Interbank Exposures: An Empirical Examination of Contagion Risk in the Belgian Banking System*

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Robust (cross-border) interbank markets are important for the proper functioning of modern financial systems. However, a network of interbank exposures may lead to domino effects following the event of an initial bank failure. We investigate the evolution and determinants of contagion risk for the Belgian banking system over the period 1993–2002 using detailed information on aggregate interbank exposures of individual banks, large bilateral interbank exposures, and cross-border interbank exposures. The "structure" of the interbank market affects contagion risk. We find that a change from a complete structure (where all banks have symmetric links) toward a "multiple-money-center" structure (where money centers are symmetrically linked to otherwise disconnected banks) has decreased the risk and impact of contagion. In addition, an increase in the relative importance of cross-border interbank exposures has lowered local contagion risk. However, this reduction may have been compensated by an increase in contagion risk stemming from foreign banks.

JEL Codes: G20, G15.

*We thank Franklin Allen, Mathias Dewatripont, Mark Flannery, Philipp Hartmann, Dirk Heremans, Alfred Lehar, Yaron Leitner, Steven Ongena, Peter Praet, Andrea Schretler, Thierry Timmermans, Kostas Tsatsaronis, Christian Upper, Mark Van Achter, Quentin Wibaut, Gunther Wuyts, an anonymous referee, the members of the Research and Analysis Group of the International Cooperation & Financial Stability Department at the NBB, and the participants at the IfW-SUERF workshop on Banking Risks in International Markets, the SMYE 2004, the Symposium of the ECB-CFS Research Network on Capital

1. Introduction

A well-functioning and robust interbank market is an essential element of the integration of a financial system. However, although interbank markets strengthen financial integration, they also increase linkages within the banking sector. Interbank markets therefore may represent an important channel of contagion through which problems affecting one bank or one country may spread to other banks or other countries.

In this paper, we empirically address the implications of domestic as well as cross-border interbank linkages for interbank contagion risk. Contagion results from the materialization of two risks: first, the risk that at least one component of the system is hit by a shock (likelihood of a shock) and, second, the risk that this shock propagates through the system (potential impact of the shock). As the former can result from a variety of unexpected situations, we focus on the latter. In particular, we evaluate the potential damages that a chain reaction in the interbank market—i.e., a situation where the failure of one bank would lead to the default of one or more of its interbank creditors—could create. We undertake a stylized exercise—resembling a stress test—in which we simulate the consequences of nonrepayment of interbank loans of an individual bank on the capital of its bank lenders, and any further domino-like effects. In order to isolate the potential impact of contagion, we assume that the initial default is caused by a sudden, unexpected, and idiosyncratic shock. Recent history has shown that this kind of shock is not totally unlikely (see, for instance, the failure of Barings in the United

Markets and Financial Integration in Europe, the FIRS conference on Banking, Insurance and Intermediation, the ECB workshop on Financial Stability, the Sveriges Riksbank conference on Banking, Financial Stability and the Business Cycle, and the Banco de Portugal conference on Financial Fragility and Banking Regulation for providing helpful discussions and comments. We especially thank Janet Mitchell for her detailed guidance and invaluable suggestions. The views expressed in this paper are those of the authors and do not necessarily reflect the views of the National Bank of Belgium. The first author acknowledges financial assistance from FWO–Flanders, NWO–The Netherlands, and the research council of the University of Leuven. Hans Degryse holds the TILEC-AFM Chair on Financial Market Regulation. Corresponding author: Degryse: CentER–Tilburg University, P.O. Box 90153, NL-5000 LE Tilburg, The Netherlands; e-mail: H.Degryse@uvt.nl.

Kingdom or Drexel Burnham Lambert in the United States) and may trigger a systemic crisis. Worries of a systemic crisis and domino effects induced, for instance, the bailout of Continental Illinois.[1]

Our empirical analysis considers contagion risk in the Belgian financial system. Why should the reader be interested in Belgium, which only covers a small part of the euro zone? The Belgian interbank market is an instructive case for several reasons.[2] First, it is very international, a feature that may become a key characteristic of many interbank markets in the future. In addition, the Belgian financial landscape contains a number of key players in the payment and securities settlement infrastructure (such as, e.g., Euroclear Bank or SWIFT). Second, the Belgian banking sector underwent a period of significant consolidation in the years 1997–2001. As a result, some large banks now have total assets that far exceed the GDP of the country, a situation that is typical for many other small countries (e.g., the Netherlands, Sweden, or Switzerland). Such countries then may face a potential too-big-to-save situation. However, only the analysis of the propagation channels of a crisis will ultimately determine its gravity. Third, the structure of the Belgian interbank market has changed over time: it has moved from a "complete" structure (where all banks have reciprocal links) toward a "multiple-money-center" structure (where a few "money-center banks" are linked together and linked to otherwise disconnected banks). These observations raise several interesting questions, which are also relevant for the analysis of contagion risk within and across financial systems of other countries. How has interbank contagion risk evolved over time? How important is the interbank market structure in explaining interbank contagion risk? To what extent could the failure of a foreign bank affect domestic banks through cross-border interbank exposures? How does contagion risk in Belgium compare with assessments for other countries? What measures can a regulator take to limit interbank contagion risk?

