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Essays on Credit Contagion and Shocks in Banking

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168</td><td>Kieli
Englanti</td></tr>
<tr><td colspan="3">Julkaisun nimike
Essays on Credit Contagion and Shocks in Banking</td></tr>
</table>

Tiivistelmä

Tässä väitöskirjassa käsitellään sokkien vaikutusta pankkeihin finanssikriisien aikana. Tarkemmin ottaen tarkastelun kohteena ovat tartuntariskit pankkien välisillä rahamarkkinoilla Suomessa ja Euroopassa. Lisäksi tarkastellaan pankkien pääomaan ja likviditeettiin kohdistuvien paineiden vaikutusta euroalueen pankkien lainanantoon ja makrotalouteen.

Ensimmäisessä esseessä tutkitaan kotimaisten ja ulkomaisten tartuntariskien välittymistä Suomen rahamarkkinoilla. Tulokset osoittavat, että kotimaisen tartuntariskin takia keskimäärin noin puolet Suomen pankkisektorista joutuu vaikeuksiin 1990-luvulla ja 66 % vuosina 2005–2011. 2000-luvulla ulkomaisen pankin kaatuminen vaikuttaa 77 prosenttiin suomalaisista pankeista. Toisessa esseessä tarkastellaan pankkien välisiä tartuntariskejä Euroopassa. Ne vaikuttavat keskimäärin 70 prosenttiin pankeista vuonna 2007 ja 40 prosenttiin vuonna 2010. Ranskalaiset, englantilaiset, saksalaiset ja espanjalaiset pankit ovat merkittävimpiä tartuntariskien lähteitä. Tutkimus myös osoittaa, että tartuntariskiä lisäävät pankin keskeinen asema rahamarkkinoilla, lainapositioiltaan suurten pankkien ryhmät, useat linkit ja pankin suuri koko.

Kolmannessa esseessä analysoidaan euroalueen pankkien sisäisiä vakavaraisuustavoitteita ja sitä, vaikuttaako tavoitteisiin pyrkiminen pankkien taseisiin. Tulokset osoittavat, että euroalueen pankit olivat alipääomitettuja vuonna 2008. Täyttäessään pääomavajeitaan pankit supistavat lainanantoa vähemmän kuin arvopaperiomistuksia. Neljännessä esseessä tarkastellaan riski-, rahoitus- ja velkakriisisokkien vaikutusta euroalueella, Saksassa, Ranskassa, Italiassa ja Espanjassa. Vuonna 2009 sokit selittävät noin 60 % euroalueen yrityslainanannon vähenemisestä ja noin kolmasosan vuosittaisen bruttokansantuotteen supistumisesta. Sokkien vaikutus on merkittävä Saksassa ja Ranskassa vuosina 2009–2011, mutta italialaisille ja espanjalaisille pankeille sokit ovat merkittäviä vasta simulointiperiodin loppupuolella.

Asiasanat

pankit, finanssikriisit, tartuntariski, interbanksaamiset, euroalue, Suomi, luotontarjonta

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Abstract

This dissertation examines the impact of shocks on banks in the context of financial crises. Specifically, it studies credit contagion in Finnish and European interbank markets as well as the effects of capital and liquidity pressures on euro area banks' lending and the macro economy.

The first essay studies the domestic and foreign credit contagion via Finnish banks' interbank exposures. The results show that domestic contagion affects, on average, almost half of the Finnish banking sector in the 1990s and 66% in 2005–2011. In the 2000s, the failure of a foreign bank impacts 77% of the total assets of Finnish banks. The second essay examines credit contagion at the European level. The average contagion affects 70% and 40% of European banks' total assets in 2007 and in 2010, respectively. Contagion is most prevalent among the French, British, German and Spanish banks. The most prominent factors for determining the magnitude of contagion are the bank's central position in the network, bank clusters with large interbank loans, number of links and bank size.

The third essay analyses euro area banks' internal target capital ratios and whether banks' adjustments towards their targets affect their balance sheets. The results indicate that euro area banks were undercapitalised in 2008. While closing the capital gap, banks reduce lending less than security holdings. The fourth essay disentangles the impact of risk, funding and sovereign shocks in the euro area as a whole and in Germany, France, Italy and Spain. In 2009 the shocks account for about 60% of the decrease in corporate lending and around a third of the decline of annual GDP growth in the euro area. While shocks exhibit a notable impact on Germany and France in 2009–2011, they are significant for Italian and Spanish banks only towards the end of the simulation period.

Keywords

banks, financial crises, contagion, interbank exposures, euro area, Finland, credit supply

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Helsinki, July 2015

Mervi Toivanen

Contents

This thesis consists of an introductory chapter and the following four essays:

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1 INTRODUCTION

After a period of relative calm and prosperity financial markets were confronted with a global financial crisis. It sent shockwaves throughout the world, impacting negatively on financial institutions and their operating environment. Especially banks came under considerable stress as their losses increased, financial performance and capital positions deteriorated and funding became scarce. As a result, governments and central banks were forced to step in and bail out several banks of relevance that were about to fail.

The crisis highlighted the importance of networks and linkages between financial institutions, by showing that a failure of bank can have negative repercussions for other banks although they are not directly connected to first failing bank. Authorities also justified rescue measures by the prevention of contagion. But how severe would credit contagion be if no measures were taken? What banks are the most contagious? And what are the leading factors determining the magnitude of domino effects? Answering these questions is of relevance from the financial stability point of view. In order to design appropriate policy measures and regulatory requirements one needs to understand the impact of network effects and the underlying dynamics. This doctoral dissertation sheds more light on credit contagion in the Finnish and European interbank markets.

The crisis also brought to light a question as to banks' ability to grant credit to private sector. As banks transmit funds from sectors with a surplus to sectors with a deficit, they support firms' investments and thus economic growth. But if financial intermediation is disturbed, a lack of adequate funding may be detrimental to economic activity. During the global financial crisis the risk, capital and funding shocks to euro area banks have been particularly severe. Hence, the monitoring of potential deleveraging pressures and implications for the macro economy are of relevance. So what happened in the recent crisis? Did euro area banks reduce their lending? And if so, what were the implications for the economy? This dissertation builds on previous research and investigates the adjustment of euro area banks.

The remainder of the introductory chapter is organized as follows. Section 2 gives a brief overview of research and theoretical fundamentals related to contagion and network theory. Section 3 describes the academic literature related to capital and liquidity shocks, bank lending and economic growth. To provide a background for the essays of the dissertation section 4 overviews the Finnish banking crisis in the 1990s and the global financial crisis in the 2000s. Section 5 summarizes the four essays of this dissertation, while section 6 concludes with the outcomes of the analyses.

2 OVERVIEW OF LITERATURE

2.1 Contagion

Contagion refers to the spreading of negative spillover effects in the economy or in the financial markets. Although the interest in contagion has gained momentum during the global financial crisis, the phenomenon has so far been mainly studied in relation to earlier currency crises, stock market crashes and banking crises. In banking, contagion is defined as a crisis that spills over from one financial institution to another institution. (Müller 2006)

Contagion may be either direct or indirect, may occur through a multitude of channels (such as interbank markets, payment systems, derivative exposures and asset holdings) and may impact both the liability and asset sides of banks' balance sheets. It can be caused by a multitude of factors. Firstly, owing to an idiosyncratic shock a borrower defaults on its interbank loans, inducing loan losses to lender. If such losses exceed the lender's equity capital, a default of a financial institution could thus trigger the failure of others and even cause a systemic meltdown of the banking system (so called credit contagion). For instance, the bailouts of American International Group (AIG) and German Industriekreditbank (IKB) were justified by these potential negative spillover effects (Upper 2011). Contagion may also be driven by information, by distressed banks' sale of illiquid assets (so called fire sales) as well as by fear of losses or negative effects from other market players/banks that run for safety at the same time. Owing to liquidity hoarding, the availability of interbank loans diminishes, inducing funding liquidity shocks and a cascade of failures. Moreover, the failure of a large number of banks could also be the outcome of a macroeconomic shock that affects institutions exposed to a common risk more or less simultaneously. (Upper 2011; Haldane & May 2011; Pais & Stork 2011)

The academic literature comprises both theoretical models which analyse specific aspects of contagion and empirical analyses. The seminal paper by Allen & Gale (2000) shows that the spreading of a financial crisis depends crucially on the banking sector's pattern of interconnectedness. They demonstrate that if the interbank market is complete and each region is connected to all other regions, the initial impact of a financial crisis in one region may be attenuated. But, if each region is connected with only a small number of other regions (the interbank market is incomplete), the initial impact of financial crisis may be felt strongly in neighbouring regions. By applying network modelling and adding further reality to models, for instance, in terms of heterogeneous banks and network structures, fire-sales and volume of shocks, recent papers show that high interconnectedness of banks may not necessarily be beneficial for financial stability (Acemoglu, Ozdaglar & Tahbaz-Salehi 2013; Battiston et al. 2012; Gai & Kapadia 2010). While increasing connectivity attenuates contagion via risk sharing and improves the ability of a banking system to absorb shocks, it also facilitates spillover effects and can make the system more fragile ("robust-yet-fragile" tendency).

The second set of papers provides further evidence on characteristics of interbank markets by modelling financial connections between banks as networks and employing simulation techniques to assess the outcomes of a bank failure. (Anand et al. 2013; Gai, Haldane & Kapadia 2011; Nier et al. 2007; Arinaminpathy, Kapadia & May 2013; Krause & Giansante 2012; Iori, Jafarey & Padilla 2006) Based on a set of assumptions, accounting identities and behavioural rules, these models present a banking sector composed of individual banks with balance sheets and a transmission mechanism for shocks. The contagion arises when the losses exceed the net equity of a bank, inducing a bank failure. An enlargement of interbank liabilities, high concentration of the banking sector and a shock to a well-connected and big bank are shown to make the system vulnerable to large systemic risks. Meanwhile, the higher the capital ratios of banks, the more resilient the system is to large systemic risks. Finally, the structure and tiering of the network are most important in explaining the magnitude of the contagion.

Thirdly, empirical studies on credit contagion in interbank markets often rely on estimations and counterfactual analyses. Upper & Worms (2004) use the method of entropy maximization to estimate the distribution of individual banks' interbank loans and deposits. Having constructed a matrix of banks' interbank exposures, the effects of a bank failure are subsequently simulated to analyse the possibility of contagion in the German banking sector. The methodology has been widely applied, and similar studies have been done for the Swiss, Belgian, English, Dutch, British and Italian interbank markets. (Sheldon & Maurer 1998; Degryse & Nguyen 2007; Wells 2004; van Lelyveld & Liedorp 2006; Mistrulli 2011) In general, all authors found a potential for significant contagion effects but regard a substantial weakening of the whole banking sector as unlikely. The negative effects differ according to loss-given-defaults (LGDs) with contagion being limited for lower values of LGDs and substantial for the worst-case scenarios. In addition, Degryse, Elahi & Penas (2010) provide evidence on cross-border contagion and show that the contagion is more widespread between countries situated geographically close to each other. Furthermore, they suggest that the risk of cross-border contagion has increased over the years.

Finally, other approaches estimate contagion by considering a wider variety of risks and factors. For instance, Müller (2006) tests the general stability of the Swiss interbank market by analysing the banking system's exposure to the aggregate risk that stems from the market's network structure. The possibility of contagion is evaluated by solving a clearing problem of a multilateral, complex network model using a recursive algorithm. Elsinger, Lehar & Summer (2006) use standard risk management techniques in combination with a network model of interbank exposures to analyse the consequences of macroeconomic shocks for bank insolvency risk. They consider interest rate shocks, exchange rate and stock market movements as well as shocks related to the business cycle. Gropp, Lo Duca & Vesala (2009) use a distance-to-default indicator, multinomial logit model and "coexceedances" to study contagion risk in the European banking market.

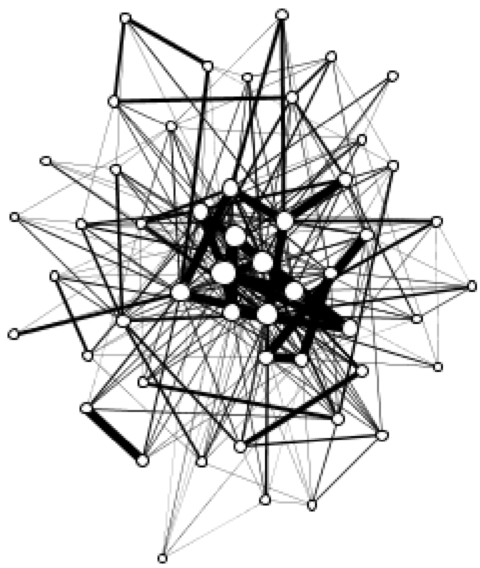
2.2 Basics for modelling scale-free networks

The global financial crisis served as a reminder of the high levels of interconnectedness in the financial markets and banking systems. But old modelling techniques failed to properly recognize the interdependencies between economic agents that determine the crucial contagion dynamics. As Haldane (2009) states, risk measurement in financial systems had been atomistic and there was little understanding of the systemic overall risks in a financial system. It was easier to assess risky investment positions of a single bank than to map interbank exposures that are hazardous from the systemic point of view.

As a consequence, the use of network models increased substantially for describing complex financial systems and interrelationships. The modelling approach provides valuable insights into large and complex networks by providing statistical methods to describe and quantify network properties (Newman 2003). The network approach is also well-suited to analyse the resiliency of financial networks and financial stability of banking sectors, as it can be used to model the externalities that a single institution may create for the entire system. (Allen & Babus 2009)

The network theory originates from mathematics and physics. A network (or graph in mathematics) describes a collection of economic agents (i.e. nodes or vertexes) and connections (i.e. links or edges) between them. The notions are fairly general, as nodes can be individuals, firms or groups of these players. Similarly, a link can be a friendship tie, an economic contract or financial obligation. In the context of financial systems, the nodes of the network represent financial institutions (banks), and the links are mutual exposures such as interbank assets and claims. (Allen & Babus 2009) Links can be either undirected or directed, representing from whom to whom the link (for example a transfer of funds or a message) goes. Links can also carry weights signifying, for instance, the volume of payments. (Newman 2003)

In mathematical terms a graph is a pair of sets G = {P,E}, where P is a set of N nodes $P_1,P_2, ..., P_N$ and E is a set of edges (or lines) that connect two elements of P. In figures, the graphs are usually represented as a set of dots, each corresponding a node, and lines that join two dots if the corresponding nodes are connected. (Albert & Barabasi 2002) As an example, figure 1 presents a graph of European banks' interbank linkages. In the figure, nodes ($P_1,P_2, ..., P_N$), i.e. banks, are presented with circles. Edges or connections between the banks are depicted with lines.



Note: A realization of the Barabasi-Albert (1999) model for the European interbank network. Each node represents a bank in the sample, and its size is scaled in proportion to the sum of interbank exposures of the given bank at the end of 2010. Similarly, the darkness of a line reflects the proportional value of a bilateral exposure.

Figure 1. A graph presenting a European interbank network

The structure of networks varies, and several models have been proposed to model the characteristics of real-world networks. The main classes of modelling paradigms are random graphs, small-world models and scale-free models. (Albert & Barabasi 2002; Keeling & Eames 2005; Newman 2003) As scale-free networks are of relevance in the context of this doctoral thesis, they are modelled by the Barabasi & Albert (1999) model that features two important characteristics of real-world networks: the growth of a network and preferential attachment.

In technical terms a scale-free network is created as follows. Starting with a small number of nodes, n_0, the network is constructed by adding one node at a time until the network contains N nodes. At each step, a new node, n_j, enters the network and connects to the existing nodes of the network via a given number of links, k_j. The new node prefers to connect with institutions that already have a large number of contacts. This is an intuitive assumption, as trust plays an important role in money markets, and banks are more likely to establish business relationships with renowned counterparties versus less-known banks (or banks with bad reputation). Thus, the probability that a new bank j connects with an existing bank i depends on the connectivity of the bank i (k_i), i.e. $\pi = k_i / \sum_j k_j$ [4]. (Barabasi & Albert 1999; Moreno, Pastor-Satorras & Vespignani 2002; Keeling & Eames 2005; Albert & Barabasi 2002; Newman 2003) It is noteworthy that although banks create equal numbers of linkages when entering the network, the final number of individual banks' linkages differs. Some banks will have more connections than others.

2.3 The relationship between bank capital, lending and the macroeconomy

The impact that variations in bank capital can have on bank lending and ultimately on the real economy and business cycles have been widely studied, especially in relation to the US and previous downturns. But the global financial crisis and the implementation of new regulatory requirements brought the issue back to the frontline of research. The following chapters give an overview, first, of studies examining how different shocks affect banks' lending, and secondly, on papers disentangling the impacts of changes in bank lending on the macro economy.

2.3.1 Bank capital, liquidity and funding in relation to bank lending

Since the beginning of the financial crisis banks' operating environment has changed drastically, and banks have been confronted with pressures such as declining profitability, new capital requirements, disruptions in banks' access to funding and the sovereign debt crisis. These shocks influence banks' capital and liquidity positions and induce banks to modify their balance sheets by increasing core capital, adjusting the security portfolio and reducing risk-weighted assets. As banks mediate funds from sectors with surplus to those with capital shortfall,

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[4] The probability has the following conditions: $\pi_i = [0, 1]$ and $\sum \pi_i = 1$.

banks and bank loans to private sector are a vital piece of a well-functioning economy. Different shocks may nevertheless be multiplied or attenuated in the financial system owing to incompleteness of the financial markets and financial frictions. Consequently, financial intermediation is distorted. Research on the relationship between bank characteristics and financial intermediation often relates to studies on bank lending channels, sharp contractions in banks' credit supply (so called credit crunches) and implementation of the Basel Accords.

First, extensive academic research exists on the impact of capital regulation (so called Basel Capital Accords) on credit supply. The research has mainly been conducted in relation to US banking markets, but some evidence exists also for European banks. In general, changes in bank capital have been shown to impact banks' willingness to lend. Regarding the implementation of Basel I, empirical papers demonstrate that new risk-based capital standards were a significant factor in explaining the decrease in lending (business lending, in particular) and the credit crunch of the early 1990s in the US. These papers also indicate that banks with capital constraints cut back lending more quickly than their better-capitalized competitors. (See Bernanke & Lown 1991; Hancock & Wilcox 1993 & 1998; Hancock, Laing & Wilcox 1995; Berger & Udell 1994; Brewer, Kaufmann & Wall 2008; Hall 1993; Wall & Peterson 1995; Peek & Rosengren 1995a, 1995b, 1997 & 2000; Brinkmann & Horvitz 1995; Shrieves & Dahl 1995) Individual bank's responses to changes in capital seem to be determined also by bank size. For instance, Hancock, Laing & Wilcox (1995) find that the capital shocks affected banks' total portfolio size and their holdings of loans for 2–3 years, and that large banks were able to adjust their portfolios faster than small banks. Also, Hancock & Wilcox (1998) show that small banks shrank their portfolios considerably more than large banks in response to the decline in their own bank capital. Studies with European data are very limited. Takala & Viren (1995) studied the potential role of changes in bank capital on bank lending in the UK and in Finland. They provided some evidence of a credit crunch. However, Vihriälä (1997) does not find evidence for Finland that would support the credit crunch hypothesis.

Similarly, Basel II requirements have been shown to increase the volatility of bank lending, especially for undercapitalised and less liquid banks (ECB 2007; Jacques 2008). Also the latest analysis on the forthcoming implementation of Basel III have concluded that the increase in capital requirement as well as the implementation of minimum liquidity requirement could exert a negative impact on banks' lending volumes (BIS 2010a).

Secondly, research on bank lending channels provides further evidence that the banks' financial position and changes in operating environment affect banks' lending in Europe and in the euro area. (see, for instance, Altunbas, Gambacorta & Marques-Ibanez 2010; Gambacorta & Mistrulli 2003; Gambacorta & Marques-Ibanez 2011; Gambacorta 2005; Jimenez et al. 2012; Hülsewig, Mayer, Wollmershäuser 2006). The lending of well-capitalised banks is shown to decline less than the lending of less-capitalised banks. Moreover, banks with relatively more liquid asset holdings and better funding positions can contain the negative effects of a shock and are in a better position to shield their loan books than banks with less liquid assets. Low-funded banks only adjustment mechanism is to restrict the provision of loans to the economy. In line with research on the impact of Basel Accords, individual bank's response to changes is conditional on the bank size, as small banks are less able to replace their balance sheet items than large banks. (Gambacorta & Marques-Ibanez 2011) Similar evidence exists also for the US (see, for instance, Kishan & Opiela 2000 and 2006)

Regarding the impact of the global financial crisis, Cihak & Brooks (2009) show that euro area banks' loan supply responds negatively to weakened soundness of banks, measured by the capital ratio or deposits-to-loans ratio. Puri, Rocholl & Steffen (2011) examine German banks in the aftermath of the global financial crisis. Banks that encountered either a capital or funding shock during the crisis rejected substantially more loan applications and reduced their domestic lending more than the non-affected banks. In the case of capital shock, the results are particularly strong for smaller and more liquidity-constrained banks. Similar evidence is also provided by Aiyar (2011), showing that a reduction in banks' external funding caused a contraction in lending. Especially foreign subsidiaries and branches reduced lending and reacted more to the funding shock than UK-owned banks. In a similar vein, US banks that were vulnerable to credit-line drawdowns, reliant on short-term debt and had limited access to deposit financing reduced their lending more than their counterparts during the latest financial crisis (Ivashina & Scharfstein 2010).

Thirdly, Berrospide & Edge (2010) and Francis & Osborne (2009) have used partial adjustment models and information on banks' target capital ratios to examine how banks' capital targets impact bank lending. By analysing US banks, Berrospide & Edge (2010) find relatively modest effects of bank capital on lending and a more important role for factors such as economic activity and the perceived macroeconomic uncertainty. Francis & Osborne (2009) concentrate on UK banks and find that banks with surplus (shortfall) of capital relative to their target tend to record higher (lower) credit growth. More recently, Kok & Schepens (2013) applied a similar method to analyse European banks. Their findings are similar to those of Berrospide & Edge (2010) and Francis & Osborne (2009), indicating low credit growth for undercapitalized banks during the recent financial crisis.

2.3.2 *Bank lending and the macro economy*

As changes in banks' loan supply conditions affect the availability of credit and firms' capacity to obtain funding, declining bank lending may have negative repercussions on firms' potential to invest. While investment supports economic growth, a lack of such may have adverse effects on the macro economy, business cycles and GDP growth. The impact of bank loans arises from the fact that many small lenders such as small and medium size enterprises are bank-dependent and are unable to substitute bank loans with other forms of financing.

Most of the research on macro-financial linkages has previously concentrated on the US. While the evidence is to some extent mixed, most of the recent papers suggest that shocks to credit markets and banks' capital lead to a reduction in credit availability and subsequent fall in GDP. Bayoumi & Melander (2008) build a stylized model and apply a stepwise estimation process to assess the impact of a negative shock to the equity ratio. They estimate that a one percentage point decline in the equity ratio of US banks leads to a 1.5 percent fall in GDP. Similarly, Lown & Morgan (2006) find that a 16 percent tightening of credit standards leads to a 1 percent decline in GDP. Analogous effects are demonstrated by Swiston (2008) who shows that a net tightening of credit standards of 20 percentage points reduces economic activity by 0.75 percent after one year and 1.25 percent after two years. Peek, Rosengren & Tootell (2003) identify a significant positive effect of loan supply on GDP in general and on business inventories, which is a major component of GDP, in particular. However, Driscoll (2004) finds no statistically significant effects of bank loans on output, albeit the multipliers in the estimations have the right (negative) sign.

Helbling et al. (2011) examine the importance of credit market shocks in the context of global business cycles in G-7 countries by estimating a VAR model. The shocks are shown to be important in driving economic activity, especially during the latest financial crisis. These results are similar to those of Bernanke (1983) and Bordo & Haubrich (2010) who show that financial crises have negative effects on financial intermediation and exacerbate cyclical downturns.

The evidence regarding the euro area indicates that a reduction in lending slows the growth of euro area GDP. Using data from ten EMU member states for 1999Q1−2010Q4, Rondorf (2012) finds strong evidence that changes in loan supply cause output fluctuations in the euro area. Moreover, Cihak & Brooks (2008) and Calza & Sousa (2005) have showed that a cutback in loan supply is likely to have a negative impact on real economic activity in the euro area. Based on the estimated effects on real economic activity, Cappiello et al. (2010) also point to the potential negative impacts of euro area banks' losses and balance sheet deleveraging on euro area real GDP. Their results indicate that a 5 % decrease in euro area credit growth below the euro area average would result in a long-run real output reduction of 1.6%. Using data on 35 European countries Buch & Neugebauer (2011) find that changes in lending by large European banks have a significant effect on GDP growth. The negative shock explains about 16% of the short-run, cyclical variation but less than 1% of long-run growth differences between countries. Regarding individual country results in Europe, the significance of bank loans on output has been proven by Anari et al. (2002) for Finland.

3 FINANCIAL CRISES

Financial crises have a long history, starting in early 1600 with events such as the Tulipmania and South Sea Bubble. Despite of advanced technology, new economic theories and increasing knowledge of market participants, the 20th century has also witnessed many new crises, including the stock market crash of 1929, Nordic banking crisis and the latest financial crisis in the US and in Europe. (Reinhart & Rogoff 2009a; Kindleberger & Aliber 2011)

The run-up to a financial crisis is often characterized by recognizable features that are classic telltales of banking crises. Usually, factors such as financial deregulation, abundant refinancing opportunities for banks, over-borrowing of firms and households, ballooning asset and real estate prices, excessive risk taking, negative macroeconomic shocks as well as lack of adequate risk management, policy and supervisory measures have played a role. At the outset of the crisis, confidence collapses, lenders withdraw and leveraged debtors find it ever more difficult to roll-over short-term debt. Banks are especially vulnerable for the wholesale run as they traditionally borrow short-term and lend long-term. At the same time, financial institutions are often compiled to sell their assets at distressed prices (i.e. fire sales) which nevertheless fail to fulfil the liquidity need. Owing to declining asset prices and worsening macroeconomic conditions banks' losses start to cascade. Depositor runs are also not uncommon. To safeguard the functioning of the financial system, governments are forced to step in and provide massive and often very expensive bailouts, increasing the cost to society as a whole. (Reinhart & Rogoff 2009a; Kindleberger & Aliber 2011)

The following sections shortly recount the story of the crises that form a background for the articles of this doctoral dissertation. The story of the Finnish banking crisis lays foundations for the first article, while the recent global financial crisis forms a background for the second, third and fourth articles.

3.1 The Finnish banking crisis in the 1990s

The systemic banking crisis in Finland took place in the beginning of 1990s and is classified as one of the worst banking crises (so-called “Big 5” crises) in post-WWII era by Reinhart & Rogoff (2009b). Owing to the crisis Finnish GDP decreased by 10% in 1991–1993. The Finnish crisis shares several common features with financial crisis in general and with other Nordic banking crises in particular. (See, for instance, Heffernan 2005, Llewellyn 2002, Jonung, Kiander & Vartia

2009, Englund 1999, Nyberg & Vihriälä 1994, Honkapohja & Koskela 1999 and Koskenkylä 1994)

The building blocks for the credit boom were laid in mid-1980 with the deregulation of the Finnish banking sectors that expanded banks' choice set of assets and liabilities. First, banks were allowed to set lending and deposit rates without any guidance from authorities. At that time, inflation was often higher than bank lending rates, real interest rates were negative and the demand for credit was high. Secondly, the interbank market was established in 1986, providing a new funding source for Finnish banks. As the securities markets had previously been almost non-existent, banks' credit supply had been bound by traditional deposit funding. Henceforth, banks could finance the growing lending stock with market funding from domestic and foreign sources. From 1980 to the peak year of 1989 the loan stock of Finnish banks quadrupled. Thirdly, restrictions on capital imports were eliminated so that the private sector could borrow from abroad. (Vihriälä 1997; Nyberg & Vihriälä 1994; Kuusterä & Tarkka 2012; Jonung, Kiander & Vartia 2009)

Private sector debt accumulated as real interest rates were low, the real economy was growing and general optimism increased the loan demand that had been suppressed during the regulation era. The demand was further boosted by tax rules that allowed a loan's interest expenses to be deduced from personal taxable income, making borrowing attractive for households. Banks also competed fiercely over market shares in private sector lending. Especially foreign-denominated loans were easy to sell because their interest rates were lower than those of markka-denominated loans. Foreign currency lending was further supported by a general trust in the pegged exchange rate regime. (Vihriälä 1997; Nyberg & Vihriälä 1994; Kuusterä & Tarkka 2012; Jonung, Kiander & Vartia 2009)

The credit expansion together with favourable economic conditions fed into asset (and especially housing) prices, which in turn magnified the demand for loans. The economy over-heated, inflation rose and wages increased. The weakened price competitiveness and loss of market shares led to declining exports and a deteriorating current account. To rein in domestic demand the Finnish government started to tighten fiscal policy and the central bank introduced a special reserve requirement in order to penalise banks' credit growth. The economy slowed down and real interest rates turned positive, leading to a decrease in private investment. The boom came to an abrupt halt during the second half of 1989. Confidence in the outlook of Finnish economy deteriorated and market interest rates increased steadily. In addition, stock and housing prices started to fall and the real estate bubble collapsed. (Kuusterä & Tarkka 2012; Nyberg & Vihriälä 1994)

The overall economic situation was further weakened by the collapse of the Soviet Union, which negatively affected Finnish exports. As a result, output and employment decreased sharply, domestic demand declined, corporate profitability plummeted and the bankruptcies increased. The change in the economic and financial outlook put the credibility of the pegged exchange rate into question and the capital inflow was reversed. For some time, authorities tried to defend the exchange rate but eventually were forced to first devaluate the Finnish markka in November 1991 and then let the currency to float in September 1992. Raising interest rates, the devaluation and rising unemployment reduced the capacity of private sector to service its (often foreign-denominated) debt. Banks' traditional loan losses started to accumulate. In addition, declining asset values meant lower collateral values, increasing banks’ losses in the case of a default. As banks' income was further squeezed by declining fee income, the first signs of bank distress and negative results for the financial year emerged. (Nyberg & Vihriälä 1994; Jonung, Kiander & Vartia 2009)

The first bank to get into difficulties was Skopbank whose profitability weakened already in the course of 1989. Together with savings banks, Skopbank’s lending had increased aggressively during the boom years and it held significant securities and real estate holdings. It also owned industrial companies, of which Tampella group was the most important. As the economic climate deteriorated and Tampella and other firms encountered severe profitability problems, the losses on risky exposures weakened the financial standing of Skopbank. Owing to increasing difficulties, a special restructuring plan for Skopbank was drawn by the authorities, and savings banks that hold a majority share of Skopbank increased the bank’s equity capital. In addition, Skopbank’s funding had been highly dependent on the short-term money markets and interbank markets. When Skopbank’s loan losses soared, markets became highly suspicious of Skopbank’s ability to fulfil its obligations. The lack of confidence prevailing on money markets increased and finally Skopbank’s liquidity collapsed in September 1991 when other banks refused to buy Skopbank’s certificates of deposit. To prevent the whole banking system from collapsing, the central bank took over Skopbank. (Kuusterä & Tarkka 2012; Vihriälä 1997; Nyberg & Vihriälä 1994; Kuusterä 1995)

Overall deterioration of the economy and increasing loan losses placed a heavy burden also on other major Finnish banks. Worst hit were the savings banks that had continued to expand their lending even as late as 1991. A significant part of their lending was denominated in foreign currencies, thus making clients vulnerable to the depreciation of Finnish markka. In addition, the savings banks had substantial investments in failing Skopbank’s shares, which had become virtually worthless. In the first half of 1992, savings banks that were on the brink of collapse merged into the Savings Bank of Finland (SBF). As loan losses doubled and the costs of market funding increased SBF's financial standing continued to deteriorate over the rest of the year. Ultimately, SBF was not able to follow its special recovery plan and the bank was split into four parts and sold to competitors in October 1993. The troubled assets of SBF were moved to an asset holding company, Arsenal. (Vihriälä 1997; Jonung, Kiander & Vartia 2009; Kuusterä 1995; Kuusterä & Tarkka 2012)

To support the faltering banking system the Finnish government bolstered the capital base of the deposit banks with a large capital injection in early 1992. Nevertheless, bankruptcy loomed for a relatively small commercial bank, STS-bank, in November 1992. The government took over the bank's risky assets and the remaining assets of STS-bank were sold to Kansallis-Osake-Pankki (KOP). To stem the erosion of confidence in the Finnish banking system, Finnish parliament guaranteed all financial commitments of the Finnish deposit banks in February 1993.[5] Despite the gradual improvement in the situation, the remaining banks continued to post substantial losses in 1994 and 1995. Owing to erosion of the capital base, two large banks, KOP and Unitas, merged to form Merita Bank in 1995. The cooperative banking group also suffered large losses but was eventually able to survive due to their more conservative strategy and the Group's joint responsibility in dealing with loan losses. (Vihriälä 1997; Jonung, Kiander & Vartia 2009; Kuusterä 2002; Kuusterä & Tarkka 2012)

3.2 The financial crisis from 2007 onwards[6]

3.2.1 The building blocks of the crisis

After a relatively long period of financial stability, the collapse of the sub-prime mortgage market in the US sent shock-waves throughout the banking systems of many advanced economies and initiated the global financial crisis in 2007. The crisis had its origins in increasing house prices, abundant liquidity, low interest rates, mitigation of financial regulation, financial innovation and new financial

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5 A new authority, the Government Guarantee Fund, was established to support the ailing banking sector. Before, companies such as Arsenal, Solidium, Scopulus and Sponda had already been established to deal with banks' problem assets and banks that had been taken into custody.

6 In addition to the stated references, this section is based on Financial Crisis Inquiry Commission (2011), Brunnermeier (2009), Coeuré (2012) and Kindleberger & Aliber (2011).

products (originate-and-distribute model and securitization). All of these factors led to a credit boom and households' excessive debt burden.

The seed for the financial crisis was the granting of home loans to customers who did not have adequate credit history or had a greater risk of defaulting (e.g. subprime customers).[7] Although subprime customers paid higher interest rates than better quality borrowers, the loans were still affordable because the prevailing interest rate level was low, the economy was relatively stable and rising house prices provided better-quality collateral. Moreover, the loans were often adjustable-rate mortgages (ARMs) with low initial payments ("teaser rate"). When interest rate on the original loan increased, borrowers refinanced it with other ARMs.

Another building block was the originate-and-distribute business model. Housing loans were now only originated by a bank or a broker, and in the subsequent stage most of the loans were sold to other (financial) institutions.[8] The financial institutions then issued securities that were backed and guaranteed by a pool of both prime and subprime mortgages (mortgage-backed securities, MBS) that they had bought. These securities were subsequently divided into different categories ("tranches") that were rated by rating agencies (Moody's, S&P and Fitch) on the basis of their riskiness. The higher the risk and the lower the credit rating, the higher the interest rate on the tranche. Investors worldwide provided a solid demand for MBSs because of the relatively high interest income in a low-interest-rate environment.

Despite the high returns, the tranches with the lowest credit ratings were often hard to sell and therefore kept by the issuing financial institutions. The solution came in the form of collateralized debt obligation (CDO) which provided a way of repackaging tranches. Instead of being backed by mortgage loans, they were now backed by lower-rated MBSs. Owing to claimed diversification effects[9] a large portion of CDOs got high credit ratings. As markets evolved, more and more exotic securities were composed such as synthetic or hybrid CDOs, which contained no actual tranches of mortgage-backed securities or other CDOs.

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7 The sub-prime borrowers were not fulfilling standard credit criteria and had a reduced debt-servicing capability owing to, for instance, lack of permanent job, divorce and the like.

8 In the traditional banking model banks kept the mortgages on their books and therefore had an incentive to monitor loan performance.

9 Although subprime mortgages were risky by their very nature, the subprime mortgages from different geographical areas were assumed to perform, *on average*, better than individual loans. If one security went bad, the second had only a very small chance of defaulting at the same time. The investments were also considered safe due to the good credit ratings.

The final layer was composed of insurance companies that provided insurance in the form of credit default swaps (CDS). The buyer of a CDS contract would pay a premium-like payment to the issuer of the CDS who promised to reimburse any losses on the underlying asset (for instance, MBS or CDO) in case of default. Such protection made the asset-backed securities attractive for investors because securities seemed to be almost risk free but offered relatively high returns. At the same time, the swap enabled banks to neutralize credit risks (related to CDOs and MBSs that banks had kept themselves) and thereby hold less capital against assets. Because CDSs were not regulated insurance products, the insurers did not need to hold capital against possible losses either.

During the first half of the 2000s the housing market boomed, and subprime mortgage lending and securitization grew rapidly in the United States. Many big American commercial and investment banks, mortgage lenders, money market and hedge funds, insurers and government-supported enterprises (GSEs) were involved in the subprime business. Everyone involved had an incentive to keep the machinery humming as they collected volume-based fees. Securitization was also viewed as an efficient way to allocate risk to those best able and willing to bear it. The business was almost always conducted via nonbank subsidiaries, leaving it beyond regulatory scrutiny. However, the lending standards slowly eroded during the years and an increasing number of loans were granted for lower and lower quality customers. At the same time, the share of subprime mortgages in MBS pools grew, eroding the ultimate quality of the securities. Although the housing prices peaked in the United States in mid-2006, things remained unchanged for a year or so. Especially the synthetic CDO market ballooned, as it provided a means to bet for and against the mortgage market. Investors could make money as long as the MBSs performed, but they stood to make even more money if the entire market collapsed.

3.2.2 The impact of the crisis in the United States

The financial crisis started in 2007 when the US subprime mortgage market toppled. Housing prices declined and households found it difficult to refinance their subprime loans. As households were unable to make mortgage payments, delinquencies rose rapidly and borrowers started to default in large numbers across the US. The collapse of the housing market proved that MBSs were highly correlated and thus the alleged diversification benefits were virtually non-existent. Owing to the deteriorating situation, rating agencies downgraded the credit ratings of low-rated securities. The action alarmed investors and the value of all securities started to decline, reflecting the higher probability that investors would not receive any return as the underlying mortgages defaulted. Due to "mark-to-market" accounting rules[10] the plummeting values of securities induced losses for financial institutions, investors and MBS and CDO originators that were keeping the instruments on their books.

Market participants became increasingly aware of subprime risks and in spring 2007 the uncertainty cornered two Bear Stearns' mortgage-focused hedge funds. As the value of the hedge funds' portfolios declined, funds' financiers and (repo) lenders[11] required more collateral against money lent to the funds (i.e. they made margin calls). To raise liquidity, funds had to sell bonds and assets at distressed prices. Simultaneously, funds' investors began to request redemptions amidst rising subprime worries. The funds were squeezed from two sides and both of them filed for bankruptcy in July 2007.

During the second half of 2007 the situation started to unravel and financial institutions reported first losses from their mortgage-related business lines. Owing to heightened mistrust, market participants wanted nothing to do with mortgage-related assets and limited their counterparty exposures. Especially lenders that provided liquidity to the commercial paper and repo markets became unwilling to fund institutions with significant subprime exposures, and the discrimination against bad and good companies increased steadily. Disruptions spread quickly to other money market instruments, and market participants increasingly hoarded liquidity. The liquidity squeeze especially affected institutions that had relied on short-term money markets for funding. These institutions were structured investment vehicles (SIVs) and money market funds, but also mortgage lenders such as Countrywide[12]. Due to funding problems, banks were forced to bail out their money market funds and commercial paper programs, bringing the mortgage assets onto their own balance sheets and transferring losses into the commercial banking system. To ease the run and to help banks to borrow US dollars the FED and the European Central Bank (ECB) provided additional liquidity to markets by means of currency swap lines in December 2007.

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10 These accounting rules required firms to use market values of securities when they valued their holdings on balance sheets (even though firms had no intention to sell the securities). As market prices declined, firms had to reflect this loss of value in their financial statements.

11 Repurchase agreements (repo) are money-market instruments that are used to obtain overnight funding from wholesale markets. In the deal the borrower sells (government) securities to a lender and receives cash. Simultaneously, borrower agrees to buy the securities back with a margin next day.

