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Interbank Linkages and Contagion Risk in the Portuguese Banking System

Abstract

Interbank money markets play a fundamental role in financial systems but they can also be a channel through which problems in one institution can spread to the remaining ones. In particular, the potential for contagion stemming from interbank money markets is closely related with the pattern of interbank lending relationships. In this study, we characterize the Portuguese overnight interbank money market between 1999 and 2009 and analyze its inherent potential for contagion, based on bilateral interbank exposures. We conclude that: (i) the Portuguese overnight interbank money market has a multiple money center structure, where some banks have, simultaneously, an important role as lenders as well as borrowers; (ii) although unlikely, the failure of one institution can have contagion effects, pushing others into failure; (iii) however, even under the most extreme assumptions, banks that fail by contagion represent less than 10 per cent of the total banking systems assets.

JEL codes: D40, G15, G21.

Keywords: Money market, Interbank lending, Financial contagion

1. Introduction

Interbank money markets play a fundamental role in financial systems, allowing financial institutions to cope with their day-to-day cash imbalances, by borrowing and lending central bank money among themselves. But, despite its crucial role in the redistribution of liquidity, interbank lending relationships are not just a way to mitigate liquidity risk. They can also be a contagion channel through which financial problems in one bank can spread to the remaining ones. Thus, interbank lending relationships might increase the risk of contagion, i.e., the risk that one financial institution's inability to meet its required obligations will unable others to meet their own obligations when due, causing significant liquidity or credit problems. Ultimately, contagion risk can be seen as a form of systemic risk as, in case of contagion, financial instability can become so widespread that it may impair the functioning of the financial system to the point where economic growth and welfare might suffer significantly. That is why one of the prime concerns of contemporary monetary authorities is to increase system resilience to contagion risk, since it can endanger financial stability.

This dual role of the interbank money market has been especially emphasized by the subprime crisis that started in 2007. Given the resulting context of uncertainty and having asymmetric information about the solvency of their money market counterparties, banks stopped lending to each other at all but the shortest maturities (Kapadia et al., 2012), resulting from several motivations (Arinaminpathy et al., 2012), thus causing the market to become dysfunctional. As a consequence, banks highly exposed to subprime mortgages or heavily dependent on the money market funding had to be intervened by national authorities and

saved from default. Such was the case of the British Northern Rock and Bradford and Bingley, the North-American AIG, the Spanish Caja Castilla la Mancha, the Danish Roskilde Bank, and the German IKB Deutsche Industriebank, Sachsen Landesbank and Depfa Bank, just to mention a few examples.

These public rescues of distressed banks are normally justified as an attempt to contain contagion risk and ensure financial stability, thus avoiding a wide systemic crisis. Nevertheless, even if, for some, this justification is enough, for others the prevention of contagion risk may not be worth the financial costs and the moral hazard involved in public bailouts. In fact, this was the perspective underlying the refusal to bail out Lehman Brothers in September 2008. Therefore, before deciding to rescue, or not, distressed banks, national authorities should carefully balance the costs and benefits imposed by those rescues, including the potential knock-on effects that a bank's default can have on the financial health of its peers, either indirectly, via the fire-sale of assets and the emergence of credibility issues, or directly, via direct exposures arising from payment systems or from the interbank money market.

In this context, any additional knowledge about the way financial systems work and, particularly, about the different channels of contagion risk and its potential effects can be of utmost usefulness when financial instability emerges, as it happened in 2007. Following this line of reasoning, the aim of the present study is to analyze the potential for contagion stemming from a very specific source, the overnight lending relationships established in the Portuguese interbank money market, in case of a participant's default. Although this exercise has been carried out for a large set of European interbank markets, to the best of our knowledge, no similar work exists for the Portuguese case. Moreover, contrary to other

studies that focus on a single point in time, we analyze the evolution of contagion risk in the interbank overnight money market over a period of eleven years, from 1999 to 2009.

Our results are in line with the findings of previous studies on other European financial markets. We find that the Portuguese overnight interbank money market is characterized by a high exposure to cross-border counterparties and by a multiple money center market structure, where some banks play simultaneously an important role as lenders as well as borrowers. As regards contagion, although unlikely, the failure of one bank can have adverse knock-on effects, pushing others into insolvency. However, even under the most extreme assumptions, banks that fail by contagion represent less than 10 per cent of the total banking system assets. Our main conclusion is that although contagion may occur through linkages between banks operating in the money market, the impact on the banking system cannot be considered a major threat to financial stability. We argue that this resilience is explained by the underlying multiple money center structure of the Portuguese interbank money market, with only a few banks accounting for a significant part of the value of both lending and borrowing transactions, is a major factor for the dissipation of the impact of financial threats.

The remainder of the study is organized as follows. Section two reviews the theoretical literature on financial contagion, respectively, within interbank money markets. Section three presents a brief characterization of the Portuguese overnight interbank market. In section four we explain the data collection process and the filtering criteria used. In section five we explain how we investigate the contagion process between banks. Section six presents the results and section seven concludes.

2. Literature review

2.1. Theoretical perspective

Despite the important role of the overnight interbank money market in the daily funding activity of banks, the theoretical literature on this subject, in particular on the potential for contagion stemming from this market is not very extensive. There is, however, general agreement on the fact that contagion risk in the interbank money market depends on the pattern of interbank linkages, i.e., on the interbank market structure. Allen and Gale (2000) provide the theoretical foundation for this approach and argue that complete structures, where all banks are symmetrically linked with each other (see Figure 1a), are more robust to contagion than incomplete structures, where banks are linked only to a small number of counterparties. The argument is that if each bank holds deposits in all the other banks and if the market is sufficiently large, the impact of the failure of one of the banks is absorbed by a high number of banks and, therefore, each bears a small share of the shock. On the other hand, in incomplete markets, each bank has a small number of counterparties and, consequently, in case of failure, the impact is felt more strongly by each one of the other banks.

As regards incomplete markets, the extent of contagion also depends on the market interconnectedness, which can be seen as the length of credit chains. In an incomplete market with a high degree of interconnectedness, banks are linked to most other banks, either directly or indirectly, as links in a chain (see Figure 1b). In an incomplete market with a low degree of interconnectedness, there may be disconnected market segments, that is, some banks may have no links to some of the other banks, as illustrated in Figure 1c.

INSERT FIGURE 1 HERE

While in an incomplete but highly interconnected structure (see Figure 1b) a liquidity shock can spread by contagion to others because all banks are financially linked, directly or indirectly, in a disconnected structure (see Figure 1c) the extent of contagion is reduced, since a bank's default effects are confined to its segment of the market. Thus, contagion can be more limited in an incomplete and disconnected structure than in an incomplete and interconnected structure.

Like Allen and Gale (2000), Freixas et al. (2000) also argue that complete structures enhance the system's resilience to withstand shocks, whereas incomplete ones increase system fragility. Additionally, they describe a different type of incomplete market structure, a money center structure, where smaller banks are linked to a central bank, the money center, but not among them. In this case, although the problems of banks in the periphery would hardly have significant adverse spillover effects, a default by the money center bank can have negative knock-on effects on peripheral banks, thus increasing the risk of contagion. Figures 1d and 1e depict connected and disconnected multiple money centers market structures.

More recently, some authors question the view that complete markets are more resilient to contagion than incomplete ones. Brusco and Castiglionesi (2007) advocate that to attain a certain level of liquidity and assuming that there are no agency problems, in a completely connected market each bank has to exchange a smaller amount of deposits with each of its counterparties, than in an incompletely connected market. However, although this results in a higher diversification of risk and lower exposures, a bank's failure also affects more counterparties. Thus, a completely connected structure can be more conducive to contagion than a connected but incomplete one, although the costs of contagion can be higher on the

latter than on the former. Gai and Kapadia (2010) also highlight that complete markets, exhibit a “robust-yet-fragile” tendency as, while the likelihood of contagion can be smaller in this kind of markets, if it occurs, it will spread through the system more easily and reach more banks. The losses imposed by a bank’s failure can be more dispersed and hence absorbed by a wider set of banks, thus lowering the probability of contagious defaults. On the other hand, as there are more financial linkages, the chances that a bank affected by the initial failure is also exposed to other defaulting counterparties increases. Thus, even if the exposed bank survives to the initial failure, additional exposures can increase its vulnerability. Georg (2011) shows that network structures with a few highly interconnected, and many less interconnected banks turn out to be more resilient than random network structures where on average all banks have equally many interconnections.

Nier et al. (2007) argue that, depending on its pattern, interbank linkages may either act as “shock absorbers” or as “shock transmitters”. While the first effect dominates when connectivity is sufficiently high, with low levels of connectivity the “shock transmitter” effect prevails. Hence, connectivity affects the risk of contagion in a non-monotonic way: in less connected systems, a slight increase in connectivity increases the contagion effect but, after a certain threshold, it improves the system’s ability to withstand shocks. Yet, these conclusions just hold true for well-capitalized systems since, in undercapitalized ones, interbank linkages only act as shock transmitters, because, in the absence of capital, there is no absorption effect. The authors argue that adequate capital buffers tend to decrease contagion, since better capitalized banks have a higher capacity to withstand contagious defaults.

Therefore, one should keep in mind that a system’s resilience to contagion does not depend solely on the pattern of interbank linkages, but also on other aspects, such as the size

of interbank exposures, the market concentration, and the capitalization level of banks. As expected, higher interbank liabilities tend to increase the risk of knock-on defaults. Similarly, as in more concentrated systems each bank tends to become bigger, a failure might also have a more significant impact on the remaining banks than in more decentralized systems. Conversely, adequate capital buffers tend to decrease contagion, since better capitalized banks have a higher capacity to withstand contagious defaults (Nier et al., 2007). Moreover, macroeconomic shocks leading to an erosion of banks' capital buffers can thus turn the system particularly susceptible to contagion (Gai and Kapadia, 2010). Kapadia et al. (2012) claim that large, well-connected banks are key for system stability and should be subject to stricter capital level demands, consistently with Drehmann and Tarashev (2011) who find that bank size is a reliable proxy of their systemic importance,

All in all, we can state that the completeness and interconnectedness of each market structure plays a key role in the determination of its inherent potential for contagion. In particular, it seems that completeness is especially important to determine the likelihood of contagion, whereas interconnectedness determines the extent of contagion. Yet it is not clear which effects are higher: the diversification effects stemming from market completeness, which decrease the contagion risk, or the increase of contagion risk due to higher connectedness. Therefore, it is not possible to deduce the potential for contagion in a specific market solely based on theoretical premises. This highlights the importance of empirically analyzing the potential for contagion in each market, as we do in the present study.