[1] The Federal Reserve decided immediately to step in. Later, Paul Volcker, then Chairman of the Board of Governors of the Federal Reserve System, argued that "if [they] had not stepped in, the ultimate domino effect that so many people have feared for so long, would have occurred and wiped out the Western financial system" (Feltham 2004).

[2] By "Belgian interbank market," we refer here to the set of interbank exposures where at least one of the counterparties is a bank incorporated in Belgium.

Our analysis goes beyond the existing literature in several respects. First, we point out that it is important to take into account time variation in interbank linkages. In contrast to most existing studies, we make use of time-series data on interbank exposures; other papers focus only on a single point in time. This enables us to examine the evolution over the past decade of contagion risk associated with the failure of Belgian banks. We find that contagion risk due to domestic interbank defaults has varied significantly over time, according to a well-identifiable pattern. In particular, contagion risk increased over the period 1993–97, decreased afterward, and flattened out at a very low level at the end of the sample period (end of 2002).

Second, we investigate the determinants of contagion in an attempt to explain the evolution of contagion risk over time. Although historical events—such as the long-term capital management (LTCM) crisis or the default on Russian debt—could potentially account for the peak in contagion risk observed in 1997, we argue that changes in the structure of the Belgian interbank market and in the capitalization of Belgian banks are the main drivers behind this evolution. Theory suggests that market structure may play an important role in determining contagion risk in interbank markets (see, e.g., Allen and Gale 2000 or Freixas, Parigi, and Rochet 2000). To our knowledge, this is the first paper to empirically investigate the impact of interbank market structure on contagion risk, employing regression analysis that allows us to control for other variables in the conditioning set. We find that a move from a complete structure toward a "multiple-money-center" structure and an increase in concentration in the banking market lead to a decrease in domestic contagion. In addition, an increase in the proportion of cross-border interbank assets further decreases the risk and impact of domestic contagion. Increases in bank capitalization also have a first-order effect in reducing interbank contagion when the loss given default (LGD) is relatively low.

Third, we investigate the contagion risk stemming from interbank linkages with foreign banks, in addition to the risk associated with linkages between domestic banks. The sharp increase in the proportion of cross-border interbank assets for Belgian banks, combined with the decrease in the indicators of domestic contagion, indeed suggests that the potential contagion risk stemming from foreign interbank exposures has gained in importance. According to our simulations, the failure of some foreign banks could have a sizable effect on Belgian banks' assets, albeit only for high values of loss given default. Since large banks are more involved in international interbank markets than small banks, contagion effects triggered by foreign banks generate higher levels of contagion.

Fourth, in addition to running simulations for a range of (exogenous) levels of LGD, we also attempt, in a supplementary exercise, to endogenize banks' LGD. This allows LGD to vary across banks. These simulations still reveal an evolution over time of contagion risk; however, at any given point in time, we no longer observe a strong correlation between the average implied LGD across banks and the level of contagion, as reflected in the worst-case scenario. This is because the average LGD interacts with the other dimensions of the market structure, which remain determinant in the propagation of contagion. In addition, we find that for a given average LGD across banks, contagion risk is higher when there is more cross-sectional variation in LGD. Heterogeneity in LGD appears to exacerbate contagion risk.

Finally, in robustness tests, we analyze several alternative scenarios. For example, we show that netting of interbank exposures—the setoff of bilateral positions—may substantially reduce contagion risk. In addition, we test the potential effect of a coordination mechanism whereby the supervisor requires some banks to merge in order to reduce contagion effects. Although mergers are often used in practice as a mechanism for dealing with ailing banks, in our simulations mergers seldom decrease contagion.

The rest of the paper is organized as follows. Section 2 reviews the literature on interbank contagion risk. Section 3 introduces the data set, describes the methodology and contagion indicators, and presents the most important features of the Belgian interbank market. Section 4 discusses the results of the various simulation exercises. Section 5 presents the regression results of the impact of the interbank market structure on contagion risk. Section 6 concludes.

2. Literature Review on Interbank Market Contagion

In some circumstances, the failure of an individual bank may lead to a domino effect. This happens when the nonrepayment of interbank obligations by the failing bank jeopardizes the ability of its creditor banks to meet their obligations to their interbank creditors. Contagion occurs then "mechanically" through the direct interlinkages between banks. *Theory* shows that the extent to which a crisis is propagated through the system depends on the structure of interbank linkages. The market structure of interbank claims can take different forms. Allen and Gale (2000) distinguish three structures: (i) the "complete structure" where banks are symmetrically linked to all other banks, (ii) the "incomplete market structure" where banks are only linked to neighboring banks, and (iii) the "disconnected incomplete market structure" where two disconnected markets coexist. They show that complete structures are less prone to contagion than incomplete market structures, since with complete structures, the impact of a financial crisis in one bank is absorbed by a large number of banks. Freixas, Parigi, and Rochet (2000) introduce a fourth structure: the "money center." The money center is symmetrically linked to all the other banks, which are themselves not linked together. They show that, in some cases, the failure of a bank linked to the money center will not trigger the failure of the money center, but the failure of the money center itself may trigger failures of the linked banks. Our paper empirically investigates how the market structure of the interbank market influences contagion risk.