12 Bank of America announced the takeover of Countrywide on 11 January, 2008.

One of the first victims was the investment bank Bear Stearns that came under increased scrutiny by its counterparties. Renewal of the bank's short-term financing became more and more difficult and Bear experienced a massive fall in its liquid assets in one week. With depleted liquidity the company was in no position to continue and on 16 March 2008 Bear Stearns was bought by JP Morgan in a government-assisted deal.[13] Despite of a brief respite, the signs of strain soon emerged among government-sponsored enterprises (GSEs) who were large mortgage originators. Owing to declining house prices and rising delinquencies the mortgage assets were losing value and huge loan losses depleted GSEs' capital. IndyMac Bank was closed on 11 July 2008, while Fannie May and Freddie Mac were taken over by the government on 7 September 2008.[14]

After the failure of Bear Stearns and GSEs, market suspicions were directed at the value of Lehman Brothers' real-estate related investments and its reliance on short-term funding. Another big concern was the firm's numerous derivative contracts. Although the company improved its liquidity and capital position throughout the summer 2008, Lehman's problem was the lack of market confidence. Similarly to Bear Stearns, Lehman's liquidity dried up. Ultimately, the rescue efforts failed and Lehman Brothers filed for bankruptcy on 15 September 2008. Meanwhile, the management of investment bank Merrill Lynch had acknowledged the bank's increasingly difficult position and was afraid that Merrill would be the next in line of collapsing dominos. A private deal was struck with Bank of America, which acquired Merrill Lynch on 15 September 2008.

During the intensification of the crisis in fall 2008, mortgage defaults multiplied, more and more mortgage-related assets were downgraded and losses of financial institutions skyrocketed. But financial institutions had bought CDSs (i.e. insurances against the losses) from insurance companies. As many insurance companies were operating with very small capital buffers, their ability to honour their obligations was brought into question. Of greatest worry was AIG, which backstopped the market in CDOs.[15] As a result, AIG had difficulties to refinance itself from markets during the second week of September. At the same time, it had to

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[13] Federal Reserve Board agreed to purchase a part of Bear's assets to get them off the firm's books, while the rest of Bear was sold to JP Morgan.

[14] As the value of shares of existing private shareholders was effectively wiped out in the takeover, the following losses caused many small banks (that held the shares of Fannie May and Freddie Mac) to fail.

[15] Also monoline insurers provided coverage for MBSs, and some of these institutions had faced solvency problems already in spring 2008. As a consequence, the monolines' role as guarantors for auction rate securities (often referring to as long-term municipal bonds) was questioned, and the crisis spread to the previously unimpaired market for municipal bonds.

fund its own commercial paper programs since investors did not want to have unsecured exposures to AIG. As the situation worsened, AIG and the FED tried to negotiate a solution, but no deal materialized. When all three rating agencies downgraded AIG on 15 September, the FED was forced to bail out the firm on 16 September 2008.

After the failure of Lehman Brothers and AIG, a major loss of confidence occurred in financial markets, panic spread and the crisis reached seismic proportions. Many money market funds and other market participants that had held Lehman's papers suffered losses. Investors pulled back from every susceptible fund and also from funds that did not have direct exposures with Lehman. Funds, in turn, pulled money out of short-term money markets, putting further pressure on investment banks and financial companies dependent on short-term funding. A liquidity crunch ensued. Due to the opaqueness of banks' balance sheets, no-one really knew how heavily each institution was exposed and to what extent the losses were to materialize. Market participants became uncertain as to the financial health of their counterparties. As difficulties of a bank could have affected each and every bank in the interbank network, banks limited their interbank exposures and even refused altogether to lend to one another.

Investment banks Morgan Stanley and Goldman Sachs as well as savings bank Washington Mutual Bank (WaMu) were able to withstand the wholesale run by counterparties, customers and funds for a week. But a massive withdrawal of funds was about to force them into bankruptcy. On 22 September 2008 Morgan Stanley and Goldman Sachs became bank holding companies. The change of status allowed them to resort to central bank liquidity support programs. WaMu collapsed on 25 September 2008 and it was seized by the US government. The banking business was sold to JP Morgan, while the holding company (together with unsecured receivables) filed for bankruptcy. Losses of WaMu's unsecured creditors created a panic among unsecured creditors of other struggling banks and especially Wachovia. The day after the failure of WaMu, uninsured depositors accelerated the withdrawals and wholesale fund providers withdrew liquidity support from Wachovia. Finally, the bank merged with Wells Fargo. At the height of the market turbulence, central banks were forced to step in and provide unprecedented liquidity support for the financial system in September-October 2008.[16] In addition, big banks (Citigroup, JP Morgan, Wells Fargo, Bank of America, Merrill Lynch, Goldman Sachs, Morgan Stanley, BNY Mellon and State Street) re-

[16] In addition to liquidity lines, US government announced large support packages such as Troubled Asset Relief Program (TARP) on 3 October 2008.

ceived capital injections from the US government. Citigroup and Bank of America also received additional support when the US government provided a guarantee for banks' troubled assets.[17]

3.2.3 The impact of the crisis in Europe

The shock waves from the US subprime crisis spread quickly throughout the global financial market during the first part of 2007. As a consequence, European banks also started to limit their exposures to subprime-related investments and counterparties with large exposures. One of the first to be directly affected by the subprime crisis was a German bank, IKB Deutsche Industriebank. IKB's fund, Rhineland, had specialised in buying structured credit instruments such as CDOs. Due to large exposures to subprime instruments, Rhineland was no longer able to get funding from the markets in July 2007. To secure fund's liquidity, IKB provided a credit line to Rhineland. Consequently, IKB's own financial position severely deteriorated, and it had to be bailed out by IKB's largest shareholder, KfW Bankengruppe. Owing to mounting losses, the value of three investment funds of a French bank, BNP Paribas, plunged. As a result, BNP Paribas suspended redemption of these funds on 9 August 2007. Together with other central banks' liquidity operations, the European Central Bank stepped up measures to ensure the functioning of interbank markets. (Financial Crisis Inquiry Commission 2012; Cour-Thimann & Winkler 2013)

The emerging shortage of international liquidity put serious pressure on several European banks that had been reliant on short-term money markets to finance their business. Especially in the United Kingdom several (mortgage) banks and building societies faced difficulties. At the same time, mortgage-related losses increased in the UK. Northern Rock received liquidity support from the Bank of England on 14 September 2007. As the news broke out, a bank run followed, forcing the central bank to guarantee all deposits in Northern Rock. The bank was eventually nationalised on 17 February 2008. Owing to solvency problems, Alliance & Leicester accepted a takeover bid by Santander on 16 July 2008, whereas HBOS and Lloyds announced a merger on 18 September 2008. In addition, Bradford & Bingley had to be rescued on 28 September 2008.[18]

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[17] Government agreed to cover a major part of losses that might arise from banks' predetermined assets (mainly loans and mortgage-backed securities).

[18] The bank was partly nationalized as UK government took over the mortgage book, treasury assets and wholesale business of the bank. Santander bought the bank's savings business and branch network.

September-October 2008 saw a constant wave of European bank failures owing to the global liquidity squeeze. The home-grown imbalances, excessive credit growth and funding mismatches started to unravel. Banks' earning capacity and capital were eroded by declining values of subprime-related securities and investments, home-made mortgage related losses as well as high refinancing costs. Benelux countries were first in the line of fire. On 28 September 2008 Fortis was rescued in a joint effort by the governments of Belgium, the Netherlands and Luxemburg. The bank had taken over ABN Amro and as the deal had weakened Fortis's solvency buffers the bank's ability to finance the acquisition had been questioned. The takeover had also proved unsuccessful, as the value of ABN Amro declined soon after the deal. Two days later, Dexia received a large bailout from Belgian, French and Luxembourg authorities. The bank's ability to finance its long-term municipal lending had been severely hampered. In addition, large potential subprime-related losses from Dexia's US subsidiary FSA threatened to deplete Dexia's capital. Eventually, Dexia was dismantled into three parts; Belgium bought and nationalised Dexia Belgium, the Luxembourg unit was sold to private investors and Dexia's French municipal finance operations came under French state control.

On 29 September 2008, a German lender Hypo Real received a liquidity lifeline from the German central bank and a consortium of German banks. The bank's position weakened due to heavy losses from its Irish subsidiary, Depfa Bank[19]. While short-term financing was not available, Hypo did not have sufficient liquidity reserves to bridge the funding gap. As the situation deteriorated further, private sector players withdrew their support and Hypo Real was finally taken over by the German government in 2009.

Iceland's banking sector was hit especially hard owing to Icelandic banks' rapidly grown (foreign exchange) lending to the private sector, large dependence on foreign and market liquidity as well as inadequate capital to cover losses. As the banking sector had grown rapidly prior the crisis, the central bank of Iceland was unable to act as a lender of last resort for the banks and supply the foreign currency that the banks needed. The three main commercial banks (Kaupthing, Glitnir and Landsbanki) eventually collapsed and were taken under government receivership on 6 and 7 October 2008. (Nielsson & Torfason 2012)

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[19] In addition to public sector financing, Depfa underwrote US municipal bonds that had their ratings downgraded during the crisis. Under the terms of the underwriting, Depfa was required to buy back the securities after the downgrade. Because of the difficulties in obtaining short-term funding in the markets at that time, Depfa's liquidity became a major concern.

Throughout the rest of the year 2008 European banks continued to lean on government support and to tap new capital from state rescue packages. In order to facilitate banks' refinancing, many governments also extended guarantees on bank bonds. On 13 October 2008 UK government designated a rescue scheme and injected new capital into Royal Bank of Scotland, HBOS and Lloyds. While supporting UBS, the Swiss government took responsibility for the bank's toxic assets, which were transferred to government owned fund. French government gave financial support to the country's largest lenders, including BNP Paribas and Société Généràl. Other European banks to receive assistance were institutions such as Austrian Erste, German Commerzbank, Dutch ING and Belgian KBC Group. In return, the above-mentioned governments often received shares of troubled banks.

In 2008, the Irish property boom came to an end and residential property prices started to fall amidst a steadily deteriorating international financial environment. Mortgage loans to households, as well as property and construction lending to developers, had increased manifold during the boom period. With large exposures to housing markets and declining property values, Irish banks' loan losses started to materialize and their solvency position deteriorated. At the same time, they found it ever more difficult to refinance their operations, and liquidity problems emerged. Government was forced to step in and extend a comprehensive guarantee to all depositors and debtors of Irish banks on 29 September 2008. Despite the guarantee, the situation of Anglo Irish bank continued to weaken, and it was eventually nationalised on 15 January 2009. Besides Anglo Irish Bank, Allied Irish Bank (AIB) and Bank of Ireland were recapitalised in February 2009. Towards the end of 2009, the National Asset Management Agent (NAMA) was formally established to deal with problem loans and toxic assets. (Donovan & Murphy 2013)

Together with the downturn of the global economy the European governments' bank rescue measures increased the debt burden of already overly indebted European countries. A trigger for the European sovereign debt crisis was the disclosure of the magnitude of Greece's fiscal deficit at the beginning of 2010. Amid the escalation of the crisis and downgrading of the Greek sovereign debt rating, the situation in the international financial markets deteriorated in early May 2010. The EU/IMF financial rescue package was given to the Greek government on 1 May 2010. As the bank bailout proved to be extremely costly in Ireland, Irish government also received financial support from EU/IMF on 29 November 2010. Portugal also received a bailout on 16 May 2011, while Greece received a second financial package in February 2012. In addition, the European Union granted funds for capitalisation of Spanish banks in June 2012.

4 SUMMARY OF THE ESSAYS

The purpose of this dissertation is to examine the impact of negative shocks on the banks and banking system. More specifically, the dissertation disentangles the effects of credit contagion in Finnish and European interbank markets and analyses how pressures on banks' capital and liquidity positions have affected euro area banks' lending and macro economy. These issues are discussed in four interrelated essays which form the main body of the study. While the essays address the topic from different angles, a financial crisis and its potential negative repercussions form a common background for all of them. The dissertation contributes to financial literature by providing evidence on the vulnerabilities of Finnish and European interbank markets, the importance of network effects for financial stability and deleveraging forces in the euro area banking sector. Furthermore, it adds to the literature by looking at the macro-financial linkages and shedding light on the adverse effects of declining lending on economic activity. A more specific description of the essays and their contributions is in following subchapters.

4.1 Essay 1: Interbank exposures and risk of contagion in crises: Evidence from Finland in the 1990s and the 2000s

Financial crises occur from time to time and generally affect negatively the financial stability of the banking sector. Crises are also often extremely costly for the economy as a whole. From a historical perspective, relatively little emphasis has, nevertheless, been placed on analysing how crises spread across institutions and borders, although the recent financial crisis highlighted the importance of the interconnectedness of financial institutions. One of the possible transmission channels for financial shocks is credit contagion (or so-called domino effect) between financial sector intermediaries in the interbank markets.

The first essay of the dissertation examines the possibility of domestic and foreign credit contagion via Finnish banks' interbank exposures during two distinctive crises, namely the Finnish banking crisis in the 1990s and the financial crisis in the 2000s. The essay contributes to the literature, firstly, by focusing on two distinctive crisis periods. The Finnish banking crisis has been classified as one of the "Big 5" banking crises by Reinhart & Rogoff (2009b), while the recent financial crisis had a truly global reach. Secondly, the analysis is of importance as the role and the potential impact of contagion in the Finnish banking crisis has not been previously discussed. The risk assessments have mainly concentrated on individual institutions and relatively little public information on network effects exist. As bank bail-outs are often justified by potential negative spillover effects, a deeper understanding of interbank linkages and transmission channels is therefore desirable to increase the knowledge of system-wide effects. Finally, as public information on network effects of the Finnish banking system, including the implications of foreign-based contagion, is almost non-existent, the essay contributes by identifying national and cross-border vulnerabilities of the Finnish banking system. The specific case of a small open economy such as Finland is interesting because of the vulnerability to cross-border risks. The Finnish banking sector is highly concentrated and nowadays dominated by foreign banking groups, making Finland a prominent example for other similar banking systems. A deeper understanding of interbank linkages and transmission channels is thus highly desirable.

The credit contagion is analysed, first, by using the method of entropy maximization to estimate interbank relationships between banks and, secondly, by simulating the domino effects with a sequential (or round-by-round) algorithm (see, Upper & Worms 2004; Upper 2011). Entropy maximization denotes the most likely outcome given a priori knowledge and it has been used to fill in the gaps of data sets. In the present context, the outcome of the estimations thus corresponds to the most likely structure of interbank lending given all the a priori pieces of information on the interbank market. In the simulations, the scope of contagion is estimated by letting banks go bankrupt one at a time. If a bank's losses from interbank loans to the failed bank are greater than the lender's own capital, the lender defaults. Contagion need not be confined to such first-round effects, but a failure of the first bank can trigger a whole chain of consequent failures (domino effect). Therefore, both direct and indirect exposures to the failing bank are taken into account. The methodology has been widely applied, and similar studies are done for the Swiss, Belgian, English, Dutch, British and Italian interbank markets. (Sheldon & Maurer 1998; Degryse & Nguyen 2007; Wells 2004; van Lelyveld & Liedorp 2006; Mistrulli 2011)

The data set covers Finnish deposit banks in 1988–1996 and 2005–2011. For 2005–2011 the analysis is based on balance sheet, counterparty exposure and liquidity risk data, whereas for 1988–1996 only balance sheet data are used, as data on foreign and domestic counterparties and liquidity risks are not available. As balance sheets and large exposure data do not give complete information on individual banks' actual counterparty exposures, the entropy maximization methodology has been used. Based on the estimates, Finnish banks' bilateral exposure matrices are constructed. The danger of contagion and the effects of a bank failure in the Finnish interbank market are subsequently simulated with the sequential algorithm.

The results suggest that during the banking crisis in the 1990s three banks out of ten were able to trigger contagion. In 2005–2011, five large and middle-sized banks were sources of contagion. In terms of average contagion, the fragility of the banking system increases before the crisis irrespective of the original source (domestic/international) of the crisis. During the 1990s the contagion would have affected almost half of the banking system (assuming 100% loss ratio) and thus the implications for society would have been severe without the authorities' rescue measures. In 2005–2011, the negative shock caused by a failure of a foreign bank (with 100% loss-given-default) affects 77% of the total assets of the Finnish banking sector, while contagion from a Finnish bank impacts 66% of the total assets of the sector. The sensitivity to foreign bank failures is worrying for a country such as Finland that has large cross-border exposures with foreign banks. Finally, the evidence indicates that the higher the concentration of the banking system, the greater the system's vulnerability to contagion.

Although the interbank market exhibits higher risk levels in the current crisis than in the 1990s, a bad outcome has not materialized owing to the absence of a trigger. The macroeconomic shock was milder and more transitory in the 2000s than in the 1990s, banks' capital buffers are currently large, interest rates are lower than in the early 1990s and many borrowers and lenders have learned from the experience of the 1990s, and so acknowledge the dangers of over-borrowing.

4.2 Essay 2: Contagion in the interbank network: An epidemiological approach

The first wave of the subprime crisis in 2007 impacted large American investment banks but soon enough financial institutions worldwide were affected as the highly interconnected modern financial world facilitated rapid transmission of the shock. Owing to the limited knowledge of counterparty exposures no bank really knew how heavily each institution was exposed and to what extent losses were to materialize. Banks' financial interlinkages in the interbank markets combined with potentially high counterparty losses led banks to limit their exposures, as they were unable to distinguish good banks from bad ones. The fear of negative impacts spread like a disease over the interbank network, ultimately causing the interbank money markets to freeze.

The second essay studies credit contagion in the European banking sector in 2007 and 2010 by applying an epidemiological model with extensions, generated networks and actual data. The paper adds to the literature by proposing a novel approach to model the transmission and the magnitude of negative spillover effects with an epidemiological SIR (susceptible – infected – recovered) model by Kermack & McKendrick (1927). Although the similarities between propagation of epidemics and contagion are striking (See, for instance, May, Levin & Sugihara 2008; Haldane & May 2011; Haldane 2009) and the SIR model has already been used to analyse the spreading of diseases, macroeconomic expectations and transmission of economic crisis from one country to another via international trade (Anderson & May 1991; Bansal et al. 2010; Carroll 2006; Garas et al. 2010), no such analyses, to the best of my knowledge, have been done for the European interbank markets. While the SIR model provides a framework to analyze the consequences of an idiosyncratic bank default via direct and indirect counterparty exposures, the model is also extended to take into account the characteristics of financial institutions. Secondly, the paper also contributes to the literature by introducing an endogenous loss-given-default (LGD) which time-dependent.

Thirdly, the essay enriches the literature by examining cross-border contagion in Europe prior to and during the global financial crisis, as the model is calibrated with actual data on large European cross-border banks. Fourthly, to provide more intuition as to driving forces of the contagion process, this essay also disentangles the importance of individual bank-specific characteristics such as size, financial strength and position in the network for contagion. The main motivation is to find leading indicators that are of relevance from the financial stability perspective. In contrast to previous papers we test a large set of *individual* indicators. Finally, the analysis also sheds light on the relevance of central bank actions by assessing whether central bank interventions are helpful in containing the negative spillover effects.

The analysis is based on balance sheet data from 51 major European cross-border banking groups with headquarters in Germany, France, Italy, Spain, the Netherlands, Belgium, Austria, Portugal, Greece, Ireland, the UK, Denmark and Sweden in 2007 and 2010. We also use information on consolidated banking statistics of the Bank for International Settlements (BIS) and monetary financial statistics of the central banks to approximate banks' interbank exposures. The bank network is modelled by a scale-free networks model by Barabasi & Albert (1999), as Boss et al. (2003) and Soramäki et al. (2007), among others, have shown that real-world interbank banking networks have the properties of scale-free networks. Furthermore, we define endogenous LGDs and bank-specific vulnerability parameters. Based on the extended SIR model, generated networks and data, we subsequently simulate credit contagion in the banking system.

The results show how the contagion segments European banks into two categories. A similar situation occurred during the current financial crisis when the European banking sector was divided into “good names” with an access to interbank lending and “bad names” that were excluded from money markets by means of larger haircuts and margin requirements. On average, contagion affects negatively about 40% of the European banks in 2010, but considerable heterogeneity remains owing to the network structure and the characteristics of the first failing bank. The magnitude of the contagion is almost twice as large in 2007, just before the onset of the financial crisis. In terms of nationality, French, British, German and Spanish banks are able to induce widespread contagion, while banks from Ireland, Greece and Portugal have only limited negative effects on the system.

Regarding the importance of bank-specific factors, a bank's size, its central position in the network, large business volumes and bank clustering are prominent in explaining the contagion. In particular, the weighted clustering coefficient, betweenness and closeness centrality, connectivity and volume of in-coming interbank loans are significant variables. Finally, central bank liquidity operations and other central bank measures are effective in alleviating contagion and financial crisis, although the impact is limited.

4.3 Essay 3: Risk, capital buffers and bank lending: The adjustment of euro area banks

During the latest financial crisis, banks’ core capital proved to be insufficient to cover impairment losses arising from loan and security portfolios. The shock to equity capital was further augmented by new stringent regulatory requirements (BIS 2010b; EBA 2011). Furthermore, in order to minimize the risk of breaching the regulatory limit banks usually operate with an additional capital buffer (ECB 2007; Harding, Liang & Ross 2013). This voluntary buffer, together with the regulatory capital, forms banks’ internal capital target, which is not observable to the general public. In the case of a capital shortfall, banks seek to close the capital gap and reach their target. As banks may either increase their own funds or reduce their exposures, the adjustment may weigh negatively on credit supply. Owing to the financial crisis and shocks on bank capital, the banks' capacity to extend credit to the private sector has been questioned.

The third essay of this dissertation investigates factors determining euro area banks’ internal target capital ratios. Moreover, it analyses whether banks’ adjustment towards their targets has an impact on their assets in general and on lending and security holdings in particular. The paper adds to the literature by analysing the impact of capital shocks on euro area banks and by providing evidence on the role and significance of euro area banks' capital gaps on the credit supply. While Francis & Osborne (2009), Berrospide & Edge (2010) and Kok & Schepens (2013) provide evidence on banks' capital buffers and adjustment towards internal target capital ratios in the US, in the UK and in Europe, no such evidence exist for the euro area. Another novel feature of this essay stems from the estimation period, covering the latest financial crisis. Previous literature tends to focus on other geographical areas and the credit crunch of the early 1990s in the US.

The analysis is based on a partial-adjustment model which consists of two separate steps. In the first step, banks' internal time-varying target capital ratios are estimated with a panel model incorporating bank-specific factors such as loan losses, expected default frequency (EDF), total assets and retained earnings. The internal targets are estimated on a bank-by-bank basis. Based on the estimated parameters, a bank's time varying capital gap between the desired (unobserved and internal) target capital ratio and the actual (observed) capital ratio is then computed for each time period. The capital gap is composed both in terms of the target Tier 1 capital ratio and the target total capital ratio. In the second step, the banks' capital gap and macroeconomic variables are used to explain the banking system's adjustment. A dynamic panel model is estimated for total loans and total securities.

The data set covers euro area listed banks and country-specific macroeconomic variables during the most recent financial crisis from the first quarter of 2005 to the last quarter of 2011. The granular bank data refer to large and listed banks domiciled in Germany, France, Italy, Spain, Belgium and Austria. Information on risk weighted assets (RWAs), total assets, retained earnings, return on equity (ROE), provisioning for loan losses, net loans, security holdings, expected default frequencies (EDFs) and solvency ratios (Tier 1 capital ratio and total capital ratio) are extracted for each bank at the consolidated group level. Country-specific macro variables include credit demand, gross domestic product (GDP) and stock prices. In addition, data on banks' credit standards and the expected loan demand of non-financial corporations are included as available from the bank lending survey (BLS) of the European Central Bank (ECB).

The results suggest that several bank-specific indicators have a positive impact on banks' internal target capital ratios. A substantial part of the movements in internal targets reflects changes in banks' risks and earnings development associated with economic conditions. Risk variables impact positively banks' internal targets, inducing the institutions to strive for higher capital levels. Meanwhile, the coefficients of income indicators are positive but remain insignificant, in line with the results of Berrospide & Edge (2010). The results hold both for Tier 1 capital ratio and total capital ratio.

In terms of the derived capital gap for Tier 1 capital ratio, the aggregated euro area banking system's undercapitalisation is close to 2.0 percentage points (p.p.) in the middle of 2008. The negative gap diminishes towards the end of 2011 but the heterogeneity across individual banks increases. Similar results are obtained for the total capital ratio. Moreover, the paper provides empirical evidence that undercapitalized banks tend to restrict the provision of loans to the economy. Estimates indicate that the closure of a 1 p.p. capital gap dampens loan growth by 2.0 to 2.3 percentage points in the medium-term. The impact on security holdings is found to be larger, around 5.8–7.1%, thereby suggesting a pecking order for deleveraging.

4.4 Essay 4: The impact of risk, funding and sovereign shocks on euro area banks and economies

The financial crisis fundamentally changed banks' operating environment and confronted banks with increasing risks, declining profitability and weakened access to wholesale funding. Together with new capital requirements the shocks induced banks to modify their balance sheets. External shocks and banks' adjustment can disturb financial intermediation and reduce banks' ability to provide credit to non-financial corporations. The impact can be especially large in the euro area, where debt markets are relatively small and a large part of firms' external financing is provided by banks. Moreover, Adrian & Shin (2011) have shown that since the beginning of the financial crises banks have not only been passive intermediaries, but banks themselves can be a source of disturbance. Indeed, the crisis brought the role of banks to the centre stage of both policy and research agendas.

The final essay examines macro-financial linkages in the euro area since the beginning of the financial crisis. It contributes to the literature by estimating how risk, funding and sovereign shocks affect the total assets, corporate lending and profitability of the banking sector as well as real economy (GDP) both at the euro area level and in Germany, France, Italy and Spain. No such analysis on macro-financial linkages is available for the euro area in the latest financial crisis. Previous academic literature analyses either the impact of different shocks on banks' lending (see, for instance, Francis & Osborne 2009; Jimenez et al. 2012; Cihak & Brooks 2009) or the impact of banks' adjustment on the macroeconomy (Buch &

Neugebauer 2011; Cappiello et al. 2010; Cihak & Brooks 2009; Calza & Sousa 2005).

The essay's contribution also resides in the implemented methodology. We adopt a panel VAR model, a sign restriction approach and impulse response functions to estimate, identify and analyze the implications of the shocks. The methodology enables us to combine individual bank level data to macroeconomic variables. The use of bank-level data is of importance, as the idiosyncratic shocks to large firms can explain a large share of fluctuations at the macro-level (Gabaix 2011). As many European banking sectors are dominated by a few large banks, company-level information is extremely valuable in assessing the impact of idiosyncratic shocks. In addition, individual data provides a micro foundation to aggregate shocks. Our sign restrictions approach also provides a flexible framework for analysis of the dynamics and interactions between variables. Another novelty is the coverage of the financial crisis period, providing evidence on the outcome of severe stress on banks.

To assess the banking sector's reactions to unexpected changes in the business environment, we first estimate a vector autoregression model (VAR) with bank-specific indicators and macro level variables for 2005–2013. Sign restrictions are subsequently used to identify three granular shocks that relate to increasing riskiness of banks (risk shock), banks' difficulties in obtaining wholesale funding (funding shock), and the impact of sovereign debt crisis in Europe (sovereign shock). We then apply impulse response functions (IRFs) in order to analyse the individual implications of the shocks for endogenous variables and to track the time paths of nominal shocks. Finally, the historical decompositions of responses are composed to analyse how much of the variations in banks' total assets, profitability and corporate lending, and in GDP growth are explained by the shocks.

The bank data set consists of large and listed banking groups that have headquarters in the euro area countries. For each bank in the sample, we extract information on total assets, risk weights, reserves for loan losses, and return on equity (ROE). In addition, we complement the data set with country-level information on corporate lending, the volume of bank debt and asset prices. We also add a credit default swap (CDS) spread variable, defined as a difference between sovereign CDSs and bank CDSs at the country level. Finally, as for the macroeconomic variables, the dataset includes quarterly real gross domestic product (GDP).

The results show that the time paths of nominal shocks capture the negative repercussions of the crisis in different banking systems and reflect the events of the financial crisis. More importantly, the risk, funding and sovereign shocks explain a substantial part of the variations in total assets, profitability, corporate lending and GDP growth. At the euro area level, three shocks explain about 60 percentage of the credit slowdown and a third of the decline in GDP in 2009. While risk and funding shocks explain most of the variation in 2009–2010, the role of the sovereign shock remains subdued. However, the sovereign shock explains approximately 10 percent of the variation in banks' profitability and GDP growth in 2009. During the latter part of the estimation period, all shocks continue to play a role, albeit their contribution declines somewhat.

Over the whole estimation period, the euro area average is affected by different country level dynamics. During the early years of the financial crisis, the contributions of shocks are substantial in Germany and France. In 2012–2013 the contributions of shocks subside in Germany and France, but they become significant especially in Italy. Moreover, the contribution of three shocks remain relevant in Spain during the latter part of the estimation period. Italian banks are affected by the risk shock and Spanish banks face increasing funding pressures. Overall, the negative implications of shocks at the euro area level are composed of the contributions of German and French banks in 2009–2011 and the contributions of shocks to Italian and Spanish banks in 2011–2013.

5 CONCLUSIONS

This dissertation studies banks, their resilience and adjustment in the aftermath of an adverse shock to their operating environment. Owing to banks' important role in financial intermediation, such shocks may be multiplied or attenuated, potentially introducing negative repercussions for the whole economy. Thus, the first and second essays study credit contagion and its implications for the financial stability in the banking sector. The second essay also looks at the importance of bank-specific factors for domino effects. Looking the issue from a different angle, the third and fourth essay shed light on the effects of banks' adjustment to a negative shock. Finally, evidence on the implications for the macro economy is provided.

To be specific, the findings indicate that in the worst case scenario credit contagion has substantial negative effects. The first essay shows that domestic contagion affects, on average, almost half of the Finnish banking sector in the 1990s and about 66% of the banking sector in 2005–2011. In the 2000s the failure of a foreign bank impacts 77% of the total assets of Finnish banks. Cross-border contagion thus increases financial stability risks in a country whose banking sector is dominated with foreign-owned banks. Similarly, the second essay demonstrates that the average contagion affects 70% and 40% of European banks' total assets in 2007 and in 2010, respectively. Country-level results suggest that French, British, German and Spanish banks are the most contagious ones, whereas banks from Ireland, Greece and Portugal induce only limited negative effects. Moreover, bank clustering, large in-coming interbank loans, the bank's position in the network and banks size are prominent factors in determining the magnitude of the contagion. Finally, central banks' interventions reduce contagion only slightly.

Shocks induce euro area banks to reduce their lending. The third essay indicates that changes in banks' risks and earnings influence banks' internal target capital ratios, and that euro area banks were undercapitalised at the eve of the financial crisis in 2008. The adjustment towards higher equilibrium capital ratios also affects significantly banks' assets. The impact is around 5.8─7.1% for security holdings and 2.0─2.3% for loans, thereby suggesting a pecking order. The findings of the fourth essay confirm that risk, funding and sovereign shocks explain substantial part of the movements in banks' total assets, profitability, corporate lending and output growth. In 2009, shock contributions account for around 60 percentage of the decrease in corporate lending and approximately a third of the decline of the annual GDP growth at the euro area level. While shocks exhibit a notable impact on Germany and France in 2009–2011, they are significant for Italian and Spanish banks only towards the end of the estimation period.

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Interbank Exposures and Risk of Contagion in Crises: Evidence from Finland in the 1990s and the 2000s

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Abstract

By analysing the risk of interbank contagion during two distinctive crises, namely the Finnish banking crisis in the 1990s and the most recent financial crisis of the 2000s, this paper provides evidence on negative domino effects in a small open economy with a concentrated banking system. Simulations based on interbank exposures and maximum entropy estimations shed light on the magnitude of the contagion and the vulnerability to cross-border risks. The results show that just before the onset of the Finnish banking crisis the contagion would have affected almost half of the banking system, indicating that without the government bailout the implications for society would have been severe. In the 2000s the domestic contagion peaked after the collapse of Lehman Brothers and amid the sovereign debt crisis. The analysis suggests that the higher the concentration of the banking system, the more vulnerable it is to severe contagion. Moreover, strong interbank linkages with foreign banks increase the domestic risks.

JEL classification numbers: G01, G21, N24
Keywords: Contagion, Interbank Exposures, Banking Crises, Finland, Maximum Entropy

1 Introduction

The history of financial crises extends to the early 20th century and beyond, including incidences such as the Wall Street Crash of 1929 and the sub-prime crisis. Frequently, the crises impact negatively on the financial stability of the banking sector and are extremely costly for an economy as a whole. From the historical perspective, relatively little emphasis has, nevertheless, been placed on analysing how the crises spread across institutions and borders, although the recent financial crisis highlights the importance of the interconnectedness of financial institutions.
The interbank markets, in which banks borrow and lend funds, may act as transmission

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channels for shocks during crises. These linkages are especially vulnerable since banks can relatively easily reduce interbank lending should their confidence in counterparties deteriorate. In the worst case scenario, the losses from interbank loans may lead to contagion (or so-called domino effect), i.e. one bank failure leads to failures of other banks even if the latter are not directly affected by the initial shock or do not hold open positions with the first failing bank [1].[2]

This paper examines the possibility of contagion via banks' interbank exposures in a small open economy with a concentrated banking sector during two distinctive crises. Academic literature is enriched, firstly, from the focus on significant crises periods, namely the Finnish banking crisis in the 1990s, which is one of the "Big 5" banking crises [5], and on the recent financial crisis of the 2000s. Insights into similarities and differences in the two crises and into the patterns of contagion are provided for the estimation periods. The specific case of a small open economy such as Finland is interesting because of the vulnerability to cross-border risks, given the dependence on foreign trade: exports of almost 40% of GDP in 2010. Moreover, Finland's GDP decreased by 8% in 2009 and by 10% in 1991–1993, causing a severe stress to the banking system.

Secondly, the role of contagion in the Finnish banking crisis has not been discussed in previous literature. The systematic nature of the crisis in the 1990s forced authorities to bail out banks in order to save the rest of the banking system by limiting the effects of contagion. The contagion simulations shed light on the magnitude of problems that society would have faced if banks had been allowed to fail.

Thirdly, there is relatively little public information on network effects of the banking system, and during the last decade risk assessments have mainly concentrated on individual institutions. A deeper understanding of interbank linkages and transmission channels is therefore desirable to increase our knowledge of contagion and to help lessen the danger of "moral hazard", i.e. excessive risk-taking. Finally, cross-border vulnerabilities of the Finnish banking system from 2005 onwards are identified. The Finnish banking sector is highly concentrated and nowadays dominated by foreign banking groups, making Finland a prominent example for other similar banking systems.

Banks' bilateral interbank lending is estimated by using the maximum entropy method and data on banks' balance sheets, interbank assets and liabilities. On the basis of these estimates, the effects of a bank failure in the Finnish interbank market are subsequently simulated.

The results suggest that during the banking crisis in the 1990s three banks were able to trigger contagion, while indicating five large and middle-sized banks as sources of contagion in 2005–2011. During the 1990s the contagion would have affected almost half of the banking system (assuming 100% loss ratio) and thus the implications for society would have been severe without the authorities' rescue measures. In 2005–2011, the negative shock caused by a failure of a foreign bank (with a 100% loss-given-default) affects 77% of the total assets of the Finnish banking sector, while contagion from a Finnish bank impacts 66% of the total assets of the sector. In addition, the estimations show that the higher the concentration of the banking system, the greater the system's vulnerability to contagion. This is worrying in terms of a country that has large

[2]Other contagion channels include information, sale of illiquid assets or joint macroeconomic shocks but they are beyond the scope of this paper. (See [2], [3] and [4])

cross-border exposures with foreign banks.

In terms of average contagion, the fragility of the banking system increases before the crisis irrespective of the original source (domestic/international) of the crisis. Although the interbank market exhibits higher risk levels in the current crisis than in the 1990s, a bad outcome has not materialized owing to the absence of a trigger. The macroeconomic shock was milder and more transitory in the 2000s than in the 1990s, banks' capital buffers are currently large, interest rates are lower than in the early 1990s and many borrowers and lenders have learned from the experience of the 1990s, and so acknowledge the dangers of over-borrowing.

The rest of the paper is organised as follows. The previous literature is reviewed in section 2, and section 3 describes the Finnish banking sector and the crisis periods. Section 4 presents the data and method of estimating bilateral exposures and simulating contagious effects. This section also briefly discusses the simulation parameters. The results are introduced in section 5 and section 6 concludes.

2 Previous Research

The Finnish banking crisis is dealt with in several papers, describing the boom and subsequent bust of the Finnish banks and economy in the early 1990s (see, for instance, [6], [7], [8] and [9]). No single, individual cause for the negative outcome can be identified, as several factors such as financial deregulation, abundant refinancing opportunities for banks, over-borrowing of firms and households, excessive risk taking, lack of adequate risk management, policy and supervisory measures, and negative macroeconomic shocks all played a role. Although the Finnish crisis shares common features with other financial crisis in general and with Nordic banking crises in particular (see [6], [7], [10], [11], [12], [13]), it is one of the worst banking crises (so-called "Big 5" crises) of the post-WW II era, as listed in [5]. Despite the extensive coverage, the role of contagion in the Finnish banking crisis has not yet been discussed.

Theoretical evidence on the consequences of the banking sector's structure for contagion is twofold. If all banks are connected with each other (i.e. the interbank market is complete), the initial impact of a financial crisis may be attenuated [14]. But if each bank is connected with a small number of other banks (incomplete interbank markets), the crisis may be felt strongly in neighbouring institutions. However, some papers provide evidence that an incomplete structure renders the banking system less vulnerable to contagion. [15], [16]

Empirical research finds potential for significant contagion effects but regards as unlikely a substantial weakening of the whole banking sector ([17], [18], [19], [20], [21], [22], [23], [24]). Other empirical studies have estimated contagion by considering a wider variety of risks and factors (see e.g. [3], [25], [26]). These studies support the above findings and also indicate significant cross-border contagion. Regarding cross-border contagion, [27] shows that the contagion is more widespread between countries geographically close to each other. Furthermore, they suggest that the risk of cross-border contagion has increased over the years.

3 The Finnish Banking Sector and the Crises

3.1 Banking Sector in Finland

In the 1990s the majority of Finnish banking market was dominated by KOP, SYP, savings banks, cooperative banking group, Post office bank and Skopbank. Of these institutions, KOP and SYP were the largest ones and were fierce rivals. The third largest banking group was the savings bank group, which comprised about 250 savings banks and Skopbank, which served as the group's central financial institution. OKO Bank financed the cooperative banks that belonged to the cooperative banking group, and Post office bank was a government-owned commercial bank. The Finnish banking market was already then highly concentrated, as the remaining banks were relatively small. ([6], [8])
According to the balance sheets, the main banking groups in Finland are currently: Nordea Bank Finland, OP-Pohjola Group, Sampo Bank, savings banks (incl. Aktia) and local cooperative banks. Nordea and Sampo banks are foreign-owned, and the Finnish banking sector is highly concentrated, as the three main players account for approximately 75% of total lending. All together, there are about 360 individual credit institutions in Finland, several of which belong to a larger consolidated banking group.

3.2 The Crises in the 1990s and 2000s

The deregulation of the Finnish financial market in the mid-1980s planted the first seeds of the Finnish banking crisis, as it expanded banks' choice set of assets and liabilities (for more details, see [7]). The interbank market was established in 1986, providing a new funding source for Finnish banks. Banks were no longer bound to traditional deposit funding but could finance the growing lending stock with market funding. At the same time, the private sector started to accumulate debt, as low real interest rates, a growing real economy and general optimism unleashed the demand that had been suppressed during the regulation era.
Moreover, banks competed fiercely over market shares in private sector lending. During the second half of the 1980s, Skopbank's and savings banks' lending increased aggressively, but other banks too were quick to react to the competition. Foreign currency loans were especially easy to sell owing to interest rate differentials and a pegged exchange rate regime.
When the overall economic situation weakened, banks' traditional loan losses started to accumulate and their situation worsened. Finally, the banking crisis was trigged by steeply rising interest rates, devaluation of the Finnish currency, and the collapse of the real estate bubble and exports to the Soviet Union. A severe depression followed, and GDP decreased by 10% in 1991–1993. The Finnish experience with financial liberalization, lending boom and systemic banking crisis resembles in many ways the crises that took place in Sweden and Norway in the 1990s although some differences remain. [6]
Turning to individual banks, Skopbank's strategy had been highly dependent on the availability of market funding and, as Skopbank's loan losses soared, the markets became sceptical as to Skopbank's ability to meet its obligations. The lack of confidence prevailing in money markets increased and finally Skopbank's liquidity collapsed in September 1991 when other banks refused to buy Skopbank's certificates of deposit. To prevent the whole banking system from collapsing, the central bank took over Skopbank.

In the first half of 1992, the savings banks that were on the brink of collapse merged to form the Savings Bank of Finland (SBF), but its financial standing deteriorated during the year as loan losses doubled and the costs of market funding increased. Ultimately, SBF was not able to follow its special recovery plan and the bank was split up between four competitors in October 1993.