2.2. Empirical perspective

Contagion risk in the interbank market has been widely analyzed empirically. Sheldon and Maurer (1998) and Müller (2006a, 2006b) study the contagion risk in the Swiss interbank market, and Furfine (2003) in the federal funds interbank market. Blavarg and Nimander (2002), Upper and Worms (2004), Wells (2004), Amundsen and Arnt (2005) assess the potential for contagion in the Swedish, German, British and, Danish interbank markets, respectively. The contagion risk in the Dutch, Austrian, Belgian and Italian markets is studied by van Lelyveld and Liedorp (2006), Elsinger et al. (2006), Degryse and Nguyen (2007) and Mistrulli (2005, 2011), respectively. More recently, Toivanen (2009) analyzes the Finnish interbank market and Krznar (2009) the Croatian one.

In general, these empirical analyses are based on a two-steps approach: the first step consists in determining the matrix of bilateral interbank exposures, and the second step is the assessment of the potential for contagion, based on scenarios where the impact of the default of each participant in the market is simulated, one at a time.

First step: Determining bilateral interbank exposures

The interbank market structure can be represented by a $N \times N$ matrix of bilateral exposures, where x_{ij} is the exposure of bank i towards bank j , i.e. the liabilities of bank j towards bank i , and N is the total number of banks. Each bank's total assets (bank lending) and liabilities (bank borrowing) is represented by a_i and l_j , respectively.

$$X = \begin{array}{c} \left[\begin{array}{cccc} 0 & \cdots & x_{1j} & \cdots & x_{1N} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & 0 & \cdots & x_{iN} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{N1} & \cdots & x_{Nj} & \cdots & 0 \end{array} \right] \begin{array}{l} \hline \sum_i \\ a_1 \\ \vdots \\ a_i \\ \vdots \\ a_N \\ \hline \end{array} \\ \hline \sum_j \quad \begin{array}{cccc} l_1 & \cdots & l_j & \cdots & l_N \end{array} \end{array} \quad (1)$$

The methodology adopted by the different authors to determine interbank bilateral exposures largely depends on the data available. Furfine (2003) and Amundsen and Arnt (2005) compute the matrix of bilateral exposures based on overnight loans obtained from Federal Reserve's large-value transfer system and from Denmark's gross settlement system data, respectively. However, normally settlement data is not available due to confidentiality issues. Therefore, most of the empirical literature on contagion risk relies on balance sheet data. This approach allows authors to cover all exposures arising from interbank lending and not just overnight exposures. However, balance sheet data only provides aggregate information about each bank's interbank assets and liabilities. Thus, authors have to estimate each element of the matrix of bilateral exposures.

One possible approach is the maximum entropy method, which assumes that banks spread their interbank lending equally among counterparties, maximizing the dispersion of their interbank exposures. This is equivalent to assuming a complete market structure, where banks symmetrically hold claims on each other, conditional on their size (Upper and Worms, 2004). Cocco et al. (2009) argue that the assumption of maximum entropy method might not correspond to the actual interbank lending pattern of the market, thus affecting the validity of the results. In fact, it is not realistic to assume that interbank activities are completely diversified, because due to transaction and information costs, banks may not lend to all the

other banks but just to a small number, for instance, just to the banks in the same geographical area, i.e., just to “neighboring banks” (Allen and Gale, 2000). To mitigate the drawbacks of the maximum entropy method, authors complement balance sheet data with additional information about interbank linkages reflected in large exposures or survey data. Such is the case of Wells (2004), Upper and Worms (2004), Degryse and Nguyen (2007), van Lelyveld and Liedorp (2006) and Toivanen (2009). van Lelyveld and Liedorp (2006) study the Dutch market and show that the maximum entropy method underestimates contagion effects, namely the number of failed banks and the percentage of total assets lost. Upper and Worms (2004) also conclude in the same direction. The maximum entropy method applied only to balance sheet data leads to an underestimation of the contagion effects. An opposite conclusion is reached by Mistrulli (2011), who finds that, in the Italian case, the maximum entropy method overestimates the scope of contagion, relative to the balance sheet method. Elsinger et al. (2006) also reach similar conclusions. Therefore, the maximum entropy method is not the most adequate estimate of the matrix of bilateral exposures, as it tends to bias the extent of contagion. According to Mistrulli (2011), this bias can either be negative or positive, depending on the actual interbank linkage structure, the loss given default rate (LGD) and banks’ capitalization.

We can conclude that the choice of methodology to determine the bilateral exposures represents a trade-off between the interbank exposures that each kind of data allows to cover and the information available on the interbank linkage structure. If, on the one hand, applying the maximum entropy method may bias the potential for contagion, on the other, using settlement data allows the identification of contagion risk stemming solely from a specific segment of interbank exposures. In our case, given the availability of a unique dataset – the data on the transactions settled in the Portuguese large value payment system –, we compute

the matrix of bilateral exposures based on settlement data, following the approach of Furfine (1999, 2011), as described in section four. In addition, this approach allows us to infer the actual pattern of lending relationships, which would be ruled out by the application of the maximum entropy method.

Second step: Assessing the potential for contagion

After estimating the matrix of bilateral exposures, it is necessary to assess the effect that a bank's failure may have on the entire system, that is, to analyze contagion risk. With that purpose in mind, authors tend to simulate the sudden and unexpected insolvency of each bank in the system due to an idiosyncratic shock, and verify the effect of that failure on the remaining banks. This approach raises two questions.

The first one relates to how much capital needs to be lost, for the event to be considered a failure. Kaufman (1994) argues that a bank is considered insolvent (i.e., it fails) when its losses exceed a specific capital threshold. Müller (2006a, 2006b) consider as an adequate threshold the regulatory capital holdings. Blavarg and Nimander (2002) consider that a bank fails if its Tier 1 capital ratio falls below the statutory level of 4 per cent. Degryse and Nguyen (2007), Mistrulli (2011), Wells (2004), van Lelyveld and Liedorp (2006) and Krzmar (2009) consider that a bank fails if losses are higher than its Tier 1 capital. Sheldon and Maurer (1998) assume that a bank is insolvent if the return on assets falls below a default threshold defined by the ratio of overheads² to total assets and by the capital-to-assets ratio. For Toivanen (2009) and Amundsen and Arnt (2005), a bank fails if its solvency ratio falls below 8 per cent. So, there is no generally consensual threshold. The second question is related to the LGD rate imposed by a bank's default, i.e., the share of assets that are not

² Taxes plus expenses on personnel, materials and office space.

recovered by creditor banks. James (1991) reports that, in the United States, in the mid-1980's, the average loss was 30 per cent of the assets of the failed bank, without taking into consideration administrative and legal costs. On the other hand, Upper and Worms (2004) point out the failure of Herstatt bank, which defaulted in 1974. Its creditor banks have by now recovered 72 per cent of their assets. They also refer the case of Bank of Credit and Commerce International (BCCI) that failed in the early 1990's and although creditors were expecting losses up to 90 per cent, they ended by recovering more than half of their deposits, though many years later. Given the uncertainties about the LGD rate related to the fact that the share of assets recovered can be influenced by several factors such as the availability of collateral or the hypothesis of bailouts, most authors assess the losses imposed by a hypothetical process of contagion using different values for this parameter (Upper and Worms, 2004; Degryse and Nguyen, 2007; Mistrulli, 2011; Blavarg and Nimander, 2002; Wells, 2004 and Toivanen, 2009).

Some empirical results

Notwithstanding the drawbacks of the methodologies, it is possible to draw some conclusions from the set of empirical studies, about: (i) the inherent contagion risk in each market and, in some cases, (ii) about the importance of the pattern of interbank linkages as a determinant of the extent of contagion.

As regards to the first issue, although contagion may occur, its impact on the banking system differs from market to market. Upper and Worms (2004), study the German interbank market, and conclude that a bank insolvency has almost always knock-on effects, mainly on small banks. Although those knock-on effects typically account for less than one per cent of

total banking system assets, large scale contagion may occur if the LGD rate is above 40 per cent. Müller (2006a) finds that there is some potential for contagion in the Swiss interbank market since a default situation can trigger the insolvency of nine per cent of the Swiss banks, accounting for three per cent of the total banking sector assets. Sheldon and Maurer (1998) also analyze the Swiss interbank market and conclude that contagion effects exist, but are small. In the Finnish interbank market, Toivanen (2009) finds that although contagion is considered a low probability event, it may occur in a large scale. In the British interbank market, Wells (2004) finds that in the worst-case scenario with a 100 per cent LGD, knock-on effects can trigger the failure of banks representing more than one quarter of the banking system assets. Even if banks do not fail, a single bank insolvency can lead banks accounting for over half of total banking system assets to suffer losses exceeding 10 per cent of their Tier 1 capital. Nonetheless, contagious bank failures are rare and with LGD rates below 50 per cent less than 1 per cent of total banking system assets are affected by contagion. Elsinger et al. (2006) find that the Austrian banking system is very stable and default events are unlikely. The median default probability of an Austrian bank is below 1 per cent and the vast majority of defaults are due to macroeconomic shocks instead of interbank contagion. In the Belgian interbank market, analyzed by Degryse and Nguyen (2007), even with a 100 per cent LGD rate, from the 65 domestic banks in the system, only four large banks are contagious and none of them are able to trigger the failure of another domestic bank. Actually, even in the worst-case scenario, the banks that lose their Tier 1 capital never account for more than 3.8 per cent of the system total assets. On the other hand, the default of some large foreign banks can trigger significant domino effects by causing the failure of seven domestic banks, accounting for 20 per cent of the system total assets. Thus, the increase in cross-border exposures lowers the risk of contagion stemming from domestic banks but increases the risk deriving from

foreign ones. The same holds true for the Dutch interbank market (van Lelyveld and Liedorp, 2006). In the remaining banking systems analyzed, although financial contagion due to exposures in the interbank money market may also occur, it does not seem to represent a big threat (Furfine, 2003 and Mistrulli, 2011).

