mechanism of financial shocks'[1] (Forbes & Rigobon (2002); Dornbusch, Park & Claessens (2000); Corsetti, Pericoli & Sbracia (2005)). The situation in which a strong linkage exists in all states of the world is referred to as interdependence.

Financial contagion is a concern for both investors and policymakers as it may change the risks to which portfolios are exposed. Diversification may fail when it is most needed. Namely, in turbulent times financial exposures may be under a lot of pressure because of a higher downside risk. Diversification partly protects investors from losses suffered within a specific sector of the economy and is based on a certain (low) level of interrelations between various elements of the portfolio. With the occurrence of a structural break in the transmission mechanism of shocks these interrelations may shift, which reduces the effectiveness of the diversification.

Academic literature on financial contagion demonstrates several empirical contradictions with respect to the causes, the international transmission mechanisms, and even the existence of contagion. According to the group of crisis-contingent theories, new or changed transmission mechanisms arise which explain the existence of (shift-)contagion as defined above. Non-crisis-contingent theories assume that large

[1] In order to differentiate between various definitions of contagion, this is often referred to as shift-contagion in academic literature. However, I will refer to this as simply 'contagion'.

cross-market correlations after a shock are a continuation of (real) linkages that existed before the crisis and so do not generate (shift-)contagion.

Crisis-contingent theories on contagion identify at least three possible channels through which contagion can be propagated across different markets. First, Kiyotaki and Moore (2002), Kaminsky, Reinhart, and Vegh (2003), and others describe mechanisms in which contagion is viewed as the transmission of information from more liquid and transparent markets to other markets. This is referred to as the 'correlated-information channel'. In this mechanism, a shock to one financial market signals a news component that is relevant for security prices in other markets. For example, distress on a bond market may cause immediate price movements on the swap market with these bonds underlying before the bond price is adjusted. This is because the swap market is more liquid than the bond market. Key feature in this mechanism is that contagion occurs rapidly via the price-discovery process. Dornbusch, Park, and Claessens (2000) describe direct effects occurring through fundamentals such as trade links. Kiyotaki and Moore (2002) describe a balance sheet channel in which losses in one market translate into declines in equity of other firms holding the distressed assets. King and Wadhwani (1990) describe a contagion model in which rational agents attempt to incorporate information from price changes in other markets.

Second, Allen and Gale (2000), Brunnermeier and Pedersen (2009), and others describe mechanisms in which contagion occurs through a liquidity shock across all markets. This channel is referred to as the 'liquidity channel'. In this mechanism, a shock to one financial market causes a decrease in the overall liquidity of all financial markets. A key implication of this channel is that distress may be associated with subsequent declines in credit availability and increases in trading activity in other markets. Allen and Gale (2000) describe a channel of banks having crossholdings of deposits across regions. Financial shocks then may cause banks to liquidate these crossholdings, causing liquidity concerns in other regions. Kodres and Pritsker (2002) describe a channel in which losses in one market forces investors to liquidate leveraged positions or to rebalance their portfolios. Brunnermeier and Pedersen (2009) describe a mechanism in which losses in a market reduce the ability to obtain funds which results in a decline in the liquidity of other financial assets in the market. These different theories indicate that shocks can be transmitted multi-dimensional; across regions, the financial sector and asset classes. However, one must note that this spiral-effect may play out over the longer period.

Third, Vayanos (2004), Acharya and Pedersen (2005), Longstaff (2008), and others describe mechanisms in which contagion occurs through a 'credit risk channel'. In this mechanism, a financial shock can affect the willingness of investors to have exposures of risk in any market. This has an effect on other markets as the risk-premium will be adjusted. Vayanos (2004) and Acharya and Pedersen (2005) describe mechanisms in which shocks resulting from financial distress cause major changes in the equilibrium of risk premia of assets in the economy. An important implication of this mechanism is that shocks to the return of the distressed security may be predictive for the subsequent returns of other assets.

In general, any tests based on the concept of financial contagion as defined above avoids taking a stance on how this shift occurs and avoids having to directly measure and differentiate between the various mechanisms of transmission. However, identifying whether structural breaks in cross-market linkages exist could provide evidence for or against certain theories of the transmission of shocks and may indicate which propagation mechanisms are most important.

There is extensive empirical literature on testing for contagion and the propagation of shocks. Most common are tests based on cross-market correlation coefficients. These tests examine whether there is a significant increase in correlation coefficients after a shock to one market, by measuring correlation in returns between two markets during both stable and crisis period. A significant increase in this coefficient then would indicate the presence of contagion. King and Wadwhani (1990) are the first that used this approach in a major paper. They test for an increase in stock market correlations between the US, the UK, and Japan. Their results show a significant increase in cross-market correlations after the 1987 US stock market crash. Lee and Kim (1993) find more evidence of contagion by extending this analysis to twelve major economies. Calvo and Reinhart (1996) and Baig and Goldfajn (1998) apply this method to test for contagion in stock and bond market prices after the 1994 Mexican peso crisis and the 1997 Asian crisis respectively.

A second often used approach to analyze comovement between markets is to use an ARCH or GARCH framework. Although these tests can provide important evidence that volatility spillovers across markets took place, they often do not test for contagion as defined in this paper. By using this approch, Hamao, Masulis, and NG (1990) and Edwards (1998) present evidence of significant volatility spillovers during the 1987 US stock market crash and after the 1994 Mexican peso crisis respectively.

A third common approach is to test for changes in the cointegration vector between markets. These analyses consider long periods of time. Longin and Solnik (1995) use this method by considering seven OECD countries from 1960 to 1990 and find that average correlations between US and countries stock market returns have risen over this 30-year period. However, this approach does not test for contagion as defined in this paper since correlations over such a long period could increase for several reasons. Moreover, short periods of contagion can be overlooked.

A final approach is that of using probit models to test how a crisis in one country affects the probability of a crisis occurring in other countries. Eichengreen, Rose, and Wyplosz (1996) estimate such models in one of the first major papers using this approach and find that the probability of crisis in a country increases when more crises are occurring in other countries. Kaminsky and Reinhart (2000) find that the probability of a speculative attack to a country increases when another country is under attack.

Although systemic analyses of currency and financial crises emphasize different empirical regularities, the above evidence suggest that most shocks are transmitted through crisis-contingent channels and thus favor the conclusion that contagion occurred during the crisis that is investigated.

However, Boyer, Gibson and Loretan (1999) and Forbes and Rigobon (2002) recognize that cross-market comovements are often consistent with a stable cross-country linkage, so that they do not necessarily reflect discontinuities in the international transmission mechanism. See also King and Wadwhani (1990): "we might expect that the contagion coefficients would be an increasing function of volatility". Forbes and Rigobon (2002) demonstrate that the presence of heteroskedasticity in market returns can significantly affect estimates of cross-market correlations. Therefore, when market volatility increases in case of a crisis, tests will overstate the magnitude of cross-market linkages and may suggest that (shift-)contagion occurred, even while the underlying propagation mechanism did not change. Forbes and Rigobon (2002) analyze the 1987 US stock market crash, the 1994 Mexican peso crisis, and the 1997 Asian crisis. Their results show that with a correction[2] for the change in variances, correlation between cross-market returns are not significantly higher during periods of crisis. Lomakin and Paiz (1999) already addressed the problem of heteroskedasticity in tests for contagion in bond

[2] Forbes and Rigobon (2002) introduced a correction for the bias of heteroskedasticity (or 'conditional correlation') under the assumptions of no omitted variables and no endogeneity.

markets. The solution to this problem implies an adjustment of the correlation coefficient for the change in the volatility of returns in the country where the crisis originates, by introducing bivariate tests under the null hypothesis that cross-market linkages do not change during periods of crisis.

By applying these tests almost no periods of international spread of financial crises should be viewed as a structural break in the transmission mechanism. Accordingly, the peaks in cross-country linkages that emerge in periods of crisis seem to be just an implication of international interdependence. As a reaction to this, Corsetti, Pericoli & Sbracia (2005) investigate whether these results can be attributed to pitfalls in the testing procedure. They show that the strong result of 'no contagion, only interdependence' is biased due to arbitrary and unrealistic restrictions on the variance of country specific shocks. This biases the test of contagion towards the null hypothesis of interdependence. Their paper "some contagion, some interdependence" builds on a standard factor model with period-specific variance of stock market returns. Moreover, they recognize that the change in the variance of a crisis country may be due to either a common factor or country idiosyncratic risk. They apply this framework to the Hong Kong stock market crisis of October 1997, and find evidence of contagion for at least 5 out of the 17 sample countries, whereas previous tests only found evidence of contagion for 1 country.

This paper extends the analysis of Corsetti, Pericoli & Sbracia (2005) to that of the global financial crisis of 2007-2009. I will first analyze how this crisis originated and spread, in such a detailed way that is unique for economic literature so far. I believe that a proper empirical study on contagion effects should account for the fact that an increase in volatility of returns during a crisis, may be caused by higher variance not only of some common factor, but also of some country-specific noise. Namely, setting restrictions on country-specific risk factors can strongly bias the test towards the null of interdependence. My goal is to make some practical adjustments to the testing framework. The empirical analysis in this paper is based on stock market index returns as a proxy for the US market and several European regions. I think this analysis really contributes to earlier bivariate correlation analyses. Furthermore, this kind of contagion analysis is not carried out before with respect to the global financial crisis of 2007-2009.

The remainder of this paper is organized as follows. Section 2 explains the causes of financial contagion in general based on existing literature. Section 3 provides a specific analysis with regard to causes and international transmission mechanisms during the

2007-2009 financial crisis, and spillover effects to Europe. Section 4 explains the methodology, models and data employed to examine cross-market linkages between the US and Europe during the financial crisis. Section 5 presents and discusses the empirical results of my analysis and section 6 concludes my findings.

2. Exploring causes and international transmission mechanisms

In this section I explain several important causes of financial contagion that bring the international transmission mechanisms into play.