Current *empirical work* mainly focuses on interbank contagion within a national banking system. Two empirical approaches are implemented, each having its strengths and weaknesses. A first approach tries to isolate contagion from other shocks affecting the economy. It simulates the consequences of an individual bank failure given observed or estimated interbank exposures and looks at the potential domino effects, i.e., first-round and potential further-round effects. This approach was applied to (part of) banking systems in several countries and—although contagion indicators were more important in some countries than in others—delivered generally reassuring results (see Sheldon and Maurer 1998, Furfine 2003, Cifuentes 2004, Upper and Worms 2004, Wells 2004, or van Lelyveld and Liedorp 2006 for Switzerland, the United States, Chile, Germany, the United Kingdom, and the Netherlands, respectively[3]).

[3]Upper (2006) provides a comparative overview of these contributions.

However, all these studies look at contagion at one moment in time and generally focus on domestic contagion only. Our paper adds to this literature by considering a time series covering Belgian banks during ten years, allowing us to investigate how and why contagion risk evolved over time.[4] Furthermore, we also try to adapt the mechanics of the exercise to better reflect real-life features. This allows us to endogenize the LGD and to subsequently analyze the extent to which the results depend upon a standard assumption used in this literature, i.e., a fixed LGD. Finally, we investigate how the failure of foreign banks affects interbank contagion within the Belgian banking market. The latter issue becomes more important as cross-border exposures grow. Following our empirical analysis on the role of interbank market structure and cross-border exposures, Mistrulli (2005) documents that the Italian interbank market also moved from a "complete" structure toward a "multiple-money-center" structure. In contrast to our findings for Belgium, he reports that the importance of cross-border exposures has decreased and that the transition toward the multiple-money-center structure has increased contagion risk. While the conclusions for Italy are drawn on the basis of simulations, our regression analysis allows us to disentangle the impact of the different determinants of contagion.

A second approach to estimate contagion risk takes into account a larger variety of shocks. Müller (2003) combines a network and a simulation approach to assess the risk of contagion in the Swiss interbank market and takes into account credit and liquidity effects in bank contagion. Elsinger, Lehar, and Summer (2006) simulate the joint impact of interest rate shocks, exchange rate shocks, and stock market movements on interbank payment flows of Austrian banks. These states of the world determine the net value of the bank and the feasibility of interbank payments. They distinguish between insolvency due to correlated exposures and due to domino effects. Their simulations indicate that although the probability of contagious default is low compared to the total default probability, there are situations in which up to 75 percent of the defaults

[4] Guerrero-Gómez and Lopez-Gallo (2004) study a short time series for interbank contagion in Mexico (December 2002–August 2003) and find considerable variation of contagion in this short time window.

are due to contagion.[5] Instead of simulating interbank contagion, another method to take into account a larger variety of shock is to investigate banks' stock price behavior. Lehar (2005) estimates correlations between bank portfolios to compute different measures of systemic risk. Gropp and Vesala (2003) use the tail properties of distance to default to study contagion risk. They find the presence of both domestic and cross-border contagion within Europe, although domestic contagion seems to dominate cross-border. The advantage of this second approach is that it takes a systemwide view. However, as we want to focus on contagion risk and perform a stress test, starting from an individual bank failure may yield more insights in the evolution of risk over time, in the propagation mechanism and ultimate consequences of contagion risk. In addition, some of these techniques require time series of stock prices. Since few Belgian banks are publicly listed, this second approach appears inadequate to study the Belgian financial system.

3. Data, Methodology, and Structure of the Interbank Market

3.1 Data

The data stem from a confidential database (Schéma A) containing banks' balance sheet statements and a set of key financial figures collected for supervisory purposes at a monthly frequency. This database provides valuable information with respect to interbank positions:

- At an aggregate level, each bank reports its total interbank loans and deposits and provides breakdowns of these "aggregate positions" according to the type of loan or deposit, the geographical origin of the lender or the borrower (Belgium,

[5] Elsinger, Lehar, and Summer (2006) also use their simulation to compare two generated matrices of bilateral exposures representing a complete and an incomplete structure. They find more contagion when they use a complete market structure. Note finally another study in that second approach: Iyer and Peydro-Alcalde (2006) study a postmortem case to see how an idiosyncratic shock that affected an Indian bank was transmitted to the other Indian banks. Their study includes indirect effects through depositors' runs and media destabilizing effects.

one of the other EU members, or the rest of the world [RoW]), and the residual maturity of interbank loans or deposits. The aggregate positions used in this paper cover a period ranging from December 1992 to December 2002.

- At an individual bank level, banks report their "large exposures" to both domestic and foreign single obligors, including their interbank exposures (i.e., exposures exceeding 10 percent of their own funds). Reliable data on large exposures are only available from 2002:Q3 onward. We use a cross-section of data on large exposures to banks for December 2002.

Figures are reported on a firm basis; i.e., they include banks incorporated in Belgium (i.e., Belgian banks and Belgian subsidiaries of foreign banks) as well as their foreign branches, and consequently exclude Belgian branches of foreign banks or foreign subsidiaries of Belgian banks. The Belgian banking system, at the end of 2002, comprises 65 banks with total assets of €792 billion. The banking system is characterized by a high degree of concentration, since the four largest banks account for 85 percent of total assets of Belgian banks. This concentration results from several mergers over the period 1997–2001 and from an overall decrease in the number of banks, from 112 in 1992 to 65 in 2002.