The recent global financial crisis started in 2007 when the sub-prime mortgage market collapsed in the US and the value of mortgage backed securities plummeted, causing large losses for financial institutions that had invested in these instruments. As the crisis deepened, panic spread in financial markets and equity values declined. Lehman Brothers failed in September 2008, after which the financial crisis intensified. Several US and European banks were either bailed out by governments or merged with other companies. Iceland's banking sector was hit especially hard, while Swedish banks booked large loan losses on lending to Baltic States, and many small banks in Denmark faced difficulties. [13], [28]

The over-indebtedness of several European countries, along with a downturn in the global economy, bursting property bubbles, as well as investment and loan losses in the European banking sector, contributed to an unfolding of the European sovereign debt crisis. The crisis began at the start of 2010 when the magnitude of Greece's fiscal deficit was revealed. Amid fears of crisis escalation and downgrading of Greek sovereign debt, the situation in the international financial markets deteriorated in early May 2010. Since then, Ireland and Portugal have also received rescue packages.

Throughout the sovereign debt crisis the international money markets have remained extremely volatile, although several policy measures have been undertaken. The situation has remained fragile, and financial markets have been repeatedly hit by renewed worries related to the debt crisis. The financial markets continue to be divided into weak banks dependent on public support and strong banks still able to access markets on their own. With limited exposures to ailing governments' bonds and low traditional loan losses, the Finnish banks have been relatively well-placed compared to their European and Scandinavian peers in recent years.

4 Methodology

4.1 Data

Contagion analyses of the Finnish interbank market in 1988–1996 and 2005–2011 include the Finnish deposit banks.[3] The analysis for 2005–2011 is based on balance sheet, counterparty exposure and liquidity risk data, whereas data were not collected on counterparty exposures and liquidity risk in the 1990s, so that only balance sheet data are used for the earlier crisis period.

Balance sheet information is based on data collected from banks' annual reports for the

[3]KOP, OKO Bank, SYP, Merita Bank, savings banks, Postbank, Skopbank, STS Bank and Bank of Åland in 1988–96 and Nordea Bank Finland, Sampo Bank, Pohjola (former OKO), Aktia Savings Bank, Bank of Åland, Evli, eQ Bank, Tapiola Bank, S-Bank, local co-operative banks and local savings banks in 2005–2011. Local co-operative banks and local savings banks are each combined into a separate banking group.

1990s and on data collected by the Finnish Financial Supervisory Authority (FSA) for the 2000s. Yearly data on aggregated interbank loans and receivables vis-à-vis financial institutions are available for the 1990s; for the 2000s we have quarterly data on interbank loans and receivables as well as on banks' bonds and certificates of deposit.[4] Table 1 shows the total assets of Finnish banks as well as interbank liabilities relative to banks' total assets in 1988 and 2006. At a maximum, interbank liabilities were approximately one fifth of total assets in 2006 although there are differences between institutions. The share of interbank liabilities has diminished over the years, as there are currently fewer institutions with exposures exceeding 10% of total assets.

Table 1: Finnish deposit banks' total assets and share of interbank liabilities in 1988 and 2006

	1988		**2006**	
	Total assets, EUR million	Interbank liabilities over Total assets, %	Total assets, EUR million	Interbank liabilities over Total assets, %
KOP	24,322	1.2 %	-	-
OKO (Pohjola) Bank	7,375	16.2 %	24,196	4.5 %
Postbank	12,582	0.7 %	-	-
Skopbank	10,681	11.5 %	-	-
STS Bank	1,832	10.2 %	-	-
SYP (Unitas)	22,305	0.5 %	-	-
Savings Banks	16,643	14.5 %	5,648	1.0 %
Bank of Åland	462	11.1 %	2,189	2.8 %
Nordea Bank Finland	-	-	130,985	22.3 %
Sampo Bank	-	-	26,627	1.8 %
Aktia plc	-	-	5,492	16.2 %
Evli Bank	-	-	698	10.7 %
eQ Bank	-	-	627	0.0 %
Tapiola Bank	-	-	546	0.0 %
Local co-operative banks	-	-	3,467	0.2 %

Source: banks' annual reports

Counterparty exposure data give accurate quarterly snapshots of interbank business and provide information on unsecured and secured loans at the group level. However, the FSA's data set covers only the 10 largest domestic and foreign counterparties of each reporting bank and does not shed light on all exposures.

In order to fill in this gap, FSA's quarterly liquidity risk data are used to clarify the

[4]In principle, there is also information on bonds and certificates of deposits in 1990s but this is not included since breakdown between domestic and foreign items is not available. Foreign exposures are deducted from all balance sheet items to get a closed system. This is a standard procedure in the literature owing to the estimation method requiring that exposures of all potential counterparties should be available for a given time period.

bilateral interbank relationship among small Finnish local banks and their central financial institutions[5]. Cross-border contagion is assessed by using counterparty data on Finnish banks' interbank lending to foreign banks.

According to the counterparty exposure data most of the banks' exposures are unsecured. In 2005–2011 the unsecured receivables from both domestic and foreign financial counterparties fluctuated between EUR 12.0 billion and EUR 19.2 billion, constituting 73–113 per cent of the banks' total capital. In September 2008, amidst the international financial crisis, the main counterparties of Finnish banks were domestic ones. Since then the share of Finnish counterparties have gradually decreased, while the share of foreign banks has increased.

Based on the available data the Finnish interbank sector does not form a complete structure in the sense of [14]. All banks are nevertheless connected to each other via common counterparties. The three largest banks, in the heart of the interbank market, have room to manoeuvre in either the domestic or international money markets. The ability to access international capital markets reduces their dependence on the national interbank market, although they interact with each other and with other Finnish banks. Middle-sized institutions are also able to raise funding from international markets but also acquire funding from the largest Finnish banks. Finally, small, local banks use other Finnish banks as their central financing institutions and thus form 'satellites' around these banks. For example, local savings banks and local co-operative banks use Aktia as their central financial institution. In a similar fashion, Pohjola finances local co-operative banks that belong to the OP-Pohjola Group.

4.2 Estimating Bilateral Matrices

As balance sheets and large exposure data do not give complete information on individual banks' actual counterparty exposures, the method of entropy maximization has been used to fill the gaps in the data sets. Following [17] and [19], this paper assesses domestic and foreign contagion in the Finnish interbank market.

The problem of estimating the matrix for banks' bilateral exposures is posed as: "Given a matrix C, determine a matrix X that is close to matrix C and satisfies a given set of linear conditions on its entries" (see [29] and Appendix). Matrix C contains all available statistical information on the bilateral unsecured exposures among Finnish banks as well as between foreign and Finnish banks, while balance sheet data on total interbank assets and liabilities provide the set of linear conditions for the estimation problem. The overall distribution of interbank loans and deposits (i.e. matrix X) is subsequently estimated by using the entropy maximization. This problem is easily solved using the RAS algorithm by [30].

The data permit us to compute two matrices of bilateral exposures. These sub-matrices are formed for loans and receivables as well as for bonds and certificates of deposit. After having estimated a bank-to-bank matrix for the sub-categories, these matrices are combined into the total domestic exposure matrix. This composite matrix is then been used to test the possibility of contagion.

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[5]The data set includes information on interbank deposits and loans between Aktia, on one side, and local co-operative banks and savings banks, on the other side. Similar data exist for Pohjola Bank and co-operative banks in the OP-Pohjola Group.

4.3 Simulating Contagion

Once the matrix of interbank linkages is in place, the scope of contagion is simulated by letting banks go bankrupt one at a time and by computing the overall effect on the banking sector due to direct or indirect exposures to the first failing bank. The simulations follow a sequential (or round-by-round) algorithm ([2], [31]). At the start, there are several banks b, b = 1,…,N, in the Finnish banking sector. All these banks have capital c_b as well as an exposure x_{bb} towards another domestic bank. Contagion simulation involves the following steps:

1. By assumption, bank i fails at t_0.
2. A lender defaults if the amount of losses from lending to the failed bank exceeds the lender's own capital. So, a bank j fails if its exposure towards bank i, x_{ji}, multiplied by an exogenously given parameter for the loss-given-default (LGD), exceeds the bank j's capital c_j. So, bank j fails if LGD * $x_{ji} > c_j$ at t_1.
3. Contagion need not be confined to such first-round effects, but a failure of the first bank can trigger a chain of failures (domino effect). A second round of contagion occurs for any bank k for which LGD * $(x_{ki} + x_{kj}) > c_k$ at t_2. Contagion stops if no additional banks go bankrupt. Otherwise, a third round of contagion takes place.

The impact of the failure of a foreign bank is successively studied by letting each of the M foreign banks go bankrupt one at a time and simulating the contagion within the domestic interbank market with a given LGD.

In the simulations, bank institutions stand alone. In reality this may not always be the case, since several Finnish banks are members of a larger group. Thus, when facing difficulties, a parent corporation may provide funding to its banking subsidiary. This funding can extend the bank's ability to sustain market turbulence and restrain contagion. However, the recent financial crisis has shown that banks may not have time to react in a crisis. A sudden drying up of interbank markets and short-term funding or a lack of other forms of safety nets on which banks could rely in a case of problems may quickly squeeze the bank out of the interbank markets. Should the analysis take into account all ramifications of a bank failure such as adjustments by depositors the impact is likely to be even more devastating.[6]

Simulations focus on gross exposures and do not take into account netting. As the focus is on maximum exposure and contagion is assumed to proceed without delays, netting is not an option. Moreover, in Finland banks cannot net interbank claims that can be used as collateral for central bank funding. What happens after all contagion rounds and the bankruptcy of a bank is beyond the scope of this paper.

[6]For instance, when prices are allowed to change, the systemic risk may be even larger than thought previously [32].

4.4 The Choice of Parameters

The key parameters in determining the existence of contagion are the loss-given-default (LGD) ratio and the solvency ratio. The LGD refers to the share of assets that cannot be recovered in the event of a bankruptcy. The choice of LGD is by no means obvious, as it can vary significantly. Historical evidence on the failures of international banks such as Continental Illinois, BCCI and Herstatt indicates that the loss ratio may range between 5–90% depending on the time period when losses are expected to materialize. ([2], [17]) The uncertainty about eventual recoveries suggests that it may not be the actual losses borne by the creditor banks but rather the expected losses at the moment of a failure that matter.

The loss ratio also depends on the availability of collateral for interbank claims vis-à-vis creditors. According to the Finnish counterparty exposure data, collateralized lending by Finnish banks is almost non-existent. Since the purpose of the study is to find the maximum negative shock that could hit the market, it is assumed that most of the interbank loans reported in the balance sheet are indeed unsecured. Given the difficulties in determining the appropriate loss rate, the possibility of contagion is tested using a broad range of values for LGD, 25%, 50%, 75% and 100%, which remain constant across banks.

The solvency ratio forms a requirement for a bank's equity. The current minimum Tier 2 capital ratio is set at 8% by regulatory authorities. In reality, banks seldom go bankrupt out of the blue; there are at least some rumours about the difficulties beforehand. If the institution is too big or too systematic to fail, regulators are likely to take action to address the issue by closing the bank, by moving doubtful assets to a special financing vehicle or by providing liquidity for the bank. This kind of policy response was evident during the Nordic banking crises and during the latest financial crises when authorities bailed out the majority of significant banks, for instance, in Ireland and the UK. Nevertheless, as the focus here is on the maximal negative effect and the short-term contagion effects, it is assumed that regulators do not have time to react.

5 Estimating the Danger of Contagion on the Finnish Interbank Market

5.1 The Banking Crisis in the 1990s

In 1988–1990 contagion was triggered by savings banks, Skopbank and OKO Bank. The magnitude of contagion in each case increased steadily. (Figure 1) If savings banks had failed in 1988, contagion[7] would have affected 26% of banking sector assets (assuming a 100% loss ratio) and the negative impact would have been somewhat smaller with lower LGDs. Two years later, just before the onset of the actual crisis, savings banks' failure would have affected 38% of the total assets of the banking sector.

The case of Skopbank is interesting, as it was actually taken over by the central bank in

[7]The magnitude of contagion is measured as the percentage of failing banks' assets in the banking sector's total assets after all banks have encountered the direct and indirect contagion effects. The assets of the first failing bank are not included.

1991. Simulations show that the bank's failure in 1988–1990 would have had a more profound impact on the markets than the failure of the savings banks. In 1988 and in 1989 the negative effect would have caused 31% and 48% of the banking sector to collapse, respectively. A year before the failure of the bank, contagion would have affected almost half of the banking system, indicating that without the bailout of the bank the implications for the society would have been severe. The contagion is somewhat milder with the lower loss-given-default (LGD) ratios.

Note: The y-axis represents the proportion of Finnish banking sector (measured by percentage of failing banks' assets in banking sector's total assets) that will run into problems as a result of a default of Savings banks, Skopbank or OKO bank, after all banks in the system have been exposed to the contagion. The extent of the effect is assessed for four different loss-given-default (LGD) rates. The assets of the first failing Finnish bank are excluded. A missing bar means that the failing bank does not trigger a domino effect.

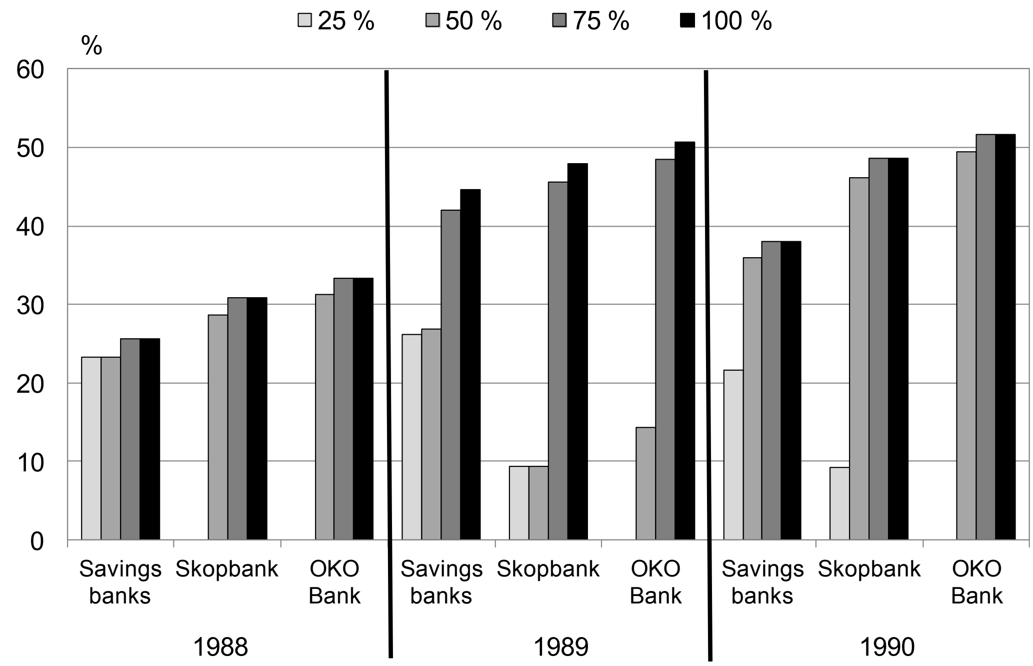

Figure 1: Contagion in Finnish banking system in 1998–1990, grouped by LGD

The fact that the analysis identifies OKO Bank as the most severe source of contagion during 1988–1990 is a new finding. The cooperative banking group did have problems during the crisis, but it is generally acknowledged that the Group was able to survive due to their more conservative strategy and the Group's joint responsibility in dealing with loan losses. The results are likely driven to some extent by the fact that OKO Bank acts as a central financial institution for the co-operative banking group, acquiring refinancing from the markets and passing on the funds to cooperative banks. And, market funding constituted an increasing share of OKO's balance sheet.

Another interesting result is that commercial banks KOP and SYP do not show up as possible sources of contagion, though they were the largest banks. Although they were active in the interbank markets their interbank lending relative to their total assets was not as large as in other banking groups (see Table 1). If certificates of deposit, which were widely used instruments in the Finnish interbank market in the 1980s, are also included in interbank assets and liabilities, the results indicate that all banks' exposures to short-term money markets were such that no bank would have survived a sudden drying up of external funding.

The contagion analysis is replicated with data on the most severe recession year 1992, followed by the recovery years 1994 and 1996. However, these data points are somewhat problematic since by that time banks had received substantial subsidies from the government. Assuming a 100% loss ratio, the contagion would have impacted 14%, 33% and 53% of the banking sector's assets in 1992, 1994 and 1996, respectively. Owing to restructuring of the banking sector, the risk of contagion declined in 1992 but started to increase after that. During these years saving banks, OKO Bank, Merita Bank and Post office bank were possible contagion sources. The savings banks were still contagious in 1992, affecting 21% of the banking sector (with 100% LGD), but after the final resolution the group did not cause contagion in 1994 and 1996. OKO Bank's exposure is due to its position as a central monetary institution, while Merita Bank was formed in a merger of two large banks in 1996, and thus constituted a large share of the banking system. It should be noted that the Post office bank's position was not, in reality, worrisome since it was owned by the state.

In light of the historical knowledge, the estimations seem to be able to identify banks that were the most troublesome during the banking crisis. The evidence also indicates that banks with a significant share of interbank assets are more prominent sources of contagion than the others.[8]

5.2 The Recent Financial Crisis

According to simulations for 2005–2011, five out of the ten banks could trigger contagion in Finland. In addition to the large commercial banks, there are also middle-sized banks that are capable of producing negative spillover effects. The five banks that are identified as a starting point for contagion remain the same for whole estimation period.

On average[9] and assuming 100% loss rate, 66% of banking sector assets would have been affected in 2005–2011 (Figure 2). Although the case of the 100% loss-given-default (LGD) is harsh, it is interesting as a "worst case scenario", portraying the outcome if everything goes badly. The result is at the upper end of earlier estimates, which vary from 4% for Belgium to 96% for the Netherlands.

While the worst case scenario might be only a theoretical possibility, the quite plausible 75% and 50% loss ratios in the short-run seem to have already significant effects on the banking market. Over the estimation period, the average negative impact on total assets is 39% and 19%, respectively.

[8]This supports [2] arguing that direct contagion happens only if interbank exposures are large compared to the capital.

[9]A simple average for the banking sector over the estimation period for stated LGD.

Assuming 25 % loss-given-default, the average contagion affects 11% of banking sector assets.[10]

The LGD ratio has an obvious effect on the speed of contagion and the outcome. This is intuitively appealing, since higher values of the ratio have the potential to increase pressure in the system. At some point, a critical mass of losses is reached and the interbank market collapses. For instance, the larger the LGD, the quicker the pace of contagion and the more severe the negative impact on the banking system.

Note: The y-axis represents the proportion of the Finnish banking sector (measured by percentage of failing banks' assets in banking sector's total assets) that will run into problems as a result of a default of a domestic bank, after all banks in the system have been exposed to the contagion. The extent of the effect is assessed for four different loss-given-default (LGD) rates. Results for each loss rate and each quarter are based on a simple average for the individual banks. The assets of the first failing Finnish bank are excluded.

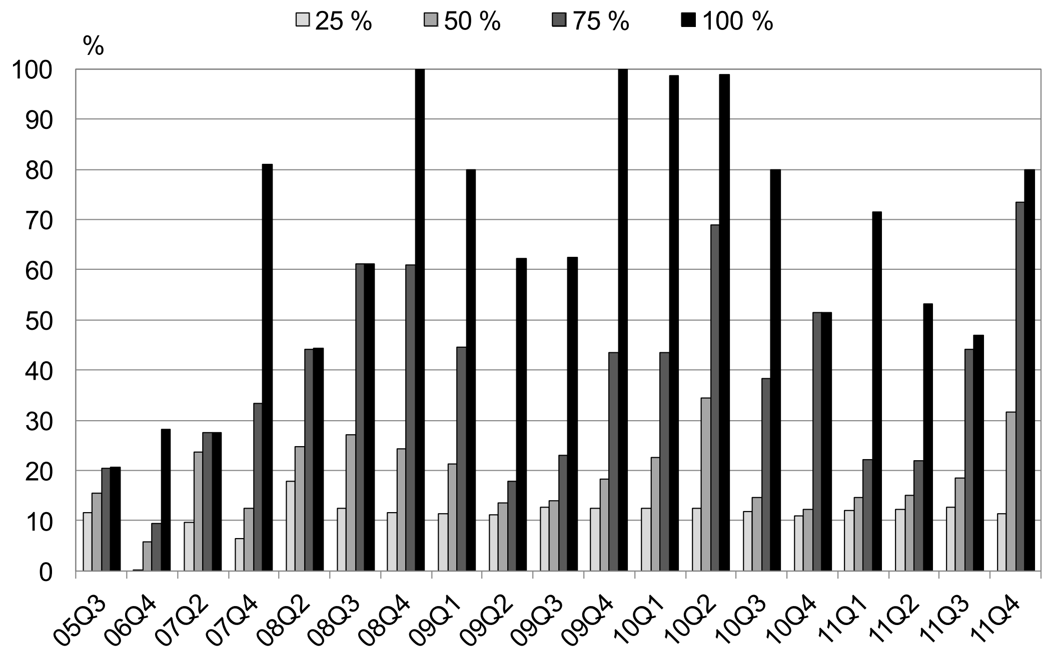

Figure 2: Contagion in Finnish banking system in 2005–2011, grouped by LGD

The volume of contagion also depends on the bank that fails first. Only one bank is extremely contagious in the Finnish banking system, being able to cause mayhem in the market already with the smallest loss ratio. With 25% LGD, around one half of the

[10] The effect of contagion is also estimated by letting local co-operative banks and local savings banks enter the simulations as individual banks instead of combining them into two representative banking groups. In this set-up, there are 42 local co-operative banks, 39 local savings banks and 8 commercial banks. The effect on the results is nevertheless negligible and the contagion is 0.1%–2.6% lower depending on the loss rate. However, in reality this difference may prove important for local communities and individual banks, as local co-operative banks and local savings banks are not liable for each others' debts.

Finnish banking system would collapse due to the problems of this bank. If the loss ratio is larger, this bank is a source of contagion that affects the whole banking system and ultimately causes the system to collapse. Of the other four banks identified as a source of the contagion, two banks are systematically important from June of 2008 onwards and with higher loss ratios. The contagion from the last two banks is usually limited in nature albeit some noticeable exceptions remain. Nevertheless, the negative effects imposed by these banks are almost non-existent if the loss rate is less than 100%. The limited number of contagious banks portrays the high concentration of the banking sector.

Turning to developments over the years, the aggregated[11] domestic contagion intensified at the beginning of the domestic and international crisis in both the 1990s and the 2000s (Figure 3). The magnitude of the contagion was relatively mild up to 2007, remaining under the levels of 1988–1990. For instance, in December 2006 the first failing bank would have caused around 11 % of Finnish banking sector to collapse. In the run-up to the banking crisis in 1990s as well as before the collapse of Lehman Brothers, the severity of contagion increased in Finland. The contagion risk peaked at the end of 2008 after the collapse of Lehman Brothers, when a first failing bank would have caused, on average, almost 50% of the banking system to collapse.

After the initial culmination of the crises, the magnitude of contagion decreased. Nevertheless, the positive development was reversed and the risk of contagion rose towards the end of 2009. The actual magnitude of Greece’s fiscal deficit was revealed at the turn of the year 2010, triggering the sovereign debt crisis and raising the contagion risk in Finnish interbank market above the 50% impact level in June 2010.

After this peak the contagion risk declined until mid-2010 but started to increase again towards the end of the estimation period, possibly reflecting renewed worries related to the debt crisis and the changing pattern of interbank linkages. The freezing of money markets may have negatively impacted cross-border interbank lending, which has been – at least partially – replaced by lending between domestic institutions. Growing importance of domestic counterparties naturally increases the magnitude of domestic contagion.

[11]Aggregation is based on a simple average over the individual banks and the loss-given-default ratios for each individual year.

Note: The y-axis represents the proportion of the Finnish banking sector (measured by percentage of failing banks' assets in the banking sector's total assets) that will run into problems as a result of a default of a bank, after all banks in the system have been exposed to the contagion. Aggregation for each time period is based on a simple average for the individual banks and the loss-given-default ratios. The assets of the first failing Finnish bank are excluded.

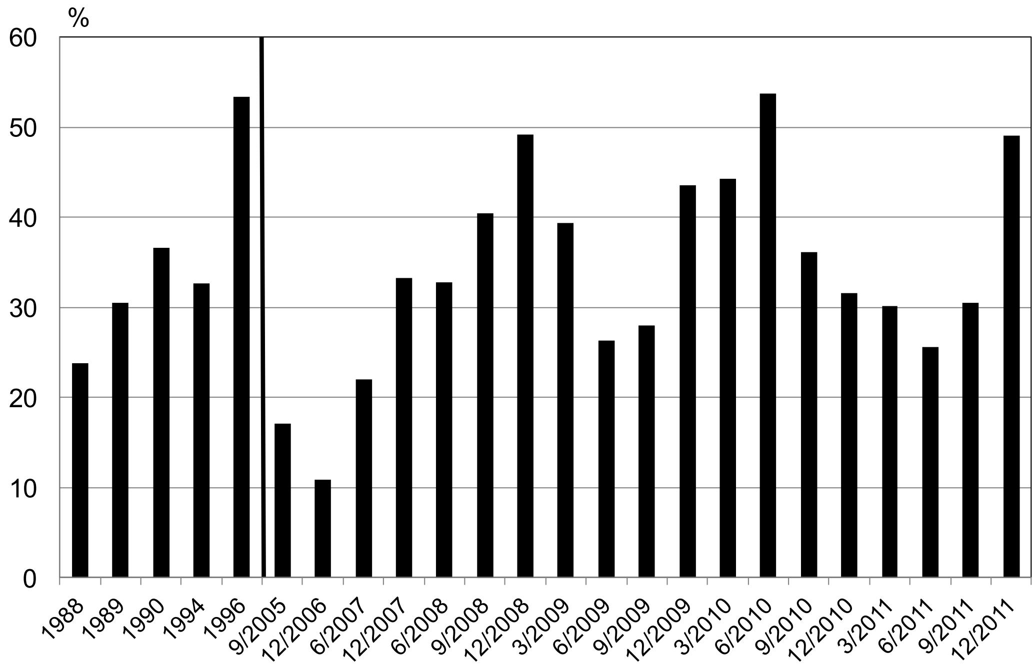

Figure 3: Aggregated contagion in 1988–1996 and 2005–2011

The results concerning banking sector structure and contagion suggest that an incomplete interbank market with highly concentrated banking sector correlates positively with contagion. In Finland, the concentration measured by the Herfindahl index[12] and contagion grew, respectively, from 2,730 and 17% in 2005 to 3,700 and 49% in 2011. The simple correlation between these two time series was 66% in 2005–2011, suggesting that there is a positive link between higher contagion and increasing concentration of incomplete markets.

This vulnerability to severe contagion gets support from previous studies, indicating that banking sectors dominated by a few large banks (such as the Dutch and Finnish banking sectors) exhibit high contagion risk. At the same time, contagion seems to have a somewhat milder effect in countries with two-tier systems and low concentration (such as Germany and Italy). ([17], [20], [23]) Furthermore, [19] finds that the change from complete structure towards a more decentralised structure reduces the risk and impact of contagion.

[12]Data for the index from Statistical data warehouse (SDW) of the ECB (www.http://sdw.ecb.europa.eu/).

5.3 Cross-border Contagion

The analysis of this section concentrates on whether a failing *foreign* bank can trigger a default of a Finnish bank and whether there is a subsequent domino effect within the domestic banking sector. As no information on bilateral financial linkages between foreign banks is available, simulations cannot take into account the overall cross-border contagion, which hinders the analysis of second-round effects abroad and potential indirect impacts on Finnish banks after the initial failure of a foreign bank. This limitation affects all the literature on financial contagion. Only [27] investigates overall contagion across countries but the paper is limited to aggregate country level data, as it lacks data on individual banks.

Overall, the default of a foreign bank can trigger contagion in the domestic interbank market, leading in general to the immediate failure of a few (from zero to four) Finnish banks. On average[13], the instant first-round impact of the failure of a foreign bank amounts to 8% of the total assets of the Finnish banking sector in 2005–2011. The magnitude of the effect varies over time, peaking at 17% in June 2007 and amounting to about 8.5% at the end of the estimation period (Figure 4).

Note: Line shows the share of Finnish banks' assets that initially go bankrupt in the first-round due to the failure of a foreign bank. Columns represent the aggregated percentage of failing Finnish banks' assets in the banking sector's total assets, after all banks in the Finnish banking sector have been exposed to the subsequent domestic contagion rounds after the initial impact. Aggregation for each quarter is based on a simple average over the individual banks and loss-given-default ratios.

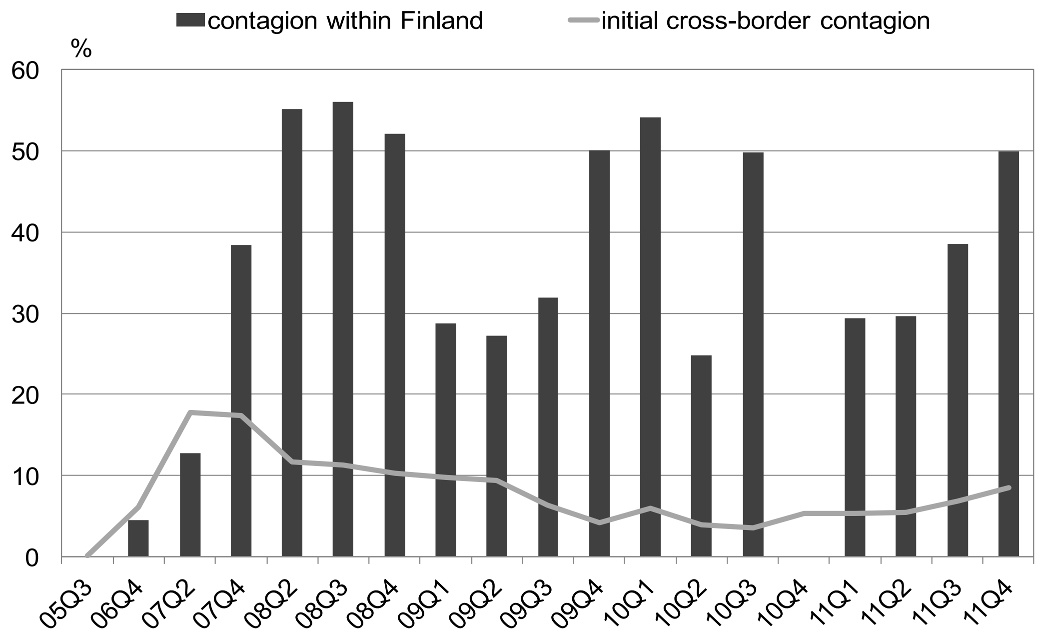

Figure 4: Contagion triggered by a foreign bank in 2005–2011

[13]A simple average over the individual banks, LGDs and quarters.

The failure of a foreign bank impacts large, medium-sized and small banks alike. In addition to French, British and American banks, the contagion is often triggered by Swedish and Danish banks. The result thus supports the findings of [27] which showed that a default of a Scandinavian bank affects the neighbouring banking systems. Nordic banks are the main international counterparties for Finnish banks and thus they form potential channels through which international contagion or market disturbances may spread to Finland.

Within the Finnish banking sector, foreign contagion follows similar patterns as domestic contagion although the high risk of domestic contagion is not reflected in the negative spillover effects of a foreign bank's default in 2009–2010. All in all, contagion caused by a failure of a foreign bank is slightly more severe than contagion triggered by a Finnish bank during the estimation period. After all contagion rounds, the contagion from a foreign bank affects 77% of the total assets of the Finnish banking sector in 2005–2011 and with a 100% LGD, while contagion from a Finnish bank impacts 66% of the total assets of the sector. Nevertheless, the impact depends on the loss-given-default, as with lower LGDs the impact from a Finnish bank is more pronounced. The findings are in line with those of [19] and [23], indicating that the more concentrated the banking system, the more vulnerable it is for foreign contagion.

5.4 The Crisis in Comparison

The operational environment of banks in the 1990s and in 2005–2011 bears several similarities. During both periods, the Finnish banking sector was highly concentrated and there were only a few large players in the market. The Finnish banks started to finance their growing lending by acquiring short-term funding from money markets at the end of 1980s. Similarly, interbank markets grew in significance in the 2000s, as liquidity was abundant in the international financial markets, which constrained the cost of financing and enabled banks to easily refinance themselves. As a consequence, some foreign banks became dependent on external (short-term) market financing and the growth of interbank assets increased the risk of contagion.

However, there are also notable differences between the periods. In 2005–2011 the interest rate level was nowhere near that of the early 1990s, the corporate sector was not as badly indebted as before and banks' capital buffers are currently larger. In addition, many borrowers and lenders are currently more aware of the dangers of over-indebtedness. In Finland, the macroeconomic shock was also somewhat milder and more transitory in the 2000s than in the 1990s. Therefore, several negative triggers and factors such as the banking system's structural weaknesses and hazardous incentive structures that were present in the 1990s were missing in the 2000s, and thus removed the initial knock-out effect. All in all, the current crisis has not eroded Finnish banks' solvency ratios, so that banks are now more resilient to domestic contagion, and bank default is a low probability event.

6 Conclusion

This paper investigates the possibility of financial contagion using data on the Finnish interbank market and the maximum entropy methodology. First, we compare the pattern and development of contagion before and during two distinctive crisis periods. These contagion simulations shed light on the magnitude of the problems that society would face if banks fail. Secondly, as the importance of network effects is recently highlighted, the analysis provides more information on the importance of interbank linkages and transmission channels. Thirdly, the paper provides evidence on the domestic and foreign-based contagion in a concentrated banking system that is dominated by foreign banking groups and thus vulnerable to cross-border shocks.

The analysis suggests that the contagion increased both in 1988–1990 and in 2005–2011, irrespective of the original source (domestic/international) of the crisis. The method identifies five large and middle-sized Finnish banks that are able to cause contagion in 2005–2011, while suggesting that three banks were contagious during the banking crisis in the 1990s.

Before the onset of the crisis in 1990 the contagion would have affected almost half of the banking system (assuming 100% loss ratio), indicating that without the bank bailouts the implications for society would have been severe. In 2005–2011, the negative impact caused by a failure of a foreign bank (with a 100% loss-given-default) affects 77% of the total assets of the Finnish banking sector, while contagion from a Finnish bank impacts 66% of the total assets. There are also indications that the more concentrated the banking system, the more vulnerable it is to severe contagion. Moreover, strong interbank linkages with foreign banks increase the risk for domestic contagion.

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Appendix

The Method of Maximizing Entropy

The concept of entropy maximization originates in information theory, in which entropy is a measure of the average information content of a random variable. The greater the entropy of the message, the greater information content of the message.

Maximizing entropy means setting up probability distributions on the basis of partial knowledge and thus denotes the most likely outcome given the a priori knowledge about the event x_i. (For more details see [33], [34], [35].) When the probability of the outcome is maximized, the uncertainty diminishes and the estimates of parameters x_i are close to real values of x_i.

$$X = \left[\begin{array}{ccccc|ccc} x_{11} & \cdots & x_{1j} & \cdots & x_{1N} & w_{1N+1} & \cdots & w_{1M} \\ \vdots & \ddots & \vdots & \iddots & \vdots & \vdots & & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{1N} & \vdots & & \vdots \\ \vdots & \iddots & \vdots & \ddots & \vdots & \vdots & & \vdots \\ x_{N1} & \cdots & x_{Nj} & \cdots & x_{NN} & w_{NN+1} & \cdots & w_{NM} \end{array}\right]$$

Figure A: Matrix of interbank loans and deposits

Sources: [17] and [19].

Suppose now that there are N Finnish banks that may lend to each other. In this case, the interbank lending relationships can be presented in an N*N matrix (see left-hand side of the matrix X in Figure A). [2] As there is usually no knowledge on individual interbank loans and deposits, individual x_{ij}:s are generally unknown. However, a priori data on actual individual interbank relationships and their magnitudes is gathered into an a priori matrix C that resembles matrix X. The diagonal of the matrix C is usually set at zero, since it is assumed that no bank lends to itself.

Balancing the matrix yields a unique estimate of matrix X. Matrix is defined to be balanced if it satisfies the given set of linear restrictions of the problem. These restrictions consist of the row sums (a_i), i.e. bank i's total claims on other banks, and column sums (l_j), i.e. bank j's liabilities in the interbank market. These sums are obtained from balance sheet data. More formally, the problem is as follows:

$$\underset{x_{ij}}{Min} \sum_{i=1}^{n} \sum_{j=1}^{n} x_{ij} \log \frac{x_{ij}}{c_{ij}} \qquad (1)$$

s.t.

$$\sum_{i=1}^{n} x_{ij} = l_j \qquad , i = 1, \dots , n \qquad (2)$$

$$\sum_{j=1}^{n} x_{ij} = a_i \qquad , j = 1, \dots , n \tag{3}$$

$$x_{ij} \geq 0 \tag{4}$$

In the case of foreign contagion, the same methodology applies, but now X becomes an (N × (N+M)) matrix (Figure A). This matrix of bilateral exposures presents the interbank exposures of Finnish banks toward the other (N-1) Finnish banks and the M foreign banks. The initial estimation problem and linear restrictions remain the same except for restriction (3), which becomes:

$$\sum_{j=1}^{n} w_{ij} = fa_i \qquad , j = 1, \dots , n \tag{5}$$

in which w_{ij} represents the gross exposure of Finnish bank i to foreign bank j and fa_i stands for interbank assets of bank i. [19]

CONTAGION IN THE INTERBANK NETWORK: AN EPIDEMIOLOGICAL APPROACH

Mervi Toivanen*

ABSTRACT

This paper applies a novel interdisciplinary approach to model the spreading of credit contagion in the interbank network by implementing an epidemiologic model. In the context of scale-free networks the model is calibrated with actual data on European banks. The average contagion is shown to affect 70% and 40% of European banks' total assets in 2007 and in 2010, respectively. Country-level results suggest that French, British, German and Spanish banks are the most contagious ones, whereas banks from Ireland, Greece and Portugal induce only limited negative effects. Furthermore, the paper sheds light on the importance of individual banks for financial stability, as it disentangles the leading bank-specific factors influencing the outcome. Estimations indicate that bank clustering, large in-coming interbank loans, the bank's position in the network and the bank's size are prominent indicators. Finally, central bank interventions are shown to reduce contagion only slightly.

JEL codes: G01, G21, C15

Keywords: contagion, banks, Europe, interbank loans, epidemiology, financial crisis

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1 INTRODUCTION

The early stages of the financial crisis demonstrated that financial institutions were to face substantial losses owing to sub-prime exposures and declining asset values. But due to the opaqueness of banks' balance sheets and limited knowledge of counterparty exposures, nobody really knew how heavily each institution was exposed and to what extent the losses would materialize. At the same time, banks were tightly connected to each other via interbank lending and borrowing that form a network through which each and every bank of the network may be affected by banks in trouble. The uncertainty regarding the financial health of counterparties and a fear of contagion spread like a disease through the interbank network, inducing banks to limit their interbank exposures. The highly interconnected modern financial world thus facilitated the rapid transmission of the shock. Central banks were forced to step in and provide unprecedented liquidity support for the banking system. (Brunnermeier 2009; Coeuré 2012)

This paper analyses the transmission and the magnitude of credit contagion that arises from banks' counterparty exposures in interbank markets. It contributes to the literature by proposing a novel interdisciplinary approach to model the credit contagion with an epidemiological model which is extended to take into account the characteristics of financial institutions and financial markets. The paper contributes to the literature by introducing an endogenous loss-given-default (LGD) which is time-dependent. As the model is implemented in a network context with actual data on large European cross-border banks, we are also the first ones to provide evidence on the cross-border contagion in European level prior and during the financial crisis. So far, most of the credit contagion analyses with real data have concentrated at the national banking systems.

Although other channels for contagion exist and a variety of shocks (for instance, common external shocks) has affected the banking sector, credit contagion continues to be prominent as regards financial stability. For instance, several financial institutions such as AIG and German IKB have been rescued by authorities because the risk of credit contagion was assessed to be too high (Upper 2011). Thus, the paper complements recent work applying network modelling (see, among others, Krause & Giansante 2012; Anand et al. 2013; Gai, Haldane & Kapadia 2011).

In this paper, the susceptible – infected – recovered (SIR) model by Kermack & McKendrick (1927) provides a framework to analyze the consequences of an idiosyncratic shock for the whole banking system. In the original SIR model the propagation of contagion depends on the existence of contacts between individuals and the transmission rate of infection. The analogy to credit contagion is eminent. The contagion in interbank markets occurs when counterparties are connected and spillover effects from a contagious bank are greater than healthy banks' buffers. As the SIR model's dynamics are very similar to the spreading of negative domino effects in a financial system, it thus can be applied in financial context.[20] Also Haldane & May (2011) and Haldane (2009) have demonstrated that the similarities between propagation of contagion and epidemics are striking as both involve the spread of negative effects that lead to increasing numbers of affected individuals/institutions, fear of contamination and to outright panics if things get really bad.[21] Owing to the similarities, the SIR model is well-suited to describe the contagion in an interbank network.