Dornbusch, Park & Claessens (2000) divide the causes of contagion into two categories. The first category emphasizes spillovers that result from the normal interdependence among market economies. Calvo and Reinhart (1996) refer to this as fundamental-based contagion. However, they argue that these forms of market comovement are not 'true' contagion, because they reflect the normal interdependencies between countries. The second category of causes of contagion refers to changes in behavior of investors or other financial agents and is not linked to macro-economic changes. Let us call this 'investor's rationality'.

Fundamental causes of contagion can be divided into common shocks, trade links, and financial links. Common shocks include common global causes, such as major economic shifts in industrial countries, changing commodity prices and a rise in world interest rates, which can trigger crises or large capital outflows from emerging markets.

Trade links are perhaps the most described fundamental causes of contagion in economic literature. The most straightforward type of trade links is bilateral trade between the crisis country and other countries. A large currency depreciation in one country could cause declines in asset prices or outflows of capital in any major trading partner of that country. This occurs because investors foresee a decline in exports to the crisis country. Another common type of trade links involves competition in a third market (Kaminsky and Reinhart (2000)). For example, think about the prominent role that the United States plays in trade with countries in Latin America. Now suppose that all these Latin American countries export bananas to the US. If one of these countries devaluates, the export competitiveness of the other countries reduces. This can put pressure on the currencies of the Latin American countries, especially those that are not freely floating. Corsetti at al. (1998) argue that a (non-cooperative) game of competitive devaluations can cause larger currency depreciations than necessary based on the fundamentals. Investors will anticipate on this by selling their holdings of securities in these countries and stop lending money.

Besides trade links, also financial links are among the fundamental causes. Financial links are similar to trade links and are part of the economic integration of an individual country into the world market. The higher a country is integrated economically, and thus the more financially linked with the rest of the world, the larger the financial effects of a financial crisis in one country has on other countries. Possible direct financial effects are reductions in trade credit, Foreign Direct Investment (FDI), and other capital flows. This could lead to an increase in the correlations of asset prices and capital flows.

Considering investors rationality, it can be argued that both ex-ante individually and collectively rational behavior which often lead to an increase in volatility, should be grouped under the fundamental causes of contagion. However, literature describes that investors behavior, whether rational of irrational, allows the transmission of shocks from one country to another. Calvo and Reinhart (1996) argue that this is 'true' contagion, which is the kind that arises when common shocks and all interconnected channels are either not present or have been controlled for (so excessive relative to the fundamentals). Again, it is useful to differentiate between the types of investor behavior. The first type includes investor behavior which is ex-ante individually rational, but leads to excessive comovements relative to the real fundamentals. Because this type of behavior is still quite broad, it can be further sorted into investors' actions related to liquidity and incentive problems, and information asymmetries and coordination problems.

Liquidity and other investor constraints are one form of individually rational behavior, which can lead to excessive comovements relative to the real fundamentals. For example, a large currency depreciation in one country or group of countries can cause international institutional investors to incur large capital losses. It may then be individually rational for these investors to sell off securities in other emerging markets in order to raise cash in anticipation of greater redemptions. Commercial banks located in a common-creditor country (for example, the US figures as a common-creditor for countries in Latin America) can also face liquidity problems if they experience a large decline in loan quality to one country. It may be rational for these banks to reduce their exposures in other emerging markets in order to reduce the overall risk on their loan portfolio. In a similar way, investors can sell holdings in other emerging markets as a reaction on a crisis in one country in order to maintain certain positions within their portfolios. This behavior can be explained by the value-at-risk models often used by commercial banks (Schinasi and Smith (1999)). These models are used as risk measure of the risk of loss on a specific portfolio or financial asset. In this way, actions undertaken by investors and financial institutions might be individually rational, but it can lead to undesired outcomes overall. Also financial derivatives, which have become very popular investment alternatives during the last decades, can lead to problems on larger scale. By lack of transparency and the often complex structures of such derivatives, banks can more easily avoid regulation and supervision.

The tendency to sell assets in several markets at the same time implicates that countries whose financial assets are globally traded and whose domestic financial markets are more liquid may be more vulnerable to contagion (Calvo and Mendoza (1998) and Kodres and Pritsker (1998)). Besides that, international financial agents try to diversify their portfolios which involves cross-market hedging of macroeconomic risks. Therefore, countries whose asset returns show high comovements with a crisis country will be more vulnerable to contagion (Kaminsky and Reinhart (1998)).

Information asymmetries and coordination problems can also cause financial contagion. In practice, investors are often not perfectly informed about a countries' true characteristics. They need to make investment decisions based on what they know, including the financial state of other countries. A financial crisis in one country may lead investors to believe that other countries will face similar problems. This imperfect information may not always reflect the true state of a countries' vulnerabilities. But in the absence of better information, this type of investors' behavior can reflect both (individually) rational as well as irrational behavior. Besides that, investors often base their decisions on the actions of other investors. In that way, informational asymmetries are generated on intra-investor behavior, which is called herd behavior. The cost of gathering and processing information partly explains why investors are not perfectly informed. Calvo and Mendoza (1998) show that in the presence of information asymmetries, fixed costs involved in gathering and processing country-specific information could lead to herd behavior, even when investors are rational. Especially for small investors it is relatively expensive to gather and process country-specific information.

Another, more general type of investors' behavior involves changes in self-fulfilling expectations that can generate multiple equilibria. For example, when there is serious threat of contagious effects from one to another emerging market, it is rational for individual depositors to either hold their funds in the bank or withdraw their funds depending on the actions of other depositors. Both a bad equilibrium, in case of a bank run, and a good equilibrium, in case of depositors keeping their funds in the bank, are possible outcomes. In practice, investors can suddenly change behavior causing a shift from a good to a bad equilibrium. In order to explain such shifts in equilibria, several models have been developed (Masson (1998) and Jeanne (1997)). However, because of the many factors by which this shift can be triggered, it is hard to model the possible outcomes empirically.

Finally, contagion can be caused by changes in investors' perspective on the rules of how international finance takes place. For example, concerns on whether banks will be bailed out in times of financial distress may change views on the rules regarding the bail out of banks. Also rules regarding the supply of liquidity might change during period of financial turbulence. If the IMF provides liquidity for one country, concerns may rise about whether the IMF will be able to handle more liquidity crises.

3. Contagion in the financial crisis of 2007-2009

In this section I first explain the causes and channels through which the US subprime mortgage crisis was able to spread in the way it did. After that I analyze the spillovers to other markets, Europe in particular.

3.1 The US subprime mortgage crisis

Looking back at the development of the financial or credit crisis of 2007-2009, it is hard to imagine that the spread of the crisis was not due to contagious effects. Especially multinational financial institutions were hit hard and seemed to fall down one by one like domino blocks. Nowadays, firms are much more interconnected than before and so problems within one firm can easily spread to another. For economic research on financial contagion, this crisis is very interesting because of the many dimensions of spreading. Problems spread from the financial sector to the real economy, from one firm to another, from one asset type to another, from country to country, and from financial institutions to financial markets. In this subsection I first analyze the origins of the crisis, followed by the different channels through which the crisis could have spread.

The 2007-2009 financial crisis started in the summer of 2007, with the outbreak of the so called 'subprime crisis' in the United states. Many financial institutions with positions in the subprime loan tranche (via securitization) faced losses. At that time, Lehman Brothers had large positions in these lower-rated tranches and faced huge losses throughout 2008. In September 2008, just after the takeover of Bear Stearns by JP Morgan Chase, Lehmon Brothers collapsed. By the end of 2008, this resulted in a worldwide deep recession often compared with the great recession of the 30's (admitted that the effects are now less severe, particularly for 'the normal citizen'). There are several theories about the origin of financial crises. One can roughly distinguish between the following five explanations: Macroeconomic developments and leverage, behavioral factors and speculation, shift to liquidity and safety, management failure and institutional weaknesses. All these factors seem to have played a role in the 2007-2009 crisis. For example, the low interest-rate policies of the Fed have contributed to the rise in housing prices since 2001, however more factors are needed in order to explain the housing bubble and the effects on the economy. Probably, one of the main causes of the crisis can be attributed to a worldwide change in society. People are being more individualistic and factors like the way of remuneration in the financial sector stimulates greedy and more risky behavior of financial agents. Deregulation pressure and new accounting rules, in combination with more complex products (structured products) made it possible for banks to operate in such way.

But how could it have come so far? And why could the losses on the collapsed US housing market led to a system wide downfall? For example, the 2001 bursting of the so called 'tech bubble' caused a greater direct wealth loss in the US then the bursting of the housing bubble. A key term occurring here is 'leverage'. Leverage is borrowing money to amplify the outcome of a deal. The financial institutions supplying real estate financing are highly leveraged. So even a modest decline on for example mortgages could be a threat for the solvency of banks with large exposures to these mortgages. However, in the presence of a proper policy for the allocation of losses, this does not need to be a major problem. Policymakers on the other hand, provide a safety net for large financial institutions because of the fear of a total system breakdown if these large financials fall. But this form of guaranteed safety triggers banks to take excessive risk on their investments and creates frictions in the allocation of losses.