The interbank market evolution in Belgium was partly determined by the overall evolution of money markets in Europe over the last decade. First, the establishment of the Economic and Monetary Union (EMU) radically changed the European financial landscape and allowed greater market integration. Baele et al. (2004) find that the euro-area money markets have reached a very advanced level of integration. This "near-perfect" integration fostered a higher internationalization of interbank transactions, also observable in the Belgian data. Second, the launch of the EMU required efficient cross-border payment systems. To this end, the 1997 implementation of TARGET (Trans-European Automated Real-time Gross settlement Express Transfer system) facilitated the integration of European money markets and the setting up of international bank exposures. In Belgium, the entry point to TARGET is the real-time gross settlement system ELLIPS (ELectronic Large value Interbank Payment System). ELLIPS is structured in two tiers, with direct and indirect participants. Direct participants must have an account with the central bank. At the end of 2002, there were seventeen direct participants and seventy-six indirect participants. In our data set, accounts that direct participants must have with the central bank are not considered interbank exposures. On the other hand, accounts between participants and subparticipants are considered interbank exposures. One might expect that the two-tier structure of payment systems and the subsequent access to international payment systems influence the structure of the resulting interbank linkages.

As shown in table 1, the interbank loans of Belgian banks represent a gross exposure of €176 billion at the end of 2002, while interbank deposits amount to €228 billion.[6] On both sides of the balance sheet, term and secured loans/deposits represent the largest portions of interbank positions. The current level of secured loans is the consequence of a shift in the strategy of Belgian banks in the beginning of the 1990s, probably nurtured by the monetary policy reform in Belgium in 1991, which stimulated the use of repos between Belgian banks. Over the period 1992–2002, interbank loans always account for 20 to 27 percent of total assets of Belgian banks, and interbank deposits account for 29 to 35 percent of their total liabilities.[7]

Another noteworthy characteristic of interbank positions of Belgian banks is their high degree of internationalization. At the end of 2002, less than 15 percent of interbank exposures of Belgian banks were to other Belgian banks. Hence, Belgian banks might be more sensitive to international bank failures than to domestic ones. Manna (2004) reports that the share of interbank deposits traded within the euro area on a cross-border basis increased from 20.6 percent in 1998 to 25.2 percent in 2002. Countries with large domestic markets

[6] In 2002, banks reported large exposures amounting to 79.5 percent of the domestic interbank loans and to 70.1 percent of the foreign interbank loans. They reported 109 large exposures to domestic banks and 226 large exposures to 135 different foreign banks. These exposures account for a total value of €126 billion. The average value of a domestic large exposure (€190 million) is lower than the average value of a foreign large exposure (€467 million).

[7] These figures are in line with EMU averages, although one can observe huge differences between some countries.

Table 1. Structure of Interbank Loans and Deposits of Belgian Banks

Interbank Loans	**Belgium**	**EMU**	**RoW**	**Total**
Demand Loans	603 *0.3%*	1,047 *0.6%*	2,017 *1.1%*	3,667 *2.1%*
Term Loans	10,909 *6.2%*	48,020 *27.2%*	22,816 *12.9%*	81,744 *46.3%*
Secured Loans	10,680 *6.1%*	32,623 *18.5%*	43,844 *24.8%*	87,147 *49.4%*
Other	3,788 *2.1%*	110 *0.1%*	16 *0.0%*	3,914 *2.2%*
Total	25,980 *14.7%*	81,799 *46.4%*	68,692 *38.9%*	176,472 *100.0%*
Interbank Deposits				
Sight Deposits	739 *0.3%*	2,892 *1.3%*	2,868 *1.3%*	6,499 *2.8%*
Term Deposits	16,771 *7.3%*	26,670 *11.7%*	80,927 *35.4%*	124,368 *54.4%*
Secured Deposits	15,308 *6.7%*	46,425 *20.3%*	35,894 *15.7%*	97,627 *42.7%*
Total	32,818 *14.4%*	75,988 *33.3%*	119,688 *52.4%*	228,494 *100.0%*

Source: National Bank of Belgium.
Note: Data are for December 2002, in € million, with percentages shown in italics.

currently exhibit a smaller share of cross-border activity.[8] In that respect, Belgium's high degree of cross-border interbank exposures could provide a good assessment of the future ingredients of national money markets and interbank linkages in other European countries.

[8]Manna (2004) reports that in 2002 the share of cross-border interbank deposits amounted to approximately 15 percent in Finland, France, and Germany; amounted to 30 percent in Italy, the Netherlands, and Spain; and exceeded 50 percent in Belgium and Portugal.

3.2 Methodology

The methodology, based on Upper and Worms (2004), aims at assessing the impact on the Belgian financial system of the sudden and unexpected default of each banking counterpart of Belgian banks. The test of contagion uses a $(N \times (N + M))$ matrix of interbank bilateral exposures, X, to study the propagation mechanisms of crises. The matrix of bilateral exposures summarizes the interbank exposures of Belgian banks toward the other $(N - 1)$ Belgian banks and the M foreign banks:

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

with

$$\sum_{j=1}^{N} x_{ij} = a_i; \ \sum_{i=1}^{N} x_{ij} = l_j \quad \text{and} \quad \sum_{j=N+1}^{M} w_{ij} = fa_i,$$

where x_{ij} represents the gross exposure of the Belgian bank i to the Belgian bank j, w_{ij} represents the gross exposure of the Belgian bank i to the foreign bank j, a_i represents the domestic interbank assets of bank i, l_j represents the domestic interbank liabilities of bank j, and fa_i represents the foreign interbank assets of bank i.