An important insight of the epidemiological model is that contagiousness follows a certain course and that each affected individual can have a varying impact on others depending on the severity of its problems. Using this approach, we are thus able to model an endogenous loss-given-default which is time-dependent. As time passes the losses induced by a contagious bank increase. This modelling approach tracks the repercussions of credit contagion in a realistic manner. At the beginning of the crisis the bank may still be able to honour a part of its obligations. But when situation becomes more difficult, bank may default and create larger externalities to the system. In a sense, the model thus captures the aspects related to market expectations. As negative market perceptions on the financial strength of a bank increase, self-fulfilling assumptions often lead to deteriorating conditions for that specific institution. The more a bank has borrowed from interbank markets, the more vulnerable it is for speculation. Finally, the SIR model also provides us additional insights on how the contagion and systemic risks build up in the banking system as time passes.

To track the negative repercussions of contagion in a realistic manner, the basic SIR model is extended to incorporate the heterogeneity of banks in terms of vulnerability to shocks, contagiousness and interbank relationships. Given the importance of banks' interconnectedness (see, for instance, Allen & Gale 2000; Acemoglu, Ozdaglar & Tahbaz-Salehi 2013; Battiston et al. 2012), network

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[20] Other epidemiological models such as SI and SIS models could have also been used for the analysis. However, these models do not incorporate the "recovery" stage. They thus fail to recognize the situation in which institution/bank often continues to exist as a legal entity after its rescue/recapitalization/bankruptcy proceedings.

[21] In addition, Garas et al. (2010) have previously used the SIR model to investigate the transmission of economic crisis from one country to another via international trade. Carroll (2006) has also used the model to analyze the spreading of macroeconomic expectations in the population over time.

modelling seems an appropriate starting point for the analysis. Therefore, the SIR model is applied in a network context. Many highly heterogeneous financial and social systems can be best described by a network in which nodes represent individuals or organizations (here banks) and links (here interbank exposures) stand for the interactions between the units. The advantage of network modelling is that it provides valuable insights into large and complex networks and offers statistical methods to describe and quantify network properties (Newman 2003). As many real-world interbank banking networks have the properties of scale-free networks (see, for instance, Boss et al. 2004; Soramäki et al. 2007), a large set of networks is simulated with a model by Barabasi & Albert (1999). Based on the extended SIR model, generated networks and data on 51 European banks, we simulate credit contagion in banking system.

Finally, to provide more intuition for the driving forces of the contagion, we analyze to what extent the simulation results are driven by the bank-specific factors such as size and position in the network. The main motivation is to find indicators that are of relevance for financial stability. The Basel Committee has already identified a few indicators for interconnectedness of systematically important banks, but these indicators refer only to the volume of intra-system assets, liabilities and securities (BIS 2013). It is of importance to identify additional indicators that supervisors and regulators could use in their efforts to safeguard financial stability. Therefore, we disentangle the relationship between contagion as well as bank characteristics and network properties. In contrast to previous contributions, we test a large set of *individual* indicators. The analysis also sheds light on the relevance of central bank policies by assessing whether central bank interventions are helpful in containing the negative spillover effects.

The results show how contagion spreads in the European banking system, segmenting banks into two categories. On average, the contagion affects negatively about 40% of the European banks in 2010, but considerable heterogeneity remains between individual simulation outcomes. The magnitude of the negative spillover effects is almost twice as large in 2007, just before the onset of the financial crisis. In terms of nationality, French, British, German and Spanish banks are able to induce widespread contagion, while banks from Ireland, Greece and Portugal have only limited negative effects on the system.

Regarding the leading factors of contagion, a bank's central position in the network, banking clusters with large interbank loans, several connections and a bank’s size are meaningful in explaining the negative spillover effects. In terms of bank-specific factors, weighted clustering coefficients, centrality measures (betweenness, eigenvalue and closeness centrality), a bank’s high connectivity, a bank's size and volume of in-coming interbank loans are significant factors in explaining the contagion. Finally, central bank liquidity operations and other central bank measures are efficient for alleviating contagion and financial crisis, although the impact is limited.

The rest of the paper is organized as follows: Section 2 overviews the previous academic literature related to interbank contagion and network analysis. The analytical framework, with the extended SIR model, model calibration, simulation parameters and generated networks, is described in section 3. Results of the contagion analysis are presented in section 4, while section 5 contains the bank and network indicators, the regression analysis and its results. Section 6 concludes.

2 RELATION TO THE LITERATURE

The number of studies on contagion and networks has increased markedly in recent years. This paper relates to the following four streams of literature. First, theoretical models indicate that contagion spreads in the network of banks' financial linkages and that the network's structure affects the financial stability of the banking system in a nonlinear way. The seminal paper by Allen & Gale (2000) finds that the negative effects depend on the structure of the interbank markets. Adding further reality to models, for instance, in terms of fire-sales, heterogeneous banks and network structures, Acemoglu, Ozdaglar & Tahbaz-Salehi (2013), Battiston et al. (2012) and Gai & Kapadia (2010) show that high interconnectedness of banks may not necessarily be beneficial for financial stability. While increasing connectivity attenuates contagion via risk sharing and improves the ability of a banking system to absorb shocks, it also facilitates spillover effects and can make the system more fragile ("robust-yet-fragile" tendency).

The second set of papers provides further evidence on the risks of a financial system by modelling financial connections between banks as networks and employing simulation techniques to assess the outcomes of a bank failure. (Anand et al. 2013; Gai, Haldane & Kapadia 2011; Nier et al. 2007; Arinaminpathy, Kapadia & May 2013; Krause & Giansante 2012; Iori, Jafarey & Padilla 2006) Based on a set of assumptions, accounting identities and behavioural rules, these models present a banking sector composed of individual banks with balance sheets and a transmission mechanism for shocks. The contagion arises when the losses arising from counterparty exposures or liquidity shortages exceed the net equity of a bank, inducing a bank failure. An enlargement of interbank liabilities, high concentration of the banking sector and a shock to a well-connected and big bank are shown to make the system vulnerable to large systemic risks. Meanwhile, the higher the capital ratios of banks, the more resilient the system is to large systemic risks. Finally, the structure and tiering of the network are crucial for explaining the magnitude of the contagion.

Third, empirical studies based on granular bank-level data analyze credit contagion at the national banking system level, thus providing insight into the vulnerabilities of existing networks (Upper 2011; Mistrulli 2011). The domino effects arise from losses related to interbank lending to the failed bank. Results point to potentially significant contagion effects, albeit a substantial weakening remains a tail event.

The fourth set of contributions provides analyses of the characteristics and structures of real-world networks (so-called network topology) by applying network metrics. Iori et al. (2008), Boss et al. (2004) and Craig & von Peter (2010), for example, investigate national interbank markets, whereas Minoiu & Reyes (2013) study the global cross-border banking network, Markose, Giansante & Shaghaghi (2012) analyze networks of credit default swaps (CDS) and Soramäki et al. (2007), among others, look at the payment systems. A typical financial network is shown to be complex and characterized by a high-level of tiering. Few banks have large numbers of counterparties; the majority of banks have only a few linkages. Thus, certain key players act as central hubs that connect otherwise remote parts of the network. In this paper, network linkages are modelled so as to replicate these properties. In addition, Minoiu & Reyes (2013) indicate that the banking network has become more tightly connected over time, but the number of bank linkages has decreased during the systemic banking crises.

3 ANALYTICAL FRAMEWORK

The framework consists of the SIR model, generated networks and additional parameters that are calibrated with data on large cross-border banks in Europe. First, the SIR model describes the contagion dynamics in the financial networks, i.e. how the contagion spreads in the system and how a non-affected bank becomes contagious. This approach allows us to model time-dependent loss-given default rate that is endogenously defined. Second, we generate multiple interbank networks by using Barabasi & Albert (1999) model as the actual bank-to-bank linkages are not observable. Finally, we extend the basic SIR model with additional parameters to reflect banks' heterogeneity in terms of vulnerability and contagiousness.

In this paper, the parameters of the model and generated networks are calibrated with BIS data and information from 51 major European cross-border banking groups. All banks in the sample were included in the EU-wide stress-test by the European Banking Authority (EBA) in 2010.[22] Their headquarters are in Germany, France, Italy, Spain, the Netherlands, Belgium, Austria, Portugal, Greece, Ireland, the UK, Denmark and Sweden. And the total assets of the banks in the sample amount to 26.6 trillion euro in 2010 and 25.2 trillion euro in 2007, constituting approximately 62 % of the whole European banking sector. The detailed use of data is presented alongside with each parameter.

Once the framework is in place, the contagion simulations are run to test the fragility of the banking system. In the short-term, these contagion simulations are based on an algorithm that is similar to the solution used by Furfine (2003). However, regarding the solution for time dimension we adhere to the approach of Eisenberg & Noe (2001).

3.1 The basic SIR model

The analysis of contagion is based on a SIR model by Kermack & McKendrick (1927). In the model, banks are divided into three sub-groups, susceptible (s_t), contagious (c_t) or recovered (r_t), at any point of time t. The number of institutions is set at N, so that the size of the banking community does not fluctuate over time.

With the number of banks fixed, $s_t + c_t + r_t = 1$ for all $t \geq 0$. At the beginning, we assume that the banking community has not previously encountered a shock, so that $r_0=0$. When an idiosyncratic shock hits the system, the initial number of contagious banks is small but positive (i.e. $c_0=\varepsilon$). These assumptions lead to the final initial condition, indicating that in the first place the majority of banks are susceptible ($s_0=1-\varepsilon$). Being susceptible means that a bank is currently non-affected by the crisis but remains vulnerable to negative domino effects.

While the main parameters of the analytical framework are depicted in table 1, the following equations define the dynamics of the model.

$$v_t = -\lambda s(t)c(t) \tag{1}$$

22 See: http://www.eba.europa.eu/risk-analysis-and-data/eu-wide-stress-testing/2010

$$c_t = \int_0^{\gamma} \lambda s(t)c(t) - \int_{\gamma}^{\infty} c(t)d(t) \quad (2)$$

$$r_t = \int_{\gamma}^{\infty} c(t)d(t) \quad (3)$$

Equation (1) defines the number of banks that leave the susceptible category at time t, v(t), by becoming contagious and a target of market speculation owing to, for instance, a deteriorating capital position or large counterparty exposures. The term λs(t)c(t) portrays the fact that susceptible banks, s(t), must have contacts with contagious banks, c(t), so that the contagion can spread, and that the contamination occurs at a certain transmission rate, λ. The second equation defines the total number of contagious banks, by subtracting from the number of banks which have become contagious, $\int_0^{\gamma} \lambda s(t)c(t)$, the number of banks recovering from the crisis ($\int_{\gamma}^{\infty} c(t)d(t)$). Finally, equation (3) defines the total number of recovered banks.

Table 1. Description of parameters and calibration

Parameter	Description	Calibration
N	Number of banks	51
s(t)	Susceptible banks at t	Endogenous variable
c(t)	Contagious banks at t	Endogenous variable
r(t)	Recovered banks at t	Endogenous variable
γ	Time to recovery	3
λ_{ij}	Contagion transmission rate between banks i and j	Depends on EXP_{ij} and m
EXP_{ij}	Share of bank j's interbank loans from bank i in relation to bank j's all interbank loans	Exogenous; From BIS data
m	Volume of the interbank funding	Exogenous; From BIS data
α_{it}	Loss-given-default rate of bank i	Endogenous variable
β_j	Vulnerability of bank j	Exogenous; From data on banks' equity ratios

In this paper, as in Garas et al. (2010), recovery means that a bank (or a part of it) overcomes the crisis and stops emanating negative externalities in the banking system until the end of the period. The recovery may occur in many ways: the bank may be rescued by its owners (via recapitalization, for instance), is rescued by the authorities or enters the resolution process[23]. Regardless the method, a bank is no longer a cause of concern or under immediate market suspicion and is again eligible as a counterparty. This assumption is realistic, taking into account what happened during the latest financial crisis. For instance, banks such as Dexia and Northern Rock came under a severe stress and were bailed out by governments but continued to exist for some time. In addition, many banks received capital injections during the financial crisis. Lately, the restructuring of Cypriot banks and the case of Banco Espirito Santo in Portugal are examples of recovery in which the institutions continue to operate in banking system albeit in somewhat altered form.

The recovery process takes time. In the baseline calibration, the recovery rate of banks, γ, is set at three time steps. The strict assumption is made for tractability of the results and can be readily relaxed without affecting the overall results. Once a bank has reached the final category, its status does not change and it no longer spreads the contagion.

In the basic SIR model all banks are similar but in reality institutions differ, for example with respect to vulnerability to shocks, contagiousness as well as number and volume of interbank linkages. To take into account the variation between banks, the SIR model is next enhanced with individual heterogeneity.

3.2 Bank-specific contagion transmission rate

First of all, following Garas et al. (2010), a single transmission rate, λ, is replaced by a set of separate transmission parameters reflecting the properties of banks. The individual contagion probability (λ_{ij}) reflects the likelihood that a contagious bank i transmits the crisis to a previously non-affected bank j. The outcome depends on the interbank exposure between banks i and j (EXP_{ij}) and the size of the overall interbank market (m) (equation 4).

$$\lambda_{ij} = EXP_{ij} \times m \tag{4}$$

[23] The new EU bank recovery and resolution directive (BRRD) entered into force on 1 January 2015. According to the BRRD shareholders and bondholders cover the first losses in the case of the bank's insolvency. While the BRRD was not effective in 2007 and 2010, we do not exclude the resolution as a means of recovery in our set up.

The interbank exposure (EXP_{ij}) depict the counterparty credit risk. It is defined as the share of bank i's interbank loans from bank j (exp_{ij}) relative to the total amount of a bank j's interbank lending (total exp_j) (equation 5). This ratio reflects the vulnerability of the lender bank j to the potential default of borrower bank i. The larger the share of interbank loans from to bank i, the more likely it is that bank j will also be negatively affected if bank i encounters difficulties.

$$EXP_{ij} = \frac{exp_{ij}}{total\ exp_j} \tag{5}$$

The interbank exposures are approximated by using consolidated banking statistics of the Bank for International Settlements (BIS). This statistical source provides information on banks' financial claims, covering the cross-border bank exposures of a country's banking sector vis-à-vis other countries. As interbank loans are allocated to the actual lender who will bear the losses in case of borrower default, the data reflect the actual financial linkages. These data come closest to approximating the real interlinkages within an interbank network since public data on actual international bank-to-bank exposures are not available. As BIS statistics do not include information on outstanding amounts of interbank lending within a country, the interbank positions of banks within the same jurisdiction are obtained from the monetary financial statistics (MFI statistics). These statistics are combined by the European Central Bank (ECB) for euro area countries and by national central banks and statistics offices for Denmark, Sweden and the UK.

Overall, BIS data on the cross-border claims of the banking sectors show that sample banks' exposures are mainly towards euro-area (EA) banks. Exposures vary between 95% for the UK and 34% for Sweden in 2010. The five largest EA countries, Germany, France, Italy, Spain and the Netherlands, constitute the majority of these cross-border counterparties. Non-euro counterparties are significant only for Sweden, Greece and Spain. Compared to 2007, the importance of the counterparties from the largest EA countries and non-euro area countries has increased while banks' exposures from other euro area countries have diminished.

From the BIS statistics, interbank receivables of country J's banking sector from country I (exp_{ij}) are divided by the total amount of country J's cross-border claims (total exp_j). These country level shares are subsequently used as the initial estimate for cross-border interbank exposures of individual banks. Similarly, weights for individual banks within a country are obtained from the MFI statistics. The estimates are likely to differ somewhat from actual interbank exposures. However, data collections (and cross-border exposures) are usually governed by large, internationally active institutions similar to those included our sample. Therefore, the current weights are assessed to be reasonable.

While the bank-specific exposure variable assigns the relative importance for each counterparty exposure channel between two individual banks at a certain point of time, it does not reflect the general development of interbank markets over time. The global volume of the interbank markets has shrunk dramatically since the onset of the financial crisis, as banks reacted jointly to changes in the operating environment. This lack of liquidity has been referred to as a funding liquidity shock by Haldane & May (2011). To account for the overall importance of interbank markets and to compare contagion results over time, the evolution of the market must be taken into account. Therefore, a parameter determining the volume of the interbank markets (m) is added to the model. Based on the BIS data, the exposures of the banking sectors in the sample were 1.8 times larger in 2007 than in 2010.

3.3 Network generation

Owing to the lack of detailed information on actual bank-level interlinkages at the certain point of time (s(t)c(t)), we generate interbank networks with the well-known scale-free network model by Barabasi & Albert (1999). The Barabasi-Albert model is also chosen because it mimics the characteristics of real-world banking networks such as a power-law distribution for the number of interbank connections.[24] The size of the network is set at N=51, reflecting the number of the banks in the sample. In the benchmark case, the scale-free network is composed by assuming that each bank creates at least six links.[25]

Preferential attachment is assumed, meaning that banks have a preference to connect to institutions that already have a large number of contacts. This is an intuitive assumption given that banks in interbank markets are more likely to establish business relationships with renowned banks rather than with less-known counterparties (or banks with bad reputation) and that trust plays an important role in money markets. Thus, we assume that the probability of a new bank j connecting with an existing bank i depends on the connectivity of the bank i (k_i),

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[24] In technical terms, the number of banks' connections (i.e. degrees (x)) that a given bank (i.e. node) has with other banks in the network follows a power-law distribution, $P(x) \sim x^{-\lambda}$, with a long-tail. (Boss et al. 2004; Soramäki et al. 2007; Craig & von Peter 2010; Iori et al. 2008)

[25] This assumption is relaxed later on.

i.e. $\pi = k_i / \sum_j k_j$.[26] (Barabasi & Albert 1999; Keeling & Eames 2005; Newman 2003) It is noteworthy that although banks create equal numbers of linkages when entering the network, the final number of individual banks' linkages differs. Some banks will have more connections than others. Ultimately, some banks have more connections in the network than others.

The generated network represents banks' connections (s(t)c(t)) and is so called adjacent matrix, ADJ_{ij}, which is 51*51 matrix and consists of zeros and ones. Zeros signify that no connection exists between banks, while one means that banks are interlinked. To combine information on banks' interlinkages and initial estimates for cross-border interbank exposures the adjacent matrices are subsequently weighted with BIS data for 2007 and 2010.[27] In essence, the generated network linkages (ADJ_{ij}) are thus weighted with bank-specific contagion transmission rates (λ_{ij}) in order to obtain weighted networks (NET_{ij}) and to implement the SIR model in a network context.

To capture the wide range of plausible interbank linkages in the banking system, we generate 10,000 networks. This approach enables us also to introduce heterogeneity into banks' interbank networks. Each realization of the generated network is independent and has a unique structure.

Figure 1 depicts a realization of the interbank network of European banks in the sample. In the figure, the circles (or so called nodes) symbolize banks[28] and lines between the circles are represented by interbank exposures. The darker the line, the higher is the volume of interbank exposures and the contagion transmission rate between two banks. Banks with a large number of connections and large interbank exposures lie in the centre of the network; other banks are on the outskirts. In other realizations of weighted networks the size of exposures and the ordering of banks differ.

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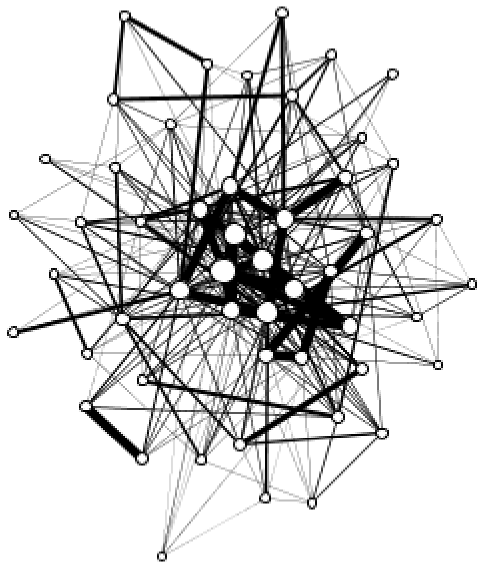
26 The probability has the following conditions: $\pi_i = [0, 1]$ and $\sum \pi_i = 1$.

27 The underlying basic set of realisations for undirected networks remains the same for both 2007 and 2010. Only the weighting of the networks with bank and exposure-specific values differentiates the directed networks.

28 In order to track the contagion results in the contagion simulations, nodes also carry information on banks' vulnerability, loss-given-default rate, volume of total assets and nationality.

Figure 1. Example of a network for European banks



Note: A realization of the Barabasi-Albert (1999) model for the European interbank network. Each circle represents a bank in the sample, and its size is scaled in proportion to the sum of interbank exposures of the given bank at the end of 2010. The lines between the circles represent interbank linkages between individual banks. The darkness of a line reflects the proportional value of a bilateral exposure.

3.4 Endogenous loss-given-default

The dynamics of the SIR model and the generated interbank networks already give a basis for the simulations of the credit contagion. However, to add further reality in the analytical framework we introduce additional variables that govern the spreading of negative spillover effects.

First, after the bank i is affected by negative spillover effects its own contagiousness is assumed to depend on time (α_{it}). The loss-given-default of a bank is thus assumed to evolve in stages and it increases as time passes; the longer bank i has encountered difficulties, the higher the probability that its counterparties will also be affected via the interbank network and the higher are the losses for bank i's counterparties. This feature is designed to capture the fact that during the first stages of the crisis, the losses are normally relatively small as banks are often able to honour their obligations. The aggravation of the crisis often increases the default rates and bank losses rise. As a result, the overall negative externalities to the whole banking system also start to mount. The increasing loss-given-default rate also reflects to some extent the heightened mistrust and uncertainty in the interbank markets as well as rising suspicions about counterparties and a reluctance to engage in business relationships with banks in trouble. Growing expectations concerning banks' inability to weather the storm cause direct losses to rise and augment contamination of the banking system. In a sense, the model thus mirrors the psychological aspects of interbank contagion.

In the baseline simulations, the loss-given-default rate variable is modelled with a stepwise function that receives three different values (equation 6).

$$\alpha_{it} = \begin{cases} 0 & , 1 \leq t > 2 \\ 0.5 & , 2 \leq t > 3 \\ 1 & , t \geq 3 \end{cases} \tag{6}$$

The values of function reflect probabilities of zero, 50% and 100% at the first, second and third time steps after the initial contact with a beleaguered counterparty, respectively. While the nominal values of loss-given-default rates remain uniform for all banks in the sample and equation (6) defines values for all banks once they are infected, the α_{it} is endogenous as it depends on the spreading of the contagion. Thus, different banks can receive different values at a given point in time. It should nevertheless be noted that high contagiousness of bank i does not necessarily guarantee the propagation of negative effects in the banking system, as other variables also play a role in the spreading of the contagion. The assumption regarding the values of equation (6) and the number of steps are relaxed and tested later on.

3.5 Bank-specific vulnerability

In reality, banks also differ in regard to their financial strength. The importance of capital buffers for financial stability has also been demonstrated in previous academic papers (see, for instance, Nier et al., 2007). To incorporate such heterogeneity into the analytical framework, we introduce a variable (β_j) to measure the vulnerability of bank j to negative spillover effects. Arinaminpathy, Kapadia & May (2013) take an analogous approach by modelling the health of a financial institution as a function of the bank's capital and liquidity positions. In this paper, the variable (β_j) portrays the bank's financial standing, as it is dependent on the equity capital of bank j. When the risks materialize, the equity capital acts as a first line of defence. If the equity ratio is low, the bank is likely to be more vulnerable than other banks in the system.

To get the parameter values (β_j) we first use data on the sample banks' annual reports to calculate bank-specific equity ratios by dividing common equity by total assets. An alternative measure would be the solvency ratio, defined as regulatory capital over risk-weighted assets. However, the financial crisis has shown that this ratio may not always be representative. Tier 1 solvency ratios and core Tier 1 capital ratios are nevertheless used in robustness tests. The equity ratios of the banking groups differ considerably and stand, on average, at 4.1% for 2007 and 4.6% for 2010. Secondly, based on the observations for the equity ratios we derive their distributional characteristics. Equity ratios of the banks in the sample follow the normal distribution in 2010 with mean 4.89 and standard deviation 1.77 and in 2007 with mean 5.06 and standard deviation 2.07.[29] Finally, with the mean and standard deviation of normally distributed equity ratios we obtain the corresponding cumulative distribution. The values of this cumulative distribution represent the parameter values (β_j) for each equity ratio, indicating the bank's financial strength.

3.6 Contagion mechanism

Based on the analytical framework and model calibration, we subsequently simulate the transmission of credit contagion in the banking network. In the short-term, these contagion simulations are similar to the Furfine (2003) algorithm. However, regarding the solution for time dimension we adhere to the approach of Eisenberg & Noe (2001).

In the simulations, contagion starts with an exogenous and idiosyncratic shock hitting a single bank in the system. Network-specific results are derived by letting each bank (N=1,...,51) one by one to be a source of the contagion and by exposing the whole banking system to the effects of direct and indirect contagion. The probability of being contagious is thus uniform for all banks irrespective of characteristics such as size and links with other banks. The contagion process is simulated for each network realization. As we generate 10,000 different networks and let 51 banks to be the original source of an exogenous shock in each network, we thus simulate 510,000 cases in a benchmark simulation.

Secondly, the contagion spreads when the losses from contagious bank i are larger than the financial strength of non-affected (susceptible) bank j ($\lambda_{ij}(s(t)c(t))$

29 Both the Jarque-Bera and Lilliefors tests confirm that the samples for both years are from normal distributions.

* $\alpha_{it} > \beta_j$). Thus, the bank fails and negative domino effects spread, if the bank's financial strength is too low in comparison to its risks and counterparty exposures in the interbank market. Finally, the contagion simulations stop when there are no more contagious banks or when all banks have been exposed to the crisis.

4 PROPAGATION OF THE CRISIS

4.1 European banking sector as a whole

The simulations demonstrate how the contagion spreads in the European banking system, splitting the banking sector in two parts. A similar thing occurred during the current financial crisis when the European banking sector was divided into "good names", with access to interbank lending, and "bad names" that were excluded from money markets by means of larger haircuts and margin requirements.

Based on the results of the benchmark simulation, figure 2 shows the average total assets of non-affected, contagious and capitalized/liquidated banks at a given point on the crisis' timeline. While some banks are strong enough to resist the crisis and are able to continue their business, the others fall under market suspicion, transmitting market distress further (contagious banks), and are ultimately segregated to the group of crisis-stricken banks. At the end of the benchmark simulation the assets of capitalised/liquidated banks total, on average, 10 trillion euro, constituting around 40% of total assets of banks in the sample.[30] The standard deviation indicates that the variation between different network structures is relatively small and that the total assets of banks hit by the crisis hover around 8.2-11.7 trillion euro. Despite the widespread contagion the rest of the banking system is able to avoid negative spillover effects and the average total assets of non-affected banks stand at 15.9 trillion euros after 27 time steps.

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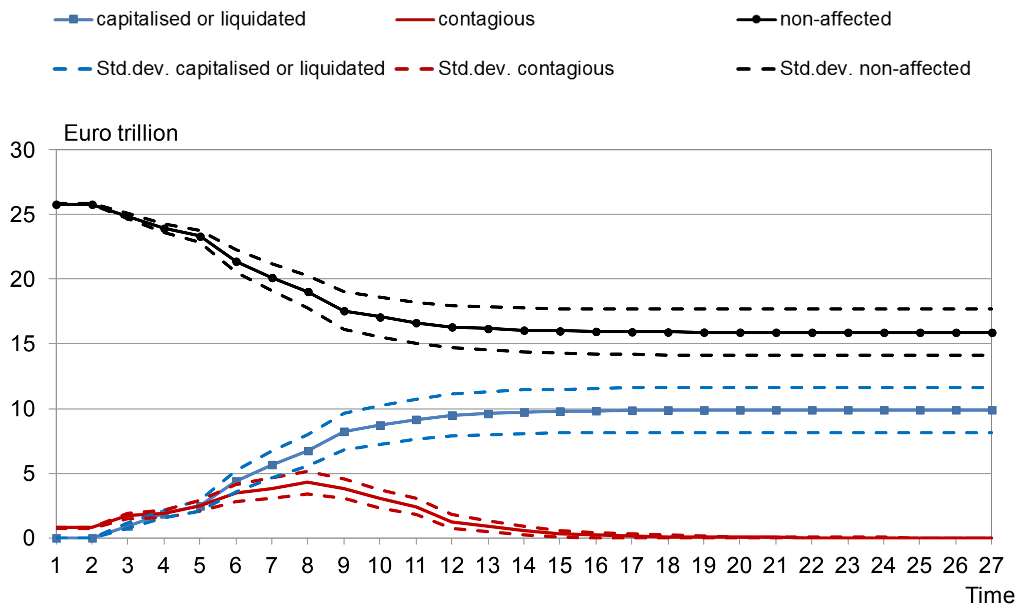
[30] The overall average for total assets is obtained by first calculating the average for each individual network over all banks (N=51) and then averaging these individual network results over all generated 10,000 networks. The average does not include the total assets of the first failing bank.

Figure 2. Average total assets of capitalised/liquidated, contagious and non-affected European banks, benchmark simulation for 2010



Note: The results are based on the benchmark contagion simulation. Average total assets for each category is calculated over all banks in the sample (N=51) and all generated 10,000 networks. Blue and black lines represent the average cumulative sum of capitalised/liquidated banks' and non-affected banks' total assets at the given point in time, respectively. Red line represents the average total assets of contagious banks at each point of time. Horizontal axis represents the time steps. Std. dev. stands for standard deviation. Results do not include the total assets of the first failing bank.

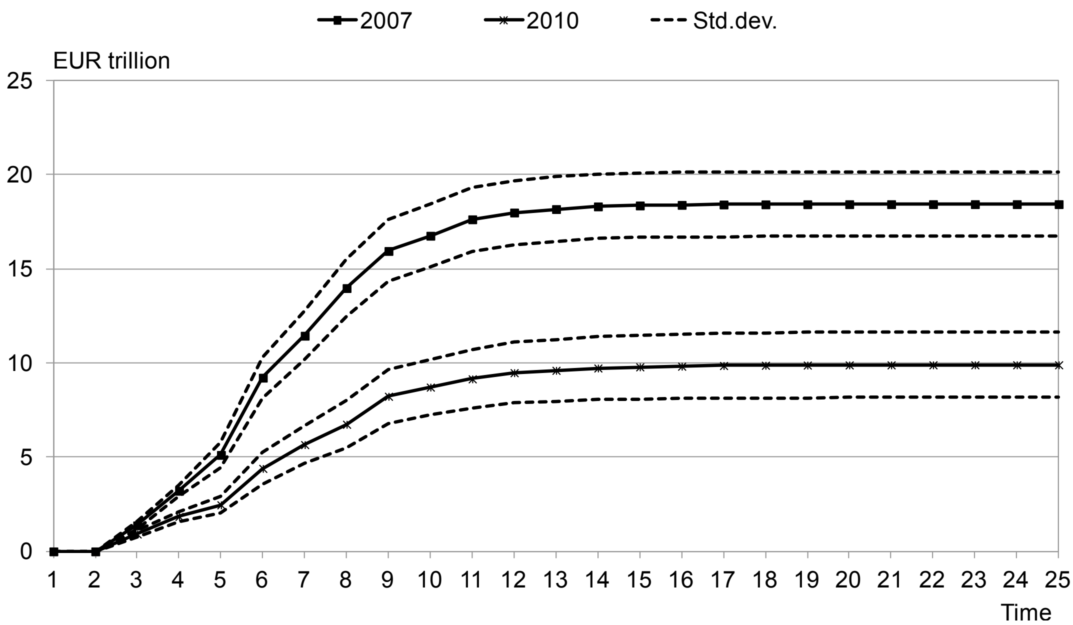
While the average cumulated sum of capitalized/liquidated banks' total assets portrays the combined effect of the contagion on the banking system over time, the average total assets of contagious banks at each point in time describes the evolution of the contagion process. Based on the benchmark simulation the majority of transmission occurs at the beginning of the crisis, as the volume of contagious banks exhibits an initial increase between the second and eighth time steps. Without any further shock to the system the force of the contagion then slowly declines towards the end of the estimation period. The system stabilizes around the steady state at the 18th time step.

However, the overall average conceals individual differences as the contagion may be considerable in individual cases. For instance, in a single network the average[31] total assets of capitalised / liquidated banks constitute up to 16.5 trillion euros after all banks in the system are exposed to negative domino effects. Thus,

[31] The average is calculated over all banks (N=51).

contagion can affect 62% of the banking system in 2010. Moreover, the failure of a single bank in a network can contaminate up to 82% of the banking system, corresponding to 21.9 trillion euro in terms of total assets. At the other end of the spectrum are the networks in which no contagion appears after the initial round of bank failures.

Figure 3. Average cumulative sum of contagious banks' total assets at each point in time, benchmark simulations for 2007 and 2010



Note: The results are based on the benchmark contagion simulations for 2007 and 2010. Lines represent the averages for the cumulative sum of contagious banks' total assets at the given point in time. Averages are calculated over all banks (N=51) in the sample and all generated 10,000 networks. Horizontal axis represents the time steps of the contagion simulation. Std. dev. stands for standard deviation. Results do not include the total assets of the first failing bank.

Compared to 2010, the magnitude of the contagion is almost twofold in 2007, just before the onset of the financial crisis (Figure 3). At the end of all simulation rounds, the average contagion affects around 70 % of the banks in 2007, corresponding to 18.4 trillion euro of total assets. Prior to the financial crisis the European banking system was therefore much more prone to negative shocks than in 2010. The outcome reflects the increasing equity as well as banks' efforts to restrict their exposures in the midst of the financial crisis.

4.2 Contagion at the country-level

In order to shed more light on contagion in the European banking system, Table 2 shows how the contagion depends on the nationality of the first failing bank.[32] At the end of 2010 Spanish, British, German and French banks are able to induce widespread contagion, while contagion from other banks is much more subtle than the average. Spanish banks are the most detrimental to the system, as the assets of banks affected by the failure of a Spanish bank total 14.5 trillion euro, corresponding to 56% of the total assets of the system. In contrast, banks from the program countries (Ireland, Greece and Portugal) have only slightly smaller impacts on the system than banks from Belgium, the Netherlands, Austria, Sweden and Denmark.

The country-level results portray the European situation at the end of 2010. Especially the Greek, Portuguese and Irish banks were facing difficulties in obtaining funding from the interbank markets and were effectively excluded from the money markets by the end of 2010. Without sufficiently large interbank positions with the rest of the European banks they are not able to initiate a widespread contagion. At the same time, the banks from relatively strong European countries such as Germany and France were still well-positioned in the interbank network, rendering them prominent sources of contagion. Throughout the sovereign debt crisis Germany has had safe-haven status, leading German banks to have strong linkages with other banks. Also, French banks were considered relatively strong counterparties in 2010. The heightened suspicion over French banks' exposures to Greek debt came into the picture only later in 2011–2012. Meanwhile, British banks have traditionally been large institutions with multinational business models and extensive connections worldwide.

[32] The results are divided according to the nationality of the bank that starts the contagion chain at the beginning of the simulation. The subsequent contagion may affect any bank in the system irrespective of its home country. The average is calculated over all generated networks (10,000) and banks that have a headquarters at a given country. It should be noted that the results reflect contagion only via interbank channels included in the model; other channels such as sovereign-banking sector linkages and trade linkages are excluded.

Table 2. Average country-level contagion according to nationality of the first failing bank, benchmark simulations for 2007 and 2010

	EUR trillion in 2007	EUR trillion in 2010	Change, %
ES	21.95	14.48	-34.0
DE	20.61	10.56	-48.8
IT	21.34	0.59	-97.2
FR	20.24	10.39	-48.7
NL	20.34	0.95	-95.3
PT	0.31	0.05	-84.5
AT	20.75	0.53	-97.5
BE	19.60	0.59	-97.0
GR	0.07	0.03	-50.9
IE	19.72	0.49	-97.5
GB	20.80	13.06	-37.2
DK	0.45	0.45	-0.7
SE	0.44	0.46	4.2
Average	**18.44**	**9.91**	**-46.3**

Note: The results are based on the benchmark contagion simulation for 2007 and 2010. Contagion is measured by the average cumulative sum of contagious banks' total assets at the end of simulation rounds. To calculate the overall average we first take a bank-specific averages over all generated 10,000 networks. Secondly, we derive a country-specific averages by averaging the results of banks that have headquarters in a given country. Thus, the averages are calculated according to the nationality of the first failing bank. The results do not include total assets of the first failing bank.

The results for Spanish and Italian banks may seem counter-intuitive at first glance. But Spanish and Italian problems reached the limelight of the crisis only in 2011–2012. Although the problems in the Spanish real estate sector were already evident in 2008, large Spanish banks continued to perform relatively well in 2010, owing to income from Latin American countries. Spain's third largest bank, Bankia, was nationalized only in May 2012, and the country received financial support in June 2012. Despite the market volatility and uncertainty over Italy's debt servicing capacity, Italian banks were not a cause of concern in 2010.

Comparing the country-level results in 2010 to the outcome in 2007 data, the contagion effects from all countries have decreased except for Sweden (Table 2). The results reflect banks' fear of counterparty risks and risk-aversion towards counterparties in deep trouble during the financial crisis, inducing banks to limit their exposures to weak market-players to the benefit of strong banks. The danger of negative spillovers from all countries diminishes, but especially so from

Ireland, Belgium, the Netherlands, Italy and Austria. British, German, French and Spanish banks remain effective in transmitting the contagion in both periods.

4.3 Robustness tests

Robustness tests with different parameter values and solvency ratios verify the overall findings presented in section 4.1. In this section, we run robustness tests by relaxing some of the assumptions regarding the parameters of the analytical framework and generated networks.

First of all, we vary the parameters defining the bank-specific contagion transmission rate (λ_{ij}), namely the size of the interbank markets (m) and exposures (EXP_{ij}). Increasing the value of these parameters subsequently magnifies the contagion, albeit in a non-linear way. The negative effects build up quickly with the initial escalation of interbank markets and exposures, but the impact on contagion abates later on. For instance, increasing the size of the banking system by multiplying the total volume of the interbank payments by 1.5, the resulting contagion is 60 percent larger than in the benchmark case. But when the volume of total interbank payments rises twofold, the total assets of contagious banks increases only by 92 percent from the benchmark.

Second, the equation (6) can be modified to test the influence of assumptions on the bank-specific endogeneity (α_{it}). In the benchmark contagion simulation, we assumed that the contagiousness of a bank evolved in three time steps, representing loss-given-default rate of zero, 50% and 100% at the first, second and third time step. We run the robustness tests by lengthening the time period during which a bank remains contagiousness. At the same time, loss-given-default rates (LGDs) increase linearly with the number of time steps. For instance, if six time steps are chosen, LGD rises linearly from zero to 100%, implying the rates of 0 %, 20%, 40%, 60%, 80% and 100%.[33]

We let the number of time steps vary from two to twelve steps. Two steps reflects a situation in which banks default rapidly and induce immediately large losses for the counterparties. Similarly, twelve time steps reflect a prolonged financial crisis. Simulations show that a smouldering crisis is more detrimental to financial stability than a quickly transmitted one. Compared to the benchmark simulations,

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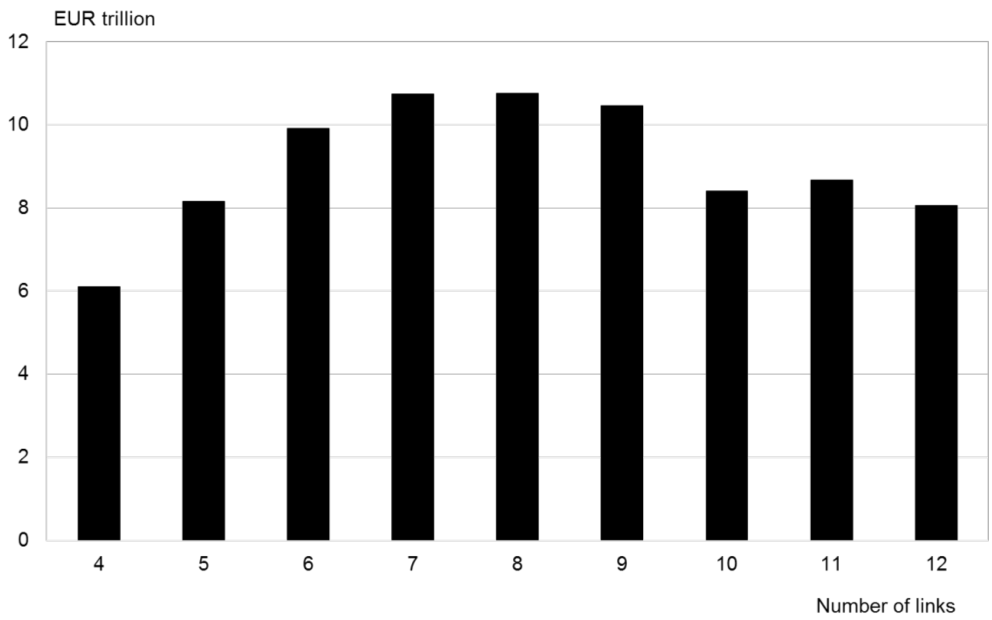
[33] Despite the fact that all banks have same number of time steps and loss-given-default rates, it should be noted that the loss-given-default is determined endogenously in the model as it depends on the spreading of the contagion.

the negative spillover effects of a crisis with a twelve time steps long incubation period are approximately 16 percent larger in 2010. We also test for the functional form of the equation (6) and let it follow a Sigmoid function with ten time steps. In this case, the contagion is around 22 percent larger than in the benchmark case for 2010.