As regards the second question, i.e., the importance of the pattern of interbank linkages as a determinant of the extent of contagion, conclusions are also not completely consensual. Upper and Worms (2004) and van Lelyveld and Liedorp (2006), analyze the German and the Dutch interbank markets, respectively, and find that the likelihood of contagion is smaller in a complete market. Furthermore, Upper and Worms (2004) conclude that the largest contagion effects occur when a money center bank fails. Müller (2006a, 2006b) highlights the significant impact of the pattern of interbank linkages on system resilience against spillover effects. She concludes that centralized markets are more prone to contagion than homogeneous ones. Wells (2004) analyses the potential for contagion in the United Kingdom's interbank market under different market structures and concludes that different interbank structures do imply different levels of contagion. The majority of failures occur as a first-round effect (i.e., as direct effect of the initial failure) and only affects small banks. The author also finds that, even though contagion is more severe on a money center structure than on a complete one, the contagion effects on a more incomplete structure are lower than in a complete one. Mistrulli (2005) also finds that the change in the interbank market structure from an almost complete one to a multiple money center, due to financial consolidation, is accompanied by an increase in the risk of contagion. Conversely, in the Belgian interbank market, its evolution from a complete structure to a more concentrated one (a multiple money center) was accompanied by a decrease in the risk and impact of contagion (Degryse and Nguyen, 2007). A possible explanation for these contradictory results may lie in the trade-off

between completeness and interconnectedness. In fact, in the Italian interbank market the increase in the risk of contagion, due to the decrease of market completeness, might have overcome the reduction in the extent of the contagion, due to the decline in market interconnectedness. The opposite applies to the Belgian interbank market: the decrease in market completeness amplified the potential for contagion, but the decline in market interconnectedness overcomes the first effect.

To sum up, some studies partially corroborate the theoretical findings of Allen and Gale (2000) and Freixas et al. (2000), since more concentrated markets are more vulnerable to contagion (Upper and Worms, 2004; van Lelyveld and Liedorp, 2006; Müller, 2006a, 2006b; Mistrulli, 2005). However, complete structures are not always less conducive to contagion. Furthermore, the extent of contagion in incomplete market structures, such as money center structures, depends on the trade-off between market interconnectedness and completeness. Indeed, as highlighted by Nier et al. (2007), tiered structures are not necessarily more prone to contagion. It depends on the connectivity of the money center bank. If connections to the money center are significant enough, that could lead to shock dissipation as in highly connected (and complete) markets.

3. The Portuguese interbank market

The Portuguese overnight interbank market has changed significantly between 1999 and 2009, especially concerning the amount of funds traded, market concentration, the number of participants, and the pattern of interbank lending relationships, as analyzed below.

Between January 1999 and December 2009, the TARGET Portuguese component³ settled around 320,000 overnight money market operations (including advances and repayments) in the value of € 23,363 billion. From those, € 11,685 billion represented loans granted⁴. As Figure 2 reveals, the period between 2003 and 2006 was marked by the greatest expansion of the overnight interbank money market. On average, until 2002, around € 2,425 million of funds were bought and sold per day. Between 2003 and 2006, that value more than doubled, amounting to € 5,685 million. From 2007 onwards, and until the first half of 2009, the overnight interbank market suffered a clear break, as the average amount traded per day did not exceed € 4,048 million. However, in the last half of 2009, the average amount of loans traded per day increased again, to € 5,417 million, as a result of a surplus on banks' liquidity arising from the measures taken by the Euro system after October 2008, in the context of the "enhanced credit support" to the European banking system.

INSERT FIGURE 2 HERE

It is also worth highlighting that, except for the last half of 2009, most of the operations held were cross-border, between a national and a foreign bank. In fact, until June 2009, cross-border loans accounted on average for 77 per cent of the total value of the overnight loans settled per month. In the last half of 2009, that share was only 33 per cent. In the second half of 2009, due to the measures taken by the Euro System within the framework of the enhanced

³ TARGET is the real-time settlement system for the euro. Its first generation started on 4 January 1999, following the launch of the Euro. It was composed of 17 national real-time gross settlement systems plus the ECB payment mechanism (EPM). In 2008, after a six-month migration phase, this first generation was replaced by TARGET2, the second generation of the system. Although based on a centralized technical platform, legally TARGET2 is still composed by the different national components of the participating countries (European Central Bank, 2009c). In our study, "TARGET Portuguese component" refers to the Portuguese component on both the generations of the system.

⁴ The remaining value corresponds to the respective loans repayments.

credit support to the banking system and the consequent liquidity surplus, there was a sharp increase in loans between Portuguese counterparties, with a monthly average of € 81,848 million, while the corresponding value of cross-border loans did not exceed € 26,378 million.

The average value of the loans has also followed the same trend. While in 1999 the average value of the loans was around € 29 million, in 2002 it reached € 57 million and between 2003 and 2006 it almost doubled, ascending to € 99 million. Between 2007 and the first half of 2009, there was a slight decrease in the average value per loan (to € 80 million), but in the last half of 2009 it reached the historical maximum of € 128 million.

Another remarkable aspect about the Portuguese overnight money market is the high concentration on the lending side, despite the relative dispersion among borrowers. Indeed, during the sample period, while the five and ten major lenders were responsible on average for 65 per cent and 78 per cent of the total amount lent each year, respectively, the five and ten major borrowers accounted on average for only 35 per cent and 47 per cent of the total amount of funds borrowed (see Table 1)..

INSERT TABLE 1 HERE

Regarding the group of lenders, its composition during the sample period was always very stable. One bank remained as the most important lender during the eleven years analyzed, being responsible on average for 30 per cent of the total loans granted each year. Three other banks remained always in the top ten lenders during the sample period and were, on average, responsible for around 16, 7 and 6 per cent of all loans granted in each year, respectively. Regarding the group of major borrowers, except for the 2004-2006 period, when the borrowing side of the market was dominated by foreign banks, in the remaining years a

subset of Portuguese banks had always a prominent role in the market, playing the roles of both major lenders and major borrowers, in what can be described as a multiple money center banking structure.

During the sample period, 772 different banks participated in the overnight money market on at least one day, either as lender or borrower. From those, 69 were national and the remaining were foreign (91 per cent). Nevertheless, 678 were present in the market only once. On the other hand, 61 banks were present in the market more than one quarter of the period, and 27 were there more than 50 per cent of the days. The number of banks participating in the market in each year gradually decreased to less than half. While in 1999, 433 banks participated in the market at least once (374 foreign), in 2009 that number only included 201 banks (171 foreign). This significant reduction can be explained by several restructuring and consolidation processes that occurred in this period. Indeed, as pointed out by Barros et al. (2010), in 2000 only, there were several consolidation moves involving four of the seven major financial Portuguese groups.

To analyze the pattern of interbank lending relationships, we use some useful measures drawn from Graph theory, following a growing literature that applies this approach to depict and analyze financial systems, namely Boss et al. (2004), Müller (2006a, 2006b), Soramäki et al. (2007), Georg (2011) and Arinaminpathy et al. (2012).

In order to analyze the interbank lending relationships in the Portuguese overnight interbank money market, we represent it as a network, where banks are nodes and the interbank lending relationships are the links between them. In our study, we model each day as a separate network, resulting in 2815 daily networks. Each lending relationship represents a directional link from the lender to the borrower and is weighted by the value of loans between them. A link between two banks in a given day, means that there was at least one

interbank loan between them, on that day. Over the sample period there was a total of 4,854 different direct links⁵ established in the Portuguese overnight money market. Nevertheless, 93 per cent of the links occurred in less than 100 days and 25 per cent occurred in just one day. Only two links occurred more than 50 per cent of the days, and they were both between banks from the same financial group. Moreover, as a consequence of the reduction in the number of active banks in the market per year, there was also a sharp reduction in the number of links. Actually, between 1999 and 2009, the number of directed links per year dropped by 69 per cent, from 2,192 to 671.

The number of links relative to the number of possible links, given the number of nodes, is a measure of the degree of completeness of a network. It varies between zero, for completely disconnected networks, and one, for complete networks. The Portuguese overnight interbank market was extremely sparse as, on average, the degree of completeness did not exceed 2 per cent. This means that 98 per cent of the potential links were not used. The maximum degree of completeness (2.4 per cent) was achieved in 2009, due to the sharp reduction in the number of active banks in the market (See Table 2).

INSERT TABLE 2 HERE

To summarize, it is possible to identify three distinct phases in the Portuguese overnight money market between 1999 and 2009. First, an “adaptation phase”, from 1999 to 2002, marked by the restructuring processes held in this period, both at national and European level, and also by the integration in the European Monetary Union, which allowed the access to wide funding sources as well as wide investment opportunities. The second phase, between 2003 and 2006, are the “peak years of the Portuguese interbank money

⁵ Each direct link is counted on both sides.

market". In 2007, a new phase in the money market started to emerge as a result of the financial turmoil. The amount of funds traded started to decrease and the national segment of the market increased in participation. This trend culminated in the actual shutdown of the interbank market following the failure of Lehman Brothers in September 2008. In an attempt to control the situation, the Euro system enhanced its intermediation role in the Euro area money market by providing unlimited liquidity to the banks that needed it, and receiving deposits from banks with liquidity surpluses. In the Portuguese case, liquidity surpluses predominated as there was an unprecedented application of funds in the central bank overnight deposit facility.