The simulations successively study the impact of the failure of each of the N Belgian banks and each of the M foreign banks for a given LGD. The initial failure is assumed to cause an additional failure when the exposure of one bank to failed banks is large enough to offset its tier 1 capital. More specifically, bank i fails subsequently to other failures when

$$C_i - \sum_{j=1}^{N} \lambda_j \theta x_{ij} - \sum_{j=N+1}^{M} \lambda_j \theta w_{ij} < 0,$$

where C_i refers to the tier 1 capital of bank i, θ refers to the LGD, and λ_j is a dummy variable equal to 1 if bank j fails and 0 otherwise. The LGD is assumed to be constant and identical for all failed banks. We assume that in the event of bankruptcy there is no netting, so we use gross exposures x_{ij} and w_{ij} rather than net exposures $(x_{ij} - x_{ji})$. The initial default may cause several successive rounds of failures. The contagion stops when banks that failed during the last round do not cause any additional failures, i.e., when the system is again stable.

The matrix of bilateral exposures is (partly) unknown and, hence, must be inferred. The inference technique (hereafter called *aggregate exposures technique*) is based on the observed aggregates a_i and l_j, which only provide incomplete information on interbank exposures of Belgian banks to Belgian banks—namely, the column and row sums of the matrix X, i.e., the marginal distribution of the x_{ij}. Since this information is partial, we need to make an assumption on the distribution of the individual interbank exposures. Following other papers,[9] we assume that banks seek to maximize the dispersion of their interbank activities.[10] This kind of problem is easily solved with the RAS algorithm.[11] Details on the methodology can be found in Upper and Worms (2004). Since we unfortunately lack the necessary data to apply this methodology to foreign banks, we cannot infer a matrix of international bilateral exposures for Belgian banks. Large exposures are used in this case to estimate the w_{ij}.

Any inference technique, and the general contagion exercise, involves biases—some of which tend toward underestimation and others toward overestimation of contagion risk. The sources of underestimation of contagion risk include the measure of interbank exposures, which is based on interbank loans and deposits only and

[9]See Upper and Worms (2004), Wells (2004), and Elsinger, Lehar, and Summer (2006).

[10]In order to test the robustness of our results, we use two additional techniques. The first one (*large exposures technique*) consists of using the matrix of bilateral exposures based on large exposures only. The second one (*mixed technique*) mixes both approaches by incorporating large exposures in the matrix of bilateral exposures and by using the a_i and l_j, net of large exposures, to calculate the residual, unreported exposures. However, since time series of large exposures are not available, analyses over time are only based on the aggregate exposures technique.

[11]See, e.g., Blien and Graef (1997).

consequently does not include other interbank exposures, such as off-balance-sheet exposures. The distributional assumption of maximum dispersion of banks' interbank exposures also potentially leads to an underestimation of contagion risk, as there are fewer peaks in the distribution[12] (on the other hand, the distributional assumption also creates interbank linkages that do not exist and that are new ways for contagion propagation). Moreover, indirect effects of the failure of foreign banks are not taken into account, since we are unable to measure contagion between foreign banks. Our results may thus suffer from a potential censoring bias. Another source of underestimation is the fact that credit risk is the only source of interbank contagion; liquidity risks are ignored. Furthermore, we use a conservative definition of bank failure, as, in reality, banks may fail before their tier 1 capital is exhausted by interbank losses.[13] Finally, bank panics by depositors are assumed not to occur.[14] On the other hand, since banks are assumed not to be able to refinance or to raise additional capital, we overestimate contagion risk. We also assume that they are not able to anticipate crises and to subsequently reduce their interbank exposures. The absence of safety nets also tends to generate an overestimation bias. Another source of overestimation is the measure of interbank exposures that is on a firm basis and not on a consolidated basis.[15] The extent to which contagion risk will actually be underestimated or overestimated in our simulations will

[12]The distributional assumption also rules out the possibility of having interbank relationship lending. Cocco, Gomes, and Martins (2003) find evidence of lending relationships in the interbank market. Interbank lending relationships could help to mitigate the risk of contagion (as, for instance, monitoring could be more efficient) but could also give rise to very high peaks in the matrix of bilateral exposures.

[13]While the contagion algorithm assumes that a bank only fails once its interbank losses amount to at least its tier 1 capital, there are situations in which a bank may fail before it reaches this threshold. For instance, even small interbank losses could generate additional non-interbank losses (e.g., if the interbank losses trigger a bank run).

[14]Bank panics may occur following an individual bank's failure if depositors make inferences about systemic weakness based on observation of the individual failure (see Aghion, Bolton, and Dewatripont 2000).

[15]Although the use of data at a company level leads to the implicit assumption that cross-border intragroup exposures are between different banks, our actual simulations reveal few cases where such exposures cause "contagion." Assuming away intragroup contagion would be equivalent to making the assumption that the subsidiary will receive assistance from its parent company. However, facing a

obviously depend upon the importance of each of these sources. We deal with some of these potential biases in section 4.2.