Finally, regarding the bank-specific vulnerability (β_j) we calculate them on the basis of solvency ratios instead of equity ratios. However, the results do not change but remain similar both at the European level and at the country level.

Figure 4. Cumulative sum of contagious banks' total assets, simulations for 2010



Note: The results are based on the contagion simulations for 2010. Horizontal axis represents the number of links that a bank creates when entering the network (connectivity). Bars represent the averages for the cumulative sum of contagious banks' total assets after all simulation rounds. Average is calculated over all banks (N=51) in the sample and all generated 10,000 networks after all simulation rounds. Results do not include the total assets of the first failing bank.

In addition to the parameter testing, the impact on contagion of a bank's connectivity (i.e. the number of linkages that a bank creates when entering the network) is analysed. In a benchmark contagion simulation, the bank creates six links with other banks in the system and the average total assets of contagious banks is 10 trillion euro (Figure 4). Should a bank create less than six links, the average contagion descends. With seven or eight created links, the average total assets of contagious banks is around 10.8 trillion euro. Nevertheless, when the connectivity increases further, the average total assets of contagious banks starts to decline. Thus, increasing connectivity first increases the negative spillover effects in the banking system, but after a certain threshold the contagion declines and the system's resilience increases. The effect demonstrates the systemic nature of connections. When the number of connections increases, the channels for negative spillover effects multiply and more banks become affected. But as the number of affected banks rise, the negative impact per individual bank declines.

5 FACTORS DETERMINING THE CONTAGION

The simulation results suggest that the contagion varies depending on the first failing bank and network, as it is almost non-existent in some cases but in a worst-case scenario it can be widespread and detrimental to the whole banking systems. Given the outcome, it is of interest to analyze which bank-specific characteristics, such as size, solvency and bank's position in the network, are important in driving the contagion. We therefore run a set of simple estimations with the purpose of providing intuition for what is driving the simulation results and of finding indicators that are of relevance for financial stability.

Furthermore, to support the ailing banking sectors during the financial crisis central banks worldwide have taken unprecedented actions by providing emergency liquidity assistance and by launching securities and bond purchasing programs. For instance, the European Central Bank started to conduct its monetary policy operations with full allotment and introduced other liquidity-providing operations. One of the reasons given for these operations was the avoidance of contagion in financial markets. Also Freixas, Parigi & Rochet (2000) and Georg (2013) indicate that the central bank can improve financial stability by providing liquidity to financial institutions. Given the magnitude of the operations, we analyze the impact of central bank actions on contagion by including two central bank related variables in the estimations. The following first describes the bank-specific statistical indicators and the estimation methodology, before turning to the results of the analysis.

5.1 Definitions and data for indicators

The indicators reflect bank-specific idiosyncratic characteristics such as size, number of counterparties and the bank's network position.

To begin with, a bank's size is measured by total assets. Data for total assets of individual banks is obtained from the sample banks' annual reports and they are expressed in levels. The network-related indicators describe banks' strength as well as their importance, position, density and clustering in the network. These indicators are commonly used to depict the topological characteristics of the network. The indicators are calculated according to formulas in Annex 1 and on the basis of all generated 10,000 networks (see section 3.3.). The indicator values are thus averages.

Network metrics include the average distance (i.e. path length), which indicates how quickly, on average, a bank may reach other banks in the system via the links. The maximum distance (eccentricity) illustrates how far away the most distant bank of the network is. We also calculate so-called connectivity of a bank, which is the probability that two banks are counterparties to each other, defined as the number of a bank's existing links over all possible links of the bank. Betweenness centrality indicates how dependent other banks are on a certain bank i, and it has also been used as a proxy for a bank's reputation. Eigenvector centrality portrays how well connected the bank i is to other central players of the interbank network. The banks with high eigenvector centrality have multiple links to other well-connected banks. The clustering coefficient depicts the probability that two counterparties of a bank are also connected to each other. A similar case occurs if two friends of a person have a mutual friendship. A volume-based parameter is deduced from the clustering coefficient by weighing it by the interbank payments. Finally, we include the number of a bank's counterparties, the volume of in-coming and out-going interbank loans as well as the closeness centrality showing how close banks are each other in the network. (Iori et al. 2008; Soramäki et al. 2007; Minoiu & Reyes 2013; Alves et al. 2013) Depending on the nature of each indicator, they are expressed either in percentages or in levels.

To analyse the impact of central bank operations on the transmission of credit contagion we include two additional variables in the estimations. As the central bank interventions are first and foremost reflected in their balance sheets, the variables include a central bank's total assets and monetary policy operations-related lending to local credit institutions. The data are from annual reports of German, French, Italian, Spanish, Dutch, Belgium, Austrian, Portuguese, Greek, Irish, British, Danish and Swedish central banks. The variables are calculated at the national level and they are expressed in annual growth rates. In the analysis, the country-level central bank data are associated with individual banks of the sample according to the location of the bank's headquarters.

Annex 2 contains descriptive statistics for contagion and bank-specific variables at the end of 2007 and 2010. Based on the data and simulated networks, the indicators are computed for each bank in the sample. In the case of network indicators, we take averages over all generated networks. Looking at total assets, the average bank is somewhat smaller in 2007 than in 2010, but the difference in size between the largest and smallest bank is more pronounced in 2007.

Based on the network indicators, banks appear to be close to each other, and the network is compact and dense. The simulated networks thus reflect nicely the real-world observations on the network of the large European banks. (Alves et al., 2013) Regarding the concentration and density of the network, the (weighted) clustering coefficient and betweenness centrality are relatively high, reflecting the fact that some banks have pivotal roles as hubs in the network. Any given counterparty of a bank in the system can be reached in less than two steps while the maximum distance (eccentricity) is no more than three steps. The connectivity shows that 21% of all possible linkages are utilized on average, but in some cases a bank's active links cover almost half of its potential connections. Moreover, a bank has 10.7 counterparties on average, but the most connected bank can have up to 24.5 links.

Finally, the extension of central bank liquidity operations is more evident in loans to financial institutions than in the total assets of central banks, as can be expected. In 2007, central bank lending to banks increased in all countries but especially so in Portugal owing to the emergence of financial market turbulence. The growth of central banks' total assets varied from -0.7 percent to 21.6 percent, being often lower than the growth of liquidity assistance. In 2010, liquidity provision continued to increase heavily in so-called program countries (Portugal, Greece and Ireland) that received EU/IMF financial support during the crisis. But loans to financial institutions declined in some countries as in Germany, Sweden and Belgium.

5.2 Estimation methodology

The main explanatory variables for the level of contagion induced by bank i at time t, $Cont_{i,t}$, consist of a bank's size ($TA_{i,t}$), financial standing ($FinRatio_{i,t}$) and network indicators ($NetMeasure_{i,t}$) as well as the central bank policy of the country (CB_policy_t) (equation 7).

$$\log(Cont_{i,t}) = \alpha_{i,t} + \delta_1 log(TA_{i,t}) + \delta_2(NetMeasure_{i,t}) + \delta_3(CB\_policy) + \varepsilon_{i,t} \quad (7)$$

Contagion ($Cont_{i,t}$) refers to the average total losses of the financial system resulting from the failure of bank i. It is obtained by running benchmark contagion simulations and letting bank i fail in each generated network. The individual simulation outcomes are then averaged over all networks to get the variable. Size is measured by total assets ($TA_{i,t}$). Network indicators consist of all indicators listed in the Annex 1. Variables for central bank policies include annual growth in the central bank's lending to banks and annual growth in its total assets. Only total assets and the volumes of in-coming and out-going interbank loans are expressed in levels; other indicators are in percentages.

Our main motivation for running the estimations is to provide intuition for main leading factors driving the contagion simulation results. To certain extent, the estimations may be argued to suffer from the endogeneity problem as the dependent variable in the regression is the output from simulations and network measures are linked mechanically to generated networks. However, in the estimations we use only explanatory variables with no direct effect on simulation results.[34] While the values of all network indicators are calculated from the networks, they do not dictate the simulation outcomes per se. They rather portray the network properties of a bank. Moreover, we hope to find the indicators that are of relevance for supervisors and regulators, while they try to assess the vulnerability of the banking sector.

In a similar vein, the central bank related variables may suffer from a different kind of endogeneity as central bank interventions tended to be largest for banks that suffered the most during the financial crisis. Nevertheless, the central bank variables' correlation with the level of contagion is not evident. For instance, the correlation is only 15 percent in 2007. Similarly, while the central banks' loans to banks decline in Spain, Germany, France, the Netherlands and Austria in 2010, Spanish, German and French banks induce high contagion but contagion from Dutch and Austrian banks is low.

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[34] For instance, we leave out the equity ratio that determines the vulnerability of the bank and thus correlates significantly with simulation results.

The OLS regression analyses are performed in log-log form[35] for both 2007 and 2010. All banks in the sample (i=51) are included in the estimations. However, owing to log-transformations the sample is reduced to 48 banks in 2010, as three banks do not induce contagion. Because the correlations between the values of individual network variables are high, these variables enter into the estimations one at a time. The only exception is the weighted clustering coefficient, for which the correlation coefficients with other network metrics are relatively low.

The coefficients for the size and volume of interbank loans that a bank has taken from its counterparties are expected to have positive signs, as they contribute positively to the bank's fragility and its importance to the system. High centrality, clustering and connectivity of a bank are also assumed to impact positively on the contagion, since they reflect the bank's prominence in the network and thus its ability to transmit negative spillover effects. In contrast, long distances between banks (as measured by path length and eccentricity) are expected to impact contagion negatively, as sparse connections hinder the transmission process. Central bank operations are most likely to exert a negative impact on contagion.

5.3 Results

As expected, many embedded bank-specific indicators emerge as natural explanatory factors for credit contagion. The size of a first failing bank and network indicators affect positively the level of contagion (table 3). According to the estimates, weighted clustering coefficient, bank's connectivity, volume of interbank business as well as betweenness and eigenvalue centralities have significant and positive coefficients in 2010, indicating the ability of these indicators to predict contagion. Since the weighted clustering coefficient depicts the proportional volume of interbank loans held by two interconnected counterparties of a bank, it highlights the importance of local clusters in the banking systems. In particular, if these clusters are composed of banks with high interbank loan volumes, the failure of one such bank can be detrimental to financial stability. Also, a strong capacity to borrow funds from interbank markets combined with a relatively large number of counterparties (i.e. connectivity) can render a bank hazardous to the resilience of the network. In a similar vein, as shown by the betweenness and eigenvalue centrality measures, a failure of a bank

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[35] As a robustness test, also log-linear estimations are performed. They, however, produce similar results.

with multiple links to other well-connected banks is apt to affect negatively on the system's stability.

Regarding the size of the coefficients, one percentage point growth of a bank's total assets in 2010 increases contagion by just 0.4-0.6 percentage point, while a similar increase in the weighted clustering coefficient of a bank increases contagion by 80-120%.[36] Moreover, betweenness centrality indicates that if an important intermediary of the banking system fails, contagion increases by 20%.

Table 3. Estimation results for 2010

	Equation 1	Equation 2	Equation 3	Equation 4
Log (total assets)	0.55	0.39	0.54	0.58
	[0.18]***	[0.16]**	[0.18]***	[0.18]***
Weighted clustering	1.18	0.82	1.18	1.15
	[0.09]***	[0.20]***	[0.10]***	[0.10]***
Connectivity	4.00	..	..	..
	[1.98]**	..	..	..
Volume of in-coming interbank	..	0.86	..	..
loans	..	[0.35]**	..	..
Eigenvalue centrality	..	..	6.79	..
	..	..	[3.49]*	..
Betweenness centrality	..	..	..	0.20
	..	..	..	[0.09]**
Growth in CB's liquidity	- 0.002	- 0.002	- 0.002	- 0.002
support	[0.001]**	[0.001]**	[0.001]**	[0.001]**
Constant	- 4.89	- 2.86	- 4.91	- 4.18
	[0.49]***	[0.92]***	[0.49]***	[0.50]***
R^2	0.85	0.86	0.85	0.85
No. of observations	48	48	48	48

Notes: Heteroskedasticity-consistent standard errors of the estimates are reported under the point estimate in the brackets and are calculated according to White procedure. (*), (**), (***) indicate statistical significance at 10%, 5%, 1%, respectively.

Central bank liquidity operations have a significant and negative effect on contagion, indicating that central bank policies are efficient in alleviating crises and negative domino effects in the financial markets. However, the impact is

[36] Recall that the clustering coefficient is expressed in percentages. Thus a one-percentage-point rise in the network variable increases the level of contagion by 100% of the estimated coefficient.

relatively subdued. The liquidity support of central banks in the form of loans to local financial institutions reduced contagion only by 0.2 % in 2010. The growth of central bank assets fails to be significant, potentially reflecting the influence of non-standard measures. The securities market program and covered bond purchase programme of the European Central Bank were both active in 2010, increasing central banks' balance sheets without direct effect on the stability of the banking system. The outcome might also be driven by the fact that in the case of the euro area countries the total balance sheet also includes the central bank's foreign-currency denominated claims on banks as well as intra-eurosystem claims, which in some cases proved to be significant in amplifying the total assets.

Table 4. Results for OLS estimation with 2007 data

	Equation 1	Equation 2	Equation 3	Equation 4
Log (total assets)	0.59	0.59	0.43	0.48
	[0.16]***	[0.15]***	[0.13]***	[0.15]***
Weighted clustering	0.87	0.83	..	1.05
coefficient	[0.15]***	[0.15]***	..	[0.13]***
Closeness centrality	5.11	..	..	..
	[2.56]*	..	..	..
Path	..	- 3.80	..	..
	..	[1.60]**	..	..
Volume of in-coming interbank	..	..	1.71	..
loans	..	..	[0.16]***	..
Growth in CB's liquidity	- 0.002	- 0.002	..	..
support	[0.00]***	[0.00]***	..	..
Growth of CB's total assets	..	..	- 0.02	- 0.02
	..	..	[0.006]***	[0.006]**
Constant	- 6.39	6.38	2.20	- 1.61
	[2.38]**	[3.50]*	[0.32]***	[0.73]**
R^2	0.72	0.73	0.74	0.71
No. of observations	51	51	51	51

Notes: Heteroskedasticity-consistent standard errors of the estimates are reported under the point estimate in the brackets and are calculated according to White procedure. (*), (**), (***) indicate statistical significance at 10%, 5%, 1%, respectively.

Table 4 presents the estimation results with 2007 data. Overall, the results are similar to 2010, confirming the positive relationship between contagion, size and network indicators. In addition, the magnitude of the coefficients in 2007 is in the similar range as in 2010. Bank clustering and the volume of in-coming interbank loans continue to be significant variables. But bank connectivity as well as a bank's position as a middleman and an important partner for other banks (betweenness and eigenvalue centralities) lose significance in 2007. However, another centrality measure – closeness centrality – turns out to be significant. Because closeness centrality can also be interpreted as a proxy for reputation, the estimation results suggest that the failure of a bank with high prestige can almost triple the contagion in the banking system. This is natural, as such a bank can be expected to be well-integrated in the banking network and its failure would have far reaching consequences for the system. Furthermore, the results indicate that as the physical distance between banks (average path length) increases, the resilience of the banking system increases.

Taken together, the results suggest that local clusters, an increase in a bank's connectivity, the central position of a bank in the network, bank reputation, the size and the volume of its interbank business are the most important factors in determining the amount of contagion in 2007 and in 2010. It would thereby seem worthwhile to continue to give prominence to network metrics in a financial stability analysis and continue to include these indicators in the tool box of micro and macro prudential supervision. From a system perspective, banks that are "too-connected-to-fail" are at least as important as "too-big-to-fail" banks.

Similarly to 2010, central bank policies manage to moderate contagion in 2007. For instance, the results regarding the positive impact of central bank liquidity operations hold also for 2007, indicating that central bank loans to banks reduce contagion by 0.2 %. The growth of central bank assets has a somewhat more pronounced impact, reflecting the influence of non-standard measures. A one percentage point increase in total assets of central bank mitigates negative spillover effects by 2.0 %. The growth of central banks' total assets may have been more related to specific problems in the banking sector in 2007 than in 2010. All in all, although central bank policies are useful in restraining contagion, they do not appear to be very efficient.

6 CONCLUSIONS

The interconnectedness of the modern interbank network enabled the rapid transmission of the financial crisis by creating a transmission channel for credit contagion and by exposing all banks in the network to potential losses. This paper proposes a novel approach to analyze contagion by applying an epidemiological model with network application and data on European banks. As some banks turn out to be more contagious than others, we also employ regression analysis to determine which bank-specific factors explain the negative spillovers.

The simulation results suggest that the crisis divides the banks in two categories: contagious and healthy banks. On average, approximately 40% of the European banks are affected negatively by the crisis in 2010, but the average contagion was almost twofold in 2007. In terms of nationality, French, British, German and Spanish banks are able to induce widespread contagion, while banks from Ireland, Greece and Portugal have only limited negative impacts.

Moreover, high clustering of the banking system, a bank's high connectivity, large interbank loans, a central position of a bank in the network, and a bank's size are shown to explain the vulnerability of the banking system. In terms of individual indicators, the weighted clustering coefficient, connectivity and volume of in-coming loans are significant explanatory factors. Also relevant are the centrality indicators that depict the bank's position in the network. It seems useful to include these indicators in the financial stability analyses and continue to give emphasis to banks' position and significance in the interbank network. Finally, central bank liquidity operations and other central bank measures are efficient in alleviating contagion and financial crisis. But as central bank policy can limit contagion only marginally during a crisis, efforts should be directed at preventive measures.

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Annex 1: Formulas and definitions of network indicators

Indicator	**Definition**	**Interpretation**	**Formula**
Number of counterparties (i.e. degree), k	The number of counterparties, k, (links) of bank i (a node). k_i is set to 1 if banks are counter-parties, zero otherwise.	The more the counterparties, the more the creditors/ debtors of a bank.	$k = \sum_i k_i$
Strength (by in-coming links),$s_i^{w,b}$	Sum of the weights, w (volume of the interbank loan) of bank i's in-coming links.	Volume of interbank loans that bank i has taken from other banks, j=1,...,N. (bank's borrowing strength).	$s_i^{w,b} = \sum_{j=1}^{N} w_{ij}^b$
Strength (by out-going links), $s_i^{w,l}$	Sum of the weights, w (volume of the interbank loan) of bank i's out-going links.	Volume of interbank loans that bank i has given to other banks, j=1,...,N. (bank's lending strength).	$s_i^{w,l} = \sum_{j=1}^{N} w_{ij}^l$
Average shortest path length, l_i	The average shortest distance, d, from node i to other nodes, j=1,...,N, in the network.	Describes how quickly a bank may reach other banks in the system, on average.	$l_i = \frac{1}{(N-1)} \sum_{i \neq j} d_{ij}$
Eccentricity, ε_{ij}	The maximum distance, d, from node i to any other node j in the network.	Describes how far away the other banks are in the network.	$\varepsilon_i = max_j d_{ij}$
Connectivity, p_i	The number of node i's existing links, k, relative to the number of a node i's all potential links.	Unconditional probability that two banks are counter-parties for each other.	$p_i = \frac{k_i}{(N-1)}$
Eigenvalue centrality, λ	The principal eigenvector, v, of adjacency matrix, A, that defines the (internally connected) network.	Describes how well connected the bank i is to other central players of the network (i.e. banks with largest number of connections)	$\lambda v = Av$

Indicator	Definition	Interpretation	Formula
Clustering coefficient, c_i	The connected neighbours of node i, a_i, relative to all possible connections among these three nodes. Thus, measures the number of triangles in the network.	Unconditional probability that bank i's counterparties are also connected to each other. (Probability that my two friends are also likely to be friends of each other.)	$c_i = \frac{2}{k_i(k_i-1)} \times \sum_{jh} a_{ij}\, a_{ih} a_{jh}$
Weighted clustering coefficient, c_i^w	Clustering coefficient is weighted by the volume of interbank payments.	Proportion of interbank loan volume held by two counterparties of a bank that are also linked to each other	$c_i^w = \frac{1}{s_i(k_i-1)} \times \sum_{jh} \frac{(w_{ij}+w_{ih})}{2} a_{ij}\, a_{ih} a_{jh}$
Betweenness centrality, $C_b(i)$	Sum of fractions of shortest paths, δ, between two nodes (s,t) that pass through node i relative to total number of shortest paths between nodes s and t.	Quantifies the number of times a bank acts as a bridge along the shortest path between two other banks. Shows how dependent these banks are from bank i.	$C_b(i) = \sum_{s \neq t \neq i} \frac{\delta_{s,t}(i)}{\delta_{s,t}}$
Closeness centrality, C_i	Inverse of the sum of the average shortest distances from a node i to all other nodes, j=1,...,N, in the network.	How quickly something that is flowing through the network (i.e. contagion, liquidity) is expected to reach bank i. Also used as proxy for reputation.	$C_i = \frac{1}{\sum l_i}$

Sources: Iori et al. (2008), Soramäki et al. (2007), Minoiu & Reyes (2013), Alves et al. (2013).
Note: N stands for the number of nodes (banks) in the network.

Annex 2. Descriptive statistics for indicators in 2007 and 2010

Year	Variable	Mean	Std.dev.	Min	Max
2007	Contagion, EUR bn	13 182	9 442	22	22 386
	Total Assets, EUR bn	494	580	23	2 510
	Equity, EUR bn	20	24	1	125
	Change of CB's loans to banks, %	153.1	217.5	4.5	750.7
	Change of CB's balance sheet, %	10.3	6.7	-0.7	21.6
	Volume of in-coming interbank loans that a bank has taken, EUR bn	1.63	1.52	0.20	5.67
	Volume of out-going interbank loans that a bank has given, EUR bn	1.63	1.32	0.48	5.70
	Weighted clustering coefficient, %	3.61	1.77	1.05	7.19
2010	Contagion, EUR bn	4 892	6 149	0	15 012
	Total Assets, EUR bn	521	569	31	1 998
	Equity, EUR bn	24	27	1	116
	Change of CB's loans to banks, %	-14.3	83.0	-99.8	155.9
	Change of CB's balance sheet, %	10.2	33.4	-47.3	63.4
	Volume of in-coming interbank loans that a bank has taken, EUR bn	1.72	1.67	0.13	6.27
	Volume of out-going interbank loans that a bank has given, EUR bn	1.72	1.36	0.52	6.03
	Weighted clustering coefficient, %	3.66	1.87	0.86	7.42
both years	Number of counterparties	10.71	4.71	5.97	24.51
	Shortest path	1.86	0.14	1.51	2.05
	Eccentricity	2.78	0.29	2.05	3.00
	Connectivity, %	21.42	9.42	11.94	49.03
	Betweenness centrality, %	1.50	2.21	0.09	9.80
	Closeness centrality, %	1.08	0.09	0.98	1.33
	Eigenvalue centrality	0.13	0.05	0.07	0.28
	Clustering coefficient, %	31.84	1.35	27.18	33.24

Note: Indicators of banks' size as well as central banks' balance sheet and liquidity operations are based on the annual reports of individual banks and central banks. Bank-level indicators are calculated for all 51 banks in the sample. Network metrics are based on all generated 10,000 networks. Std.dev. stands for standard deviation and CB for central bank.

• Journal of Banking and Financial Economics 1(3)2015, 113–129 113

Risk, capital buffers and bank lending: The adjustment of euro area banks

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ABSTRACT

This paper estimates euro area banks' internal target capital ratios and investigates whether banks' adjustment to the targets affects their credit supply and securities holdings during the financial crisis in 2005–2011. Based on data on listed banks and country-specific macro-variables, a partial adjustment model is estimated in a panel context. The results indicate, first, that an increase in the riskiness of banks' balance sheets positively influences banks' target capital ratios. On the euro area level, we find banks' undercapitalisation in terms of Tier 1 capital ratio to be close to 2 percentage points in the middle of 2008. While median capital gaps diminish towards the end of 2011, the heterogeneity across individual banks increases. Second, the adjustment towards higher equilibrium capital ratios has a significant impact on banks' assets. The impact is more sizeable on security holdings than on loans, thereby suggesting a pecking order of bank assets for deleveraging.

JEL classification: G01; G21

Keywords: banks, euro area, capital ratios, credit supply, partial adjustment model

1. INTRODUCTION

During the latest financial crisis, banks' core capital was often insufficient to cover impairment losses arising from both loan and securities portfolios. The increasing vulnerability of the banking sector and considerable pressures from markets, regulators and policy makers highlighted the necessity to strengthen banks' capital base and to reduce their exposure. While new stringent regulatory requirements for financial institutions call for higher capital levels (BIS, 2010a), banks usually operate above minimum regulatory solvency ratios with an additional capital buffer in order to minimise the risk of breaching the regulatory limit (ECB, 2007; Harding et al., 2013). This voluntary buffer, together with the regulatory capital, forms banks' internal capital. Target

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capital ratios are also entity specific and vary over time, partly reflecting banks' reaction to regulatory and market pressures. (Berger et al., 2008; Stolz and Wedow, 2011).

In the case of a capital shortfall, banks seek to close the capital gap and to reach their internal targets. They do so by increasing their core capital, adjusting their securities portfolios or decreasing their lending to the economy. In practise, the fastest ways to adjust to the new situation involve raising capital and selling off securities. As increasing core capital may be costly, especially during downturns when it is often needed to absorb losses, banks' adjustment to target capital ratios is likely to negatively affect their loan supply. The decreasing availability of credit and higher cost of financing for the economy at large, in turn, exert adverse effects on economic activity.[2] Hence, monitoring banks' capital gap and the implied deleveraging pressures is important for policy makers. Although deleveraging has been a popular topic since the financial crisis and although several policy measures, such as TARP and EU bank capitalisation exercises, have been implemented to avoid deleveraging, academic evidence of deleveraging in the euro area is still lacking.

This paper contributes to the literature by analysing the impact of the financial crisis on euro area banks. The analysis sheds light on two issues: First, what are the determinants of euro area banks' internal target capital ratios? Secondly, has the financial crisis affected euro area banks' balance sheets in general and banks' lending and security holdings in particular? Banks' internal targets are estimated on a bank-by-bank basis by using bank-level data on large and listed euro area banks, and the banking system's adjustment to target capital ratios is analysed by using capital targets and country-specific macroeconomic variables and by applying a partial adjustment model. The data period covers the latest financial crises starting from the first quarter of 2005, prior to the crisis, and extending to the last quarter of 2011.

Overall, several indicators are shown to have a positive impact on banks' internal target capital ratios. We find that a substantial part of the movement in internal targets arises from changes in banks' risks and earnings associated with the economic conditions. On an aggregate basis, we find undercapitalisation in terms of the Tier 1 capital ratio close to 2.0 percentage points (p.p.) in the middle of 2008. The negative gap prevails at the end of 2010 but vanishes towards the end of the estimation period. While median capital gaps diminish, the heterogeneity across individual banks increases. The estimations suggest that more than a half of the individual institutions do not have a capital shortfall in the beginning of 2011. At the same time, some weak banks continue to lack adequate capital. Similar results are obtained for the total capital ratio.

Turning to the impact of banks' adjustment to target capital ratios on assets, the estimates indicate that closing a 1 p.p. capital gap dampens loan growth by between 2.0 and 2.3 p.p. in the medium term. The impact on security holdings is found to be larger, approximately 5.8–7.1%, thereby suggesting a pecking order of bank assets for deleveraging.

The literature supports the analysis approach by showing that bank-specific factors are important in terms of capital levels and lending. In relation to solvency positions, large banks have lower capital ratios than smaller banks, while banks maintain higher ratios in countries with stringent capital requirements, active supervisors and effective corporate governance (Brewer et al., 2008). Further evidence is provided by Memmel and Raupach (2010), who indicate that banks with high asset volatility tend to have higher capital ratios. In addition to the importance of entity-specific characteristics, the speed of adjustment towards the desired capital level is shown to vary across institutions.[3] For instance, private commercial banks and banks with a high share of liquid assets adjust their capital ratios more quickly (Memmel and Raupach, 2010).

[2] See BIS, 2010b; Miles et al., 2010; Ötker-Robe et al., 2010.

[3] See, for instance, Jokipii and Milne, 2008; Memmel and Raupach, 2010 and Brewer et al., 2008.

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Banks' adjustment towards the desired capital levels may consequently have implications for banks' asset composition and lending activity.[4] Such an adjustment can be triggered, for instance, by new regulation, notably the Basel Accords. Empirical papers suggest that in the US, the Basel I regulatory framework led to slightly decreased lending (particularly with respect to business lending), and that the risk-based capital standards were a significant factor in explaining the credit crunch of the early 1990s.[5] In addition, using a structural model and data on large US commercial banks, Furfine (2000) indicates that changes in capital regulation influence banks' decision making, affect commercial loan portfolios and explain the decline in loan growth. Similarly, Basel II requirements are shown to increase the volatility of bank lending, especially for undercapitalised and less liquid banks (Jacques, 2008; Gambacorta and Mistrulli, 2004). Additionally, analysis regarding the Basel III regulations suggests that the increase in capital requirement could exert a negative impact on banks' lending volumes (BIS, 2010b).

In addition to changes in the regulatory environment, bank-specific factors influence the credit supply. Puri et al. (2011) study German banks that were affected by the US financial crisis and that endured heavy losses from the subprime exposures and show that these banks rejected relatively more loan applications and thus restricted their lending to a greater extent than less-exposed banks.[6] In a similar vein, Brinkmann and Horvitz (1995) indicate that the loan growth of poorly capitalised banks is lower than that of better-capitalised competitors owing to reductions in bank capital. Banks with binding capital constraints also seem to reduce lending more than other banks in reaction to unanticipated drops in capital (Hancock et al., 1995; Peek and Rosengren, 2000).[7] Furthermore, Spanish banks with weaker capital and liquidity ratios as well as European and US banks with low solvency ratios, large shares of market-based funding and non-interest income are shown to reduce lending to a greater extent than other banks. (Jimenez et al., 2012; Gambacorta and Marques-Ibanez, 2011)

An individual bank's response to changes in capital is also conditioned on the bank's size. The results of Puri et al. (2011) are particularly strong for smaller and more liquidity-constrained banks as well as for mortgage loans. Hancock and Wilcox (1998) also show that small banks decreased their portfolios considerably more than large banks in response to the decline in their own bank capital.

Lastly, banks' capital targets and financial institutions' adjustment towards these targets affect banks' lending (Francis and Osborne, 2009; Berrospide and Edge, 2010). By using partial adjustment models, estimates on banks' internal capital ratios and data on UK banks, Francis and Osborne (2009) show that banks with a surplus (shortfall) of capital relative to their target tend to record higher (lower) credit growth. Berrospide and Edge (2010) analyse US banks but find relatively modest effects of bank capital on lending. They indicate that factors such as economic activity and perceived macroeconomic uncertainty also play a role.

The rest of the paper is organised as follows. Section 2 presents the dataset together with stylised facts on developments in the euro area banking sector since 2005. The partial adjustment model and the estimation results are discussed in Section 3, while Section 4 concludes.

4 Disentangling the impact of supply factors (which may be driven by changes in capital requirements) from demand factors is nevertheless difficult, as both factors contribute to loan growth.

5 See, for instance, Bernanke and Lown, 1991; Hancock et al., 1995; Berger and Udell, 1994; Berger et al., 1995; Wall and Peterson, 1995; Peek and Rosengren, 1995 and Brinkmann and Horvitz, 1995.

6 Furthermore, Ivashina and Scharfstein (2010) show that banks that were more vulnerable to credit-line drawdowns, that were more reliant on short-term debt and that had limited access to deposit financing reduced their lending to a greater extent than their counterparts during the latest financial crisis.

7 The existence of a negative link between the capital gap and lending has also been confirmed by theoretical models. For example, based on a static model, Thakor (1996) shows that capital requirements linked solely to credit risks raise the cost of lending relatively to alternative investments, thus increasing credit rationing and reducing aggregate demand.

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2. DATA AND STYLISED FACTS

2.1. Bank data

Our dataset is based on the balance sheets and income statements of euro area listed banks available from Thomson Reuters Datastream. The dataset includes large and listed banks domiciled in Germany, France, Italy, Spain, Belgium and Austria. While some observations are available from 2003 onwards, our estimation period extends from the first quarter of 2005 until the fourth quarter of 2011 in order to ensure reasonable data coverage. Over the sample period, the total assets of the banks included in the sample constitute, on average, 60% of the total assets of credit institutions in the above-mentioned countries.[8]

Data are collected at the consolidated group level, including banks' foreign subsidiaries and branches. Although the majority of banks report balance sheets and income statements on a quarterly basis, some banks publish bi-annual data. In this case, missing quarterly observations are linearly interpolated in order to ensure a sufficiently large sample. Over the sample period only 10 percent of all observations consist of interpolated data, on average.

We extract information from Datastream on risk-weighted assets (RWAs), total assets, retained earnings, provisioning for loan losses, total investments[9] and net loans (that is, total loans excluding inter-bank loans). Data on these variables are subsequently used to compute bank-specific indicators that reflect the riskiness of the assets and earning capacity of the bank. To get the indicators, we divide the variables with total assets for each bank in the sample. Thus, the indicators include loan loss provisioning over total assets, total investments over total assets and risk-weighted assets over total assets (so called risk weights). Retained earnings over total assets is also calculated but we modify the indicator further and take quarterly growth for it. In addition, Datastream is used to obtain information on banks' return on equity (ROE) and solvency ratios[10], both the total capital ratio and the Tier1 capital ratio. ROE and capital ratios are in percentages.

In respect of balance sheets, the total assets of euro area listed banks increased from 2003 to 2008. However, the financial crisis interrupted this increasing trend in 2009, and total assets started to decline. For instance, total lending declined by approximately 5% per year in 2009 and 2010. While the mean ROE was relatively weak, banks' risk weights remained high in 2005–2001. (See Table 1 for summary statistics on several bank-specific variables.)

Table 1
Summary statistics of bank-specific variables used in the estimation (2005Q1–2011Q4), %

	Mean	Median
Return on equity (ROE)	8.67	9.92
Risk weight	64.50	67.41
Expected Default Frequency (EDFs)	0.68	0.10
Tier1 capital ratio	8.57	7.55
Total capital ratio	11.41	10.76

Note: Return on equity (ROE) as well as Tier 1 and total capital ratios are obtained directly from Thomson Reuters Datastream. Risk weight is calculated by dividing risk-weighted assets with total assets (both series obtained from Datastream). In case of missing quarterly observations, authors have interpolated the data. Expected default frequencies are from Moody's.

Source: Authors' computations based on Datastream and Moody's.

[8] Data on credit institutions are obtained from balance sheet items (BSI) statistics reported by the ECB. The possibility of using BSI data in our analysis is limited because it includes neither regulatory concepts, such as risk-weighted assets or solvency ratios, nor income statements. Moreover, BSI data are only available at the aggregated level for the euro area as a whole and euro area countries; thus information on individual banks is lacking. Given that the average for a country can reflect many individual combinations of bank-specific variables, bank-level data is necessary to analyse the adjustment of banks properly.

[9] According to the data manual of Datastream, the series includes a bank's investments in securities such as government bonds, municipal bonds, securities under repo agreements, trading account securities and mortgage backed securities. Also securities that are available for sale are included.

[10] The solvency ratios are defined as regulatory Tier 1 (or total) capital over risk-weighted assets. Banks calculate these ratios according to supervisory regulations and Thomson Reuters Datastream collects the information from banks' annual and interim reports.

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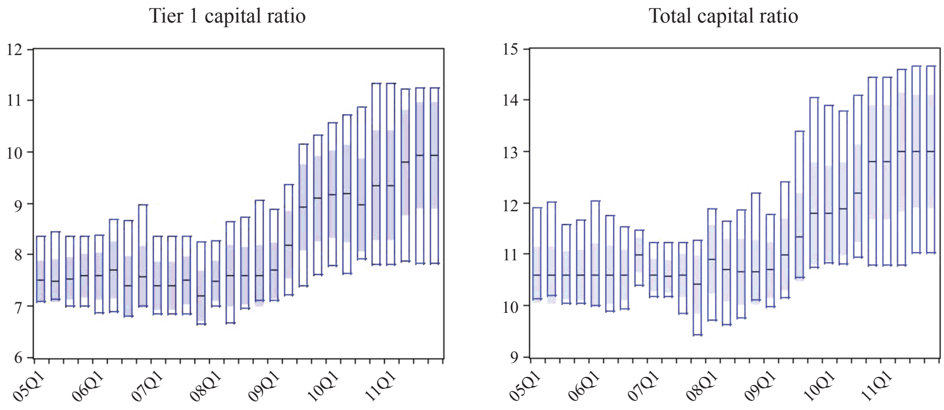
Turning to the solvency ratios, both the Tier 1 and the total capital ratios of listed euro area banks remained relatively stable from 2005 until the end of 2008. Since this time, the solvency ratios have started to increase (see Figure 1). Over the estimation period, the Tier 1 capital ratio stood at 8.6%, and the total capital ratio, at 11.4%, on average.

Looking at the distribution among the sample, the capital ratios of the banks in the sample were rather close to each other until the beginning of the financial crisis, while from 2009 onwards, the ratios have improved faster for the upper part of the distribution and for an average bank than for the lower part of the distribution. Nevertheless, throughout the sample period, the banks' ratios remained above the regulatory minimum, on average. Given the broadly stable risk-weighted assets from 2009 onwards, the increases in the banks' Tier 1 and total capital ratios were mainly driven by developments on the liability side of the banks' balance sheets. In addition to the new capital raised from market sources via the issuance of shares, the banks benefited capital injections from public authorities and resorted to internal capital accumulation in the form of retained earnings. Indeed, after having recorded losses in 2008, the listed euro area banks returned to profit in the second half of 2009. It is only towards the end of the sample period that the importance of reshuffling assets towards less risky exposures and deleveraging pressures increased.

Figure 1
Tier 1 capital ratio and total capital ratio for listed euro area banks (%)



Notes: Individual bank-level capital ratios are collected by the Thomson Reuters Datastream from banks' annual and interim reports. Banks calculate the ratios according to supervisors' regulations and definitions. A capital ratio is defined as the Tier 1 capital ratio or total capital ratio over risk-weighted assets. In case of missing quarterly observations, authors have interpolated the data. The horizontal line in the bars represents the median of the distribution, and the blue area, the 95% confidence intervals. The limits of the boxplots indicate the first and third quartiles of the distribution.

Source: Thomson Reuters Datastream and authors' calculations

2.2. Other data sources

In addition to the information on banks' financial statements, other statistical data sources are used to capture the riskiness of a bank's balance sheet, the bank's credit standards, loan demand factors and the macroeconomic conditions of individual countries. In the estimation, country-level data on different indicators and macro-variables are associated with each individual bank according to the location of the bank's headquarter.

First, we add expected default frequencies (EDFs) computed by Moody's for each bank in the sample. EDFs provide an estimate of the probability that a bank will default within one year, and therefore represent the market's perceived riskiness of the institution. From the beginning of the 2000s, the expected default frequencies of euro area listed banks have remained stable at a low

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level, before increasing abruptly in the wake of the financial crisis. This holds both for the mean and the distribution measured at the inter-quartile range. The perceived risk increased to a greater extent for banks in the upper part of the distribution, namely the weakest banks, than for the strongest banks in the beginning of 2009.

Second, we include country-specific statistics on credit standards available from the Bank Lending Survey (BLS) compiled by the European Central Bank (ECB).[11] In this survey, the senior loan officers report on the importance of factors such as the perception of risks related to the industry- or firm-specific outlook, expectations regarding economic activity and the impact of changes in a bank's own funding conditions on the bank's credit standards applied while approving loans and credit lines to enterprises. Moreover, the loan officers share their views on the expected and actual loan demand by firms. Since the onset of the financial crisis, aggregate credit standards and expectations regarding loan demand have co-moved with the macroeconomic developments in the euro area. The credit standards tightened substantially in 2008–2009, while demand exhibited cyclical behaviour, increasing in 2005–2007 and declining during the crisis. The aggregate figures nevertheless mask any notable country differences.

Lastly, to control for macroeconomic conditions, the dataset includes quarterly macroeconomic variables for each country. Gross domestic product (GDP) is taken from Eurostat in nominal and real terms.[12] The annual growth in stock prices is calculated on the basis of the Euro Stoxx 50 index, reflecting the development of the 50 largest companies in terms of capitalisation, as available from Thomson Reuters Datastream.