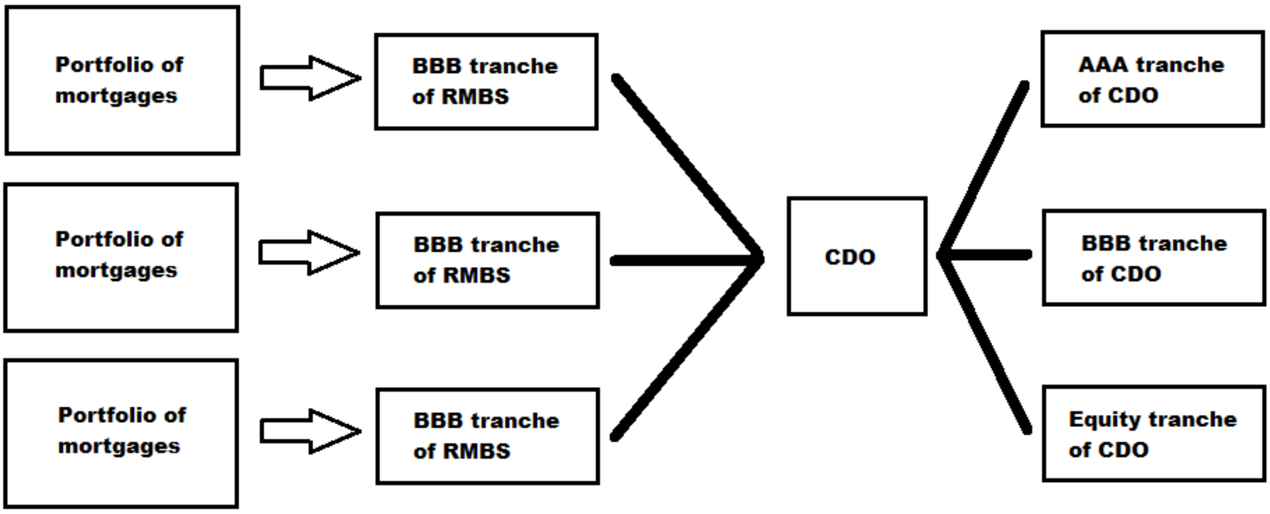
Despite the fact that financial crises often have similar origins, the way shocks are transmitted between markets are quite unique. Dungey et al. (2011) examine five different crises (among which the global financial crisis of 2007-2009, from now on called GFC) to find out which of the three channel-types is responsible for the majority of observed volatility in each crisis. The three channel-types are: market, country and idiosyncratic. The results[3] clearly show that, considering the US during the GFC, contagion via idiosyncratic channels is responsible for the major part of the observed volatility, followed by market channels. Country channels are not significantly responsible for any of the observed volatility. These results differ a lot with the other observed crises, for example the Russia (LTCM) crisis of 1998 and the 2001 Tech crisis, which generally indicates that crises are very different in nature of how they spread.

The key to understand how the GFC could have spread are the so called 'subprime securities'. These are securities based on subprime mortgage loans. Subprime mortgages are commonly defined as loans issued at high rates to borrowers with lower credit quality. Triggered by the worldwide demand for exposures in the US housing market, complex structured financial products were created, called Collateral Debt Obligations (CDO). These are a type of structured asset-backed security often issued by special purpose entities and collateralized by debt obligations including bonds and loans.

[3] Based on stock market return volatility.

Nowadays, banks often sell mortgages instead of holding it to maturity. These mortgages are sold to an investment bank, who securitize these mortgages by putting a whole bunch of mortgages together to form a Residential Mortgage Backed Security (RMBS). These RMBS are sold to investors, who receive the payments on mortgages by households. However, not all holders of the RMBS bare the same risk as these securities are cut into 'tranches'. Each tranche is rated from AAA to equity level. First the highest/ safest AAA tranche receives the mortgage payments. If there are funds remaining, the lower tranches receive payments making them more risky. CDO's are created from tranches of RMBS's and the CDO is again cut into tranches which are rated from AAA to equity level and has the same waterfall structure of payments. The complex structure of CDO's build up from mortgages is illustrated in figure 1.

Figure 1: CDO structure



This figure shows how a Collateral Debt Obligation (CDO) is produced out of portfolios of mortgages. CDO's are cut into several tranches, each representing a certain amount of risk.

As long as everyone is paying off the mortgages, the CDO structure does not have to be a problem. The thing is, if some people stop paying off their mortgages how much are the CDO tranches then worth? This is very hard to determine, since the value of the CDO depends on the underlying mortgages. Moreover, CDO's are traded over the counter instead of on exchange with readily available market prices. But what exactly went wrong? Until 2007 housing prices in the US rose substantially, but then began to fall. This was mainly because people with subprime mortgages defaulted on their loans and banks had to sell the houses creating more supply then demand. Also people with fixed-rate mortgage contracts that ended by this time had to suddenly pay a higher interest rate on their loans. Because of the decline in housing prices, more people (also with prime mortgages) stopped paying off their mortgage. Now the investment banker has a portfolio of worthless mortgages and investors don't want to buy the CDO's anymore. Funds flowing on the CDO's dried up. The banker has a huge problem since it borrowed huge amounts of money to buy the CDO and can't pay this back. Since CDO's were purchased by entities all around the world, the risk was spread far outside the borders of the US and the whole financial system froze. Moreover, also problems with the valuation of CDO's created great concerns across the financial system about the solvency of many financial institutions. These problems were heightened with the bankruptcy of Lehman Brothers.

More important in light of my empirical research is to analyze the rapid transmission of the US subprime mortgage crisis to other economies around the world. It is important to notice that during turbulent times, new transmission mechanisms establish through which liquidity shocks and credit risks are being transmitted from one market to another. I will first analyze through which transmission mechanisms liquidity shocks were transmitted across financial markets during the GFC. A key question within this analyses is how the funding illiquidity of complex structured products like CDO's could have led to severe solvability problems of several financial institutions.

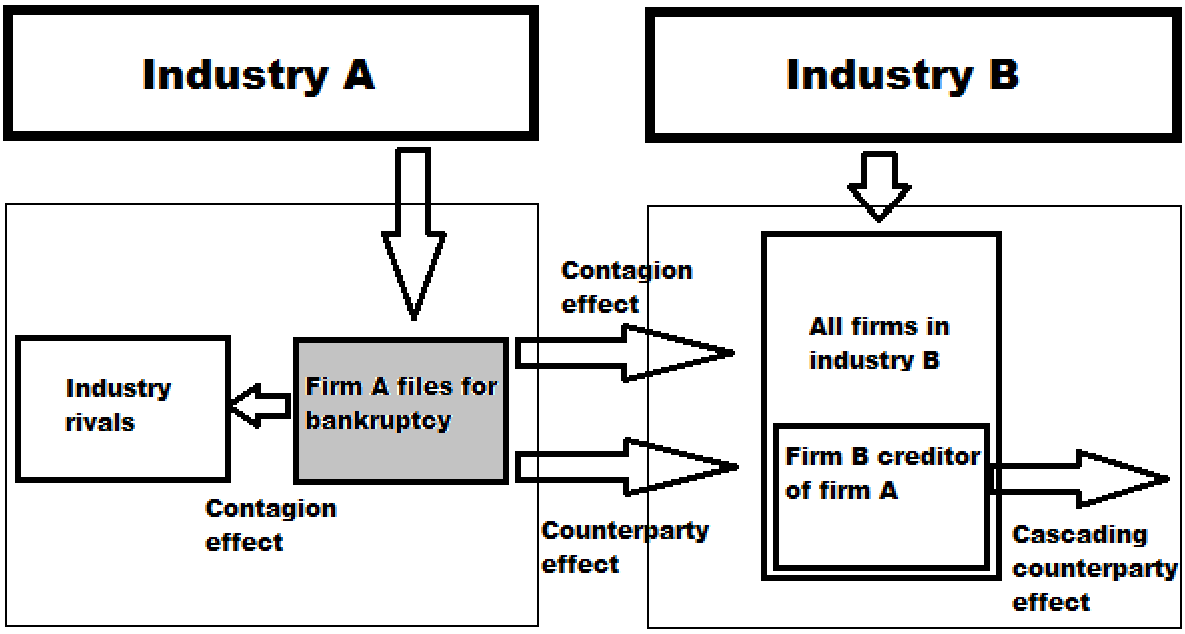
The nature of liquidity shocks, or actually illiquidity shocks, is different between stable and crisis periods. During stable periods, liquidity shocks are typically short lived as they create arbitrage opportunities for traders. This in turn provides liquidity within the market which eliminates the imperfection and contributes to a fairer price. However, during more turbulent times several new established mechanisms may amplify liquidity shocks across financial markets, creating systemic risks. These shocks can be directly transmitted through balance sheets of financial institutions and indirectly through asset prices. Namely, if financial institutions face mark-to-market losses price movement are set in motion. In order to sustain the same leverage position, more debt has to be paid off. But if asset prices are significantly affected, the creditworthiness of the financial institutions deteriorates because of increasing default risk. As a consequence yields will rise and leverage is pro-cyclical and amplifies the financial cycle. This is what also happened during the recent GFC. To get a better understanding of what happened within the various segments of US financial markets, I will distinguish between market liquidity and funding liquidity. Market liquidity is the ease with which an asset can be sold without causing a significant movement in its price and with a minimum loss of value. On the other hand, funding liquidity is the ease with which a solvent agent is able to borrow in the market in order to service outstanding obligations.

So what happened during the GFC? The initial shock in the form of deteriorating quality of subprime mortgages in the US in the summer of 2007 was rather a credit than a liquidity shock. This shock could easily spread because of a high degree of asymmetric information associated with the complexity of the structured mortgage products. Also a widespread reprising of risk and decreasing risk appetite of investors contributed to the spread. The consequent increase in delinquencies on subprime mortgages affected the value of structured products with these mortgages underlying. The following losses, downgrades and changes in methodologies by rating agencies crushed investor's confidence in the rating agencies' abilities to determine risk associated with complex products. As soon as it became clear that a wide range of financial institutions had huge exposures to these mortgage-backed securities, often through off balance entities such as structured investment vehicles (SIV), banks came under increasing pressure to rescue those that they had sponsored by providing liquidity or taking assets on their own balance sheets. Both the market for mortgages and leverage dried up mainly because investors became unwilling to roll over short-term asset backed contracts with which the SIV's were financed. Because of increasing liquidity and credit risk, the interbank lending decreased which severely affected money markets. Funding cost increased as LIBOR spreads widened. As the uncertainty and turbulence related to subprime mortgages heightened, investors massively moved away from complex structured products to safer and more liquid assets. This is commonly referred to as 'a flight to liquidity' (and transparency). The reduced liquidity also affected hedge funds that held asset backed securities. More often, margin calls were needed and more liquid parts of portfolios were offloaded in order to meet the margin requirements. Many European banks with large exposures to the US asset-backed securities suffered from funding illiquidity, which resulted in subsequent market illiquidity in different market segments.

The deterioration of market and funding liquidity had implications for the solvency positions of banks for several reasons. First, the decline in value of the asset-backed securities affected the balance sheets of financial institutions, resulting in huge write-downs. Second, funding (il)liquidity shocks forced rapid deleveraging by banks, which reduces asset prices. Third, increasing money market spreads further increased funding liquidity. These pressures resulted in declining capital ratios across the financial sector and increased credit default swap spreads.