Despite the different phases that the overnight money market went through during the period 1999 to 2009, it has been always characterized by an underlying multiple money center structure, evident both in the number of days that each bank was in the market and in the level of market concentration, in terms of lending and borrowing. Moreover, the degree of completeness of the market during the sample period was very low. These results are in line with Craig and von Peter (2010), who claim that interbank markets are sparse and tiered⁶, mostly functioning between a reduced number of core banks, which act both as lenders and borrowers.

4. Data

To analyze the contagion risk in the Portuguese interbank market we use a unique data set provided by the Payment Systems Department of Banco de Portugal, which contains

⁶ Tiering occurs when the market is organized in layers as, instead of participating in the market directly, banks use other banks as intermediaries. In other words, tiering arises when some banks (on the upper tier) intermediate between others (on the lower tier), that simply participate in the market via the upper tier banks (Craig and von Peter, 2010).

information about all operations settled through the TARGET Portuguese component between 1999 and 2009. TARGET is the Euro system's real-time gross settlement system and is normally seen as the "backbone" of the Euro financial infrastructure. It allows the settlement in central bank money, in real-time, of every kind of transaction in a fast and reliable way. Most important, it reduces systemic risk as, once settled, all transactions are final and irrevocable.

Since the aim of our study is to analyze the exposures in the Portuguese overnight interbank market, to distinguish overnight loans from the remaining transactions settled via TARGET, we have applied the search procedure described by Furfine (1999, 2001). This is a two-step procedure. First, we identify "candidate" transactions to qualify as interbank loans in day d ; second, we look for the respective repayments in the following business day ($d+1$). This has to be a payment between the same counterparties but in the opposite direction and involving a slightly large amount, the difference being the accrued overnight interest. Additionally, the implied interest rate has to be within a reasonable range.

Regarding the first step, following Farinha and Gaspar (2008), who also apply this procedure to the Portuguese TARGET data, we identify candidate transactions as those above a minimum threshold amount of €100,000 and in round lots.

In the second step, the main issue is to decide what the reasonable range for the interest rate is. We start by allowing the interest rates to fluctuate within an interval defined by the official interest rates fixed by the ECB council for the Euro system's standing facilities: the marginal lending facility and the deposit facility. It is important to note that the standing facilities interest rates should be a reference for the interbank money market interest rates since, at least theoretically, banks have no motivation for lending below the overnight deposit interest rate, or borrowing above the marginal lending facility interest rate. Nevertheless,

intra-group loans might have smaller interest rates. Moreover, since loans from the Euro system have to be fully collateralized, banks can find it preferable to pay an interest rate slightly higher than the marginal lending facility interest rate. Allowing for this, we run the procedure using alternative limits for the interest rate range, defined by the EONIA⁷ plus and minus 100 basis points and the EONIA plus and minus 50 basis points. The value and volume of transactions identified with these different intervals are not significantly different from the ones obtained with the interval defined by the standing facilities interest rates. In the end, we decide to use as upper limit the marginal lending facility interest rate, or the EONIA plus 50 basis points, if wider, and, as lower limit, the overnight deposit interest rate, or the EONIA minus 50 basis points, if lower, since this was the range that enabled us to achieve the most accurate results.

In addition to the need of establishing a reasonable range for the interest rates, Furfine's procedure has some other caveats. First, it fails to identify operations made through correspondents⁸ or other large value payment systems, like EURO1, the net clearing system of the European Bankers' Association and the main competitor with TARGET. Second, it does not allow the identification of overnight operations where principal and interest are paid separately or when several initial loans are repaid through a single repayment. Despite these caveats, there is no doubt that Furfine's procedure allows the identification of interbank exposures, mainly unsecured, stemming from the overnight money market. Indeed, in addition to the in-depth analysis about the Portuguese banks participation on the euro money market between 1999 and 2005, a major contribution from Farinha and Gaspar (2008) is precisely the assessment of Furfine's procedure accuracy on the identification of overnight

⁷ EONIA (Euro OverNight Index Average) is an effective overnight interest rate computed as a weighted average of all overnight unsecured lending transactions in the interbank market.

⁸ Since operations made through correspondents are recorded just in the correspondent bank books (in the debtor's and creditor's accounts with the correspondent) and not in the central bank books.

money market operations. The authors test the algorithm adequacy by comparing the results obtained with the application of the procedure to the Portuguese TARGET data and the actual interbank money market operations recorded in SITEME, the Portuguese market electronic payment system. They conclude that the procedure allows an accurate identification of 95 per cent of the overnight money market transactions.

Millard and Polenghi (2004) and Amundsen and Arnt (2005) also report the successful identification of overnight operations using Furfine's procedure. They apply it to settlement data from the British Clearing House Automated Payment System (CHAPS), the Danish large value payment system (Kronos), and the Dutch TARGET component, respectively.

5. Methodology

Following the approach adopted by previous empirical studies on financial contagion, we measure the contagion risk stemming from overnight lending in the Portuguese interbank market by performing a scenario analysis where each bank is left to fail at once due to a sudden, idiosyncratic and exogenous shock. Then, we estimate the knock-on effects on the remaining participants using different recovery levels.

Hence, given the initial failure of a particular bank, any creditor bank that has an exposure to the failed bank larger than its capital (which represents each bank's capacity to withstand shocks) is also considered insolvent. To put it differently, given the matrix of bilateral exposures, bank i is considered insolvent if

$$LGD(x_{ij}) > c_i \quad (2)$$

where LGD is the loss given default rate, i.e., the loss rate imposed to bank i by the default of bank j , x_{ij} the exposure of i towards j and c_i , the capital of bank i . Bank i default is a first

round failure. Second round failures occur if, given bank Z , its combined exposure to all the first-round failures exceeds its capital, i.e., if

$$LGD(x_{Zj} + x_{Zi}) > c_Z \quad (2)$$

The process is iterated until there are no additional failures. The chain of failures triggered by the initial failure is the “domino effect”, which can persist for several rounds.

Following previous studies (van Lelyveld and Liedorp, 2006; Mistrulli, 2011; Wells, 2004; Toivanen, 2009), to measure the potential for contagion we need to assume that: (i) The time span between the increase of debtors’ credit risk and their failure is too short for creditor banks to react, for instance, by decreasing their exposure to the affected bank or by raising capital to compensate for the losses suffered; (ii) The LGD rate is constant across banks and over time; therefore, it does not reflect an increased risk awareness following the initial default nor banks’ heterogeneity; (iii) The analysis focuses on the propagation of shocks among domestic banks, due to domestic or foreign shocks. Since we do not have information about capital buffers nor interbank lending relationships with foreign banks, we are not able to measure contagion between them. As a result, in our analysis foreign banks can only cause contagion by acting as the source of the initial shock, never can never fail by contagion. This might underestimate contagion risk since spillover effects of a domestic failure on foreign banks and the possible repercussions of those effects on the domestic market are not taken into consideration. However, these underestimation effects can be offset by the overestimation implied by assumptions (i) and (ii) since, in practice, it is more common that banks experience a gradual weakening rather than a sudden failure. Therefore, their counterparties can prevent losses by taking corrective actions (Wells, 2004). For instance, they can fix the rates charged on the interbank loans granted or even alter their

degree of participation in the market (Iori et al., 2006). Moreover, we also assume that the Central Bank, due to its role as last resort lender, never fails.

To sum up, there are four key elements in this contagion process that determine the severity of the spillover effects stemming from a bank's failure: its assets' structure, its liabilities' structure, the level of capital, and the LGD rate imposed to its creditors (Wells, 2004). The assets' structure determines whether or not the bank is affected by the previous default of another bank. The level of capital defines the relative strength of each bank to support losses. If the bank has enough capital to support the losses without jeopardizing its counterparties, it can even stop the contagion process. On the other hand, if losses are higher than the bank's capital, thus pushing it into default, that will amplify the dynamics of the contagion process, since the shock transferred to other banks congregates the spillover effects not only from the initial failure, but also from this second failure. The way the shock is transferred, and to whom, depends on the interbank liabilities structure. The LGD rate determines the impact of the shock transmitted to creditors and, as most part of the studies highlight, the danger of contagion is crucially dependent on the assumed LGD rate, i.e. the losses experienced by the creditor bank in case of insolvency of the debtor bank.

In our study, the assets and liabilities of each bank within the framework of the overnight interbank money market are provided by the matrix of bilateral interbank exposures computed from the information obtained through the application of Furfine's procedure to the TARGET settlement data, as explained previously. The information about banks' capital level was obtained from the Portuguese bankers' association (Associação Portuguesa de Bancos). Therefore, we gather all the necessary elements to simulate the contagion process, except for the LGD rate, which has to be defined as an assumption. Given the uncertainty involving the losses imposed to other banks due to one of their peers' failure, we decide to

run the contagion process assuming four different LGD rates: 25 per cent, 50 per cent, 75 per cent and 100 per cent. Our results are presented in the next section.

6. Results

A general result from our contagion simulations is that, even though it can materialize in a few scenarios, the risk of contagion stemming from the interbank market never represented a significant threat to the Portuguese financial system and it has even decreased over the sample period 1999-2009.

As shown in Table 3, from the 190 possible scenarios of contagion that existed on average per year, even assuming a LGD rate of 100 per cent, contagion could have only occurred in 3.2 per cent of the cases. If we assume a more reasonable LGD rate, such as, for instance, 75 per cent, contagion could have occurred in just 2 per cent of the cases. With a 25 per cent LGD rate, contagion hardly occurs. These results are similar to the ones obtained by van Lelyveld and Liedorp (2006), Degryse and Nguyen (2007) and Mistrulli (2011), who also found that, for LGD rates below 75 per cent, contagion is unlikely.