3. ESTIMATION BASED ON A PARTIAL-ADJUSTMENT MODEL

Macroeconomic and bank-specific shocks affect banks' internal target capital ratios and banks' responses, which involve adjusting their asset management strategies, lending policies and securities holdings. This adjustment process is modelled with a partial adjustment model, which is developed in two separate steps.[13]

In the first step, we concentrate on the relationship between bank-specific characteristics and the target capital ratio. Risk indicators are used to estimate a target capital ratio for each entity, while controlling for the bank's capacity to generate income and accounting for certain structural characteristics, such as bank size. To account for risk, both market evaluation and bank accounting items are considered. Based on the estimated parameters, a bank's time-varying capital gap between the desired (unobserved and internal) target capital ratio and the actual (observed) capital ratio is then computed for each time period. In the second step, the adjustment of loans and securities is explained using the estimates on the bank's capital gap and variables related to the macroeconomic environment.

3.1. Estimating the target capital ratio

The first step focuses exclusively on the link between a bank's target capital ratio and the riskiness of the bank's balance sheet, the bank's earning capacity and the degree to which the bank is exposed to market discipline. Banks' internal time-varying target capital ratios, $k^*_{i,t}$, which are not known to the public, are modelled as a function of bank-specific risk indicators, $RISK_{i,t}$, and variables that capture the bank's capacity to accumulate income, $INC_{i,t}$ (see equation 1). Other

[11] For more information on the euro area BLS, see http://www.ecb.europa.eu/stats/money/surveys/lend/html/index.en.html.

[12] More information on GDP data is available at http://epp.eurostat.ec.europa.eu/portal/page/portal/national_accounts/introduction.

[13] Another option would be to model deleveraging process with the partial adjustment model. However, we concentrate on capital as we want to induce the impact of changing equity on banks' assets.

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factors, such as market pressures, the bank's business model, the bank's strategy and specificities of the market in which the bank operates, are included in α_i.

$$k^*_{i,t} = \alpha_i + \theta_1 RISK_{i,t} + \theta_2 INC_{i,t} \tag{1}$$

Owing to market frictions and adjustment costs, it takes several periods for banks to adjust from their current capital levels towards their internal targets. Hence, a partial adjustment model is applied to describe how a bank closes the gap between its capital ratio in the previous period, $k_{i,t-1}$, and its internal target capital ratio, $k^*_{i,t-1}$. This process is presented in equation (2): the observed change in publicly disclosed capital ratio, $\Delta k_{i,t}$, is a function of the gap between the internal target and (observed) capital ratio ($k^*_{i,t-1} - k_{i,t-1}$) in the previous period. This gap is closed at speed λ, which lies between 0 and 1. In addition, an error term, $\varepsilon_{i,t}$, captures idiosyncratic shocks during the adjustment.

$$\Delta k_{i,t} = \lambda(k^*_{i,t-1} - k_{i,t-1}) + \varepsilon_{i,t}, \quad 0 < \lambda < 1 \tag{2}$$

Substituting (1) into (2) and rearranging the expression gives equation (3).

$$k_{i,t} = \lambda\alpha_i + (1-\lambda)\, k_{i,t-1} + \lambda\theta_1 RISK_{i,t-1} + \lambda\theta_2 INC_{i,t-1} + \varepsilon_{i,t} \tag{3}$$

The equation (3) is estimated using the panel of euro area listed banks over 2005Q1 – 2011Q4 period, constituting 28 quarters per bank. The estimations are run with two-stage least squares (TSLS) method with cross-sectional fixed effects for both regulatory solvency ratios (Tier 1 capital ratio and total capital ratio) as the dependent variable.[14] We apply the TSLS estimation method because standard OLS estimation may arguably suffer from endogeneity bias.[15]

By construction, the first lag of capital ratio is incorporated as an explanatory variable to account for a bank's lagged adjustment and it is expected to correlate positively with the capital ratio. Regarding the risk and income indicators, we also include the first lags of these variables in the equation (3). Several combinations of explanatory variables are tested to account for the different channels that affect the target capital ratio. Indicators referring to a bank's income capacity include return on equity (ROE) and retained earnings over total assets. The coefficients are expected to be positive, as a bank's earnings support the capacity to accumulate capital through retention.[16] To reflect the riskiness of a bank, we consider indicators based on balance sheet items, namely, loan loss provisioning over total assets and total investments over total assets, as well as indicators based on the market's view of the bank's situation, i.e., expected default frequency (EDF) and log-odds EDFs.[17] For all of these indicators, risk is expected to exert a positive impact on the target capital ratio, as a bank with riskier balance sheet should have a higher capital buffer to cover its exposures.[18]

14 For more information on the estimation method, see Baltagi (2008).

15 With endogeneity, the idiosyncratic shocks captured by the error term, $\varepsilon_{i,t}$, are correlated not only with dependent variable (target capital ratio) but also with explanatory variables related to banks' income capacity and riskiness. Such a bias makes estimated OLS coefficients biased and inconsistent.

16 In principle, profitability ratios may also exert a negative impact on the capital ratio since they also reflect the implicit cost of capital, in that part of the profits are paid out to stakeholders. However, as banks usually keep part of their profits as retained earnings, we expect higher net income to result in a higher capital ratio.

17 Log-odds ratios, LOR, are calculated as LOR = log((EDF)/(1–(EDF)).

18 However, credit risk and market perceptions may exhibit pro-cyclical behaviour. For instance, loan losses tend to increase during economic downturns, depleting banks' capital position and solvency ratios. Moreover, EDFs started to increase only at the beginning of the financial crisis. Hence, these indicators may be negatively correlated with capital ratios. The first lags of capital ratios are introduced in the regressions to reduce the impact of cyclicality.

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The TSLS method requires instrumental variables. We instrument explanatory variables ($k_{i,t-1}$, $RISK_{i,t-1}$ and $INC_{i,t-1}$) with their corresponding second and third lags ($k_{i,t-2}$, $k_{i,t-3}$, $RISK_{i,t-2}$, $RISK_{i,t-3}$, $INC_{i,t-2}$ and $INC_{i,t-3}$).[19] The idea in using the lagged values of explanatory variables is that they are less likely to be influenced by current shocks. Theoretically, we have good reasons to expect that these instruments perform well. From the statistical perspective, instruments are judged to be valid when they are relevant and exogenous. The selected lags are indeed relevant as each of the exogenous variables ($k_{i,t-1}$, $RISK_{i,t-1}$ and $INC_{i,t-1}$) is strongly correlated with its corresponding second and third lag. As for instrument exogeneity, we can use the Sargan J-test. This test for overidentifying restrictions indicates that the instruments are valid in all our specifications and the test statistics is reported with the results.

The results for the target capital ratio measured with the Tier 1 capital ratio are presented in Table 2. Overall, the estimated coefficients are in line with our a priori expectations. The lagged dependent variable has a positive sign and is statistically significant, consistent with a partial adjustment model that assumes some delay in the closure of the capital gap.

Regarding the income indicators, return on equity (ROE) and quarterly change in retained earnings over total assets exert positive effects on capital ratios, although the coefficients are not statistically significant. This positive (but not significant) correlation between profitability and solvency ratios is in line with the results of Berrospide and Edge (2010), who report that the bank holding companies tend to increase capital when profits, measured with return on assets, rise. The lack of significance for the coefficient may reflect the fact that the income indicators also reflect banks' cost of capital, as mentioned by Francis and Osborne (2009).

Table 2
Determinants of the target Tier 1 capital ratio

	Equation 1	**Equation 2**	**Equation 3**	**Equation 4**
Lagged capital ratio	0.86 [0.03]***	0.83 [0.03]***	0.77 [0.03]***	0.86 [0.03]***
Change in retained earnings over total assets	0.07 [0.07]	0.03 [0.07]	0.03 [0.06]	.. ..
Provisioning over total assets	1.32 [0.40]***	.. ..	.. ..	1.38 [0.40]***
Expected default frequency (EDF)	.. ..	0.08 [0.02]***	.. ..	.. ..
Log-odds EDFs	.. ..	.. ..	0.15 [0.02]***	.. ..
Change in return on equity	.. ..	.. ..	.. ..	0.01 [0.01]
Constant	1.05 [0.21]***	1.35 [0.23]***	2.94 [0.38]***	1.09 [0.22]***
Number of observations	756	728	728	756
Cross-section	27	26	26	27
Sargan J-test statistics	5.81	4.98	2.57	3.70

Notes: The estimation period covers 2005:1–2011:4. Standard deviations are reported under the point estimates in brackets. (*), (**), and (***) indicate statistical significance at 10%, 5%, and 1%, respectively. The Sargan J-statistic indicates the validity of the model. The critical value for the Sargan J-test is 40.11 (38.89), with 27 (26) degrees of freedom at a significance level of 5%. As test statistics is below the critical value, null hypothesis of valid instruments can be accepted.

[19] In addition, cross-section fixed dummies also serve as instruments.

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Turning to the risk indicators, increasing risk is shown to have a positive effect on banks' internal targets, inducing the institutions to strive for higher capital levels. The ratio of loan loss provisions over total assets is statistically significant and positively correlates with the Tier 1 capital ratio.[20] Meanwhile, the ratio of total investments over total assets, another measure of risk, exhibits a positive relationship with the Tier 1 capital ratio. This relationship is not significant at the 10% level, however. In addition, expected default frequencies (EDFs) are significantly and positively related to the solvency ratios. This result can be interpreted to indicate markets' ability to recognise that a bank's risks call for a higher capital position in the future. Markets' perceptions regarding a bank's riskiness and need to raise more capital to cover its risk exposure are subsequently reflected in the bank's internal target.

The results obtained for the Tier 1 capital ratio also apply to the total capital ratio to a large extent (see Table 3). In both cases, the lagged dependent variable and indicators for risk enter the equations with positive signs. Overall, the positive relationships between the target capital ratios and the various risk indicators confirm the view that banks with high risk in their balance sheets also orient themselves towards high capital levels.

Table 3
Determinants of the target Total capital ratio

	Equation 1	**Equation 2**	**Equation 3**
Lagged capital ratio	0.67 [0.05]***	0.60 [0.05]***	0.52 [0.06]***
Change in retained earnings over total assets	0.15 [0.13]	0.09 [0.13]	0.10 [0.13]
Provisioning over total asset	2.03 [0.76]***	.. ..	.. ..
Expected default frequency (EDF)	.. ..	0.18 [0.04]***	.. ..
Log-odds EDFs	.. ..	.. ..	0.28 [0.04]***
Constant	3.59 [0.51]***	4.50 [0.59]***	7.34 [0.90]***
No. of observations	756	728	728
Cross-section	27	26	26
Sargan J-test statistics	15.11	10.26	6.41

Notes: The estimation period covers 2005:1─2011:4. Standard deviations are reported under the point estimates in brackets. (*), (**), and (***) indicate statistical significance at 10%, 5%, and 1%, respectively. The Sargan J-statistic indicates the validity of the model. The critical value for the Sargan J-test is 40.11 (38.89), with 27 (26) degrees of freedom at a significance level of 5%. As test statistics is below the critical value, null hypothesis of valid instruments can be accepted.

[20] Berrospide and Edge (2010) and Francis and Osborne (2009) also show that larger charge-off rates and provisions support higher capital ratios.

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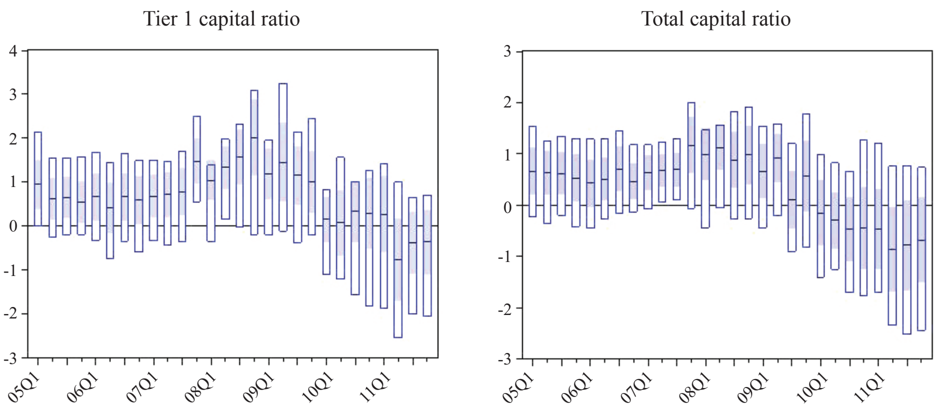
3.2. Deriving the capital gap

Based on the estimated equations for the Tier 1 capital ratio and the total capital ratio, target capital ratios ($k^*_{i,t}$) are computed for each individual bank by making use of the estimated parameters of equation (3) in equation (1).[21] The capital gap, $GAP_{i,t}$, for each individual bank i at time t is subsequently derived as follows:

$$GAP_{i,t} = 100 * \left(\frac{k^*_{i,t}}{k_{i,t-1}} - 1 \right) \quad (4)$$

where $k^*_{i,t}$ represents the bank's target capital ratio at time t and $k_{i,t-1}$ is the bank's actual capital ratio at time t–1. Equation (4) thus presents the deviation of a bank's actual capital ratio in period t–1 from the target at time t in terms of the Tier 1 capital ratio and total capital ratio. A positive (negative) value of the capital gap represents a capital shortfall (surplus) relative to the long-run target capital ratio.

Figure 2
Estimates of the capital gap for the banks in the sample (percentage points)



Notes: The latest observation is 2011Q4. The capital gap is expressed in terms of percentage points (i.e., the needed capital over risk-weighted assets). A positive value indicates a capital shortfall, indicating that banks' actual capital ratio is below the target. The horizontal line in the bars represents the median of the distribution, and the blue area, the 95% confidence intervals. The limits of the boxplots indicate the first and third quartiles of the distribution.

Source: Authors' calculations.

Figure 2 presents the capital gap (expressed in percentage points, i.e., the needed capital over risk-weighted assets) and its distribution across euro area banks over time. The gap regarding the Tier 1 capital ratio is presented on the left-hand side, and the gap regarding the total capital ratio, on the right-hand side. Comparing the two set of results, the gaps estimated for both capital ratios are quite similar. At the beginning of the estimation period, both capital gaps are positive, indicating that the banks lag behind their internal targets. The analysis thus suggests that the banks' capital is not adequate to cover the risks that they are accumulating in their balance sheets. In economic terms, this outcome is logical, as low levels of equity help banks to obtain high short-term ROE and thus profitability, which is lucrative for investors. Implicit government guarantees and moral hazard may have further facilitated the omission of prudent standards. The gaps subsequently start to widen as risks materialise, loan losses increase and the financial crisis

21 Thus, the target capital ratios are bank-specific and vary over time.

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deepens in 2007–2008, reaching their highest point of approximately 2.0% in the middle of 2008. From then onwards, the capital gaps start to slowly narrow as the banks are forced to recapitalise.

While the median gap based on the total capital ratio becomes negative in the beginning of 2010, the median gap based on the Tier 1 capital ratio remains positive until the first quarter of 2011. Although median capital gaps diminish towards the end of 2011, variation across banks increases and high heterogeneity between banks remain in the euro area banking sector. While some weak banks continue to lack adequate capital, the estimations suggest that more than a half of the individual institutions do not have a capital shortfall in the beginning of 2011. This result is important since banks with a capital shortfall cannot expect banks with a capital surplus to compensate for their deficit at the sector level. Hence, the situation may be more adverse than the mean capital gap suggests.

3.3. Estimating the adjustment towards the target capital ratio

Banks have several possibilities to close their capital gap by adjusting the liability side or asset side of their balance sheets. However, in practise, the fastest way for a bank to balance its capital position is to issue new equity, to increase retained earnings or to reduce the amount of its loans and the size of its portfolio. However, as issuing equity can be costly during the time of a crisis, we assume in this paper that the adjustment operates mainly through deleveraging.

Thus, in the second step of the estimation, we use the obtained capital gap as an explanatory variable while controlling for macro-variables. A dynamic panel model is estimated for two different balance sheet items, $item_{i,t}$, namely, the total loans and total securities (see equation 5). The estimations are run with two-stage least squares (TSLS) method with cross-sectional fixed effects.

$$\Delta\log(item_{i,t}) = \beta_0 + \beta_1 Gap_{i,t-1} + \beta_2 \Delta\log(GDP_{j,t-1}) + \beta_3 X_{j,t-1} + \beta_4 \Delta\log(item_{i,t-1}) + \varepsilon_{i,t} \quad (5)$$

We specify the model in growth rates as we are interested in the implications of capital gaps on banks' balance sheets. The explained variables, loans and security holdings, are expressed in terms of quarterly change. And the explanatory variables are also expressed in growth rates or depict a change between two subsequent time periods. The specification also takes into account non-stationary of the variables.

Regarding the capital gap of a bank, $Gap_{i,t-1}$, we use the two alternative variables based on the target Tier 1 capital ratio and the target total capital ratio.[22] In both cases, the capital gap, measured as the difference between the bank's target and actual capital ratio, is expected to have a negative impact. If the capital ratio of a bank is below its target, the gap is positive (see equation 4), and the growth in the balance sheet items should be adversely affected since banks partly deleverage to increase their solvency ratios.

To control for macroeconomic conditions, the annual growth rate of gross domestic product ($GDP_{j,t-1}$) is also included in the model. The variable refers to the economic activity in the country j in which the bank i's headquarter is located.[23] GDP growth is expected to have a positive impact on asset growth and loan growth.

[22] We use equations 1 and 2 in Table 1 to calculate the Tier 1 capital gap. Similarly, when deriving the capital gap for the total solvency ratio, equations 1 and 2 in Table 2 are used. These equations incorporate the changes in retained earnings over total assets, expected default frequencies (EDFs) and loan loss provisioning over total assets as explanatory variables.

[23] The combination of the bank-specific capital gap with country-specific macro-variables reflects the lack of publicly available data that would enable us to consider the geographical dispersion of exposure at the institutional level. Nonetheless, internationally active banks may not be affected by the developments in the home country alone. Still, an individual bank's capital gap is defined at the bank group level, representing a group's capital shortfall/surplus in relation to its overall risk position (including foreign lending).

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Other exogenous variables ($X_{j,t-1}$) are incorporated to account for either supply or demand channels. First, we include information from the ECB bank lending survey. In the survey, banks reply to questions concerning the perceived changes in loan demand and questions on banks' own credit standards (indicating supply factors). Loan demand is expected to correlate positively with loan growth, while a tightening (easing) of credit standards is expected to dampen (increase) loan growth and thus to correlate negatively with loan growth. Second, we include stock prices to reflect the overall financing conditions of the economy. Stock prices are expected to correlate positively with the explained variables. Lastly, the dynamic model also includes the lagged growth rate of dependent variable ($item_{i,t-1}$) as well as an error term.

Regarding the instrumental variables, we use the second and third lags of the explanatory variables ($Gap_{i,t-1}$, $GDP_{j,t-1}$ and $X_{j,t-1}$) as instruments.[24] However, the lags for the total loans and total securities ($item_{i,t}$) are not included in the instrument list. As the lagged values of explanatory variables are less likely to be influenced by current shocks, they are expected to perform well. Indeed, based on the statistical examination, the instruments are valid as they are relevant and exogenous.

The results for the estimations on balance sheet adjustments are presented in Table 4 (where the capital gap is calculated on the basis of the Tier 1 capital ratio) and Table 5 (where the capital gap is based on the total capital ratio). The left-hand side of the tables presents the adjustment effect for net loans, while the right-hand side of the tables contains the results for the adjustment of securities portfolio.

Starting with the adjustment of net loans, the capital gap enters the estimations with a negative sign, as expected, and is statistically significant in explaining the development of the loan portfolio. Moreover, GDP growth and loan demand by non-financial corporations (NFCs) are found to be significant in explaining loan growth. The credit standards applied by banks on loans to NFCs appear to exert a negative impact on loans, reflecting the adverse effect of tightening the credit supply; however, this effect is not statistically significant.

The estimated adjustment based on the Tier 1 capital ratio target seems to be somewhat higher than that based on the total capital ratio target. This result reflects the distinct composition of the capital on which capital ratios are based. While Tier 1 capital is more narrowly defined and mainly contains equity capital, which is more readily usable to absorb losses, total capital includes also other capital-like instruments. When risks materialise, Tier 1 equity capital acts as a first line of defence and is more severely affected, as it buffers against losses. Therefore, the capital gap between the target Tier 1 capital ratio and the actual Tier 1 capital ratio induces larger changes in a bank's balance sheet than the capital gap between the target and the actual total capital ratios.

[24] In addition, cross-section fixed dummies also serve as instruments.

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Table 4
Balance sheet adjustments based on the Tier 1 capital gap

	NET LOANS	SECURITIES
Capital gap	-2.78 [1.66]*	-8.2 [3.35]**
Lagged nominal GDP growth	0.44 [0.17]***	0.14 [0.13]
BLS credit demand NFCs realised	0.07 [0.02]***	.. ..
Annual growth in stock prices	.. ..	0.09 [0.05]**
Lagged explained	-0.31 [0.16]**	-0.41 [0.17]**
Constant	6.60 [2.06]***	11.01 [4.00]***
Long run impact of the capital gap	-2.126	-5.816
No. of observations	624	648
Cross section	26	27

Notes: The estimation period covers 2005Q1 to 2011Q4. Standard deviations are reported under the point estimates in brackets. (*), (**), and (***) indicates statistical significance at 10%, 5%, and 1%, respectively. Net loans exclude interbank loans. NFCs stand for non-financial corporations. Two dots mean that the variable was not used in the model. For the calculation of long-run impact, see footnote 25.

Turning to the adjustment of securities portfolios, a bank's capital gap (i.e., a shortfall of capital with respect to the bank's target), exerts a negative and significant impact on the bank's securities portfolio. Although GDP fails to be statistically significant, its coefficient remains positive. Banks are likely to rely more on market prices than on demand indicators in deciding on their investment portfolios. Indeed, the annual growth of stock prices positively correlates with a bank's securities portfolio, possibly reflecting that swift changes in the market environment and investor expectations positively influence a bank's decision to invest in securities.

Overall, the estimates suggest that the capital gap plays an important role in explaining loans offered within the euro area banking sector throughout the estimation period. Compared to a situation in which banks' actual capital ratios do not deviate from the target, a 1-percentage-point capital shortfall is estimated to reduce loan growth by 2.0 to 2.3 percentage points over the long term.[25] Given that at the trough of the financial crisis, the capital gap is estimated to have reached 2 p.p., banks' adjustment to a higher target capital ratio could have decreased loan growth by more than 4% in cumulated terms.

[25] The long-run impact is computed by dividing the short-term coefficient of the capital gap (β_1) by the dependent variable's speed of adjustment (λ), which is defined as $(1 - \beta_4)$. (See Francis and Osborne, 2009). While the speed of adjustment (λ) is fixed in this set-up, it would be possible to experiment with time and bank-specific adjustment speed. This is, however, beyond the scope of this paper.

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Table 5
Balance sheet adjustments based on the total capital gap

	NET LOANS		SECURITIES
	Equation 1	Equation 2	Equation 1
Capital gap	-2.93 [1.23]**	-2.74 [1.05]***	-10.00 [4.04]**
Lagged annual growth in real GDP	.. ..	0.66 [0.25]***	.. ..
Lagged nominal GDP growth	0.61 [0.24]**	.. ..	0.12 [0.15]
BLS credit demand NFCs realised	0.06 [0.02]**	0.08 [0.02]***	.. ..
Annual growth in stock prices	.. ..	.. ..	0.13 [0.05]**
Lagged explained	-0.29 [0.16]*	-0.33 [0.17]*	-0.42 [0.19]**
Constant	5.09 [1.05]***	4.98 [0.98]***	5.61 [2.02]***
Long run impact of the capital gap	-2.262	-2.061	-7.050
No. of observations	648	648	648
Cross section	27	27	27

Notes: The estimation period covers 2005Q1 to 2011Q4. Standard deviations are reported under the point estimates in brackets. (*), (**), and (***) indicates statistical significance at 10%, 5%, and 1%, respectively. Net loans exclude interbank loans. NFCs stand for non-financial corporations. Two dots mean that the variable was not used in the model. For the calculation of long-run impact, see footnote 25.

Based on the estimations, the long-run elasticity of securities portfolios is higher than that of net loans. The estimated long-term elasticity for securities varies by approximately 5.8–7.1 percentage points, well above the corresponding elasticity for loans. This result supports the view that, since the onset of the financial crisis, euro area banks have deleveraged their assets along a "pecking order", reducing securities holdings to a greater extent than the loan supply. This finding can be explained by several factors. First, as the maintenance of customer relationships is an important part of the prevailing banking business model, credit institutions would be reluctant to jeopardise important client relationships by refusing to roll-over existing loans or to grant new ones. Second, the banking sector has received support via a number of government schemes that include conditions to maintain a minimum level of credit growth to the private sector. Third, loans are typically rather illiquid assets, and shedding existing loans from the balance sheet is difficult, particularly during a crisis when the securitisation and syndication markets are at a standstill.

3.4. Robustness

As a robustness test, the second-step estimations are run by defining all the explanatory variables in levels.[26] These estimations confirm the previous results, revealing the capital gap, GDP, credit supply, demand factors and stock prices as significant variables. Moreover, the long-term impact on securities portfolios is again found to be more pronounced than that on net loans, with a long-term impact of approximately 3.4 for securities and 2.4–2.8 for net loans.

[26] In this case, instead of equation 5, we estimate the following equation: $item_{i,t} = \beta_0 + \beta_1 Gap_{i,t-1} + \sum_{j=1} \delta_{1,j} GDP_{t-j} + \sum_{j=1} \delta_{2,j} X_{t-j} + \varphi item_{i,t-1} + trend + \varepsilon_{i,t}$.

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Our estimates suggest that the deleveraging of loans is relatively stronger in the euro area than in the UK or in the US, as the estimated impact found in this paper is more pronounced than that reported by Berrospide and Edge (2010) and Francis and Osborne (2009). The former authors find that a 1-percentage-point increase in the capital ratio of US banks leads to an increase of 0.7−1.2 percentage points in annualised loan growth in the long term, while the latter authors suggest that the total effect of changes in the regulatory requirements of UK banks is approximately 1.2 percentage points. The differences in the results may be partly explained by the different estimation periods. Francis and Osborne (2009) use British data from 1996 to 2007, and Berrospide and Edge (2010) analyse the 1992Q1−2009Q3 period in the US, while we examine the years of the financial crisis, during which most of the deleveraging took place in the euro area.

In addition, although our estimation methodology broadly follows that of Francis and Osborne (2009) and Berrospide and Edge (2010), some differences remain. Francis and Osborne (2009) implement GMM to estimate the target capital ratio in the first step and use OLS with fixed effects in the second step, as there is no lagged dependent variable in the second-step equations. Berrospide and Edge (2010) estimate OLS with fixed effects for both steps. We apply TSLS with fixed effects in both steps.

4. CONCLUDING REMARKS

Operating above minimum capital requirements, banks maintain an additional capital buffer, which, together with the regulatory requirements, composes banks' internal capital target. Occasionally, banks' actual capital ratios may differ from their internal targets, leading to a capital surplus or deficit vis-à-vis the target. If a bank's capital position constitutes a deficit, pressures to close its capital gap and to increase its solvency ratios may trigger an adjustment process. To restore its capital ratios, the bank may reduce lending or otherwise adjust its balance sheet. Indeed, the recent financial crisis has highlighted the importance of financial intermediary characteristics and equity capital as determinants for the provision of credit to borrowers. As a continuous flow of credit is of vital importance to maintain investment and real activity, banks' capital gap and implied deleveraging pressures are important issues for the conduct of monetary policy.

In this paper, we have estimated a partial adjustment model in a panel context using various indicators to examine the impact of risk in a bank's balance sheet on the bank's internal target capital ratio and to determine the implications of closing the capital gap on the bank's lending and securities holdings. Our paper adds to the literature by concentrating on euro area banks and by providing evidence on the impact of deleveraging pressures during the latest financial crisis, while previous studies have disentangled the effects in the US and UK banking sectors over different time periods, during which such pressures may have been more difficult to detect.

We provide empirical evidence that the internal capital targets play a significant role in the adjustment of euro area banks. Based on the estimates, we find undercapitalisation in terms of the Tier 1 capital ratio close to 2.0 p.p. in the middle of 2008, and the negative gap remains at the end of 2010. Movement in internal target capital ratios arises from changes in banks' risks and earnings, although the estimated range of the impact remains large. Only from 2010 onwards, the capital gaps start to narrow as the banking sector is slowly recovering from the crisis. The heterogeneity across banks nevertheless remains considerable. The results for the total capital ratio are similar.

As our results show bank undercapitalisation in relation to banks' risks and earnings just before the onset of the latest financial crisis, the new Basel III capital and liquidity requirements as well as new macroprudential policy measures seem well-placed. The purpose of these new regulatory initiatives is to strengthen banks' capital and liquidity positions, improve the quality of the capital and decrease bank leverage. All these measures should reduce the vulnerability of

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the banking sector and improve financial stability, making the occurrence of financial crisis less frequent.

The undercapitalised banks tend to restrict the provision of loans to the economy, as the relatively higher cost of bank equity leads banks to deleverage in order to reach their target capital ratios. Regarding the banks efforts to close the capital gap, we find evidence for significant impact on lending in the euro area. The estimates indicate that closing a 1 p.p. capital gap dampens loan growth by between 2.0 and 2.3% in the long-term. Given that at the trough of the financial crisis, the capital gap is estimated to have reached 2 p.p., banks' adjustment to a higher target capital ratio could have decreased loan growth by more than 4% in cumulated terms. Compared to loans, the impact on security holdings is found to be more pronounced and to be approximately 5.8−7.1%. The results thereby suggest that euro area banks have deleveraged their assets along a pecking order.

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THE IMPACT OF RISK, FUNDING AND SOVEREIGN SHOCKS ON EURO AREA BANKS AND ECONOMIC GROWTH

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ABSTRACT

This paper analyses the effects of risk, funding and sovereign shocks on banks and economic growth in the euro area and in four largest euro area countries. Bank-level variables and macroeconomic data for 2005–2013 are used to estimate a VAR model, after which the shocks are identified with sign restrictions. Based on the impulse response functions and historical decompositions the results show that three shocks explain the development of banks' total assets, profitability, corporate lending and output growth. In 2009, shock contributions account for around 60 percentage of the decrease in corporate lending and approximately a third of the decline of the annual GDP growth at the euro area level. Risk and funding shocks are more prominent than the sovereign shock. While shocks exhibit a notable impact on Germany and France in 2009–2011, they are significant for Italian and Spanish banks only towards the end of the simulation period.

JEL Classification: G01, G21

Keywords: euro area banks, shocks, credit supply, VAR, impulse response functions

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1 INTRODUCTION

Since the beginning of the financial crisis a continuum of shocks has negatively affected euro area banks’ business environment, implying – among other things – increasing risks, declining profitability and weakened access to wholesale funding. Together with the implementation of the new regulatory requirements, these shocks have exerted pressure on banks' balance sheets and liquidity positions. In addition to the direct effects of the initial shocks, the shocks have continued to propagate and induce second round effects.

While banks’ adjust to the new environment, potential changes in banks’ credit supply conditions may influence corporate capacity to finance investments. The impact can be especially large in the euro area, where debt markets are relatively small and a large part of firms' external financing is provided by banks. Furthermore, the existence of financial imperfections can amplify the interactions between financial variables and macro economy. The amplification occurs through the financial accelerator mechanism, which can translate shocks in the credit market into much larger cyclical fluctuations in the real economy. (Bernanke et al. 1999) Adrian & Shin (2011) have also shown that since the beginning of the financial crisis banks themselves can be a source of disturbance. Hence, the adjustment of bank lending is an important channel through which initial shocks affect the economy. The tensions in credit markets, the availability of bank loans and, ultimately, the weakening of economic activity have brought the role of banks to the centre stage of both policy and research agendas.

This paper contributes to the literature by estimating how financial shocks affect banking sector and economy at the euro area level and in four largest euro area countries, namely in Germany, France, Italy and Spain. The analysis of macro-financial linkages is based on the estimation of a vector autoregression model (VAR) with bank-specific indicators and macro level variables for 2005–2013. We use sign restrictions to identify three granular shocks that relate to increasing riskiness of banks (risk shock), banks' difficulties in obtaining wholesale funding (funding shock), and the impact of sovereign debt crisis in Europe (sovereign shock). These shocks are also the novelty of this paper as very little previous literature on such shocks exists. We then apply impulse response functions (IRFs) in order to assess the implications of the shocks for endogenous variables and to track the time paths of nominal shocks. Finally, the historical decompositions of responses are composed to analyse how much of the variations in banks’ total assets, profitability and corporate lending as well as in GDP growth are explained by the shocks.

The contribution of the paper also resides in our approach as VAR methodology provides a flexible framework for analysis of the dynamics and interactions between micro and macro variables. The methodology links individual bank level data to macroeconomic variables in a coherent manner and allows the feedback effects between banks and the economy. And it does not require any presumption about the direction of the causal relationship.

The above mentioned technical qualities of the methodology are important in order to disentangle the question at hand. While macro variables are traditionally used to explain movements in granular firm- and bank-level data, Gabaix (2011) shows that large micro-level entities can have a sizeable impact on macro variables. Idiosyncratic productivity and growth shocks affecting the largest US firms can explain about 30 percent of fluctuations in GDP growth. The effect arises from the uneven distribution of companies as a few large firms dominate the market and a large number of small firms have only a small market share.

Many European banking sectors exhibit similar market structure, highlighting the importance of large banks. For instance, a sample of about 130 banks in the European Central Bank's (ECB) comprehensive assessment exercise covers approximately 85 % of euro area bank assets. The high concentration of the banking sector implies that company-level information is extremely valuable in assessing the impact of idiosyncratic shocks in the euro area. Given the importance of bank financing in the euro area economy, idiosyncratic bank shocks can have large impacts on aggregate loan supply, investment financing and ultimately the economic activity. Thus, a proper analysis requires looking at the banking sector from a micro perspective and combining granular data with macro variables. Individual data provides also a micro foundation to aggregate shocks.

The results show that risk, funding and sovereign shocks have played a significant role in the development of euro area banks' balance sheet items. In addition, they have affected output growth in the euro area and large euro area countries. Overall, the contribution of three shocks in 2009 represents approximately a third of the decline of the annual GDP growth and around 60 percentage of the decrease in lending to non-financial corporations at the euro area level. Regarding the individual shocks, the contribution of risk and funding shocks are significant in explaining the development of the variables, while the impact of sovereign shock is more subdued.

Looking across the largest euro area countries, the shock contributions explain a substantial part of the country-level variation of total assets, profitability, corporate lending and GDP growth. The time pattern nevertheless differs across countries. While shocks exhibit a notable impact on Germany and France in 2009–

2011, the contributions of shocks became prominent for Italian banks only towards the end of the estimation period. At the same time, the contribution of three shocks remain relevant in Spain throughout the whole estimation period. Overall, the negative implications of shocks at the euro area level are composed of the contributions of German and French banks in 2009–2011 and the contributions of shocks to Italian and Spanish banks in 2011–2013.

The rest of the paper is organised as follows. Section 2 reviews the academic literature and section 3 presents the dataset. The methodology, together with the implemented sign restrictions, is presented in section 4. Section 5 contains the discussion on results, while section 6 concludes. Most of the tables and figures are in the annex owing to their large scale.

2 REVIEW OF THE ACADEMIC LITERATURE

Our paper is related to two strands of academic literature. While first set of studies examines how different shocks affect banks' lending, other papers disentangle the impact of banks’ adjustment on macro economy.

Using partial adjustment models, granular data and information on banks’ target capital ratios, Berrospide & Edge (2010), Francis & Osborne (2009) and Maurin & Toivanen (2015) examine how banks’ capital targets impact on banks’ lending in the US, in the UK and in the euro area, respectively. Researchers show that a capital shortfall relative to the bank’s target exerts a negative impact on credit growth. In addition, Maurin & Toivanen (2015) find some evidence of pecking order to bank deleveraging, with the security portfolio being more responsive to the adjustment than the loan book.

In a similar vein, previous literature on bank-lending channel indicates that the banks’ financial position and changes in operating environment affect banks’ lending in Europe and in the euro area.[37] After a negative shock the lending of poorly-capitalised and less-liquid banks declines more than the lending of their better-capitalised and well-funded competitors. Financially sound banks are in a better position to shield their loan books than constrained banks whose only adjustment mechanism is to restrict the provision of loans to the private sector.

[37] See, for example, Jiménez et al. (2012), Gambacorta & Marques-Ibanez (2011), Altunbas, Gambacorta & Marques-Ibanez (2010), Gambacorta & Mistrulli (2003), Gambacorta (2005), Hülsewig, Mayer & Wollmershäuser (2006).

Some papers also suggest that an individual bank's response is conditional to the bank's size as small banks are less able to replace their balance sheet items than large banks. Furthermore, banks with substantial share of market-based funding and non-interest income are shown to reduce lending more strongly than other banks. Similar evidence exists also for the US (see, for instance, Kashyap & Stein 2000; Kishan & Opiela 2000).

Focusing on the impact of the latest financial crisis, Cihak & Brooks (2009) show that the euro area banks' loan supply responds negatively to a weakened soundness of banks, measured with capital ratio or deposit to loans ratio. Examining the effects of US financial crisis on the retail lending of German banks, Puri, Rocholl & Steffen (2011) also provide evidence on loan supply changes by the affected institutions. The banks that encountered a capital shock during the crisis rejected substantially more loan applications than the non-affected banks. The results were particularly strong for small and liquidity-constrained banks. Also Hempell & Kok Sörensen (2010) demonstrate that euro area banks' supply-side constraints affect overall euro area bank lending activity in general and during the financial crisis in particular. Furthermore, shocks to banks' foreign funding has caused substantial pullback in domestic lending in the UK (Aiyar 2011).

The second set of papers relates to the impact of bank lending on the macro economy and on GDP growth. The impact of bank loans arises from the fact that many small lenders such as small and medium size enterprises are bank-dependent and are unable to substitute bank loans with other forms of financing. The evidence regarding European countries indicates a negative link between lending and GDP growth. Buch & Neugebauer (2011) indicate that changes in lending by large European banks explain approximately 16 % of the short-run variation in GDP. Similarly, using data for 1999Q1−2010Q4 and for ten EMU member states, Rondorf (2012) finds strong evidence that loan supply has an impact on growth.

In the case of the euro area, Cappiello et al. (2010), Cihak & Brooks (2009) and Calza & Sousa (2005) have showed that a cutback of the loan supply is likely to have a negative impact on real economic activity in the euro area. Cappiello et al. (2010) also point to the potential negative effects of euro area banks' losses and balance sheet deleveraging. Cihak & Brooks (2009) indicate that a 10 percentage point decline in credit supply is likely to lead to a decrease in real GDP of about 1 percentage point. According to the estimates, the output grows by 0.206 percentage points if bank loans rise by one percentage point above the average.

In a similar vein, recent papers on US macro-financial linkages suggest that shocks on credit markets and banks' capital lead to a reduction in credit availability and subsequent fall of GDP. Bayoumi & Melander (2008) estimate that a one percentage point decline in the capital to assets ratio of US banks leads to a 1.5 percent fall of GDP, while analogous effects are demonstrated by Lown & Morgan (2006) after a tightening of credit standards. Helbling et al. (2011) examine the importance of credit market shocks in the context of global business cycles and show that these shocks are important in driving the economic activity especially during global recessions.

3 DATA

Our analysis is based on the following individual bank data and macroeconomic data which are included in the VAR model. Both data sets cover the period from the first quarter of 2005 to the last quarter of 2013. All variables are also demeaned.

Data on euro area banks are obtained from Datastream of Thomson Reuters. The sample refers to large and listed banking groups that have headquarters in the euro area countries, namely in Germany, France, Italy, Spain, Austria, Portugal and Belgium. Data are collected at the consolidated group level, which excludes intragroup items. To avoid double counting, separately reported foreign subsidiaries of a banking group are not included in the sample. Although the majority of banks report balance sheet and income statements on a quarterly basis, some banks publish bi-annual data. In this case, missing quarterly observations are interpolated in order to ensure a large sample.

The sample mainly consists of banking groups from large countries. From the total sample, 42 % of banks are French, 23% are German, 17% are Spanish and 11% come from Italy. Over the sample period, the total assets of the banks included in the sample constitute, on average, 51% of the total assets of consolidated banking groups in the above-mentioned countries. The representativeness of the sample varies across countries. While the sample’s Austrian and Belgian banking groups constitute around 27% of the total banking sector of these countries, French banking groups in the sample represent around 76% of the whole French banking sector.