Second, I analyze through which transmission mechanisms credit shocks can be transmitted across financial markets during financial crises. Credit contagion often refers to the clustering in default probabilities. Recent developed models attempt to account for this default clustering. These models can be classified into two approaches. The first is referred to as the common factor approach. These models can be made more complex by putting in multiple factors and account for non-linear relations between certain factors (for instance by implementing copulas). The second approach refers to credit contagion from counterparty risk. Figure 2 shows channels of credit contagion.

Figure 2: Credit contagion



This figure illustrates how credit contagion can occur through counter-party and common factor effects within and across industries.

This figure can be interpreted as follows. When firm A files for bankruptcy, one generally expect negative effects for other firms in the same industry. These negative contagion effects reflect negative common shocks to the prospects of the industry. This may lead to further failures in Industry A. However, there is also a positive competitive effect because the failure of a firm could help competitors to gain market share. Generally, the net effect is intra-industry contagion.

Credit contagion from common factors can arise within an industry, but also across industries. Suppose Industry A is a major client of Industry B. The failure of firm A could have a negative effect on sales prospects for firms in Industry B. This may lead to failures in Industry B.

Like already mentioned, there is also credit contagion from counterparty risk. This effect arises when the default of a firm causes financial distress for its creditors. Going back to figure 2, suppose that firm B has an outstanding loan to firm A and firm A goes bankrupt. This would cause a direct loss to firm B, possibly causing financial distress, even if it is in a different industry. On top of that, this may cause cascading counterparty effects to other firms. However, this makes an analysis very complex as firms may hold each other's debt and because of the complex structure of interdependencies. Think about the web of interdependencies that are present throughout the financial sector during the GFC. Upper (2007) suggests that pure counterparty contagion in the interbank market is rare, but when it happens the costs could be high. Moreover, when the first bank failure is due to common factors that affect other banks, the probability of a systemic crisis increases greatly.

Empirical results from Jorion and Zhang (2009) suggest that in case of a borrowers bankruptcy, creditors experience negative excessive equity returns and increases in their credit spreads. However, the counterparty effect on equity prices seems to be more important for industrials than for financials. But price movements cannot fully identify the cascading of counterparty effects for large financial institutions as they are often bailed out by regulators. So probably other effects play a more prominent role. Further research of Jorion and Zhang (2009), which allows to evaluate counterparty risk directly, is based on the bankruptcy announcement of Lehman Brothers Holdings in September 2008. The results suggest that counterparty risk is indeed a channel of credit contagion. The effect seems to be stronger when the originator is a financial firm and during turbulent periods.

3.2 Spillover effects to Europe

The US subprime crisis, which started in the US financial sector, rapidly spread to other sectors of the economy but also to other countries. This resulted in a collapse of the banking sector, stock market crashes, illiquidity on credit markets, economic recession, and caused sovereign solvability problems for many countries. Drops in productivity growth, increases in unemployment rates, and a slowdown of international trade were among the effects on the real economy. In this subsection I analyze some findings on contagion of the US subprime crisis to international stock markets, particularly Europe.

An important feature of the GFC is that investors became relatively late apparent of the seriousness of the crisis. In earlier stages of the crisis, right after the bursting of the housing bubble, investors rebalanced their portfolios from risky assets related to the subprime mortgages to other risky assets. Only when prices of most risky assets declined and large US financial institutions failed (Lehman Brothers, Bear Stearns, Merrill Lynch, Goldman Sachs and Morgan Stanley), investors panicked and started to rebalance their portfolios from risky assets to risk-free assets. Because credible information was relatively expensive during the crisis, investors followed major investors in making decisions, which is referred to as herd behavior. This behavior led to a sudden increase in dependencies between international stock market returns.

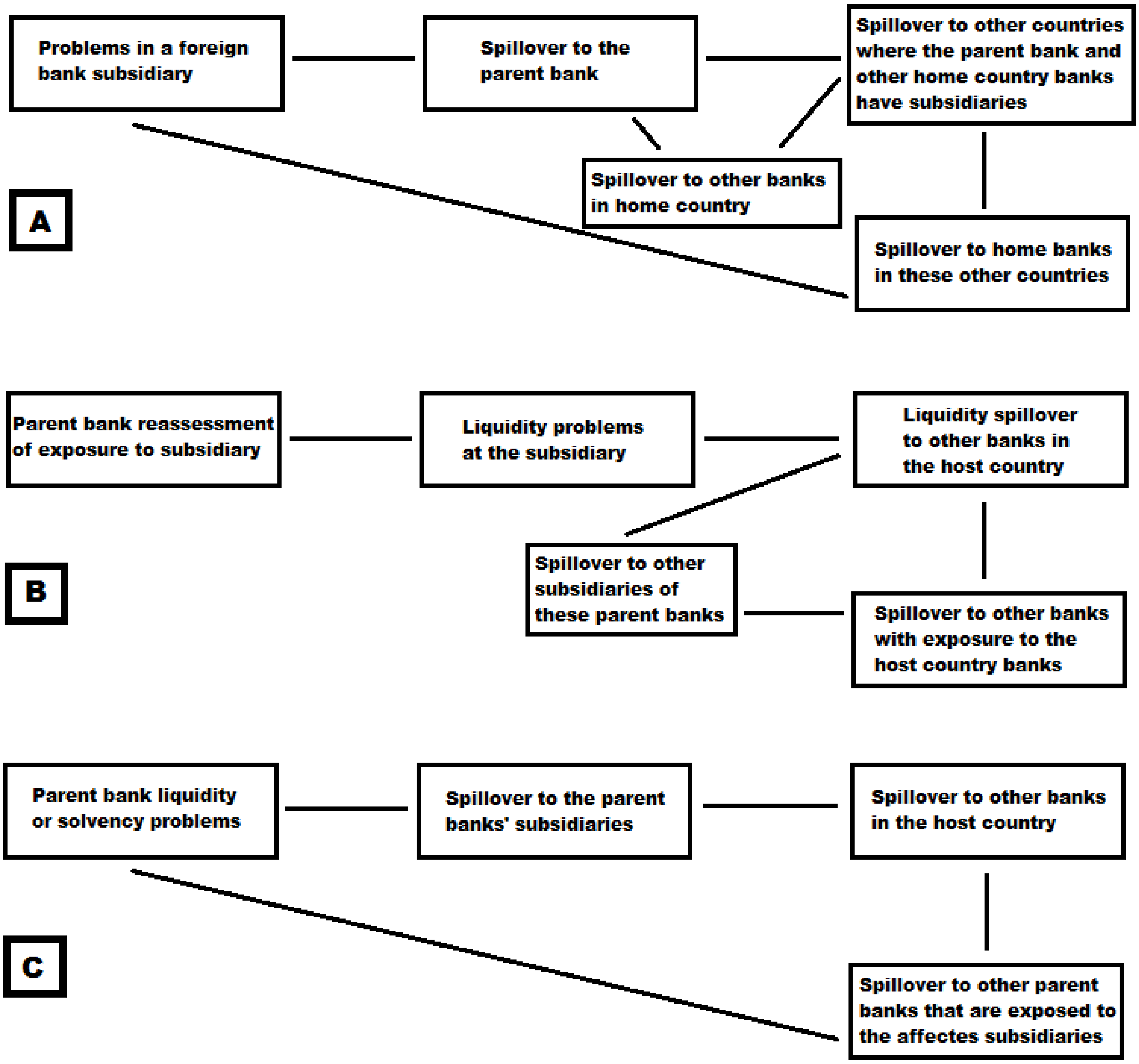
A prominent spillover effect during the GFC is that of announcements regarding sovereign credit ratings. This can have major implications for investors because sovereign bond markets figure as benchmark for all other bond markets and they give an indication of a countries risk level. Gande and Parsley (2005) divide the spillover effects of sovereign credit ratings in two categories, namely common information effects and differential effects. Common information effects basically mean that a positive sovereign credit event causes a positive credit event in other sovereigns, because it could signal a widespread common trend. In this case, the financial markets across countries would be more correlated. On the other hand, differential effects mean that a positive sovereign credit event causes a negative credit event in other sovereigns, because it could reveal the relative unattractiveness to investors of these other countries. In this case, financial markets across countries would be less correlated. Empirical research done by Hwang, Francis, and Kim (2010) suggests that there were indeed spillover effects on dependencies for both up- and downgrades of sovereign credit ratings during the GFC. However, the effects are different for up- and downgrades. Sovereign credit rating upgrades seem to have differential effects, while downgrades seem to have common information effects.

The US subprime mortgage crisis could easily spread to markets in Europe, because of the high exposures European financial institutions had in the US subprime market via structured products. Moreover, within Central, Eastern, and Southeastern European countries (CESE) the foreign ownership levels of the banking system are among the highest in the world. Important to notice is that also the financial interlinkages between these CESE and the more developed Western European countries has grown substantially in the past decade. Especially because of Western European banks taking advantage of the opportunity to expand their presence in the CESE banking systems. Private sector credit grew rapidly and dependence on non-deposit funding increased in many CESE countries, resulting in high loan-to-deposit (LTD) ratios. Deposit growth in these countries has not been able to keep up with the rapid credit growth, resulting in credit-to-GDP ratios exceeding deposit-to-GDP ratios. The increasing LTD ratios in CESE countries made them more dependent on foreign funding through the banking sector. This increased the risk of emerging European countries to shocks in advanced economies. The problem is that these countries are less able to handle large variations in liquidity and fund flows.

With the outbreak of the GFC, many so called 'parent banks' in Western Europe faced liquidity problems. Although reputational risk and long term business links give these banks incentives to support their subsidiaries, funding conditions in the home countries forced banks to slow lending and liquidity provision abroad and at home.

There are several channels through which financial shocks can be transmitted between home and host countries banking systems. Figure 3 illustrates some of these channels.

Figure 3: Transmission channels of financial shocks



This figure shows three possible ways through which financial shocks to an international financial system of parent- and subsidiary banks can cause negative spiral effects.