INSERT TABLE 3 HERE

When contagion could have occurred, assuming a median scenario and any LGD rate, banks' failings were never more than 3 and never represented more than 2.6 per cent of the total banking system assets. As shown in Table 3, except for the years 1999, 2003, 2004 and 2006, assets represented by the failing banks never exceeded half per cent of the total banking system assets. It should be noted that, following Degryse and Nguyen (2007), our median

scenario represents the average impact across all the scenarios where contagion could have occurred, expressed as the average percentage of total banking systems assets represented by (and the average number of) failed banks per scenario.

Yet, in the worst-case scenario under contagion (i.e., the scenario among the ones where contagion occurs for which the share of the total banking system assets represented by the failing banks is higher), and assuming a 100 per cent LGD rate, the impact of contagion could have had a more significant effect. In fact, as shown in Table 3, in some cases the percentage of banking system assets affected could have surpassed 5 per cent. For instance, in 1999, 2003, 2004 and 2006, the percentage of the total banking assets represented by the failing banks reached 5.9, 8.6, 9.8 and 7.2 per cent, respectively. Nevertheless, we should keep in mind that these results just hold true for the worst-case scenario and assuming a 100 per cent LGD rate, which is an extreme assumption. In addition, 2003-2006 was the period when interbank exposures were also higher, as discussed in section 3. Moreover, as Figure 3 illustrates, bank's capital levels have increased substantially from 2004 onwards, thus increasing the median buffer available per bank to withstand shocks.

INSERT FIGURE 3 HERE

As a result of the reinforcement on capital levels, the proportion of exposures representing more than 20 per cent of capital declined, with the corresponding increase in the proportion of exposures that represent less than 10 per cent of banks' capital (see Figure 4).

INSERT FIGURE 4 HERE

The increase in banks' capital contributed to a substantial decline in the severity of contagion effects throughout the time, measured as the percentage of banking system assets represented by the failing banks, as graphically shown in Figure 5.

INSERT FIGURE 5 HERE

In 2008 and 2009, with the decrease in the money market activity and the reinforcement of the average capital levels per bank, even in the worst-case scenario assuming contagion, banks failing by contagion would represent a negligible share of the total banking system assets (not exceeding half per cent).

The potential for contagion can also be expressed by the number of banks whose default causes at least another bank's failure (contagious banks). As presented in Table 4, the high number of contagious banks in 1999 and 2000 (10, if we assume a 100 per cent LGD rate), decreased sharply in 2001 and 2002 (when there were just 5 contagious banks). With the exception of 2003 and 2004, when it almost reached the 1999 and 2000 levels, the number of contagious banks remained relatively constant until 2009 (averaging 5, considering a 100 per cent LGD rate). However, it is important to highlight that, as shown in Table 4, most of the exposed banks in the overnight interbank money market over the sample period are contagion proof-banks, i.e., they never fail, irrespective of the LGD rate assumed and of the defaulting bank. On average, contagion-proof banks always account for more than 82 per cent of the banking system total assets.

INSERT TABLE 4 HERE

Wells (2004) argues that even if a bank does not fail, the losses suffered can deteriorate its financial health and trigger rating downgrades, collateral calls or even turn it unviable. Therefore, in addition to the number and share of assets represented by failed banks, another important measure of the potential impact of a bank failure on the banking system is its spillover effect on other banks' capital (i.e. their capital loss), even if the latter do not fail.

INSERT FIGURE 6 HERE

As Figure 6d illustrates, the worst-case scenario (insolvency) does not always occur when there is contagion. In 2001, 2005 and 2007, although no contagious failures would have happened, the default of a given counterparty could have imposed losses above 25 percent of capital on banks representing around 5, 8 and 9 per cent of the total banking system assets, respectively (under the assumption of a 100 LGD rate). It is also noteworthy to highlight that in the situations where contagion could have occurred (and irrespective of the loss rate assumed), the contagious banks were mainly national ones. The analysis of the worst-case scenario also highlights the decrease of the spillover effects' severity stemming from a given counterparty default over the sample period. Indeed, assuming a LGD rate of 100 per cent, in the worst-case scenario, in 1999, a counterparty failure could have affected 33 banks, representing about 84 per cent of the total banking system assets, and almost half of them would lose more than 25 per cent of their capital. In 2009, that effect would be felt just by 6 banks, most of which would lose less than 25 per cent of their capital. The conclusions are similar if we assume a loss given default of 25 per cent, 50 per cent or 75 per cent, as shown in Figures 6a, 6b and 6c, respectively.

To sum up, contagion risk in the overnight interbank money market is a very low probability event and, even if it had occurred between 1999 and 2009, it would not have led to the collapse of the Portuguese banking system. Yet, it is possible to observe a change over time in the possible impacts of contagion. Thus, in case of contagion, in the worst-case scenario, it could have had sizable effects in 1999 and also in 2003, 2004 and 2006. As we have seen in section 3, the Portuguese banking system went through a profound restructuring process between 1999 and 2002, which can justify the decrease in the potential for, and severity of, contagion in the period after 2001. On the other hand, the increased effects of contagion in 2003, 2004 and 2006 can be explained by the fact that these were the years when the interbank money market most expanded, particularly concerning cross border activity. In our opinion, the underlying multiple money center structure of the Portuguese interbank money market contributed to maintain the potential effects of contagion at relatively low levels. These conclusions are in line with Degryse and Nguyen (2007), who have similar findings for the Belgian interbank market, which can also be described as a multiple money center.

7. Conclusions

Despite the deep commitment of public authorities central banks to ensure financial stability, this stability can be affected by events such as the recent the subprime crisis and the undergoing sovereign debt crisis, and has happened many times, in different times and region of the world. Financial instability can be exacerbated by contagion effects between financial banks. Therefore, it is important to understand if, given the structure of financial systems, and the level of exposures that banks have to each other, systemic risk, in general, and contagion risk, in particular, can be a threat to financial systems.

In this study we investigate whether contagion risk emerging from the interbank lending relationships established in the overnight money market would have been a threat to the Portuguese financial system, in the period 1999 to 2009.

Our results for the Portuguese interbank market are in line with the results regarding other financial markets such Italy, Belgium, Austria and The Netherlands. Although contagion between banks might have occurred, its impact on the banking system cannot be considered a major threat to financial stability. Even in the worst-case scenario, banks that would have failed by contagion represent less than 10 per cent of the banking system total assets.

Note, however, that contagion risk inherent in the Portuguese interbank money market was not stable during the period under analysis, as we can identify three distinct phases. In the first phase, between 1999 and 2002, contagion risk decreased significantly, as a result of a profound restructuring process that led to higher concentration in the market. In the second phase, between 2003 and 2006, coinciding with a rapid increase of transactions in this market, and an increase of bank exposures to each other, led to the increase of contagion risk again. Finally, in the third phase, between 2006 and 2009, interbank lending decreased

sharply as a consequence of the financial turmoil, and capitalization levels increased consistently, both facts leading contagion risk to become lower. As expected, with the interbank market frozen after the failure of the Lehman Brothers in September 2008, the risk of contagion almost ceased to exist. However, the interbank market also ceased to play its redistributing role and forced banks to turn to the Euro system's standing facilities operations to adjust their day-to-day cash imbalances. Thus, the risk of contagion disappeared, but the interbank market also became inoperative, affecting the intermediation role of the banking system in the economy.

Our results are in line with Nier et al (2007) who argue that incomplete market structures, such as money center ones, are not necessarily more prone to contagion, as it depends on the connectivity of the money center banks. In the Portuguese case, it seems that the specific multiple money center structure leads to the dissipation of shocks, and not to their amplification. We have also confirm Nier et al.'s (2007) views that, as expected, an increase in the banks' capitalization levels leads to a decrease in the potential for, and severity of, contagion, and that the risk of contagion is higher when interbank liabilities are also higher.

Thus, our results empirically sustain Nier et al.'s (2007) findings. Yet, a major contribution of our work was to fill a gap in the existing research on financial contagion as, even though this exercise has already been carried out for the majority of the European interbank markets, at least to the best of our knowledge, no similar work existed for the Portuguese case until the moment. Moreover, contrary to other studies that focus on a single point in time, we have analyzed the evolution of contagion risk in the interbank overnight money market over a period of eleven years.

More importantly, with this work we have also contributed to a better understanding of the Portuguese interbank market. Furthermore, we have also attempted to draw attention to a

unique kind of data – the data about the settlements on the large value payment systems – based on which we can obtain valuable insights regarding the behavior of the financial system and, in the limit, about the economic activity in general almost on a real-time basis, since the data is available to the central banks directly running the payment systems on a daily basis.

However, despite our achievements, there is room for improvement. In fact, since the analysis was carried out considering just overnight exposures, future developments of this work could include, however subject to the availability of data, the run of the simulation process based on information covering a wide range of interbank exposures, thus complementing the data about overnight interbank exposures with data about longer-term exposures.

In addition, as pointed out by Mistrulli (2005), due to the increasing internationalization of interbank linkages in most of the markets, the failure of a foreign counterparty can pose a higher threat to the national financial system than the failure of a domestic bank. However, since the majority of contagion analyses are limited to domestic markets, disregarding the possible effects of second-round failures of foreign banks on domestic banks can lead to an underestimation of contagion risk, especially in high internationalized markets such as the Belgian and the Portuguese one. Therefore, one possible extension not only of this work, but also of research on empirical financial contagion in general, would be to carry out the analysis including the information about the interbank exposures to cross-border counterparties. However, due to the confidentiality issues that the disclosure of this type of information normally raises, probably this kind of analysis could only be done, for instance, at the Eurosystem level and not at an academic level.

Still within the field of financial contagion, since contagion risk can also arise from the interbank exposures established through payment systems, it would also be interesting to analyze this source of contagion using the TARGET settlement data. Actually, there are already some works in this field, such as the ones by Soramäki et al. (2007), who have analyzed the Fedwire Funds Service, the Federal Reserve Banks real-time gross settlement system and, Becher et al. (2008), who have examined the Clearing House Automated Payment System (CHAPS), the United Kingdom's large value payment system.