For each bank in the sample, we extract information on total assets, risk weighted assets, reserves for loan losses, gross lending[38] and return on equity (ROE). We

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[38] Gross lending includes loans to financial institutions.

derive bank-level variables by calculating annual growth rates for total assets. On the basis of the data, we also define our own indicator for risk weights by dividing a bank's risk-weighted assets with its total assets. In addition, the indicator for loss accruals is defined as loan loss reserves over gross lending. This reserves for losses variable reflects the riskiness of banks at an earlier stage than actual loan loss provisions as the materialization of losses takes some time and reserves are often booked already against non-performing loans before the actual write-offs. Risk weights, loss accruals and return on equity (ROE) are expressed in percentages.

We weight each above-mentioned bank variable with the total asset of the individual bank, as a bank's impact is likely to depend on its size. The weighted variables are subsequently summed according to the nationality of the banks to get representative figures for the banking sectors of individual countries. As we are interested in the developments in the four largest euro area countries, the country-specific bank data refer only to banks resident in Germany, France, Italy and Spain. In contrast, euro area aggregate is composed by adding up all individual bank observations in the sample.

As the group-level bank data lacks detailed information on banks' lending to different economic sectors and on their debt issuance, we complement the data set with information from official balance sheet items statistics (BSI) of the ECB.[39] This data source refers to all monetary financial institutions (MFIs) in a country. Bank loans to non-financial corporations (NFCs) contain monetary financial institutions' lending to euro area firms. In addition, the issued bank debt refers to debt securities that MFIs had issued and held in the liability side of their balance sheets. This variable includes both long-term and short-term securities. Both variables are collected at the aggregated level for the whole euro area and the largest euro area countries. The variables are expressed as annual growth rates.

Furthermore, we use data on bank stock prices and country-level house prices in order to get information on asset price movements during the estimation period. In line with the theory of financial accelerator (Bernanke et al. 1999), the inclusion of asset prices helps to disentangle the question at hand. They reflect an important channel through which shocks can impact the macro economy via wealth effects and collateral values. Moreover, as stock prices adjust quickly, they can also be interpreted to reflect confidence in financial markets. The stock prices of individual banks in the sample are taken from Thomson Reuters' Datastream.

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[39] See http://www.ecb.europa.eu/stats/money/aggregates/bsheets/html/index.en.html.

After having calculated annual growth rates for the individual bank's stock price, we derive country-level data by averaging the observations on the basis of the banks' home country. To derive the annual change for house prices, we use residential property price statistics by BIS. Finally, we derive our asset price series by calculating a simple average over the annual growth rates of national stock and house prices.[40] A somewhat similar approach to combine stock and house price growth rates has been taken by Gulan et al. (2014).

We also obtain data on sovereign and bank credit default swaps (CDS)[41]. The CDS prices are taken from market sources and refer to quarterly average quotations. Our CDS variable is calculated by deducting the average price for banks' credit default swaps in each country from the CDS price of that particular sovereign. The variable is designed to distinguish whether the shock is experienced by banks or by the sovereign during the crisis. If the financial stress faced by banks is larger than that of the sovereign, our indicator gets negative values, and vice versa. The CDS spread indicator is in basis points.

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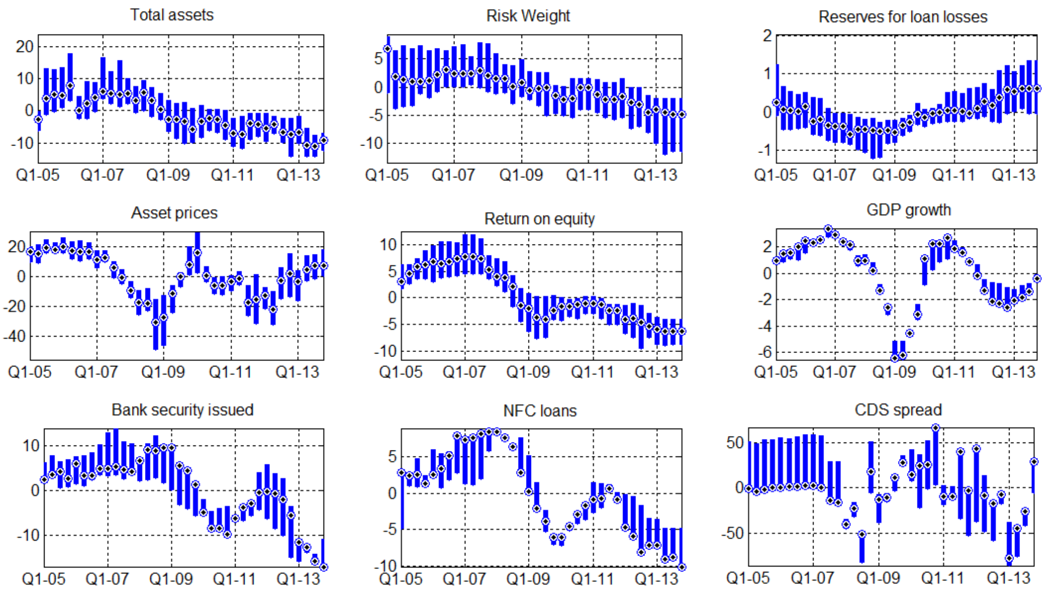
[40] We have also run the analysis by including as a variable only bank stock prices and only house prices. This robustness test provides analytically similar results.

[41] Credit default swaps are a kind of insurance contract in which buyer pays a premium. The buyer receives financial compensation from the seller of the contract in the case of a default of the company underlying the contract. The higher the price of the insurance fee, the higher is the probability for the company's default.

Figure 1. Variables



Note: Total assets, asset prices, GDP growth, bank debt and loans to non-financial corporations (NFCs) are expressed as annual growth rates, while risk weights, reserves for losses and return on equity (ROE) are in percentages. The CDS spread indicator is in basis points. The circle represents the median of the distribution. The vertical bars indicate the quantiles of the distribution at 20% (lower part) and 80% (higher part).

Finally, as for the macroeconomic variables, the dataset includes quarterly real gross domestic product (GDP) for Germany, France, Italy and Spain as well as for the euro area. Real GDP growth is computed as an annual growth rate and is taken from Eurostat.

The variables and their distribution are depicted in Figure 1. Since the beginning of the financial crisis banks' profitability (measured with return on equity) has declined, while reserves for loan losses have increased. The issuance of debt also decreased at the beginning of the crisis, reflecting the worsening of the financial market conditions and reduced availability of external funding. Debt issuance nevertheless recovered for a short time period in 2011–2012. In addition, banks' total assets and risk weights track a general downward trend as banks adapt their portfolios owing to the financial crisis.

4 METHODOLOGY

This section presents the vector autoregression (VAR) approach, sign restrictions as well as the impulse response functions (IRFs) that are used to disentangle the individual banks' responses to shocks as well as the impact of banks' adjustment on the macro economy.[42]

4.1 Granular approach

As a starting point, consider a multi-bank vector-autoregressive (VAR) model. In its most general form this model can be written as

$$x_{i,t} = \alpha_i + A_i(L)X_{i,t-1} + \varepsilon_{i,t} \qquad t = 1, \dots, T \tag{1}$$

where x_i is a n x 1 vector of variables of each of the *N* banks, $i = 1, \dots N$. $X_{i,t-1} = (x_{1,t-1}, \dots, x_{N,T})$ contains the lagged values of these parameters, $A_i(L)$ is a lag polynomial with the coefficients and α_i is an individual unobservable bank-specific fixed effect. The error terms, $\varepsilon_{i,t}$, have zero mean, country specific variance (σ^2_i), and constant covariance matrix ($cov(\varepsilon_t)=\sum$) that comprises the instantaneous relationships between the variables. In essence, the VAR model thus summarizes the data by describing the endogenous variables, x_i, as a linear function of their past evolution.

In this paper, the each equation of the VAR model contains all bank and macro indicators described in section 3 and their lagged observations as explanatory variables. Bank-level variables include total assets, risk weights, reserves for loan losses and return on equity (ROE), while country-specific macroeconomic series are GDP growth, bank debt issued, bank loans to non-financial corporations (NFCs), asset prices and CDS spread. The model is estimated with OLS over the period of 2005Q1–2013Q4 both for the euro area as a whole and for the four largest euro area economies. A lag selection criterion is used to select the number of lags and two lags are retained. The estimations are performed in levels since differencing generally leads to the loss of information on long-run relationships between the variables.

As we want to study the overall impact of different shocks into the banking system, the residuals of the VAR model, ε, are interpreted as shocks. In order to see the importance of this notation clearly and to highlight the system's responses to impulses, the equation (1) can be written in the moving average (MA) form. Using a lag operator to define the matrix polynomial A(L) as $B(L) = A_1L - \dots - A_TL^T$ and after rearranging the terms one gets the following formula.

[42] For more information on the methodology, see Uhlig (2005), Fry & Pagan (2011) and Eickmeier, Hofmann & Worms (2009).

$$x_{i,t} = \left(I - B(L)\right)^{-1} \varepsilon_{i,t-1} = \sum_{k=0}^{\infty} C_{ji,k} \varepsilon_{t-k} \quad (2)$$

where $C_{ji,k}$ is the *k*th period impulse response of variable x_i to a unit change in x_j. Thus, an impulse response function, C, tracks the effect of a shock to endogenous variables at the time of the event and over subsequent periods in time.

However, the estimation results for original error terms, ε_t, are not interesting as they often lack economic interpretation. To interpret the results in an economically meaningful way, one needs to disentangle the error terms into "structural" (economic) shocks, e_t, that are of interest. A solution is to write the original VAR model in structural form, $Ax_{i,t}=A(L)x_{i,t} + \varepsilon_{i,t}$. Dividing both sides with matrix A gives $x_{i,t}= A(L)A^{-1}x_{i,t} + A\varepsilon_t$. Now, let us use the notation $A\varepsilon_t=e_{i,t}$.[43] Structural shocks that we seek to measure are therefore linear combinations of the original VAR errors weighted with an appropriate set of weights, A.

4.2 Shock identification and sign restrictions

In order to define the structural shocks, $e_{i,t}$, from the vector of residuals of the VAR, the weighting matrix needs to be defined. This is done by using an algorithm that produces a set of weights, A, by drawing from a uniform distribution. The vectors containing the weights must nevertheless be orthogonal so that the fundamental shocks are uncorrelated and that they produce uncorrelated impulse response functions. Orthogonality also ensures that an occurrence of one shock does not lead to the occurrence of shocks in all error terms and create unexplained causal relationship between variables. The individual impact of a variable on the system is thus singled out which helps to determine the impulse response functions. However, the orthogonalisation is not straightforward as many different combinations of weights can produce candidate structural shocks that are uncorrelated. One possibility to solve this identification problem would be to use Choleski decomposition and the standard ordering of shocks that are widely used in macroeconomic studies. But, to the best of our knowledge, there is no agreed view in the literature regarding the timing of bank adjustment. As no *a priori* ordering of shocks exists for banking variables, we resort to identification strategy that uses sign restrictions (see, for instance, Uhlig 2005; Eickmeier, Hofmann & Worms 2009).

[43] This structural form error term is iid white noise with covariance matrix $\Sigma e=A\ \Sigma\ A'$.

The main idea of the sign restrictions is, first, to calculate the candidate structural shocks, $e_{i,t}$, and, secondly, compare the candidates to sign restrictions. Only those shocks and impulse response functions that satisfy the postulated sign information are retained. On the basis of the accepted shocks, we subsequently derive impulse response functions. Typically there are many different shocks that satisfy the sign restrictions, thus leading to a shaped distribution of the initial response.

We identify three shocks with sign restrictions, namely a risk shock, funding shock and sovereign shock. These shocks are quite unique in terms of the previous literature, as only a few papers have previously disentangled the impact of similar shocks on macro variables. When describing the shocks below, we refer to the relevant literature. The signs of the contemporaneous effects of the shocks are summarized in table 1.[44]

Table 1. Sign restrictions imposed on the endogenous variables to identify the shocks

	Response to risk shock	Response to funding shock	Response to sovereign shock
Total asset	-	-	+
Risk weight	+	-	?
Reserves for losses	+	?	?
Asset prices	-	-	-
Return on equity (ROE)	?	?	-
Bank debt	?	-	?
GDP growth	?	?	?
Loans to NFCs	?	?	?
CDS spread	-	?	+

Note: The shocks are listed in the headings of the columns and endogenous variables are in horizontal rows. The responses of the endogenous variables are presented with signs. A negative (positive) sign means that an endogenous variable declines (increases) after the shock. The response is left free when no sign is specified.

Risk shock means that a bank's riskiness increases and its asset quality deteriorates at given macroeconomic conditions. It may be due to changes in risk environ-

[44] While modelling the target liability structure of banks is beyond the scope of the paper, a decomposition of endogenous bank variables' shock dynamics and the variables' responses to the macro-financial environment can be drawn from historical regularities with minimal identifying assumptions.

ment, liquidation risk, collateral values or regulatory environment (for instance, asset quality review, Basel III). The volume of non-performing loans picks up, leading banks to set aside increasing reserves for impairments and loan losses. As banks are less willing to take risks, the shock also induces banks’ total assets to decline. Several factors support this assumption. First, banks’ traditional lending is likely to decline owing to increasing risks and pressures on equity capital. Such an effect has been shown by Peersman & Wagner (2015). Based on a model of a profit maximizing bank they indicate that if the stress at banks increases, lending declines and it becomes less desirable for banks to hold more risk on balance sheet. Second, general risk appetite declines, inducing a sell-off of risky investments from banks’ balance sheets. And third, banks start to remove bad loans from their balance sheets, albeit this process is arguably very slow. The risk weight indicator is assumed to increase owing to the deteriorating quality of assets and declining total assets.

Owing to short-term inelasticity of banks' other revenues and costs, banks' profitability is likely to be weakened by slowly materializing losses. However, as this process is delayed we leave the response of banks' return on equity (ROE) free and do not specify any restrictions for it. The risk shock nevertheless triggers a decline in the value of assets. As bank’s future prospects and profits decline, investors immediately take a negative view on bank stocks. Mounting risks also reduce loan supply and increase interest rate spreads, which in turn puts a downward pressure on the house prices. Declining house prices can also reflect the end of asset exuberance or burst of a bubble. In a way, our risk shock resembles the outcome of adverse asset price shock of Gulan et al. (2014). Moreover, following Meeks (2012), we assume that an adverse financial shock increases expected default rates.[45] As the risk shock affects primarily banks, banks' CDSs are increasing more than the sovereign CDS, inducing our CDS spread indicator to decline. Finally, the responses of bank debt, GDP and corporate lending are left undetermined.

The *funding shock* is related to deteriorating conditions in financial markets. The shock may be due to increasing uncertainty, declining risk appetite of investors, increasing funding costs in terms of rising money market interest rates and risk premia or a combination of these factors. As a consequence, banks' issuance of debt securities declines as banks find it increasingly difficult to obtain funding from money markets. While banks' easy access to short-term funding has often lead to excessive risk-taking and ballooning balance sheets (see, for instance,

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[45] Also Helbling et al. (2011) use default rates to identify a credit market shock.

Reinhart & Rogoff 2009), we assume that a funding shock negatively affects banks' willingness to take risks. As banks' external funding is limited, risk-taking diminishes, leading to declining risk weights and total assets. Similarly to the risk shock, asset prices decrease as house prices decline and the expectation on banks' future earnings are shifted downwards amidst the adverse conditions. The signs of reserves for loan losses, ROE, GDP growth, corporate lending and CDS spread indicators are not specified.

The *sovereign shock* portrays the impact of the sovereign debt crisis. In principle, the initial direct macroeconomic implications and negative repercussions of a sovereign shock could have materialized via increasing risk weights of sovereign bonds and portfolio valuation changes of banks' sovereign debt holdings. However, the large changes in the prices of some government bonds resulted in relatively limited shifts in the book value of bank assets. The asset values declined only a little and the initial losses remained low, because a relatively small part of the sovereign portfolio was held for trading purpose and had to be priced to market value under supervisory rules.[46] Without an explicit reaction pattern the response of our risk weight variable cannot be properly defined and it is left ambiguous.

The crisis nevertheless went through other channels such as deteriorating market confidence impacting negatively on overall business environment. Rising sovereign risk is reported to have a negative impact on banks by pushing up the funding costs and adversely affecting the composition of euro area banks' funding (BIS 2011). Furthermore, banks' profitability and asset prices are likely to be hampered owing to negative circumstances. For instance, Chan-Lau et al. (2012) document the negative relationship between banks' stock prices and sovereign risk. We also assume that our CDS spread indicator increases as sovereign credit default swaps rise initially more than bank CDSs. Banks' total assets are also set to increase after the sovereign shock. The reasoning relies to the fact that the sovereign shock impacts primarily countries and its direct immediate impact on banks is limited. Indeed, data shows that total assets of financial institutions continued to grow in euro area immediately after the Greek sovereign shock in May 2010. Despite of the shock, banks still had to honour their previous engagements and relied to central bank funding to fund their activities. The responses of other variables are left undefined.

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[46] According to Basel II framework, the regulatory risk weight for bonds issued by EU sovereigns may in many cases be set to zero. As a result, evolving sovereign risks are not reflected in the risk weights and balance sheets of banks.

A nested identification scheme is applied in order to ensure a proper identification. In the first step we introduce simultaneous restrictions for risk shock and funding shock. And in the second step, further restrictions are added on top of the previous ones in order to identify the sovereign shock. Following a standard approach in the empirical literature these restrictions are imposed over two quarters to account for the possibility of lagged adjustment.

Other shocks: In addition to three above-mentioned shocks, the analysis framework contains an unidentified part. It consists of all other possible shocks that are orthogonal to the identified shocks and may affect the dynamics of the banking sector and macro variables. Taking into account the significant role of the ECB's conventional and unconventional measures to ease the monetary policy stance during the period under study, one obvious candidate is a monetary policy shock. Such a shock would be manifested by falling interest rates and increasing liquidity in the banking system. Theoretically, expansionary monetary policy shock should induce increasing bank lending and low lending rates (via bank lending and interest rate channel), leading to improving financing conditions for firms and supporting economic growth (see, for example, ECB 2009). The policy action is also associated with raising spending, increasing consumption and investments, higher inflation, higher risk-taking (so called risk-taking channel) and positive wealth effect. By promoting recovery in the real economy, unconventional monetary policy lowers delinquency and default rates, raises profits and improves solvency. (Chodorow-Reich 2014).

However, the financial crisis affected negatively the functioning of interbank markets, banks' funding and financial standing. As a result, monetary policy was conducted in highly exceptional circumstances. While the ECB's measures alleviated the situation in financial markets, the pass-through of the monetary policy shock was hampered by several other factors such as banking and corporate sector deleveraging, declining loan demand and increasing non-performing loans of the banking sector. Thus, the impact of the ECB's accommodative policy stance on credit supply is not easily determined. For instance, Peersman & Wagner (2015) leave the impact of monetary policy shock on lending undetermined. It is also difficult to disentangle the magnitude and timing on other variables. The final impact of monetary policy shock on our bank and macro variables is thus unclear, making it difficult to assess the effects of expansionary monetary policy.[47] Nevertheless, our funding shock may to some extent incorporate the monetary policy

[47] It is clearly an avenue for future research.

shock as it is a positive mirror image of our negative funding shock. In this sense, our model partly contains the monetary policy shock.

5 ESTIMATION RESULTS

This section presents the results of the VAR estimations and analyses the responses of the endogenous variables by using impulse response functions (IFRs). We then study the propagation of these shocks to the economy and the implication of banks' adjustment in the four largest euro area countries and the euro area as a whole over the estimation period. Finally, we track the effect of the estimated shocks on banks’ total assets, corporate lending and average return on equity as well as on GDP growth.

5.1 Responses to shocks

Starting with the estimation results of the VAR model, dependent variables are mainly explained by their own history (table 1 in the annex).[48] Indicators such as GDP growth, banks' profitability, CDS spread, bank debt issuance, total assets and reserves for loan losses are also significant explanatory variables for other endogenous parameters. As banks' riskiness and funding are often related to exogenous changes in banks' operating environment, their importance as explanatory variables for other bank-level indicators highlights the vulnerability of banks to external shocks. Overall, the explanatory power of the models varies between 61% and 95%, indicating that they capture a large part of the volatility in the endogenous variables.

On the basis of the VAR estimation results and sign restriction approach, we next derive banking system's responses to risk, funding and valuation shocks. The estimated responses of the endogenous variables to a one-standard-deviation shock are depicted with bank-specific orthogonalized impulse response functions (IRFs).[49] As several IRFs satisfy the given sign restrictions, we report the median

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[48] The VAR model is estimated with OLS. The equation (1) can be estimated efficiently by OLS for each equation separately. As no restrictions are imposed on the parameters, the estimator has the usual asymptotic properties of standard estimators. Another option would have been to use Bayesian VARs. However, Bayesian estimation technique mainly improves out-of-sample forecasts which is outside the scope of our paper.

[49] In essence, the IRFs trace the long-term effects of a one-time shock (i.e. impulse) to one of the dynamic system’s endogenous variables. By analysing the IRFs, we are thus able to analyse

of the accepted impulse responses in order to summarize the estimation results (figures 2-4).[50] Moreover, we include the distribution of IRFs with 20% and 80% confidence bands. The confidence bands around the median IRFs show some uncertainty regarding the responses, indicating the wide variability of bank responses. Our simulation horizon covers 15 quarters.

A *risk shock* induces an overall negative impact on banks' income statements and balance sheets (figure 2). When the shock occurs, reserves for losses rise about 8 basis points during the first two quarters. The accruals continue to increase over the subsequent periods owing to late materialization of risks. While the loss reserves increase throughout the estimation period, their relative growth rate nevertheless declines towards the end, reflecting the one-off nature of the shock. Owing to the shock, risk weights increase immediately by 0.8 percentage point and total assets decline by 1 percentage point. After the initial impact, the risk weights start to decline after 4 quarters as banks adjust their balance sheets and portfolios. The adjustment is also reflected in total assets, which continue to decline over the whole simulation horizon, albeit at the slowing pace. The response of asset prices is much more pronounced as they instantly decline by 4 percentage point. Asset prices nevertheless rebound after 4 quarters and recover in the middle of the simulation period before the response subsides close to zero. In addition, our CDS spread indicator declines and does not return to positive territory, indicating that markets continue to consider banks riskier than sovereigns several quarters after the initial shock.

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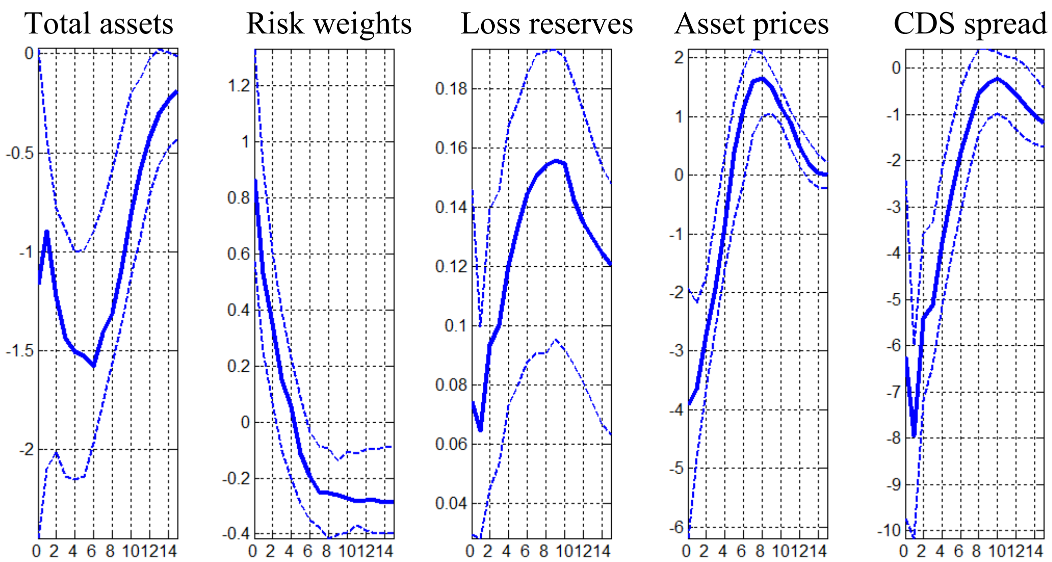
the internal behaviour of the dynamic system and endogenous variables in the case of exogenous disturbances.

50 The median could also be interpreted as a point estimate of the spatial impulse response (SIR) at each point in time following the shock.

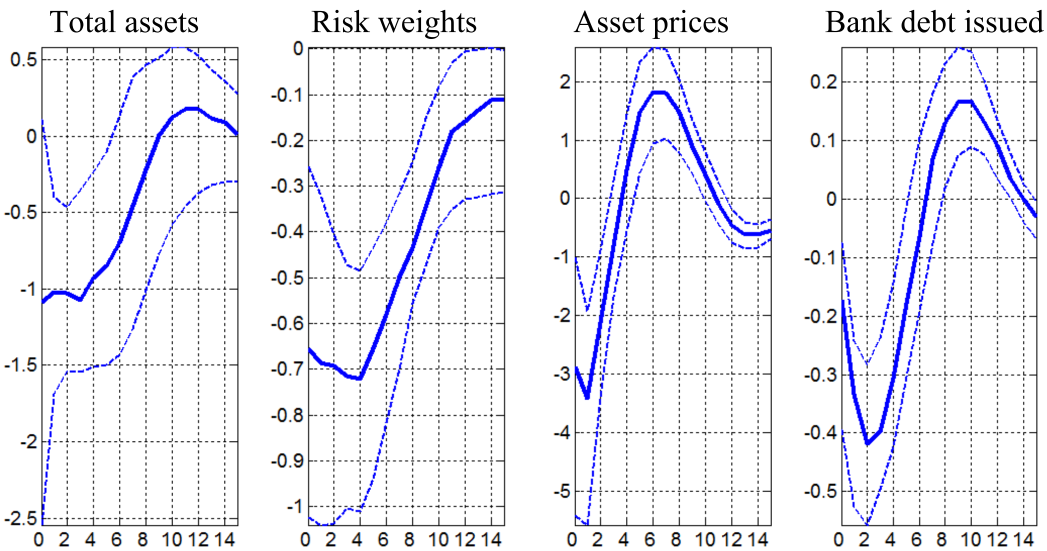
Figure 2. Impulse responses to a risk shock



Note: The horizontal axis shows the number of quarters after the initial shock. The vertical axis indicates the response of the relevant variable. Total assets, asset prices and bank debt are expressed as annual growth rates, while risk weights, return on equity (ROE) and reserves for losses are in percentages. The CDS spread indicator is in basis points. The solid line represents median impulse response, while the lower and the upper dotted line stand for distribution at 20% and 80%, respectively.

Turning to *funding shock*, total assets, risk weights and bank debt issuance exhibit profoundly negative responses (figure 3). As the market conditions deteriorate, the annual growth of banks' debt issuance declines 0.2-0.4 percentage points during the first quarters. After the peak impact, bank debt issuance continues to decline albeit at the slowing pace. The funding conditions improve after seven quarters, when the annual growth rate of bank debt turns positive. In a similar fashion, total assets decline immediately about 1 percentage point and recover towards the end of the estimation period. In contrast, risk weights decline steadily after the initial shock as their impulse responses remain negative after 15 quarters. Finally, asset prices drop rapidly after a negative funding shock but recover relatively quickly during the subsequent quarters.

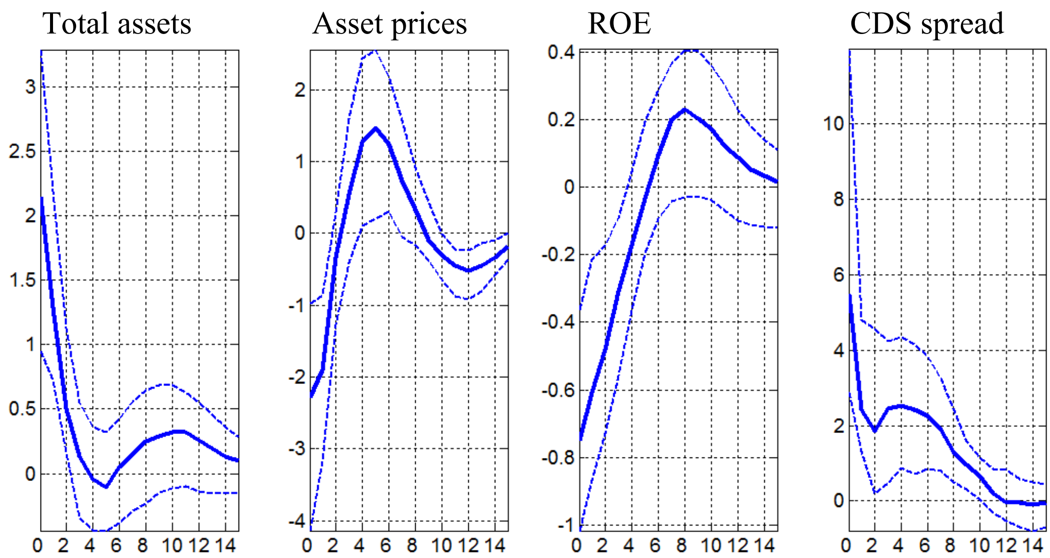
Figure 3. Impulse responses to a funding shock



Note: See note Figure 2.

The *sovereign shock* implies an initial negative impact on asset prices and bank profitability, declining 2 percentage points and 0.7 percentage points, respectively (figure 4). The response of asset prices is thus larger than that of return on equity. The negative effects are nevertheless transitory in nature as the response of both variables turns positive in subsequent quarters. But the responses slowly fade away as time passes, reaching the baseline at the end of the estimation period. The annual growth rate of total assets increases by 2 percentage points but the growth rate subsequently declines to around 0.1 percentage points. The median impulse response function of our CDS variable increases rapidly after the initial shocks and remains positive almost throughout the whole estimation period. On average, the CDS variable stands at around 2 percentage point higher than without the exogenous shock. However, the response is not permanent and fades towards the end of the simulation period, potentially reflecting the fact that the euro area sovereign crisis affected also the outlook of the banking sector and induced bank CDSs to rise towards the end of the simulation period.

Figure 4. Impulse responses to a sovereign shock



Note: See note Figure 2. ROE stands for return on equity.

5.2 Time pattern of the shocks

While impulse response functions depict the responses of the endogenous variables to a one-standard-deviation shock, such a shock corresponds to a different-sized impact for each country in the sample. Moreover, the responses may differ at each point in time. Based on the estimated parameters of the VAR and the identified shocks, we therefore compute historical dynamic effects of the shocks for each country. The computations are done for each draw that fulfils the sign restriction, and then a simple average from individual outcomes is calculated. The time paths of median shocks are depicted in figures 1-3 of the annex for euro area as well as for France, Germany, Italy and Spain. Although the shocks vary considerably over time and across countries, the negative impact of sub-prime crisis and European sovereign debt crisis can be clearly seen from the time paths of these nominal shocks.

Starting with the *risk shock*, its effect is relatively subdued before the beginning of the global financial crisis (figure 1 of the annex). When the financial crisis erupted in the United States at the end of 2007, the magnitude of the risk shock is nevertheless pushed upwards in all countries of the sample. After the initial shock, the dynamic effects of the shock remain positive in Germany and France as they were affected by the failures of money market funds in 2008. In addition, French banks incurred losses from their Greek subsidiaries. At the same time, the impact of the risk shock is limited in Spain and Italy which did not encounter the first negative shock waves of the crisis. Towards the end of 2009, the estimated shocks subsequently decline owing to rescue measures by European governments and the extraordinary policy measures by the central banks. However, the risk factor increases again in the middle of 2010 owing to the outbreak of the euro area debt crisis. Banks were negatively affected by the deteriorating economic growth and increasing impairments both form traditional lending and holdings of Greek debt. From the second quarter of 2012 onwards German and French banks are less affected by the risk shock than Italian and Spanish banks, facing large write-offs.[51] In 2013, the negative effects abate in all countries, possibly reflecting the brighter prospects of the economy and improving risk outlook.

The *funding shock* exhibits large volatility over the estimation period (figure 2 of the annex). In September 2008 the funding shock peaks in all countries owing to the bankruptcy of Lehman Brothers. Amidst of the constant wave of European bank failures and severe tensions in money markets, central banks took extraordinary liquidity measures and provided special refinancing operations at the end of 2008. Such measures reduced the impact of estimated funding shock considerably in 2009. Nevertheless, the shock intensifies again after the magnitude of Greece’s fiscal deficit was revealed at the beginning of 2010. In early May 2010, the funding shock peaks again as the situation in the international financial markets deteriorated amid the escalation of the crisis and downgrading of the Greek sovereign debt rating. The shock intensified again in the middle of 2011 when concerns over the euro area’s debt crisis affected funding conditions negatively. Towards the end of the estimation period, the effects of the funding shock differ across the countries in the sample. The relatively good standing of banks abated the estimated shock in Germany, France and in the euro area as a whole, while the distress in financial markets affected Italian and Spanish banks negatively. The adverse impact on the Spanish banks continues to persist until June 2012, when the negative effects decline somewhat after European Union granted funds to bank capitalisation.

The nominal path of the *sovereign shock* reflects in many ways that of the funding shock, albeit with differences in timing and in magnitude (figure 3 of the annex). While the sovereign shock affects banks only at the beginning of 2009, banks face funding shock already in 2008. Similarly, the Greek debt problem increases the

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[51] One might have expected that the effect of risk shock on Spanish banks would have been larger. To some extent the results are likely to be affected by our sample of listed banks. In 2010–2011 large Spanish banks benefited from diversification effects and profits from abroad, while the bursting of the Spanish housing bubble affected mainly small savings banks ('cajas'), which are not included in the sample.

dynamic effects of the sovereign shock in all countries, but only towards the end of 2010. In general, the effects of the sovereign shock remain also subdued in 2011–2013. A notable exception is the Spanish banking sector that is adversely affected by the sovereign shock in mid-2012. It is also of interest that in Germany the sovereign shock is negative, reflecting actually a favourable impact on German banks. The outcome reflects potentially the country's safe-haven status amid the sovereign debt crisis.

5.3 The impact on banks and macro economy

To assess the driving forces of the dynamic evolution and to show the contributions of individual shocks on the variation of the macroeconomic variables, we calculate the historical decompositions of the shocks. Using historical decompositions we estimate the individual contributions of each shock to the change in total asset, loans to NFCs, return on equity and GDP. In technical terms, the equation (2) can be written as follows:

$$x_{i,t}^{(j)} = \sum_{k=0}^{t-1} C_{ji,k}\varepsilon_{j,t-k} + A_1^t x_0 + \ldots + A_p^t x_{-p+1} \tag{3}$$

where $C_{ji,k}$ contain the structural impulse responses defined earlier and the A_i are such that $[A_{1,\ \ldots,}\ A_p]$ consists of the rows of the matrix A. In other words, the model variables at each point in time, x_t, can be presented as a sum of each structural shock of the model to the component series of x_t, given by x_0, …., x_{-p+1}.[52]

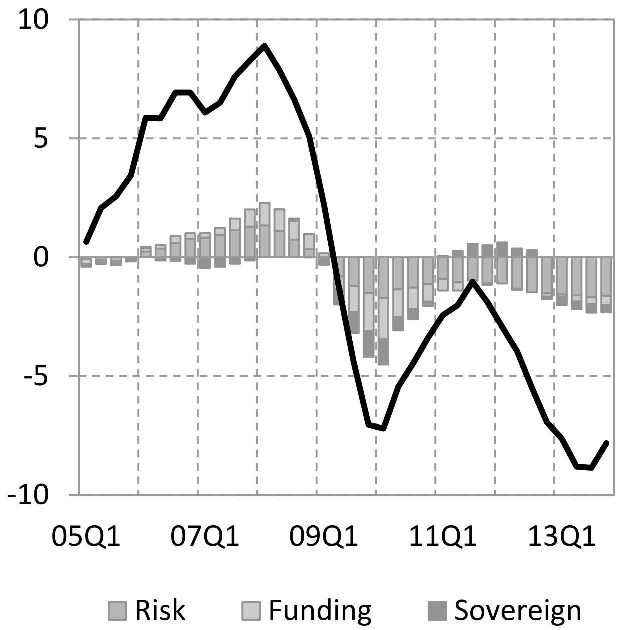
The figures 5 and 6 as well as figures 4-21 of the annex show how much of the historical variation in the annual growth rate of banks' total assets and loans to non-financial corporations, in banks' average return on equity (ROE) and in annual GDP growth is due to risk, funding and sovereign shocks. Overall, the identification schemes are successful in capturing the broad interaction among the set of variables. The responses of the variables, which are not imposed, are also intuitive.

In the case of *lending to non-financial corporations* (NFCs), the shocks start to weigh banks' ability to provide financing from 2009 onwards (figure 5). From a euro area wide perspective, the estimated shocks explain around 60 percentage of the credit slowdown at the end of 2009. Both the funding shock and risk shock

52 In a way, historical decomposition could be considered as a counterfactual analysis. Each component shows what the history of $x_{i,t}$ would have been if the j th shock had been the only one affecting the system.

constitute individually about 20 percentage of the total impact of euro area shocks. Meanwhile, the contribution of the sovereign shock on banks' loans to NFCs has been limited. Risk and funding shocks remain relevant throughout 2009–2010, but the contribution of the funding shocks diminishes from 2011 onwards. Meanwhile, the sovereign shock remains relevant towards the end of the estimation period.

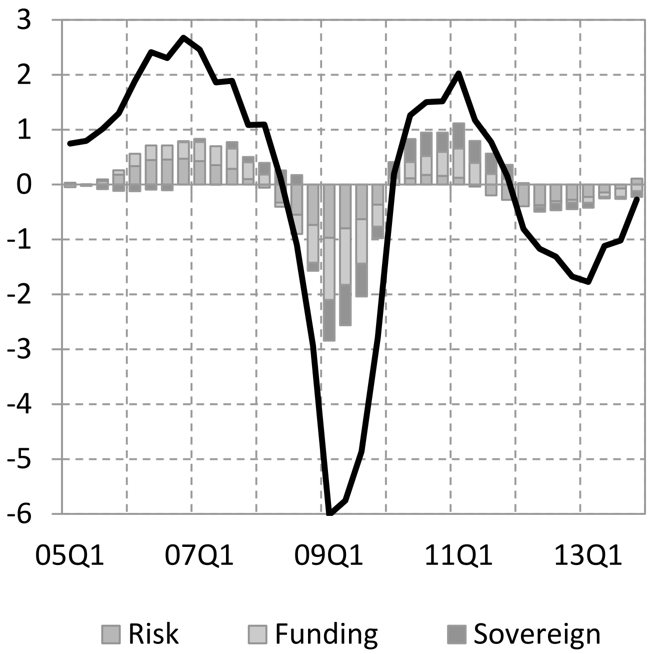
Figure 5. Estimated contribution; the annual growth of corporate lending in euro area (%)



Compared to the total contribution of shocks at the euro area level, the total contribution is somewhat larger in Germany and France, but remains smaller in Italy and in Spain during the first two years of the crisis (figures 4-7 of the annex). The risk and funding shocks have been a major contributor in German, French and euro area corporate loan growth. In 2012–2013 the contribution of the risk shock becomes also prominent in Italy, depressing Italian banks' ability to grant credit. A similar effect is evident in the case of the Spanish banks, although the risk shock is relatively subdued and plays a part only from the beginning of 2013 onwards.[53] In Spain, the impact of the funding shock is also more pronounced than that of the risk shock.

While the sovereign shock exhibits mainly negative impact in all countries of the sample, it is somewhat more relevant in Spain and in Italy. It is of interest that German banks have actually benefited from the sovereign shock. In Germany the contribution of the shock was positive in 2011–2012 when German banking sector was shielded by the country's strong public finances and the safe-heaven status. Moreover, the financial strength of German banks was considered to be relatively stronger than many other European counterparties, leading investors to be more willing to fund German counterparties than other banks in the euro area countries. For instance, the Spanish banks continued to face sovereign distress throughout the whole estimation period. The sovereign shock thus eased the pressures faced by German banks and abated the negative contribution of other shocks.

Figure 6. Estimated contribution; the annual GDP growth in euro area (%)



[53] The results reflects the fact that the sample includes only large banks that start to write off bad loans later than small savings banks ('cajas').

The shocks have played a role in a slowdown of *annual GDP growth* (figure 6 and figures 8-11 of the annex). The contribution of the shocks in 2009 amounts to about a third of the decline of the euro area GDP. The impact is considerably larger in Germany, while being of similar magnitude in France. Thus, although the uncertainty regarding the impact of the micro-level shocks on macro series remains, shocks' adverse effect on activity could have been substantial. Overall and similarly to corporate lending, risk and funding shocks appear to have been more important contributors to GDP decline than the sovereign shock. Nevertheless, the sovereign shock explains approximately 10 percent of the variation in GDP growth in 2009. In Spain, the contribution of the sovereign shock remains even more notable. In 2010–2011, positive development of GDP is supported by shock contributions. Towards the end of the estimation period the importance of shock contributions nevertheless varies across the large euro area economies. While they abate in Germany and France, the risk and funding shocks have a negative impact on Italy and Spain. In 2012–2013 the sovereign shock does not seem to be major component behind the decline of annual GDP growth.