Figure 3A illustrates the situation in which the private sectors of two countries, call them A and B, borrow mainly from the banking system of a third country C (the parent bank). Assuming that C is highly exposed to A, a financial shock to A may result in liquidity or solvency pressures on the banks of C. Subsequently, the problems may spill over to B, even while A and B are not directly linked economically. Other parent banks with exposures to the affected subsidiaries may also be affected, creating second-round effects.

Figure 3B illustrates the situation in which a parent bank reassesses its exposure to its subsidiary. A withdrawal of deposits or credit lines and reduced lending to a subsidiary may cause liquidity problems for the subsidiary. These problems may spill over to other banks in the host country and in turn to parent banks with exposures to the affected subsidiaries, creating spiral effects.

Figure 3C illustrates the situation in which contagion goes in the other direction, namely subsidiaries affected by problems started in a parent bank. Liquidity or solvency problems in a parent bank may spill over to its subsidiaries. Other banking systems in the host country may be affected through a deterioration in confidence and may in turn spill over to other parent banks, again creating spiral effects.

The magnitude of these possible contagion effects generally depend on the size of the exposures of parent banks to the host country, and the dependence of the host country on foreign funds.

4. Methodology and data

4.1 Methodological testing framework

In this section I present the empirical model and specific methodology that is used to test for contagion in the 2007-2009 financial crisis. Moreover, I discuss the data that is used in my analysis and I explain how the tranquil and crisis period are determined.

In order to test for structural breaks in the international transmission mechanism I use a correlation analysis approach. The tests are based on the theoretical and empirical framework issued by Corsetti et al (2005) and consists of two elements. The first is a data generating process of stock market returns in one of several European countries (i) and the USA (j), in which the latter is the country of 'origin' of the international financial crisis. As a starting point for the analysis, I specify a standard single-factor model:

$$r_j = \alpha_0 + \alpha_1 f + \varepsilon_j$$

$$r_i = \beta_0 + \beta_1 f + \varepsilon_i$$

where r_j and r_i are stock market returns in country j and i respectively, α_0 and β_0 are constants, α_1 and β_1 are country specific factor loadings indicating the strength of cross-country linkages, f is a common factor, ε_j and ε_i denote idiosyncratic country-specific factors, with f, ε_j and ε_i being mutually independent random variables with finite variance. The use of stock market returns in my analysis is valid based on empirical literature. Moreover, Candelon, Hecq, and Verschoor (2005) presume that adopting different real variables, such as industrial production may indicate which propagations mechanisms are most important. However it is not my goal to indicate specific mechanisms, market stock indices also capture these real variables. And specifically, Johnson (2010) suggests that the banking sector was not the primary cause of the 2007-2009 financial crisis, so that the crisis may have been triggered by other complex factors in the overall economy. Therefore I use market stock indices rather than financial/banking stock indices.

The second element consists of two important assumptions: (1) 'tranquil' (T) and 'crisis' (C) periods can be identified using institutional information, and (2) the variance of r_j is higher in the crisis period as a result of changing periods. These assumptions mainly correspond to existing literature. However, I recognize that the variance of r_j may be due to either the common factor f, or the country-specific risk ε_j, or both. Namely, I assume:

$$Var(f|C) = (1+\delta_1)Var(f|T)$$

$$Var(\varepsilon_j|C) = (1+\delta_2)Var(\varepsilon_j|T)$$

$$Var(\varepsilon_i|C) = Var(\varepsilon_i|T) = Var(\varepsilon_i)$$

$$Cov(\varepsilon_i,\varepsilon_j|C) = Cov(\varepsilon_i,\varepsilon_j|T) = 0$$

where δ_1 and δ_2 are the proportional increases of the variance in the common factor and country-idiosyncratic risk respectively. So less algebraic I assume that the change in variance of f and ε_j are determined uniquely. Further I assume that the variance of ε_i and covariance between the country-specific risk factors is equal for both tranquil and crisis period.

Based on the standard single-factor model and set of assumptions just described, the correlation coefficient (ρ) between r_i and r_j can be formulated as:

$$\rho^T = \left(1+\frac{Var(\varepsilon_i)}{\beta_1^2 Var(f|T)}\right)^{-\frac{1}{2}}\left(1+\frac{Var(\varepsilon_j|T)}{\alpha_1^2 Var(f|T)}\right)^{-\frac{1}{2}}$$

in tranquil periods and

$$\rho^C = \left(1+\frac{Var(\varepsilon_i)}{\beta_1^2 Var(f|C)}\right)^{-\frac{1}{2}}\left(1+\frac{Var(\varepsilon_j|C)}{\alpha_1^2 Var(f|C)}\right)^{-\frac{1}{2}}$$

in crisis periods. The problem with these correlation measurements is that the ρ depends on how movements in the common factor affect returns ($\alpha_1^2 Var(f)$ and $\beta_1^2 Var(f)$), relative to the movements in the country-specific risk factors ($Var(\varepsilon)$). Suppose that in the occurrence of a crisis the volatility of r_j increases. Holding α_1 and β_1 constant, the effect on the correlation coefficient will depend on the extent to which the increase in volatility is due to the variance of the common factor, relative to the variance of country-specific noise. If movements in the common factors are relatively large, the correlation rises. If country-specific movements are relatively large, the correlation falls. The point is*, that even if the strength of cross-country linkages α_1 and β_1 do not change, correlations may still increase or decrease during a period of crisis*. So this does not provide evidence in favor of contagion as I defined it, since this does not indicate a structural break in the transmission mechanism of shocks (a change in α_1 and β_1).

Therefore, a test of contagion should at least distinguish between breaks due to shifts in the variance of common factors, and changes in the values of α_1 and β_1. Corsetti et al (2005) define a measure of interdependence (Φ)[4] which corrects for the increase in the variance of r_j:

$$\Phi = \rho^T \left(\left(\frac{1+\lambda_j^T}{1+\lambda_j^C} \right) \frac{1+\delta}{1+(\rho^T)^2 \left(\frac{(1+\delta)(1+\lambda_j^T)}{1+\lambda_j^C} - 1 \right)(1+\lambda_j^T)} \right)^{\frac{1}{2}}$$

where λ_j^T and λ_j^C, the 'variance ratios', reflect the relative importance of the variance of idiosyncratic shock ε_j compared to the variance of the common factor in tranquil and crisis period respectively:

$$\lambda_j^T = \frac{Var(\varepsilon_j|T)}{\alpha_1^2 Var(f|T)} \qquad \lambda_j^C = \frac{Var(\varepsilon_j|C)}{\alpha_1^2 Var(f|C)}$$

so that a larger variance ratio implies a relatively smaller importance of the common factor during tranquil and crisis period, and vice versa. The formula of the measure of interdependence adjusts for a change in this relative importance of both type of factors during crisis periods. Furthermore, δ is the proportional change in the variance of stock market returns in the crisis country:

$$Var(r_j|C) = (1+\delta)Var(r_j|T)$$

The measure of interdependence is the correlation under the assumption that the intensities of cross-country linkages α_1 and β_1 do not change between tranquil and crisis periods. Therefore, the null hypothesis assumes a continuation of the international transmission mechanism of shocks (interdependence). As opposed to interdependence,

[4] For the derivation of this formula I refer to Corsetti, Pericoli & Sbracia (2005), appendix I.

contagion occurs if the increase in correlation during a crisis turns out to be too strong to be explained by the behavior of the common factor and the country-specific factors. In that case ρ^c will be significantly larger than Φ. Although this testing framework is symmetrical and therefore can be applied to both increases and decreases in cross-market correlations[5], I test for contagion as an increase in these correlations. Hence, I test the following hypothesis:

$$H_0 : \rho^c \leq \Phi$$

$$H_a : \rho^c > \Phi$$

Based on this testing framework Corsetti et al (2005) first test threshold values for λ_j^T and λ_j^C at which the test would reject the null of interdependence in favor of contagion at a certain confidence level. They choose this approach because they want to express the importance and central role of the variance ratios in this testing framework. Moreover, to clarify the meaning of the critical thresholds for λ_j^T and λ_j^C, they first consider the case in which $\lambda_j^C = \lambda_j^T = \lambda_j$[6]. Therefore they look for the minimum value of λ_j for which the null of interdependence would be rejected at a certain confidence level. In a similar way they consider the case in which $\lambda_j^C \neq \lambda_j^T$. They look at the minimum value of λ_j^C for any given λ_j^T for which the null of interdependence would be rejected at a certain confidence level. They do this by deriving λ_j^C as a threshold function of λ_j^T. As a second step they compare these threshold values with estimates of the variance ratios. When these estimated values are above the thresholds, they interpret these results as evidence for contagion.

In my opinion the testing approach used by Corsetti et al (2005) focuses too much on highlighting the sensitivity of test results to different values of the variance ratios (which indeed is the specific goal in their paper!), and with it the threshold values of these ratios. My goal is to make this testing procedure more applicable for empirical testing purposes.

First, I ignore considering the case in which $\lambda_j^C = \lambda_j^T = \lambda_j$. This assumption is purely of theoretical nature in order to make a comparison with previous research. In fact, this implies the unrealistic assumption that there is no relative change in shocks due to

[5] Also see this point as a contribution to the discussion later on in this paper.

[6] See the discussion later on in this paper about the sensitivity of this test to the variance ratios and why they consider this case.

common as opposed to country-specific factors during a crisis. Moreover, the relationship between variance ratios and correlation coefficients is already made clear by Corsetti et al (2005).

Second, as opposed to their testing approach, I take regression-estimated variance ratios as a starting point to calculate the Φ statistic. After that I test whether ρ^c is significantly larger than Φ by using a Fisher Z-transformation[7]. In formula:

$$z = \frac{z_1 - z_2}{\sqrt{\frac{1}{N_1 - 3} + \frac{1}{N_2 - 3}}}$$

where N_1 and N_2 are the number of observed returns in tranquil and crisis period, and z_1 and z_2:

$$z_1 = \frac{1}{2}\ln\left(\frac{1+\rho^c}{1-\rho^c}\right) \qquad z_2 = \frac{1}{2}\ln\left(\frac{1+\Phi}{1-\Phi}\right)$$

From the z-score obtained from the Fisher test, I calculate the corresponding p-values from which I conclude whether there is evidence of contagion or not[8]. Note that the difference with Corsetti et al (2005) is that in my analysis p-values, based on regression-estimated variance ratios, rather than threshold values play a central role in finding evidence of contagion.