Since we want to investigate extreme events, our main indicator of contagion over time is the worst-case scenario (WCS). It is defined as the scenario for which the percentage of total banking assets represented by banks losing their entire tier 1 capital due to contagion is largest. We also provide information on the next-to-worst-case scenario. For brevity, and as the results are in line with the WCS, we do not report the results for two other contagion indicators—i.e., the number of cases of contagion, which measures the likelihood of the occurrence of a contagion effect conditionally to a bank failure, and the number of rounds of contagion, which provides some information on the interbank market structure.[16]

3.3 Structure of the Belgian Interbank Market

Table 2 presents a matrix of bilateral exposures based on the aggregate technique. For presentation purposes, we grouped banks by size in five groups (designated G1–G5). Natural thresholds in the empirical bank-size distribution were used in order to determine groups' composition. G1 comprises the four banks whose assets exceed €99 billion, G2 comprises five banks with assets between €8 and €14 billion, G3 comprises seven banks with assets between €3 and €6 billion, G4 comprises fifteen banks with assets between €1 and €2.6 billion, and G5 comprises thirty-four banks with less than €700 million in assets. Recall that bilateral interbank positions are determined before the grouping procedure. Note also that EMU, RoW, and total interbank rows and columns are directly observed and are thus independent of distributional assumptions.

Most domestic interbank transactions seem to involve large banks. Indeed, positions between G1 banks and other banks exceed by far positions between G2–G5 banks. This structure has not always been prevalent in Belgium. Table 3 shows the evolution over time of the total amount G2–G5 cells can account for. The first row of

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large shock, the parent company may not be in a situation in which such a rescue is possible. Therefore, we prefer to treat intragroup exposures similarly to other exposures. Using consolidated data would implicitly rule out the possibility for banking groups to close down an ailing subsidiary.

[16]Results can be found in Degryse and Nguyen (2004).

Table 2. Bilateral Interbank Exposure by Size Categories—December 2002

	% of Assets of Banking System	G1	G2	G3	G4	G5	EMU	RoW	Total Interbank Loans	Foreign Interbank Loans as % of Total Loans
G1	85.10%	15.1	1.0	0.9	2.8	1.1	70.6	64.0	155.4	86.6%
G2	6.80%	2.6	0.1	0.1	0.4	0.1	4.2	2.8	10.4	67.9%
G3	3.50%	2.1	0.1	0.1	0.3	0.1	5.1	0.2	8.0	66.1%
G4	3.40%	2.7	0.1	0.1	0.4	0.2	0.9	1.4	5.7	39.4%
G5	1.30%	1.9	0.1	0.1	0.3	0.1	1.0	0.3	3.8	35.8%
EMU		71.4	3.0	0.6	0.8	0.2				
RoW		111.7	3.3	1.5	2.6	0.6				
Total Interbank Deposits		207.4	7.7	3.4	7.5	2.5				
% of Foreign Interbank Deposits		88.3%	81.5%	61.3%	45.6%	32.4%				

Notes: Data are for December 2002, in € billion, except when expressed as percentages.
Domestic Exposures: Estimates of the matrix of bilateral exposures are based on the aggregate technique, which maximizes the distribution of total interbank loans and deposits.
Banks were grouped by size for expositional purposes. Natural thresholds in the empirical bank-size distribution were used in order to determine groups' composition. G1 comprises the four banks whose assets exceed €99 billion, G2 comprises five banks with assets between €8 and €14 billion, G3 comprises seven banks with assets between €3 and €6 billion, G4 comprises fifteen banks with assets between €1 and €2.6 billion, and G5 comprises thirty-four banks with less than €700 million in assets.
Foreign exposures are based on reported figures.

Table 3. Interbank Share of Nonlarge Banks

	1993:Q2	1994:Q2	1995:Q2	1996:Q2	1997:Q2	1998:Q2	1999:Q2	2000:Q2	2001:Q2	2002:Q2	2002:Q4
Maximum	68.1%	42.4%	48.2%	46.5%	53.6%	40.4%	33.5%	40.0%	40.4%	23.2%	25.8%
Aggregate Exposures Technique	36.4%	30.0%	32.0%	30.7%	35.4%	17.1%	14.6%	20.5%	18.5%	6.1%	8.1%

Note: Figures are for Q2 of each year. "Maximum" and "Aggregate Exposures Technique" represent the percentage of total aggregate exposures of Belgian banks' domestic interbank exposures accounted for by small and medium-sized banks. "Maximum" is based on the minimum of the total interbank loans and total interbank deposits of small and medium-sized banks. "Aggregate Exposures Technique" is computed on the basis of the aggregate exposures technique.

the table shows the maximum amount these cells can represent. This maximum is calculated independently from any distributional assumption. It is defined as the minimum between the sum of domestic interbank deposits of G2–G5 banks (i.e., the sum of the l_j of G2–G5 banks) and the sum of their domestic interbank loans (i.e., the sum of their a_i).[17] The second row of the table presents the calculated G2–G5 total in the aggregate exposures technique. Both series show a downward time trend. In 1993, the structure of the interbank market was similar to a complete structure where estimated exposures between G2–G5 banks represent 36 percent of the domestic market (and could not exceed 68 percent with any alternative distributional assumptions). However, the interbank positions between G2–G5 banks decrease drastically between 1993 and 2002 (it is estimated to 8.1 percent with the aggregate exposures technique and to 10 percent with the mixed technique). So, although we still assume a complete structure,[18] small and medium-sized banks do not seem to have significant exposures to each other in 2002. We observe the same time trend in the maximum. In fact, it mainly reflects the very high concentration of interbank positions involving large banks on both sides of the balance sheet.[19] The evolution over time of the matrix of bilateral exposures thus demonstrates that the aggregate exposures technique is able to capture changes in the market structure, despite the initial assumption of maximum entropy.