Regarding balance sheets, the historical decompositions indicate that all shocks contribute negatively also on the *annual growth of banks' total assets* (figures 12-16 of the annex). Banks reduce their assets at the euro area level, in France and in Germany due to the impact of the risk and funding shocks in 2009–2010. From 2012 onwards the impact of these shocks is nevertheless limited in Germany and France. Meanwhile, the risk and funding shocks intensify in Spain and in Italy during the latter part of the estimation period, inducing the euro area average to remain unchanged. The sovereign shock has a subdued effect on the annual growth of total assets during the estimation period. It nevertheless has a small and temporarily positive effect in Germany and France during the first part of 2009. In 2012–2013, the sovereign shock also induces a limited negative impact on banks' total assets.

Turning to banks' average *return on equity* (ROE), shock contributions on banks' profitability are significant (figures 17-21 of the annex). Amidst market turbulence and uncertainties at the trough of the financial crisis, in 2009, the average adverse contribution of three shocks on euro area banks' profitability represents about 56 percent of the recorded decline. At the country level, German and French banks are most affected by the shocks in 2009, potentially reflecting the increasing losses from investments and money market funds owned by the banks. At the same time, some banks (including Hypo Real) faced difficulties in obtaining wholesale funding. After the initial shock, the impact of shocks on German banks has declined and became almost non-existent in the latter part of the estimation period. Meanwhile, the profitability of Italian banks was hit heavily by risk shock in 2011–2013. In 2013, the shock contribution explained about 60% of variation in the case of Italy. In case of Spain, the contribution of shocks remains limited.

6 CONCLUDING REMARKS

The recent financial crisis reminded economists and analysts alike of the role and importance of financial intermediaries. Banks are not only passive intermediaries through which central bank actions influence the broader economy, but can also be a source of disturbance. The negative shifts in banks' business environment can spillback to overall economy and create negative feedback loops as banks channel funds to borrowers and changes in banks' credit supply affect the corporate capacity to finance investments. Banks' increasing risks, declining profitability and weakened access to wholesale funding can thus have negative repercussions on overall output.

This paper contributes to the literature by estimating the impact of risk, funding and sovereign shocks on the banking sector and macro economy at the euro area level and in the largest euro area countries. The analysis is based on the estimation of VAR model with bank-level variables and macroeconomic data for 2005–2013. First, we identify the shocks by using a sign restrictions approach. Second, impulse response functions (IRFs) are applied to assess the individual implications of the shocks for endogenous variables. Finally, the historical decompositions of responses are composed to analyse how much of the variation in banks' total assets, profitability and corporate lending as well as in GDP growth is explained by the shocks.

The results show that the time paths of nominal shocks capture the negative repercussions of the crisis in different banking systems and reflect the events of the financial crisis. More importantly, the risk, funding and sovereign shocks explain a substantial part of the variations in total assets, profitability, corporate lending and GDP growth. At the euro area level, three shocks explain about 60 percentage of the credit slowdown and a third of the decline in GDP in 2009. While risk and funding shocks explain most of the variation in 2009–2010, the role of the sovereign shock remains subdued. However, the sovereign shock explains approximately 10 percent of the variation in banks' profitability and GDP growth in 2009. During the latter part of the estimation period, all shocks continue to play a role, albeit their contribution declines somewhat.

Over the whole estimation period, the euro area average is affected by different country level dynamics. During the early years of the financial crisis, the contributions of shocks are substantial in Germany and France. In 2012–2013 the contributions of shocks subside in Germany and France, but they become significant especially in Italy. Moreover, the contribution of three shocks remain relevant in Spain during the latter part of the estimation period. Italian banks are affected by the risk shock and Spanish banks face increasing funding pressures. Overall, the negative implications of shocks at the euro area level are composed of the contributions of German and French banks in 2009–2011 and the contributions of shocks to Italian and Spanish banks in 2011–2013.

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Annex. Tables and figures

Table 1. VAR estimation results (equations in columns)

	Total assets	Risk Weights	Reserves for losses	Asset prices	ROE	GDP growth	Bank debt issued	NFC loans	CDS spreads
Total assets (t-1)	0.62**	0.064**	-0.003	0.217**	-0.002	0.002	-0.012	-0.006	0.042
	(0.067)	(0.023)	(0.003)	(0.109)	(0.02)	(0.007)	(0.025)	(0.017)	(0.251)
Total assets (t-2)	0.092	0.042	-0.001	-1.59**	-0.127*	-0.123**	-0.284**	-0.051	0.1
	(0.241)	(0.084)	(0.012)	(0.394)	(0.072)	(0.024)	(0.089)	(0.061)	(0.906)
Risk weights (t-1)	-0.014	-0.029	-0.002	-0.058	0.024	0	0.016	0.032*	-0.152
	(0.067)	(0.023)	(0.003)	(0.11)	(0.02)	(0.007)	(0.025)	(0.017)	(0.253)
Risk weights (t-2)	0.01	0.003	-0.022	0.414	0.207	1.065**	-0.08	0.18	-0.364
	(0.651)	(0.227)	(0.032)	(1.066)	(0.193)	(0.066)	(0.241)	(0.165)	(2.449)
Reserves for losses (t-1)	0.193	0.894**	-0.005	0.499*	0.033	0.057**	0.07	0.031	-0.904
	(0.193)	(0.067)	(0.009)	(0.316)	(0.057)	(0.019)	(0.071)	(0.049)	(0.725)
Reserves for losses (t-2)	0.172	0.019	0.01	-2.317**	-0.293*	-0.332**	0.079	0.14	-0.654
	(0.608)	(0.212)	(0.03)	(0.995)	(0.181)	(0.061)	(0.225)	(0.154)	(2.286)
Asset prices (t-1)	-0.259	-0.041	0.011	-0.607**	-0.055	-0.054**	-0.051	-0.022	0.921
	(0.177)	(0.062)	(0.009)	(0.291)	(0.053)	(0.018)	(0.066)	(0.045)	(0.668)
Asset prices (t-2)	-0.058	-0.067	-0.016*	-0.077	0.068	0.008	1.156**	0.062	0.363
	(0.174)	(0.061)	(0.009)	(0.284)	(0.052)	(0.018)	(0.064)	(0.044)	(0.653)
ROE (t-1)	-2.09*	-0.996**	0.532**	0.744	-0.168	-0.041	0.055	0.134	-14.294**
	(1.165)	(0.407)	(0.057)	(1.908)	(0.346)	(0.118)	(0.431)	(0.295)	(4.384)
ROE (t-2)	0.164	-0.001	0.014*	0.395	-0.049	0.01	-0.315**	0.044	-0.132
	(0.168)	(0.059)	(0.008)	(0.275)	(0.05)	(0.017)	(0.062)	(0.043)	(0.631)
GDP growth (t-1)	2.996**	0.379	0.398**	3.344*	0.156	0.157	-0.035	-0.124	10.666**
	(1.211)	(0.423)	(0.06)	(1.983)	(0.36)	(0.122)	(0.448)	(0.307)	(4.556)
GDP growth (t-2)	-0.228	0.039	-0.016	-0.127	-0.007	0.042*	0.304**	1.047**	-0.14
	(0.261)	(0.091)	(0.013)	(0.428)	(0.078)	(0.026)	(0.097)	(0.066)	(0.982)
Bank debt issued (t-1)	0.001	0.013	-0.001	0.676**	0.022*	0.021**	-0.024	0.004	0.573**
	(0.045)	(0.016)	(0.002)	(0.073)	(0.013)	(0.005)	(0.017)	(0.011)	(0.169)
Bank debt issued (t-2)	0.207	0.034	0.015	0.229	0.053	-0.046*	-0.146*	-0.297**	-0.709
	(0.244)	(0.085)	(0.012)	(0.4)	(0.073)	(0.025)	(0.09)	(0.062)	(0.919)
NFC loans (t-1)	0.014	0.018	0	-0.069	0.014	-0.003	0.022	0.015	-0.451**
	(0.046)	(0.016)	(0.002)	(0.076)	(0.014)	(0.005)	(0.017)	(0.012)	(0.174)
NFC loans (t-2)	0.035**	0.007	-0.001	0.057**	0.019**	0.001	0.018**	0.001	0.508**
	(0.018)	(0.006)	(0.001)	(0.029)	(0.005)	(0.002)	(0.007)	(0.005)	(0.067)
CDS spreads (t-1)	0.344	-0.074	-0.01	1.408**	0.922**	0.11**	0.32**	0.082	0.231
	(0.243)	(0.085)	(0.012)	(0.399)	(0.072)	(0.025)	(0.09)	(0.062)	(0.916)
CDS spreads (t-2)	-0.009	-0.009	0.002**	-0.02	-0.005	0.002	-0.005	-0.013**	0.204**
	(0.018)	(0.006)	(0.001)	(0.03)	(0.005)	(0.002)	(0.007)	(0.005)	(0.069)
No. of observations	1178	1178	1178	1178	1178	1178	1178	1178	1178
R-squared	72.9	88.82	88.18	69.71	90.21	92.32	94.26	95.29	61.23

Note: Estimations are run with OLS and estimation period covers 2005:1—2013:4. Equations are reported in columns and explanatory variables in rows. Total assets, asset prices, GDP growth, bank debt and loans to non-financial corporations (NFCs) are expressed as annual growth rates, while risk weights, reserves for losses and return on equity (ROE) are in percentages. Standard deviation of the estimate is under the point estimate in brackets. One (two) asterisk denotes that the coefficient is significant at 10% (5%).

Figure 1. Estimated nominal risk shock 2005Q1–2013Q4

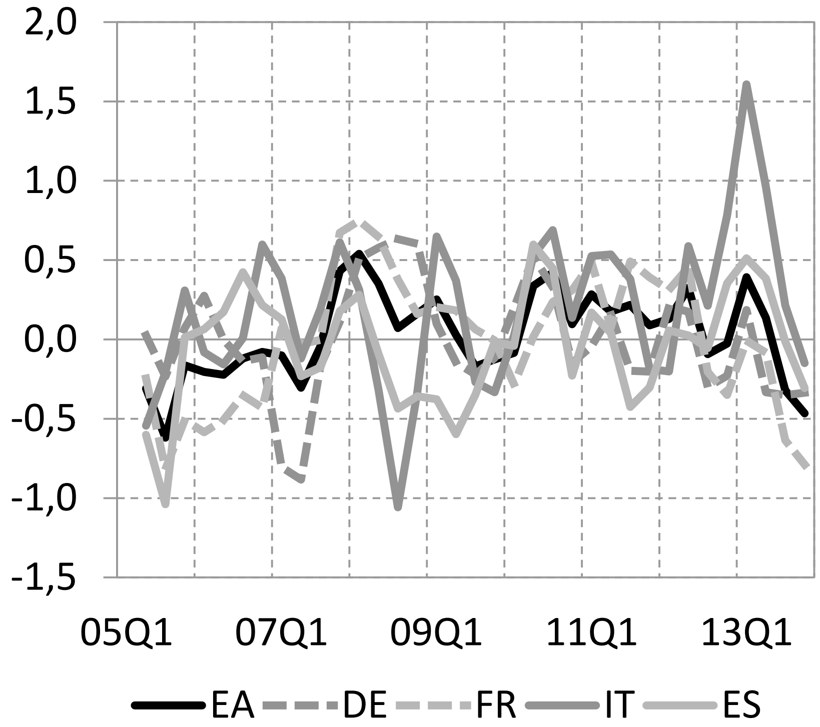

Figure 2. Estimated nominal funding shock 2005Q1–2013Q4

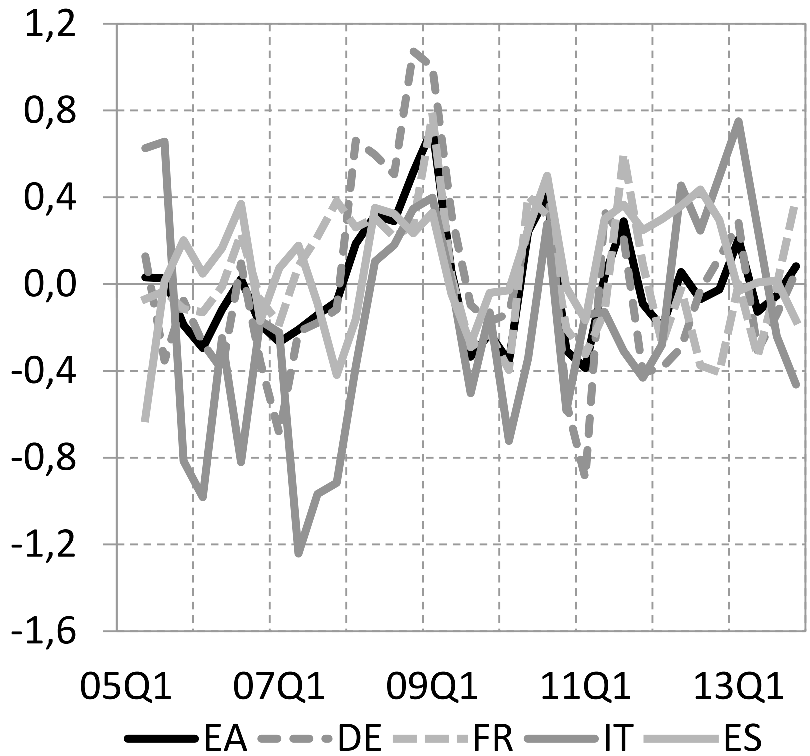

Figure 3. Estimated nominal sovereign shock 2005Q1–2013Q4

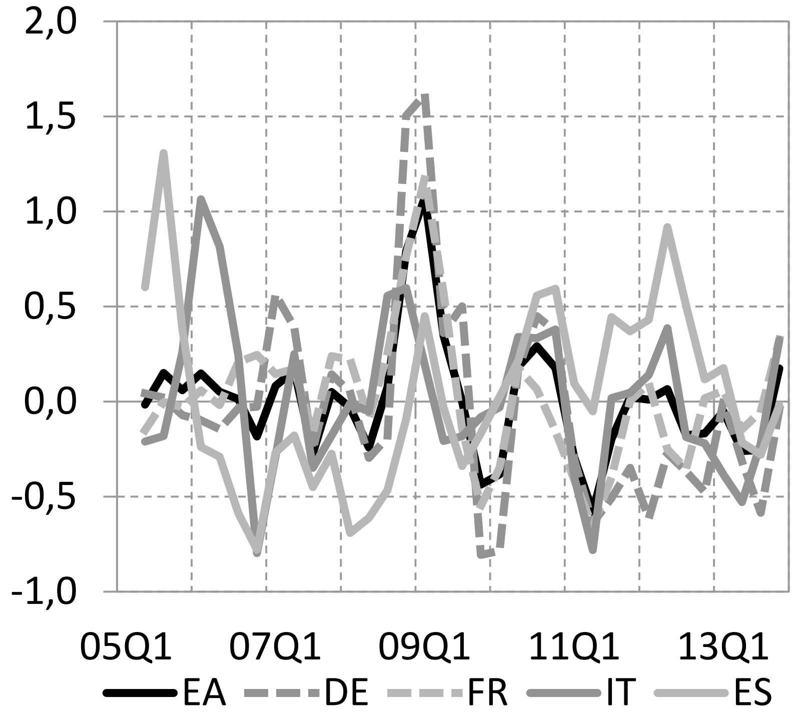

Figure 4. Estimated contribution; the annual growth of corporate lending in Germany (%)

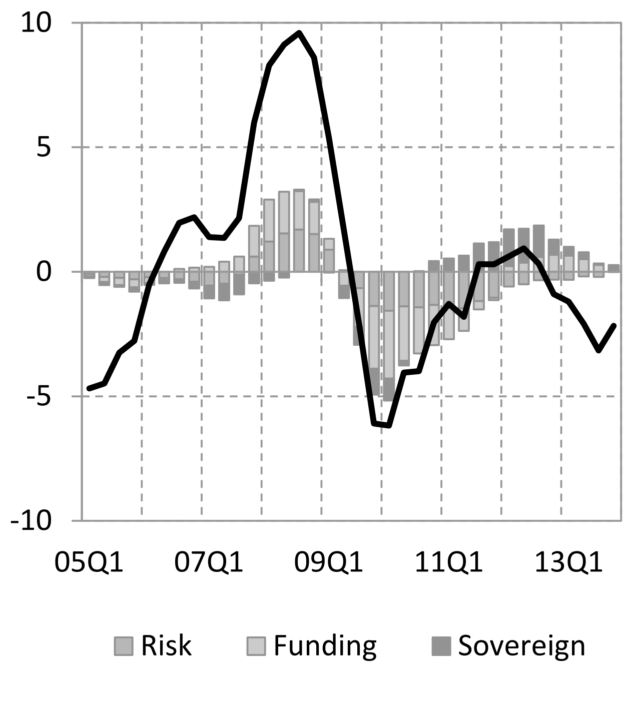

Figure 5. Estimated contribution; the annual growth of corporate lending in France (%)

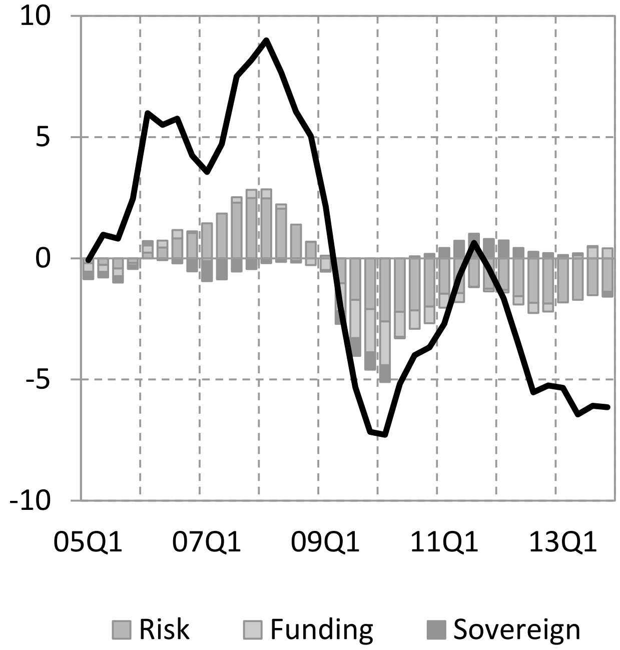

Figure 6. Estimated contribution; the annual growth of corporate lending in Italy (%)

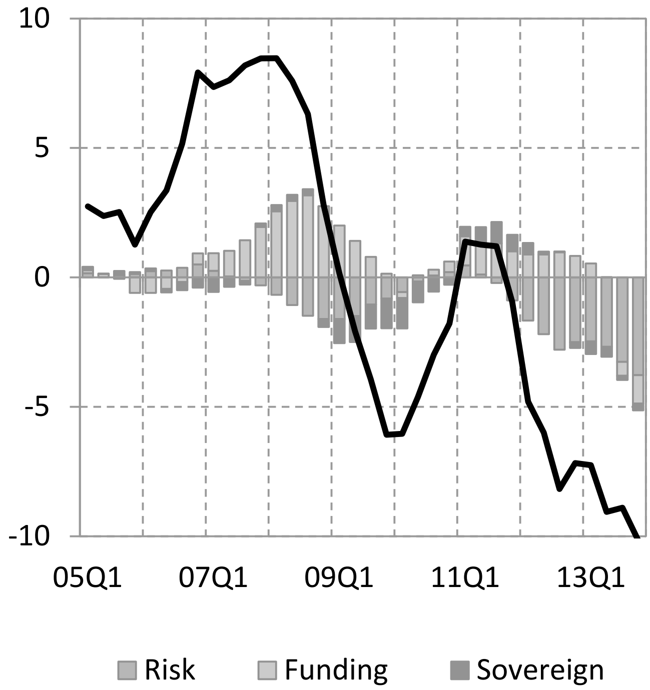

Figure 7. Estimated contribution; the annual growth of corporate lending in Spain (%)

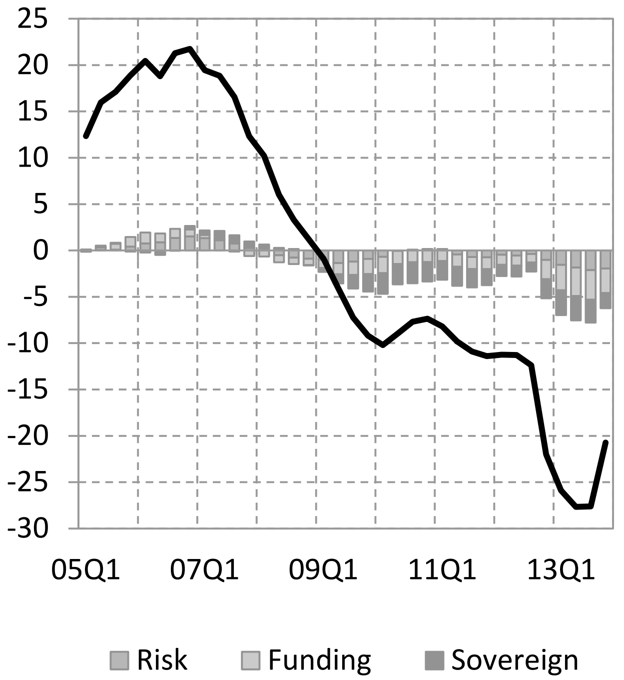

Figure 8. Estimated contribution; annual GDP growth in Germany (%)

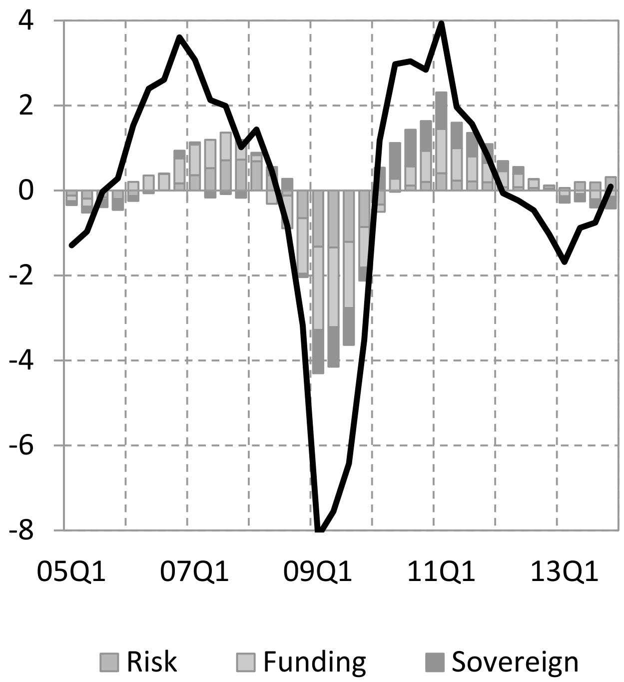

Figure 9. Estimated contribution; annual GDP growth in France (%)

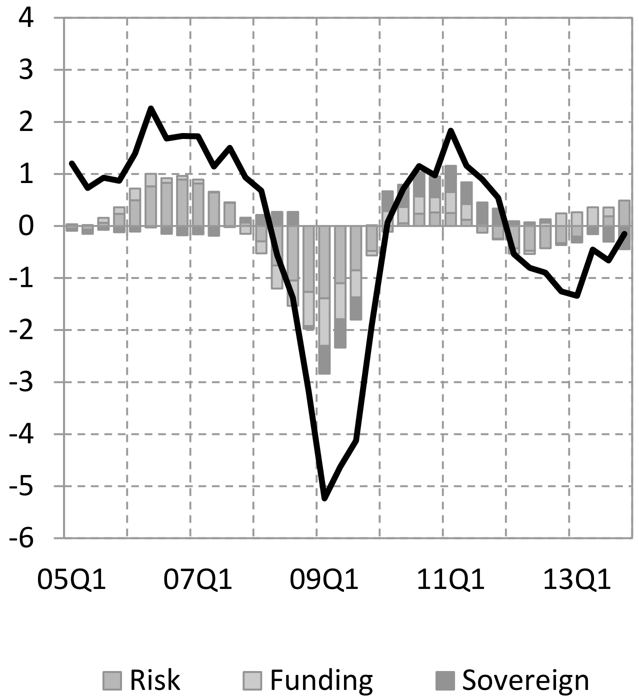

Figure 10. Estimated contribution; annual GDP growth in Italy (%)

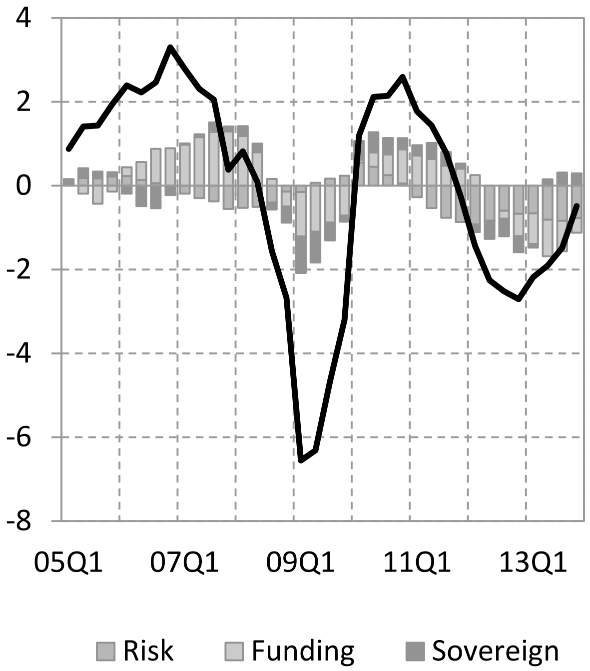

Figure 11. Estimated contribution; annual GDP growth in Spain (%)

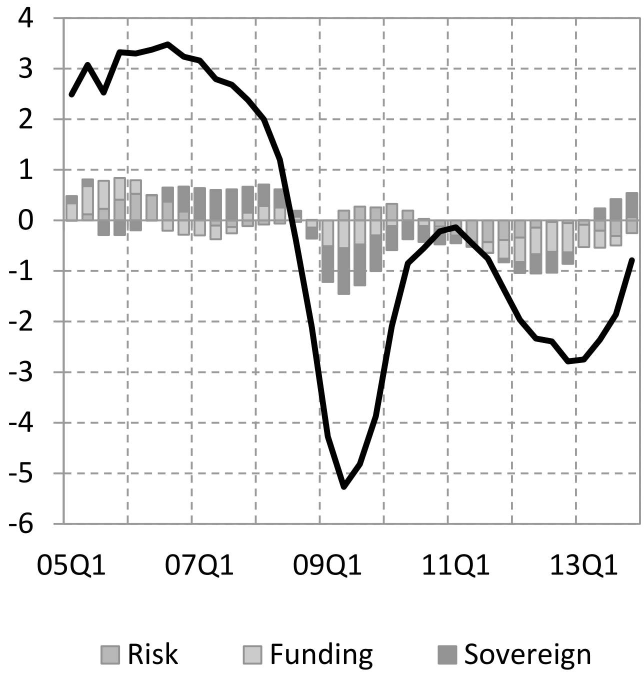

Figure 12. Estimated contribution; the annual growth of total assets in euro area (%)

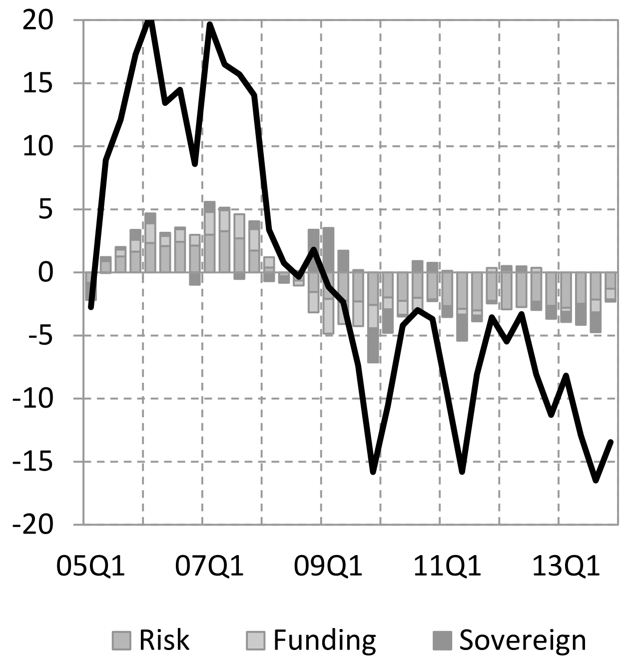

Figure 13. Estimated contribution; the annual growth of total assets in Germany (%)

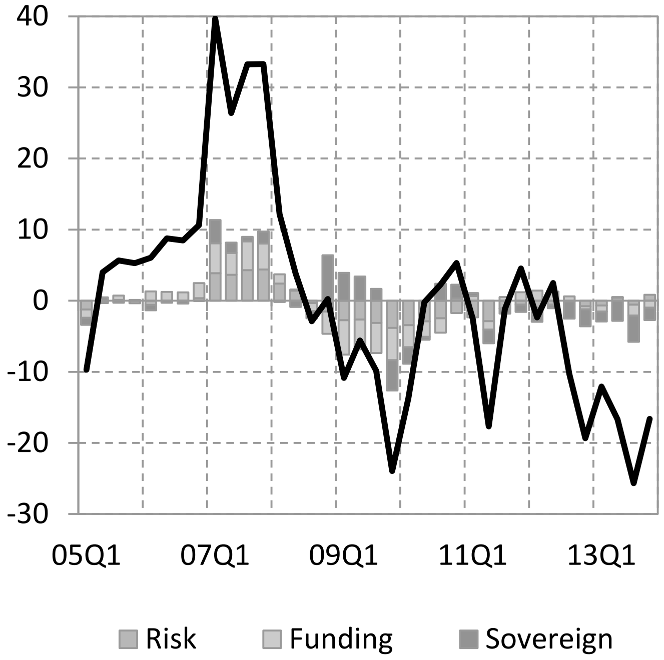

Figure 14. Estimated contribution; the annual growth of total assets in France (%)

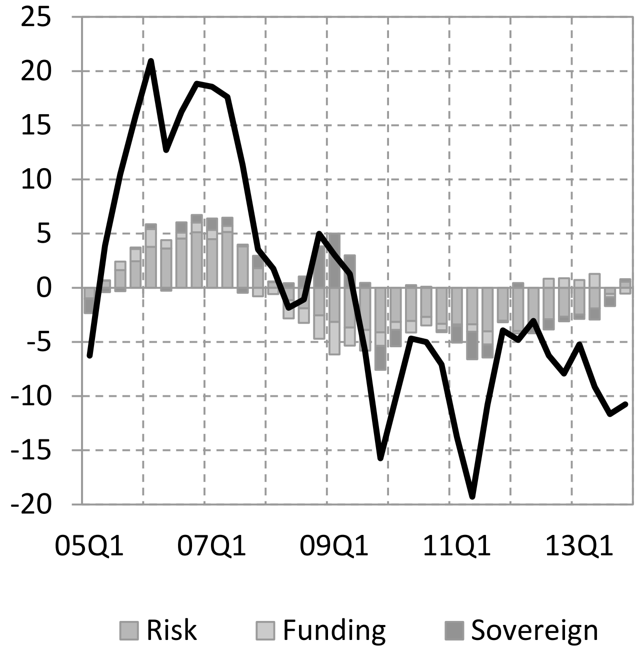

Figure 15. Estimated contribution; the annual growth of total assets in Italy (%)

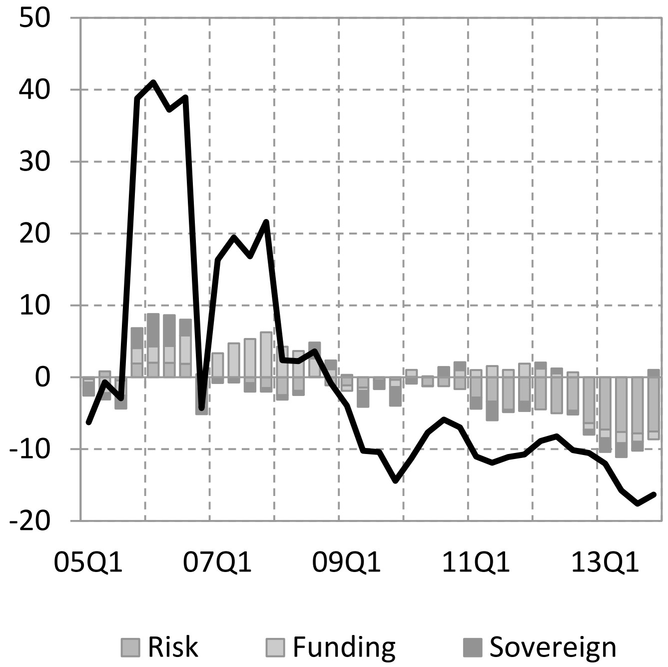

Figure 16. Estimated contribution; the annual growth of total assets in Spain (%)

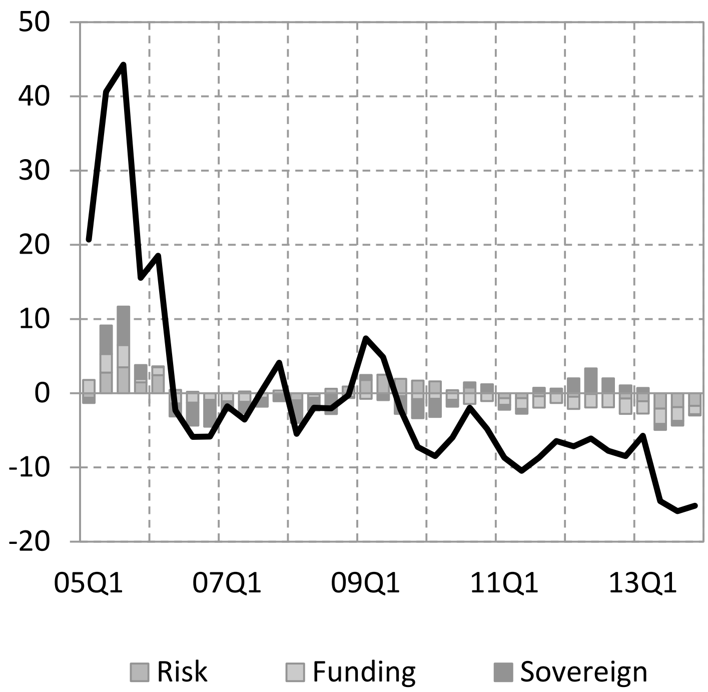

Figure 17. Estimated contribution; average return on equity in euro area (p.p.)

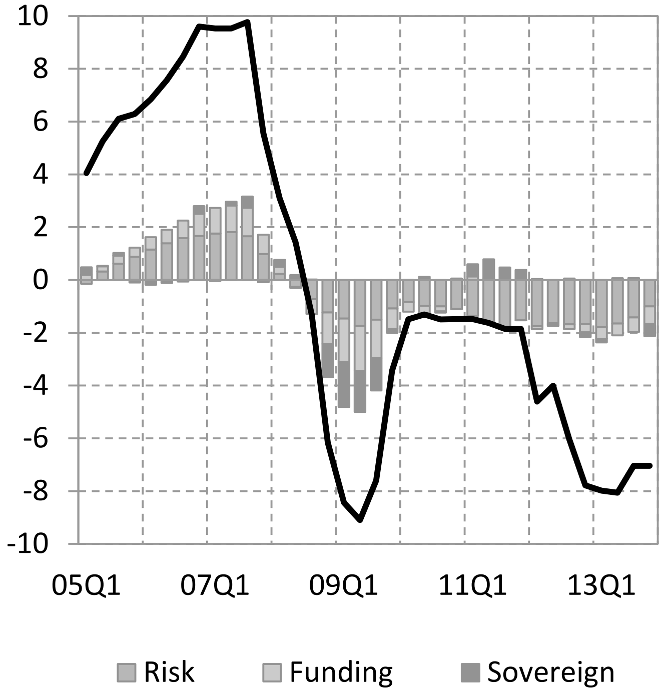

Figure 18. Estimated contribution; average return on equity in Germany (p.p.)

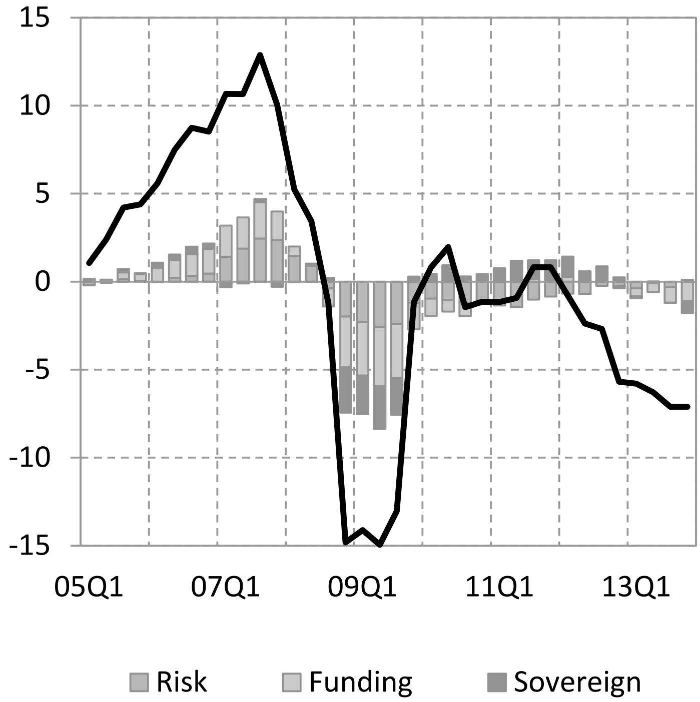

Figure 19. Estimated contribution; average return on equity in France (p.p.)

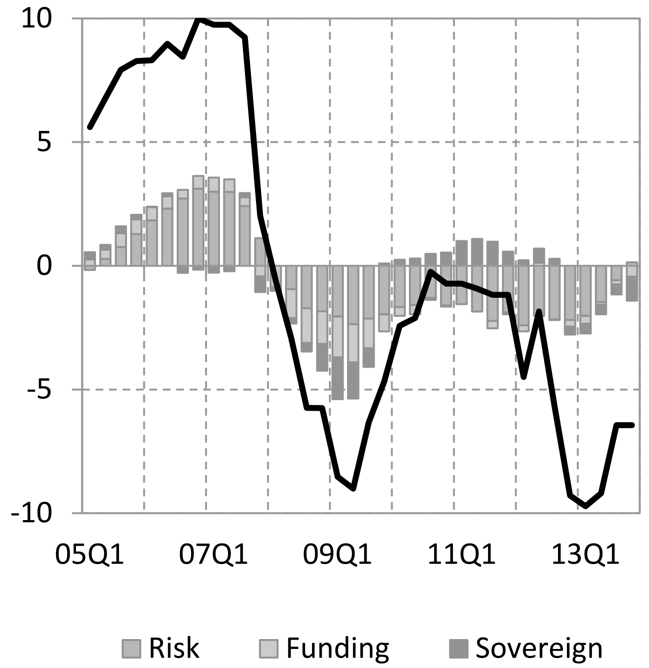

Figure 20. Estimated contribution; average return on equity in Italy (p.p.)

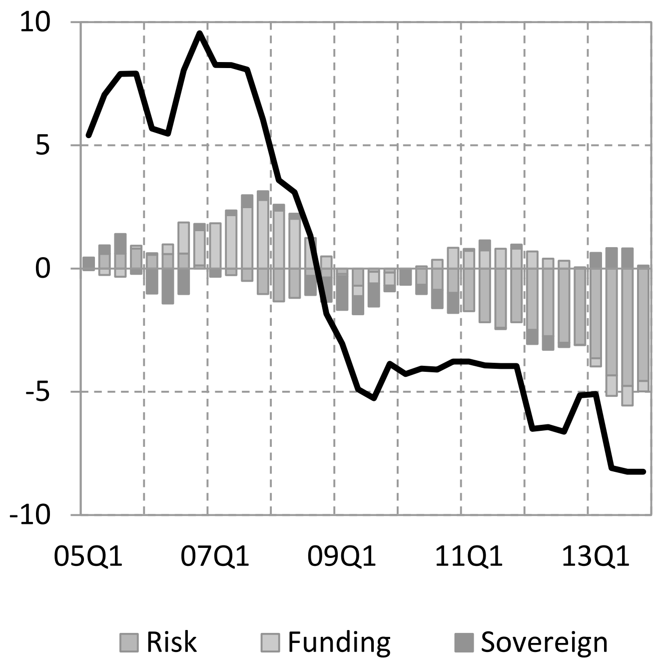

Figure 21. Estimated contribution; average return on equity in Spain (p.p.)