Third, besides these results I calculate the threshold values of the variance ratios for which the null of interdependence would be rejected at a 5% confidence level. I derive the threshold values for λ_j^T and λ_j^C in a way that is slightly contradicting to the article of Corsetti et al (2005), but is way more practical. In case of the assumption that λ_j^T is equal to λ_j^C, the threshold values can easily be derived from the threshold function:

$$z(\rho^c) - z\left(\Phi\left(\lambda_j^T, \lambda_j^C\right)\right) = \psi\sigma_z$$

[7] This procedure is also adopted by Corsetti et al (2005).

[8] At a 5% and 10% confidence level.

where $z(\rho^c)$ and $z\left(\Phi\left(\lambda_j^T, \lambda_j^C\right)\right)$ are equal to z_1 and z_2 respectively, ψ is the z-score limit (a constant) and thus depending on the chosen confidence level, and σ_z is equal to:

$$\sqrt{\frac{1}{N_1 - 3} + \frac{1}{N_2 - 3}}$$

as in the Fisher formula. Corsetti et al (2005) state that in case of the assumption that λ_j^T and λ_j^C are not equal, the threshold function can be rewritten to:

$$\left[1 + \frac{{\rho^T}^2\left(\delta\left(1 + \lambda_j^T\right) + \left(\lambda_j^T - \lambda_j^C\right)\right)}{1 + \lambda_j^C}\left(1 + \lambda_j^T\right)\right]\left(\frac{1 + \lambda_j^C}{1 + \lambda_j^T}\right)^2 - \left(\rho^T * \frac{\omega + 1}{\omega - 1}\right)^2 (1 + \delta) = 0$$

where ω is:

$$\exp[2(z(\rho^c) - \psi\sigma_z)]$$

and which implicitly defines λ_j^C as a function of λ_j^T,δ, ρ, and ω.

However, instead of setting λ_j^T fixed as in the latter function, I determine threshold values for λ_j^T and λ_j^C by letting them both float, based on the former threshold function. This is accomplished by solving the threshold function for variations in both threshold values. By using the Solver function in Excel I set the initial calculated p-value equal to 0,05 (corresponding to a 5% confidence level) to find the corresponding values of both variance ratios, restricted under the threshold function.

As the threshold values of variance ratios are not of central concern in my analysis, I choose for this approach, because I simply want to show the sensitivity of the applied testing procedure to the variance ratios. Therefore, it is not of crucial concern to determine λ_j^C conditional on λ_j^T which can form a basis for testing on contagion. Moreover, the latter conditional threshold function violates the assumption of independent samples, as δ depends on both the tranquil and the crisis period samples. This is not the case if I use the first approach, as δ is different for λ_j^T and λ_j^C.

4.2 Data

From Thomson Reuters DataStream I collect daily US, European, individual European countries, and global stock market index prices as well as Euro-to-Dollar and Pound-to-Dollar exchange rates, all of the period march 2000 until march 2012. From this data I calculate two-day rolling averages of daily Dollar[9] returns. These returns form the basis for my regression analyses performed with Eviews. Cross-country linkages α_1 and β_1 are obtained by regressing the stock market returns of country j and i on the global stock market returns.

As a proxy for the US market (country j) I use S&P500 and NYSE composite (from now on: NYSE) stock index returns. As a proxy for the European market (country i) I use Euronext and S&P350 stock index returns as well as stock index returns from several national stock indices.

As a proxy for the common factor (f) Corsetti et al (2005) calculate the average daily return in a cross-section of sample stock markets. As an alternative proxy, they prescribe to use a world stock market index. I choose to use the latter option, for which I collect MSCI world index returns from Thomson Reuters DataStream.

In order to calculate variances of returns and common factors I use the following formula[10]:

$$Var = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2$$

The variances of the error terms are calculated by squaring the standard errors obtained from regressions.

Determination of the tranquil and crisis period is not that easy. Economic research shows that, despite strong market comovements, cross-market correlations are not always higher in periods of crisis. There are peaks of correlation in both tranquil and crisis periods[11]. This again raises the importance of determining between country-specific factors, as opposed to common factors. In my analysis I define tranquil and crisis

[9] I use US Dollar returns because they represent profits of investors with international portfolios. Two-day rolling averages are in general preferred, as stock markets in different countries are not simultaneously open.

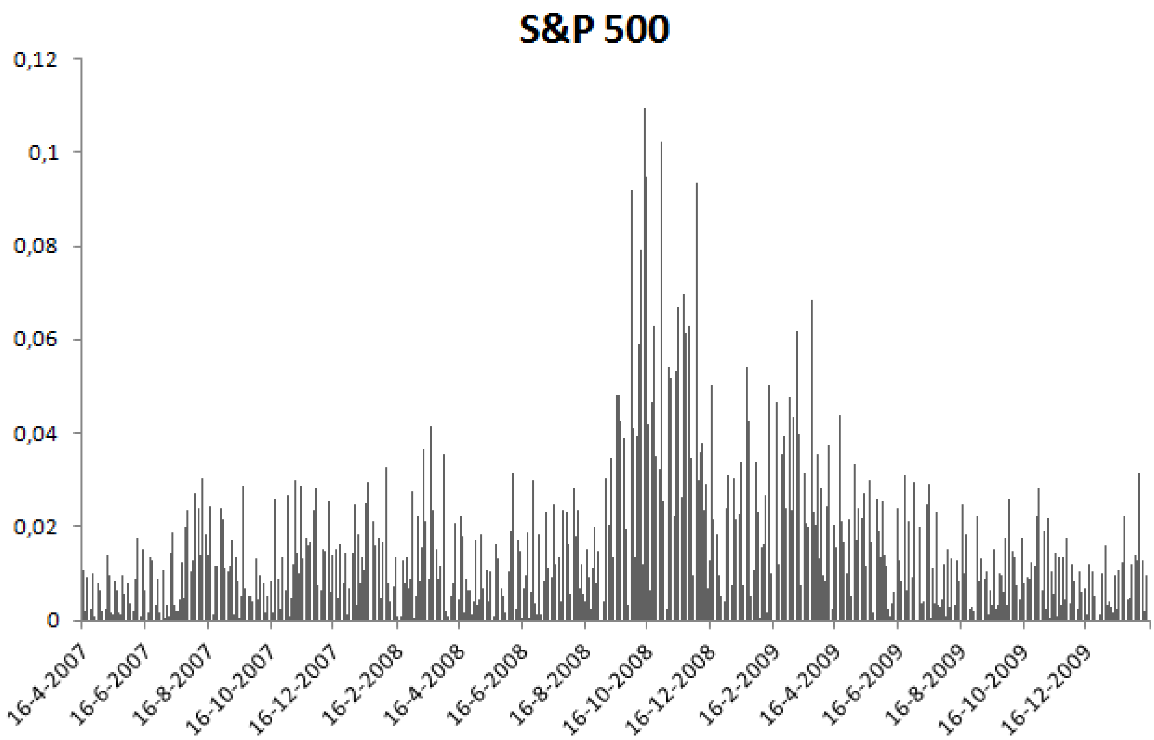
[10] Performed in Excel.

[11] See Pericoli and Sbracia (2003) and Claessens et al. (2001). Corsetti et al. (2001)

periods as stretching from 16 April 2007 to 14 September 2008 and from 15 September 2008 to 15 February 2010 respectively. This definition of the crisis period follows the fall of Lehman Brothers causing immediate economic losses and a domino effect to other large financial institutions around the world.

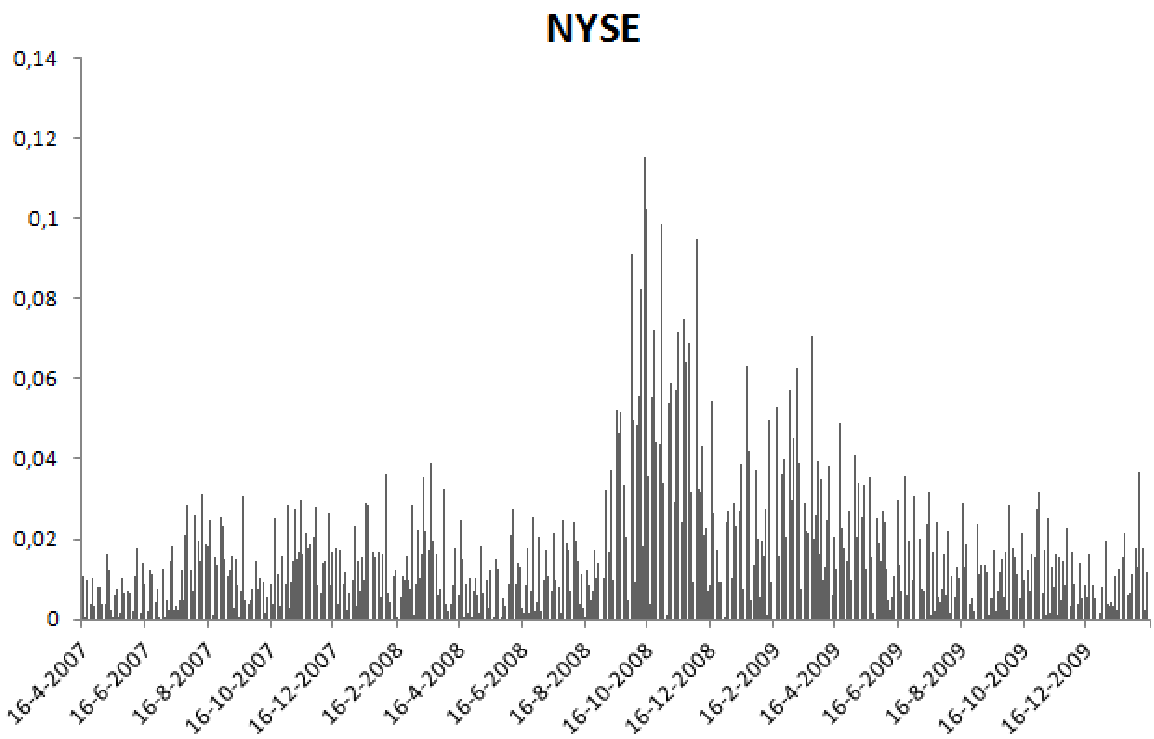
Figure 4 and 5 give an overview of absolute returns for the specified tranquil and crisis period for the S&P 500 and NYSE indices respectively. Both graphs show an immediate huge increase of volatility from around 2% to roughly 10% absolute returns after the fall of Lehman Brothers at 15 September 2008, after which absolute returns keep on being high until at least the summer of 2009.