On the other hand, in this work, network theory was only used as a useful tool to draw some conclusions about the pattern of interbank lending relationships. However, another interesting line of research would be to carry out a deeper network analysis of the interbank money market which, combined with the contagion simulations, would help to identify the role of each bank in the market. That would help to design measures adjusted to the systemic risk that each bank's problems represent, which is of utmost importance as problems from one (systematically important) bank can represent a higher threat to financial stability than problems in another (non-systematically important) bank. This approach could also help to justify (or not) the assistance provided to some distressed banks, by assessing the possible contagion effects of their default.

Finally, it would also be of major interest to analyze the interbank relationships established through the payment systems following a network approach, since it could reveal important information for the operators of these systems (for instance, the strongest and the weakest nodes). This could be especially useful in the context of real-time settlement systems, where the window to solve problems is very short and the measures required to solve it may be different, depending on the role played by the bank in trouble. For example, in case of technical disruptions that prevent banks from carrying out their normal payment business

and redistributing their liquidity, or in case of a participant's lack of liquidity, the measures to overcome the problem may differ, depending if the bank is a money center bank or a small bank with very few counterparties.

To sum up, databases of real-time gross settlement systems, as the one of the Portuguese TARGET component, make it possible to explore multiple lines of investigation around the behavior of financial institutions, either in the field of payment systems or in the field of interbank money markets. This work results from the study of one those lines, namely the structure of the overnight interbank money market and its inherent potential for contagion, although it would also be of major interest to explore others, as the ones mentioned above.

References

- Allen, F. and Gale, D. (2000), Financial Contagion, *Journal of Political Economy* **108** (1), 1-33.
- Amundsen, E. and Arnt, H. (2005), Contagion Risk in the Danish Interbank Market, Danmarks Nationalbank Working Paper 25.
- Arinaminpathy, N, Kapadia, S. and May, R. (2012) Size and Complexity in Model Financial Systems, *Proceedings of the National Academy of Sciences of the United States of America* 109 (45), 18338-43.
- Blavarg, M. and Nimander P. (2002), Interbank Exposures and Systemic Risk, *Sveriges Riksbank Economic Review* 2, 19-45.
- Brusco, S. and Castiglionesi, F. (2007), Liquidity Coinsurance, Moral Hazard and Financial Contagion, *The Journal of Finance* 62, 2275-2302.

- Cocco, J., Gomes, F. and Martins, N. (2009), Lending Relationships in the Interbank Market,, *Journal of Financial Intermediation* 18 (1), 24-48.
- Craig, B. and von Peter, G. (2010), Interbank Tiering and Money Center Banks. *Deutsche Bundesbank, Discussion Paper* 12/2010.
- Degryse, H. and Nguyen, G. (2007), Interbank Exposures: An Empirical Examination of Contagion Risk in the Belgian Banking System. *International Journal of Central Banking* 3 (2), 123-171.
- Drehmann, M and Tarashev, N (2011), Systemic Importance: Some Simple Indicators, *BIS Quarterly Review*, 25-37 available online from: http://www.bis.org/publ/qtrpdf/r_qt1103e.htm.
- Elsinger, H., Lehar, A. and Summer, M. (2006), Risk Assessment for Banking Systems, *Management Science* 52 (9), 1301-1314.
- Farinha, L. and Gaspar, V. (2008), Portuguese Banks in the Euro Area Market for Daily Funds. *European Central Bank Working Paper* 985.
- Freixas, X., Parigi, B. and Rochet, C. (2000), Systemic Risk, Interbank Relations and Liquidity Provision by the Central Bank, *Journal of Money, Credit and Banking* 32 (3), 611-38.
- Furfine, C. (1999), The Microstructure of the Federal Funds Market, *Financial Markets, Institutions and Instruments* 8 (5), 24-44.
- Furfine, C. (2001), Banks as Monitors of other Banks: Evidence from the Overnight Federal Funds Market, *The Journal of Business* 74 (1), 33-57.

- Furfine, C. (2003), Interbank Exposures: Quantifying the Risk of Contagion, *Journal of Money, Credit and Banking* 35 (1), 111-128.
- Gai, P. and Kapadia, S. (2010), Contagion in Financial Networks. *Proceedings of the Royal Society A*, 466 (2120) 2401-23.
- Georg. C.-P. (2011), The Effect of the Interbank Network Structure on Contagion and Common Shocks, Reserve Bank of New Zealand Working Paper
- Iori, G., Jafarey, S. and Padilla, F. (2006), Systemic Risk on the Interbank Market, *Journal of Economic Behaviour & Organization* 6, 525-542.
- James, C. (1991), The Losses Realized in Bank Failures. *The Journal of Finance* 46 (4), 1223–1242
- Kapadia, S., Drehmann, M., Elliott, J. and Sterne, G. (2012), Liquidity Risk, Cash Flow Constraints, and Systemic Feedbacks. Forthcoming in Haubrich, J.G. and Lo, A.W. (eds), *Quantifying Systemic Risk*, University of Chicago Press.
- Kaufman, G. (1994), Bank Contagion: A Review of the Theory and Evidence, *Journal of Financial Services Research* 8 (2), 123-150.
- Krznar, M. (2009), Contagion Risk in the Croatian Banking System, Croatian National Bank Working Papers 20.
- Millard, S. and Polenghi, M. (2004), The Relationship Between the Overnight Interbank Unsecured Loan Market and the CHAPS Sterling System. *Bank of England Quarterly Bulletin*, 42-47.
- Mistrulli, P. (2005), Interbank Lending Patterns and Financial Contagion, *Banca D'Italia, Working Paper* 641.

- Mistrulli, P. (2011), Assessing Financial Contagion in the Interbank Market: Maximum Entropy vs. Observed Interbank Lending Patterns, *Journal of Banking and Finance* 35, 1114-1127.
- Müller, J. (2006a), Interbank Credit Lines as a Channel of Contagion, *Journal of Financial Services Research* 29 (1), 37-60.
- Müller, J. (2006b), The Potential for Contagion in the Swiss Interbank Market, *Mimeo*.
- Nier, E., Yang, J., Yorulmazer, T. and Alentorn, A. (2007), Network Models and Financial Stability, *Journal of Economic Dynamics and Control* 31, 2033-2060.
- Sheldon, G. and Maurer, M. (1998), Interbank Lending and Systemic Risk: An Empirical Analysis for Switzerland, *Swiss Journal of Economics and Statistics* 134 (4.2), 685-704.
- Soramäki, K., Bech, M., Arnold, J., Glass, R. and Beyeler, W. (2007), The Topology of Interbank Payment Flows, *Physica A* 379, 317-333.
- Toivanen, M. (2009), Financial Interlinkages and Risk of Contagion in the Finnish Interbank Market. Bank of Finland Research Discussion Papers 6.
- Upper, C. and Worms, A. (2004), Estimating Bilateral Exposures in the German Interbank Market: Is There a Danger of Contagion, *European Economic Review* 48 (4), 827-849.
- van Lelyveld, I. and Liedorp, F. (2006), Interbank Contagion in the Dutch Banking Sector: A Sensitivity Analysis, *International Journal of Central Banking* 2 (2), 99-133.
- Wells, S. (2004), Financial Interlinkages in the United Kingdom's Interbank Market and the Risk of Contagion, *Bank of England Working Paper* 230.

Table 1. Evolution of market concentration

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
5 major lenders	31.4	44.8	50.4	59.8	76.2	82.1	79.0	79.5	65.5	65.8	76.9
10 major lenders	42.4	55.8	64.3	73.7	91.0	91.5	90.3	91.5	84.3	83.3	86.5
5 major borrowers	52.2	35.5	33.2	33.0	21.5	24.5	23.6	27.5	34.5	35.5	59.6
10 major borrowers	64.3	48.7	46.2	45.0	34.6	39.8	37.8	43.4	44.7	46.0	67.7

Note: This table presents the percentage of the total amount lent in the interbank market, by the five or ten major lenders, and by the five or ten major borrowers, in each year in the period 1999-2009.

Table 2. Network descriptive statistics

Year	Daily number of active banks (nodes)			Daily number of links			Daily degree of completeness (%)		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
1999	62	101	4	74	173	2	2.1	16.7	1.3
2000	58	103	12	61	135	9	1.9	6.8	1.1
2001	51	78	15	51	91	9	2.1	4.6	1.4
2002	48	73	13	47	84	9	2.2	5.8	1.5
2003	58	81	17	62	116	12	2.0	4.4	1.3
2004	54	77	21	54	94	16	1.9	3.8	1.4
2005	53	73	26	53	80	22	2.0	3.6	1.4
2006	50	69	24	48	80	20	2.0	3.8	1.5
2007	53	71	19	50	76	14	1.9	4.1	1.4
2008	53	69	23	52	80	18	1.9	3.6	1.4
2009	42	58	12	40	65	11	2.4	8.3	1.6

Note: This table presents the average, maximum and minimum of: (i) number of banks active in the interbank market in each day (number of nodes); (ii) the daily number of interbank lending relationships; and (iii), the daily degree of completeness of the interbank market (in percentage). The daily number of interbank lending relationships is counted two times, both on the side of the lender and on the side of the borrower. The degree of completeness ranges between 0 (if there are no lending relationships on that day) and 1 (a complete market, where all the banks establish lending relationships with all the other banks, or nodes, present in the market, on that day).