Although interbank activities with foreign banks are mainly concentrated in large banks (table 2), access to international interbank markets does not seem to be strictly limited to large banks only. Nevertheless, we observe that the proportion of foreign interbank loans or deposits tends to decrease with bank-size category. Possible explanations are that smaller banks may not reach the critical

[17]By definition, the sum of G2–G5 cells will never exceed the minimum of domestic interbank loans and domestic interbank deposits of these banks. In fact, taking the minimum even constitutes an overestimation of the total G2–G5, as it does not take into account constraints such as a null diagonal.

[18]Assuming a maximum dispersion of interbank activities is similar to assuming a complete structure of claims as described in Allen and Gale (2000).

[19]The concentration on the interbank market increased over the last decade. As far as interbank activities are concerned, the Herfindahl index currently exceeds 0.25, while the market share of the five main players reaches about 90 percent.

size and be internationally less known to tap into the international interbank markets. This would be in line with one of the scenarios presented in Freixas and Holthausen (2005), where large banks with a good international reputation act as correspondent banks for their domestic peers in order to overcome asymmetric information problems.

The few interbank positions between G2–G5 banks, combined with their decreasing share of international financing, suggest that large banks (G1) tend to operate as money centers à la Freixas, Parigi, and Rochet (2000). One important difference in relation to their structure is that several money centers would be linked together, as reflected by the substantial position between the G1 banks.[20] Thus, each large bank tends to function as a money center connected to the other money centers. The Belgian interbank market would thus be characterized by a multiple-money-center structure versus the single money center of Freixas, Parigi, and Rochet (2000).

4. Simulation Results

This section presents the results of the simulations. Section 4.1 discusses the impact of both domestic and foreign contagion in the simulation for 2002:Q4. In section 4.2, the evolution of contagion risk over time is investigated using the algorithm with standard assumptions, such as described in section 3 (4.2.1), but also with additional assumptions aiming at endogenizing the LGD (4.2.2) and aiming at modifying players' behavior as robustness tests (4.2.3).

4.1 Simulations for 2002:Q4: Domestic and Foreign Contagion

Table 4 presents the results of the contagion exercises. Results are reported for five different LGD rates (first column). The second column gives the number of scenarios that generate contagion. The third column presents the median scenario. The median scenario

[20]In unreported data, we find that large banks hold cross-deposits in other large banks.

gives the median value of the percentage of total banking assets represented by banks losing their tier 1 capital, across all of the scenarios where contagion occurs. The two following columns provide information about the state of the banking system in the next-to-worst-case scenario and in the WCS, respectively. For the latter, we display the percentage of assets represented by, and the number of, failing banks and banks losing, respectively, between 100 percent and 70 percent, between 70 percent and 40 percent, between 40 percent and 10 percent, or less than 10 percent of their tier 1 capital. Finally, the last column presents an indicator of risk associated with the "domino" generating the WCS—namely, the rating of the first domino. Since few Belgian banks are publicly listed, neither a rating nor any other market-based indicator is available for a large number of Belgian banks.[21]

Panel A of table 4 reports the result of the simulations for *domestic contagion*, i.e., where contagion is triggered by exposures toward a Belgian bank. In December 2002, there were sixty-five banks incorporated in Belgium, i.e., sixty-five potential sources of domestic contagion. The frequency of domestic contagion occurring is limited. Under the assumption of 100 percent LGD, only four out of these sixty-five banks' defaults cause the failure of at least another Belgian bank. The knock-on effects are also limited. In the median scenarios, the percentages of assets represented by banks losing their tier 1 capital are extremely low. In the WCS, which is always caused by the default of a large bank, simulations show that banks that would lose their tier 1 capital as a result of the interbank defaults never represent more than 3.8 percent of the total assets of Belgian banks. Thus, the default of a Belgian bank in the interbank market does not cause a large Belgian bank to lose its entire tier 1 capital.

[21] Accounting risk measures for Belgian banks, such as the level of tier 1 capital of the domino generating the WCS (as a percentage of its total assets) or the level of its losses for bad loans (as a percentage of its commercial loans), are imperfect measures of risk, as there could be specific reasons, not necessarily linked to risks, justifying special levels for these ratios for a given bank (e.g., a large diversified bank may have a lower capital ratio). Similarly, an apparently sound bank may fail because of fraud, risk concentration, etc. Since presenting such indicators of risk could be misleading, we prefer to present no risk indicator for Belgian banks.