Figure 4: S&P 500 absolute returns



This figure illustrates absolute returns on the S&P 500 index over the period 1/3/2006 to 31/21/2008.

Figure 5: NYSE absolute returns



This figure illustrates absolute returns on the NYSE index over the period 1/3/2006 to 31/21/2008.

5. Empirical results

In this section I present the empirical results of the tests for both the S&P 500 and NYSE. I interpret the results based on general patters or dissimilarities, the influence of variance ratios, and linkages to previous research. The empirical results are presented in Table 1.

Table 1: Results of correlation analyses

S&P500 index								
Region	**ρ^C**	**Φ**	**λ^T**	**λ^C**	**p-value**	**Fisher-test**	**$*\lambda^T$**	**$*\lambda^C$**
Europe (Euronext)	0,901	0,833	0,355	0,156	0,000	C**	0	0
Europe (S&P 350)	0,902	0,836	0,355	0,156	0,000	C**	0	0
Belgium	0,876	0,821	0,355	0,156	0,004	C**	0,244	0,112
France	0,899	0,833	0,355	0,156	0,000	C**	0	0
Netherlands	0,900	0,829	0,355	0,156	0,000	C**	0	0
Germany	0,892	0,819	0,355	0,156	0,000	C**	0	0
United Kingdom	0,898	0,832	0,355	0,156	0,000	C**	0	0
Spain	0,876	0,811	0,355	0,156	0,001	C**	0,175	0,111
NYSE								
Region	**ρ^C**	**Φ**	**λ^T**	**λ^C**	**p-value**	**Fisher (5%)**	**$*\lambda^T$**	**$*\lambda^C$**
Europe (Euronext)	0,927	0,891	0,192	0,092	0,002	C**	0,130	0,086
Europe (S&P 350)	0,929	0,893	0,192	0,092	0,002	C**	0,131	0,087
Belgium	0,901	0,878	0,192	0,092	0,069	I	0,203	0,089
France	0,925	0,890	0,192	0,092	0,004	C**	0,137	0,087
Netherlands	0,926	0,887	0,192	0,092	0,001	C**	0,118	0,084
Germany	0,918	0,877	0,192	0,092	0,002	C**	0,119	0,055
United Kingdom	0,925	0,890	0,192	0,092	0,004	C**	0,137	0,087
Spain	0,902	0,869	0,192	0,092	0,017	C*	0,157	0,086

This table presents the results of correlation analyses, where ρ^c is the calculated correlation coefficient in the crisis period, Φ is the calculated measure of interdependence, λ^T and λ^C are the calculated variance ratios, and $*\lambda^T$ and $*\lambda^C$ are the threshold variance ratios for which the Fisher test rejects the null of interdependence at the 5% significance level. A value of zero indicates that even with the smallest ratios the null of interdependence is still rejected. C* and C** indicate that the null hypothesis is rejected on the 5% and 1% confidence level respectively.

This table shows the results of cross-country correlation analysis between several European stock markets and the S&P 500 and NYSE US stock indices. Euronext and S&P 350 represent Europe as a whole, while the others are individual major European countries represented by the Bel 20, Cac 40, AEX, Dax 30, FTSE 100, and IBEX35 stock market index respectively. The results are based on two-day rolling averages of daily Dollar returns.

The first two columns of the table report the correlation coefficients in the crisis period and the measure of interdependence for the sample countries. These statistics are based on the calculated variance ratios reported in the third and forth column respectively. The variance ratios are based on regression estimations and the test specific assumptions. Consistently with the logic of the test, if the pair of variance ratios is higher, the lower the measure of interdependence will. Therefore, the difference between ρ^c and Φ will be larger and the likelihood of rejecting the null of interdependence will increase. The fifth column reports the p-values as determined by the Fisher-test. The sixth column report the results based on the Fisher-test on a 5% and 1% confidence level respectively. The last two tables report just one pair of threshold variance ratios, for which the Fisher-test would reject the null of interdependence on a 5% confidence level. Like explained, these thresholds are not conditional on a predetermined threshold value of λ_j^T.

Overall, the results show overwhelming evidence in favor of contagion. Out of the 16 sample cases I find evidence of contagion in 15 cases, of which 14 on the 1% confidence level. This provides strong empirical evidence in line with Corsetti et al (2005), who show that the strong result of 'no contagion, only interdependence', stressed by earlier contributions (particularly Forbes and Rigobon (2002)), is due to arbitrary and unrealistic restrictions on the variance of country-specific shocks. However, my results provide even stronger evidence in favor of contagion. First, a possible explanation for this is that I failed to correct enough for the variances of returns. Second, these strong results may just be correct considering the specific 2007-2009 financial crisis. This can be explained by the key role that leverage plays in this crisis. Because of leverage, small shocks can cause relatively more damage. Even while the fall of Lehman Brothers did not directly cause an enormous wealth loss relatively to earlier crises, this break in the international transmission mechanism may just be way more virulent in affecting other markets.

Probably the most noticeable fact is that the results for the S&P500 index are slightly different than the results for the NYSE index. Overall, the p-values are relatively higher for the NYSE index. In case of the S&P 500 index, evidence in favor of contagion is found for all cases (Europe as a whole, Belgium, France, the Netherlands, Germany, the UK, and Spain) on the 1% confidence level. Considering the NYSE index, the null of interdependence is rejected for Europe as a whole, France, The Netherlands, Germany, and the UK on the 1% confidence level. Evidence of contagion is found for Spain at the 5% confidence level. In the case of Belgium, the null of interdependence is not rejected at the 5% confidence level. This is in contradiction to what I would expect if I look at the country-specific factor loadings α_1. Namely, α_1 increases with only 4,1% in case of the S&P 500 index, as opposed to 8,7% in the case of the NYSE index during a crisis. However, the difference can be explained by the corresponding variance ratios, which are higher in case of the S&P 500 index than in case of the NYSE index. Therefore, these results indicate that one must be careful in choosing a proxy for the country where the crisis originated. Namely, for some cases the results can significantly depend on which US stock index is chosen.

In order to find an explanation for this difference I compare the S&P 500 and NYSE index with each other. Table 2 gives an overview of fundamental characteristics of both indices.

Table 2: S&P 500 and NYSE characteristics

S&P 500	NYSE
US stock market index	US stock market index
Common stock prices of 500 top publicly traded American companies	All common stocks listed on the NYSE Foreign listings
Free-float market capitalization weighted	Free-float market capitalization weighted

This table shows the type of index, the type of included stocks, and the type of weighting.

An important difference between both indices is that the NYSE also includes foreign listings. Over 2000 stocks are covered in the index, of which over 360 are foreign listings. However, these foreign companies represent a large part of capitalization. This may be the main explanation for the differences in results in table 1.

The results show that the variance ratio in relatively lower in the crisis period. This applies for both the S&P 500 (λ_j^T=0,355 and λ_j^C=0,156) and NYSE (λ_j^T=0,192 and λ_j^C= 0,092) index. This is an important piece of evidence in favor of the hypothesis that during international turbulent periods, most of the crisis-country idiosyncratic risk becomes systemic (due to a common factor), directly affecting other markets.

As will probably be clear, these results are very sensitive to the variance ratios. The threshold values show that only a small increase in a pair of λ_j^T and λ_j^C can turn a result of interdependence into a result in favor of contagion. For example, look at the case of Belgium with the NYSE index as proxy for the crisis country. With a p-value of 0,069 the null of interdependence is not rejected on the 5% confidence level. Changing the pair of λ_j^T and λ_j^C from [0,192 ; 0,092] to [0,203 ; 0,089] would already cause a rejection of this null hypothesis in favor of contagion.

6. Conclusion and recommendations

First, this paper considers the main channels through which financial contagion can be propagated across different markets. Crisis-contingent theories identify a correlated-information channel, a liquidity channel, and a credit risk channel. Generally, literature divides the causes of contagion into two categories, namely fundamental-based causes and changes in the behavior of financial agents, called investors rationality. It is argued that the latter type implies true (shift-)contagion, as it can cause shifts in cross-country relations that are too strong conditional on the normal interdependencies.

Correlation analysis of the 2007-2009 financial market crisis is very interesting for economic research, as the economy is more interconnected than ever before and because of the multidimensional character of the spread of the crisis. Particularly the liquidity and credit risk channels seem to have played a role in the spread of this crisis. A change in society and a high level of economic-interconnections seem to be the major causes of the crisis. Deregulation pressure, accounting rules, and a lack of understanding of complex financial products have had an accelerating effect.

Second, this paper provides empirical analysis for contagion regarding the 2007-2009 financial crisis. The testing framework builds on a single standard factor model issued by Corsetti et al. (2005). They investigated whether the strong result of 'no contagion, only interdependence' can be attributed to pitfalls in the testing procedure. Accordingly, in testing for contagion I distinguish between breaks due to changes in the variance of common factors, and changes in the variance of country-specific factor loadings.

Overall, the results show overwhelming evidence of contagion. Out of the 16 sample cases I find evidence of contagion in 14 (15) cases, on the 1% (5%) confidence level. The S&P 500 and NYSE index show small differences in results, indicating that it is important to carefully choose a proxy for the crisis country. For the S&P 500 index, I find evidence of contagion for all cases at the 1% confidence level. For the NYSE index, I find no evidence of contagion in case of Belgium. The rest of the cases show evidence of contagion on the 1% confidence level, except for Spain, for which the null is only rejected on the 5% level. Moreover, the results are sensitive to the determined variance ratios.