Table 3. Impact of contagion on the interbank market

Year	Number of possible scenarios	% of scenarios where contagion occurs				Median case scenario								Worst case Scenario							
						Number of failing banks				% of total assets				Number of failing banks				% of total assets			
		LGD rate				LGD rate				LGD rate				LGD rate							
		25	50	75	100	25	50	75	100	25	50	75	100	25	50	75	100	25	50	75	100
1999	217	0.0	0.7	2.8	4.4	0	≤2	≤2	≤2	0.0	1.1	0.9	1.1	0	≤2	4	7	0.0	1.5	2.0	5.9
2000	215	0.0	0.5	2.8	4.7	0	≤2	≤2	≤2	0.0	≤0.5	≤0.5	≤0.5	0	≤2	≤2	5	0.0	≤0.5	1.9	2.4
2001	201	0.0	0.5	1.0	2.2	0	≤2	≤2	≤2	0.0	≤0.5	≤0.5	≤0.5	0	≤2	≤2	≤2	0.0	≤0.5	≤0.5	0.9
2002	207	0.5	1.5	1.7	2.9	≤2	≤2	≤2	≤2	≤0.5	≤0.5	≤0.5	≤0.5	≤2	≤2	≤2	≤2	0.9	0.9	0.9	0.9
2003	223	0.0	1.3	2.5	4.0	0	≤2	≤2	3	0.0	≤0.5	1.1	1.6	0	≤2	≤2	3	0.0	0.9	8.5	8.6
2004	200	0.0	1.8	2.3	3.3	0	≤2	≤2	≤2	0.0	1.7	2.6	1.9	0	≤2	≤2	≤2	0.0	9.3	9.8	9.8
2005	186	0.5	1.3	1.6	1.6	≤2	≤2	≤2	≤2	≤0.5	≤0.5	≤0.5	≤0.5	≤2	≤2	≤2	≤2	0.6	0.6	0.8	0.8
2006	151	0.0	1.3	2.3	4.0	0	≤2	≤2	≤2	0.0	≤0.5	≤0.5	1.2	0	≤2	≤2	≤2	0.0	0.7	≤0.5	7.2
2007	180	0.3	1.1	1.7	2.5	≤2	≤2	≤2	≤2	≤0.5	≤0.5	0.6	0.7	≤2	≤2	≤2	≤2	≤0.5	0.7	1.6	1.6
2008	178	0.0	1.1	1.7	2.8	0	≤2	≤2	≤2	0.0	≤0.5	≤0.5	≤0.5	0	≤2	≤2	≤2	0.0	≤0.5	≤0.5	≤0.5
2009	136	0.0	0.7	2.2	2.9	0	≤2	≤2	≤2	0.0	0.0	≤0.5	≤0.5	0	≤2	≤2	≤2	0.0	0.0	≤0.5	≤0.5
Yearly Avg.	190	0.1	1.1	2.0	3.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Note: The median case scenario is the average number of failed banks and the average share of total banking system assets represented by failed banks (except the one that is left to fail at first), across all the scenarios where contagion occurred. The worst case scenario gives the maximum number of banks failed and the maximum percentage of banking assets represented by banks failing (excluding the initial failure) in a given scenario where contagion occurs. In order to avoid banks' identification, cells with two or fewer banks are signed with "≤2". The same applies to the cells regarding the percentage of assets affected by contagion, which are filled with "≤0.5".

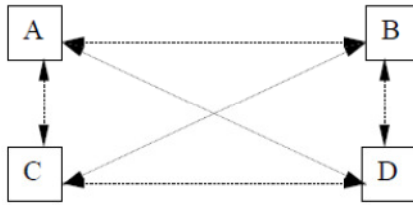
TABLE 4 – Contagious and contagion proof-banks

Year	Number of contagious banks				Contagion-proof banks							
					Number				% total banking system assets			
	LGD rate				LGD rate				LGD rate			
	25	50	75	100	25	50	75	100	25	50	75	100
1999	0	2	6	10	38	36	34	30	90.2	88.7	87.6	84.6
2000	0	1	6	10	36	36	33	31	88.8	88.6	86.8	86.4
2001	0	1	2	5	33	32	32	31	85.2	85.1	84.9	85.3
2002	1	3	4	6	31	31	31	30	86.2	86.0	86.0	86.0
2003	0	3	6	9	31	29	27	25	89.8	88.5	89.2	80.3
2004	0	4	5	7	29	27	26	25	86.9	81.3	76.8	76.3
2005	1	3	3	3	27	26	25	25	83.7	83.0	82.6	82.6
2006	0	2	4	6	25	23	23	21	85.1	84.5	83.7	79.2
2007	1	2	3	5	26	25	24	22	84.2	83.3	82.4	81.4
2008	0	2	3	5	22	20	19	19	83.0	82.3	82.1	82.2
2009	0	1	3	4	22	21	20	19	82.1	82.1	81.9	81.7

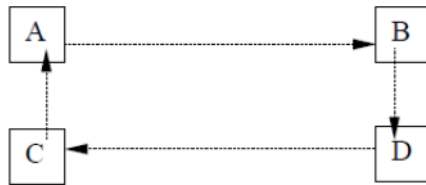
Note: This table presents: (i) the daily number of contagious banks (banks whose default causes at least another bank's failure); (ii) the daily number of contagion-proof banks (banks which do not fail, given a default in any other bank); (iii) the daily percentage of the total banking assets represented by the contagion-proof banks. The LGD rate is the assumed loss given default, i.e., the percentage of money lent which is lost by the lender bank, in case the borrower bank defaults. The results are presented for four different loss given default scenarios: losses of 25%, 50%, 75% and 100%.

Figure 1. Interbank market structures

1a. Complete market structure



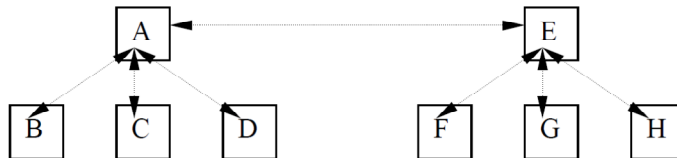
1b. Incomplete and interconnected market structure



1c. Incomplete and disconnected market structure



1d. Interconnected multiple money centers market structure



1e. Disconnected multiple money centers market structure

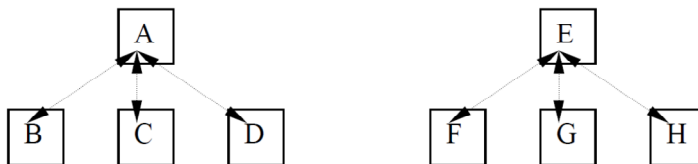
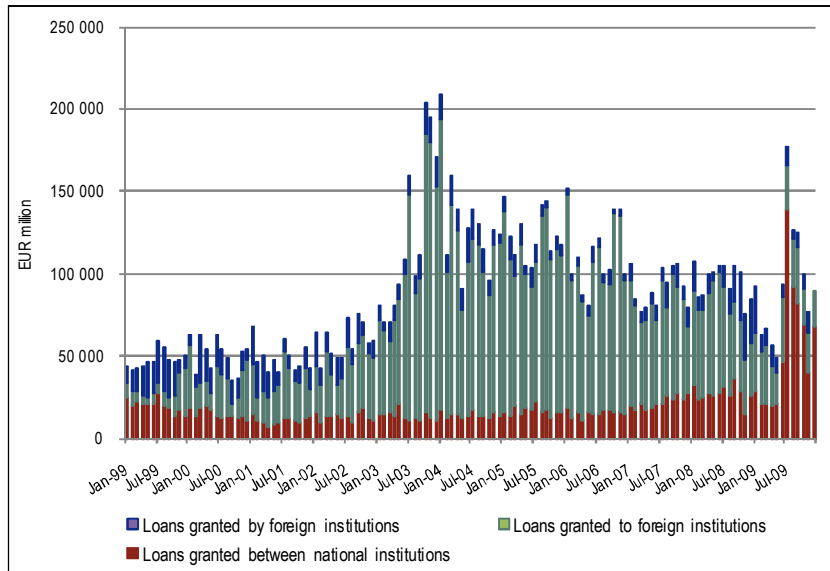
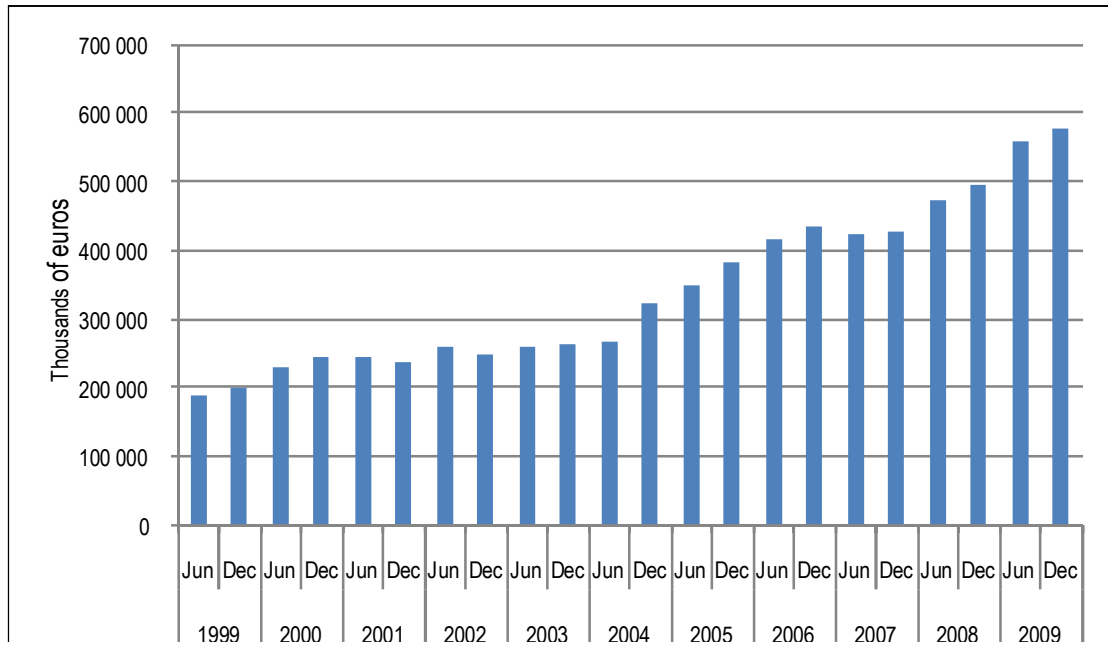