Further research on contagion via correlation analysis should not only consider stock markets, despite the fact that it seems appropriate for this specific crisis. Moreover, the use of multivariate factor analysis can uncover latent variables and can provide new insights on the spread of financial shocks.

7. Discussion and robustness check

Empirical literature testing for contagion often assumes that a shock to some common factor increases comovements of prices. However, the country where the crisis originates may also be subject to shocks due to idiosyncratic risk. As is often the case, cross-market correlations may fall rather than increase during crises. Therefore, tests for contagion should not be conditional on observing a rise in sample correlation. The test performed in this paper is symmetrical, so that it is applicable to both increases and decreases in factor loadings.

As already discussed, the test results depend strongly on the size of the variance ratios. Corsetti et al (2005) illustrate this point by plotting particular case statistics for the Hong Kong stock market crisis of October 1997. In order to make their graph directly comparable with a similar graph in Forbes and Rigobon (2002), they simplify the measure of interdependence by assuming that the variance ratio does not vary across tranquil and crisis periods ($\lambda_j^C = \lambda_j^T = \lambda_j$). This means that the variances of both the common factor and country-idiosyncratic risk increase by the same proportion $(1+\delta)$ during a crisis, so that there is no distinction anymore between shocks due to an increase in either of the two factors in the model. Moreover, they plot an inverse transformation[12] of the measure of interdependence so that λ_j is expressed in the measurement formula. They find that by increasing the value of λ_j, the inverse measure shifts upward indicating that evidence of contagion is found more often. This of course is in line with my results, which show that a higher pair of $[\lambda_j^T$ and $\lambda_j^C]$ increases the likelihood of rejecting the null of interdependence in favor of contagion.

Other points worth noting are that first, proxies are used in order to represent the markets and the common factor. These proxies never fully reflect the characteristics of these markets and so come with some biases in returns. Second, sample errors may be reflected in the estimated variance ratios. Namely, these ratios are calculated by using error term variances of returns of the crisis country. These error terms may also reflect other factors. Third, there may be more appropriate testing frameworks. For example, using a multifactor model may be more appropriate than a single factor model. Forth, by applying standard tests one assume normality of returns, while this is not necessarily the case. Also see Corsetti et al (2005) on this point: out of 17 sample countries, they

[12] By substituting Φ with ρ^c, posing $\lambda_j^C = \lambda_j^T$, and finally solving for ρ^c. Testing for contagion implies now comparing this inverse measure to ρ^T instead of ρ^c.

reject the hypothesis of normality for five countries in the tranquil, and four countries in the crisis period at the 5% confidence level. Fifth, it is important to stress that biases in tests of contagion do also occur if one overcorrects for changes in variances, instead of failing to correct for this. This case can be illustrated by setting $\lambda_j^C = \lambda_j^T = 0$ and is consistent with the analysis of Forbes and Rigobon (2002). This implies the unrealistic assumption that in the country where the crisis originates there is no idiosyncratic shock, and therefore correlation always increases with the variance of r_j. Because of overcorrection, tests on contagion will be biased towards the null of interdependence. Sixth, instead of using a world stock index as proxy for the common factor, also a cross-sectional average return can be used. This might have an effect on the results.

I perform several checks in order to test the robustness of my results. First I redefine tranquil and crisis periods as stretching from 1 March 2006 to 31 July 2007 and from 1 August 2007 to 31 December 2008 respectively, which implies the same length of periods but shifts the start of the crisis period. This definition of the crisis period follows the bursting of the US housing bubble, after which the incidence of additional spillovers from the US system to Europe increased, particularly in August 2007 and from the beginning of July 2008 onwards (periods of high distress)[13]. Moreover, it is argued that periods of higher volatility do not implicitly increase cross-market correlations.

The results are shown in table 3. Overall, the reports indicate that there is less evidence of contagion. In case of the S&P 500 index, 5 out of 8 cases reject the null of interdependence in favor of contagion on only the 5% confidence level. In case of the NYSE index, no evidence of contagion is found for all cases. Also the variance ratios in tranquil en crisis period move closer to each other, indicating that less idiosyncratic risk has become systemic. Moreover, these results clearly point out the differences in results between the different proxies for the crisis country. From table 3 I conclude that the results are very sensitive for the definition of tranquil and crisis period.

[13] See Eichengreen et al. (2012).

Table 3: Results following the bursting of the US housing market

S&P500 index						
Region	ρ^c	ϕ	λ^T	λ^c	p-value	Fisher-test
Europe (Euronext)	0,892	0,861	0,322	0,213	0,033	C*
Europe (S&P 350)	0,894	0,862	0,322	0,213	0,027	C*
Belgium	0,883	0,857	0,322	0,213	0,068	I
France	0,890	0,860	0,322	0,213	0,039	C*
Netherlands	0,892	0,859	0,322	0,213	0,029	C*
Germany	0,883	0,859	0,322	0,213	0,086	I
United Kingdom	0,892	0,858	0,322	0,213	0,025	C*
Spain	0,881	0,854	0,322	0,213	0,069	I
NYSE						
Region	ρ^c	ϕ	λ^T	λ^c	p-value	Fisher (5%)
Europe (Euronext)	0,928	0,925	0,146	0,121	0,378	I
Europe (S&P 350)	0,930	0,926	0,146	0,121	0,333	I
Belgium	0,919	0,920	0,146	0,121	0,541	I
France	0,926	0,924	0,146	0,121	0,417	I
Netherlands	0,927	0,923	0,146	0,121	0,330	I
Germany	0,919	0,923	0,146	0,121	0,636	I
United Kingdom	0,927	0,921	0,146	0,121	0,288	I
Spain	0,917	0,918	0,146	0,121	0,528	I

This table shows the results when the tranquil and crisis periods are defined as stretching from 1 March 2006 to 31 July 2007 and from 1 August 2007 to 31 December 2008 respectively. Based on two-day rolling averages.

Second, I analyze what happens to the results if I shorten the tranquil and crisis period. Table 4 shows the results if I redefine tranquil and crisis periods as stretching from 1 January 2008 to 14 September 2008 and from 15 September 2008 to 31 March 2009 respectively. Note that the start of the crisis period is not changed.

Overall, the reports indicate that this change does not significantly affect the results much. However, p-values rise in all cases for both indices. The null of interdependence is mostly still rejected on the 1% confidence level in case of the S&P 500 index. In case of the NYSE index, the null is mostly rejected on the 5% confidence level, except for Belgium. I conclude that the results are not significantly sensitive to this shortening of tranquil and crisis period.

Table 4: Results in case of shorter periods

S&P500 index						
Region	ρ^C	ϕ	λ^T	λ^C	**p-value**	**Fisher-test**
Europe (Euronext)	0,906	0,831	0,391	0,162	0,003	C**
Europe (S&P 350)	0,909	0,833	0,391	0,162	0,002	C**
Belgium	0,883	0,821	0,391	0,162	0,020	C*
France	0,905	0,830	0,391	0,162	0,003	C**
Netherlands	0,906	0,828	0,391	0,162	0,002	C**
Germany	0,901	0,824	0,391	0,162	0,003	C**
United Kingdom	0,907	0,830	0,391	0,162	0,002	C**
Spain	0,893	0,824	0,391	0,162	0,009	C**
NYSE						
Region	ρ^C	ϕ	λ^T	λ^C	**p-value**	**Fisher (5%)**
Europe (Euronext)	0,933	0,892	0,211	0,095	0,013	C*
Europe (S&P 350)	0,936	0,894	0,211	0,095	0,011	C*
Belgium	0,910	0,882	0,211	0,095	0,109	I
France	0,932	0,892	0,211	0,095	0,015	C*
Netherlands	0,933	0,890	0,211	0,095	0,011	C*
Germany	0,928	0,886	0,211	0,095	0,016	C*
United Kingdom	0,934	0,892	0,211	0,095	0,011	C*
Spain	0,920	0,886	0,211	0,095	0,050	C*

This table shows the results when the tranquil and crisis periods are defined as stretching from 1 January 2008 to 14 September 2008 and from 15 September 2008 to 31 March 2009 respectively. Based on two-day rolling averages.

Third, I analyze what happens to the results if I simply use daily returns instead of two-day rolling averages of returns. The results are shown in table 5. Overall, the p-values are higher and in case of the NYSE index, I found no evidence of contagion for Belgium, the UK, and Spain. The can be explained by the fact that stock markets in the US and Europe are not open simultaneously. Therefore, price changes in the US cannot always be directly incorporated in prices in Europe. This problem can be solved by using two-day rolling averages. I conclude that this can have a significant effect on the results.

Table 5: Results based on daily returns

S&P500 index						
Region	ρ^C	ϕ	λ^T	λ^C	**p-value**	**Fisher-test**
Europe (Euronext)	0,838	0,770	0,504	0,251	0,004	C**
Europe (S&P 350)	0,839	0,773	0,504	0,251	0,005	C**
Belgium	0,809	0,759	0,504	0,251	0,040	C*
France	0,837	0,771	0,504	0,251	0,005	C**
Netherlands	0,839	0,763	0,504	0,251	0,002	C**
Germany	0,837	0,759	0,504	0,251	0,002	C**
United Kingdom	0,831	0,770	0,504	0,251	0,010	C*
Spain	0,811	0,750	0,504	0,251	0,016	C*
NYSE						
Region	ρ^C	ϕ	λ^T	λ^C	**p-value**	**Fisher (5%)**
Europe (Euronext)	0,866	0,826	0,316	0,173	0,027	C*
Europe (S&P 350)	0,866	0,828	0,316	0,173	0,033	C*
Belgium	0,836	0,815	0,316	0,173	0,191	I
France	0,864	0,827	0,316	0,173	0,036	C*
Netherlands	0,867	0,818	0,316	0,173	0,011	C*
Germany	0,864	0,814	0,316	0,173	0,010	C*
United Kingdom	0,858	0,826	0,316	0,173	0,064	I
Spain	0,838	0,806	0,316	0,173	0,086	I

This table shows the results based on daily returns instead of two-day rolling average returns.

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