Figure 2. Amount of funds traded in the overnight interbank market



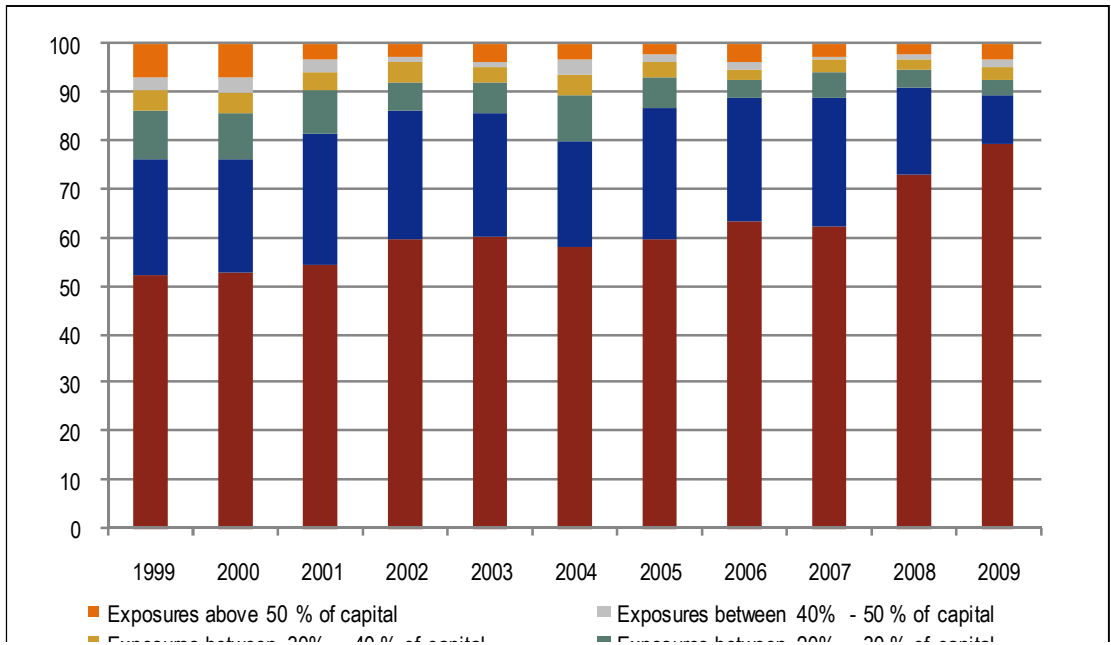
Note: This figure presents the monthly amount of funds traded in the Portuguese interbank market, in the period 1999-2009. The columns show the decomposition of the loans between: (i) loans granted between national banks; (ii) loans granted by foreign banks to national banks; (iii) loans granted by national banks to foreign banks.

Figure 3. Average capital level per bank



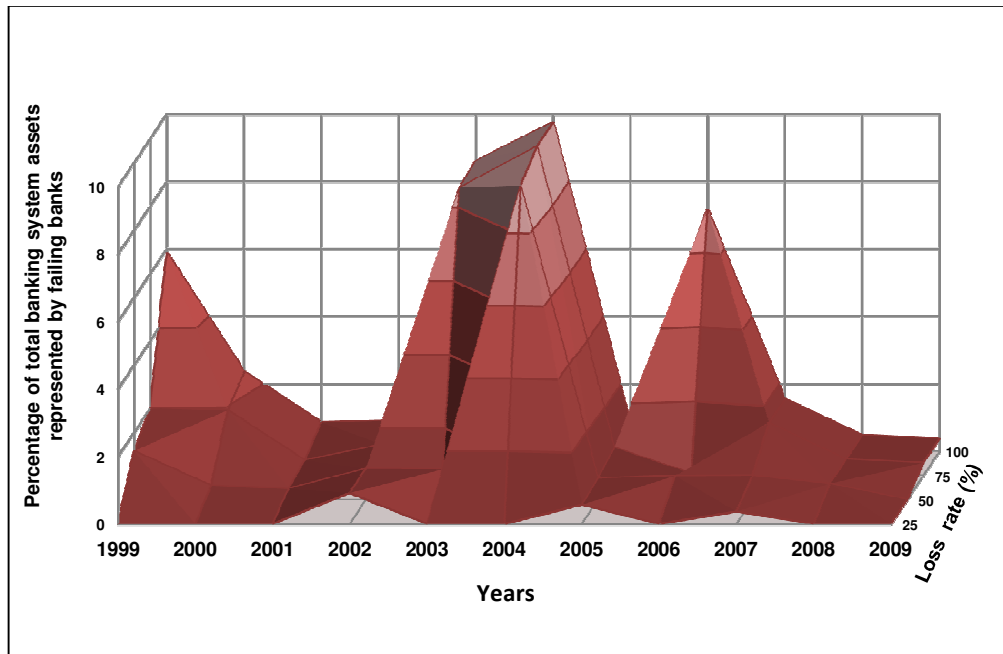
Note: This figure presents the average capital level of Portuguese banks, in thousands of euros and by semester, in the period 1999-2009.

Figure 4. Weight of exposures in banks' capital



Note: This figure presents the average exposure that the interbank loans represent in each year, relative the capital level of the lender. The average exposure has declined steadily, in the period 1999-2009.

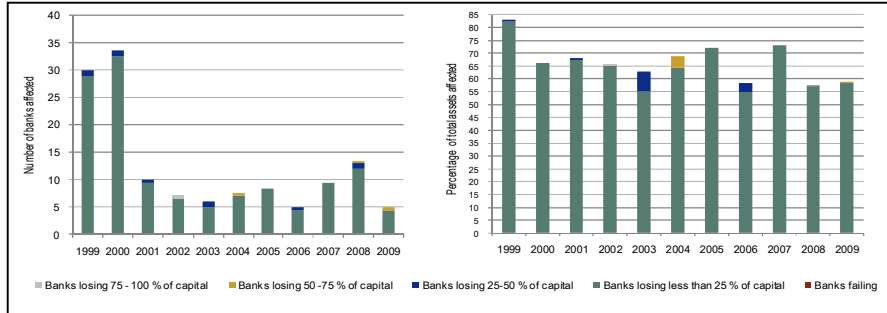
Figure 5. Severity of contagion (worst-case assuming contagion)



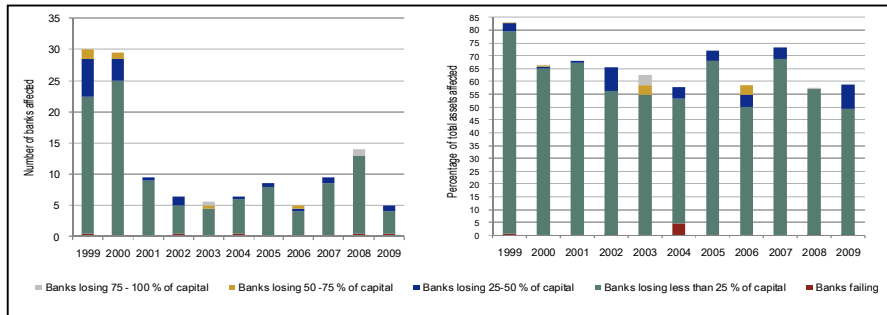
Note: This figure presents the percentage of the total assets of the Portuguese banking system, represented by the failing banks, in each year of the period 1999-2009. The loss rate is the assumed loss given default, i.e., the percentage of money lent which is lost by the lender bank, in case the borrower bank defaults. The results are presented for four different loss given default scenarios: losses of 25%, 50%, 75% and 100%.

Figure 6. Impact of a bank failure
(worst-case not conditional to contagion), excluding the initial failure

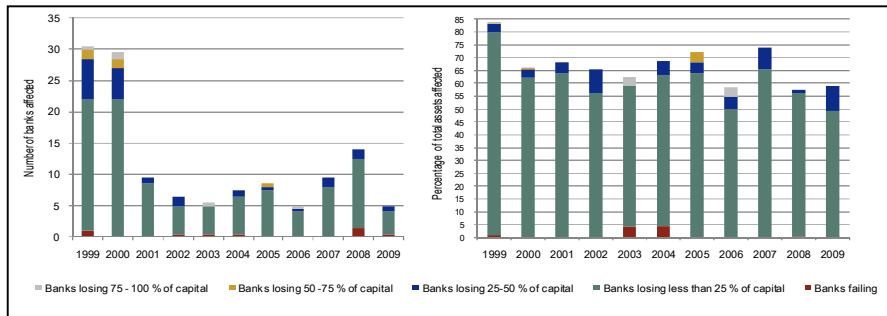
(a) Assuming a 25 per cent LGD rate



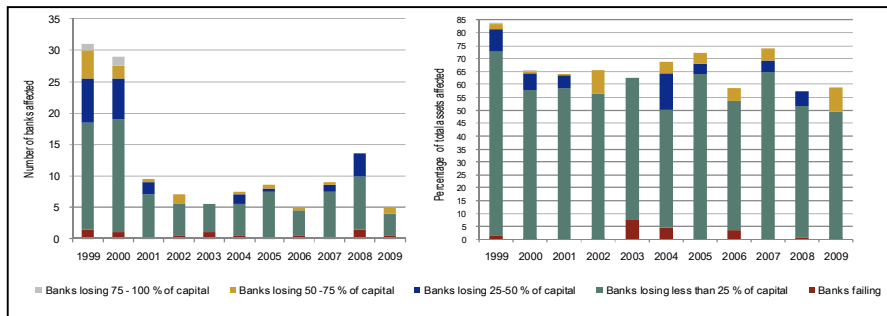
(b) Assuming a 50 per cent LGD rate



(c) Assuming a 75 per cent LGD rate



(d) Assuming a 100 per cent LGD rate



Note: This figure presents the impact of the worst-case of a bank failure on the other banks. The columns depict the number of banks affected and the percentage of the total assets affected, decomposed by its impact on the capital level of the affected banks.