Table 4. Contagion Exercise 2002:Q4

LGD (%)	Number of Scenarios Where Contagion Occurs	Median Scenario Assuming Contagion. Percentages of Balance Sheet Assets Represented by Failing Banks (Excluding Assets of "First Domino")	Next-to-Worst-Case Scenario: Banks Failing		Worst-Case Scenario (Excluding First Domino): Banks Failing		Banks Losing 100%–70% of Tier 1 Capital		Banks Losing 70%–40% of Tier 1 Capital		Banks Losing 40%–10% of Tier 1 Capital		Banks Losing Less Than 10% of Tier 1 Capital		Rating of the First Domino
			% Balance Sheet Assets	# of Banks	% Balance Sheet Assets	# of Banks	% Balance Sheet Assets	# of Banks	% Balance Sheet Assets	# of Banks	% Balance Sheet Assets	# of Banks	% Balance Sheet Assets	# of Banks	
A. Domestic Exposures															
100	4	3.33%	3.75%	15	3.79%	17	0.09%	3	53.67%	17	2.29%	12	40.17%	16	n.a.
80	4	2.13%	3.75%	14	3.75%	15	0.03%	≤2	0.94%	9	55.01%	21	40.27%	18	n.a.
60	4	1.73%	3.04%	9	3.33%	11	0.42%	4	0.12%	5	55.67%	25	40.46%	20	n.a.
40	2	2.98%	2.91%	5	3.04%	9	0.29%	≤2	0.45%	6	55.23%	25	40.98%	23	n.a.
20	2	0.50%	0.50%	3	0.50%	3	0.00%	≤2	2.54%	6	1.31%	12	95.66%	44	n.a.

(continued)

Table 4 (continued). Contagion Exercise 2002:Q4

LGD (%)	Number of Scenarios Where Contagion Occurs	Median Scenario Assuming Contagion. Percentages of Balance Sheet Assets Represented by Failing Banks (Excluding Assets of "First Domino")	Next-to-Worst-Case Scenario		Worst-Case Scenario (Excluding First Domino)										
			Banks Failing		Banks Failing		Banks Losing 100%–70% of Tier 1 Capital		Banks Losing 70%–40% of Tier 1 Capital		Banks Losing 40%–10% of Tier 1 Capital		Banks Losing Less Than 10% of Tier 1 Capital		Rating of the First Domino
			% Balance Sheet Assets	# of Banks	% Balance Sheet Assets	# of Banks	% Balance Sheet Assets	# of Banks	% Balance Sheet Assets	# of Banks	% Balance Sheet Assets	# of Banks	% Balance Sheet Assets	# of Banks	
B. Foreign Exposures															
100	13	0.07%	20.01%	0.07	20.01%	7	0.00%	≤2	1.02%	5	67.36%	8	11.61%	45	AA−
80	9	0.04%	0.29%	≤2	19.97%	6	0.04%	≤2	0.44%	3	32.34%	6	47.21%	49	AA+
60	8	0.04%	0.08%	≤2	18.15%	4	1.82%	≤2	0.04%	≤2	32.78%	9	47.21%	49	AA+
40	3	0.08%	0.08%	≤2	18.08%	≤2	0.04%	≤2	1.89%	4	20.22%	7	59.77%	51	AA+
20	1	0.08%	0.00%	≤2	0.08%	≤2	0.00%	≤2	0.00%	≤2	0.00%	≤2	99.92%	64	A

Note: The table presents the results of the contagion exercises for December 2002. Results are reported for five different LGDs. The second column gives the number of scenarios that generate contagion. The third column presents the median scenario. The median scenario gives the median value, across all of the scenarios where contagion occurs, of the percentage of total banking assets represented by banks losing their tier 1 capital. The remaining columns provide some statistics on the state of the banking system in the next-to-worst-case and worst-case scenarios. The table presents the percentage of assets represented by, and the number of failing banks and banks losing, respectively, between 100% and 70%, between 70% and 40%, between 40% and 10%, or less than 10% of their tier 1 capital. Cells with two or fewer banks are marked "≤ 2" in order to make single bank identification impossible. The last column presents the rating of the first domino in the WCS. Panel A presents the results of the contagion exercises assuming that the first defaulter is a Belgian bank. It is based on a matrix of bilateral exposures estimated with the aggregate exposures technique. Each line is based on 65 different scenarios (i.e., the individual failure of each of the sixty-five Belgian banks). Panel B, simulating the default of a foreign bank, is based on a matrix of bilateral exposure estimated with the large exposures technique. It is based on 135 different scenarios.

In addition, losses decrease in parallel with the LGD.[22] Although the losses in the next-to-worst-case scenario are lower, they remain very close to the WCS outcome.

As results are very similar to the results of the aggregate exposures technique, and for the sake of brevity, we do not report the results based on the large exposures and on the mixed techniques.[23] This comparability across techniques validates our use of the aggregate exposures technique for the estimation of contagion risk over time.[24]

Panel B of table 4 displays the results for *foreign contagion*. We identify 135 foreign banking counterparts for Belgian banks. For a 100 percent LGD, the default of 1 large foreign bank can lead to

[22]The statistical estimation of an LGD for Belgian banks is very difficult, since fortunately very few Belgian banks have failed in the last decades. Moreover, actual losses on a defaulting bank can prove very complicated to calculate, since they depend on the time horizon chosen. Altman and Kishore (1996) estimate average recovery rates on defaulting bonds of financial institutions (for the period 1978–95) to be about 36 percent. However, recovery rates vary by type of institution, from 68 percent for mortgage banks to 9 percent for savings institutions. Moreover, the LGD for bonds is probably very different from the LGD for comparable loans (which in our case comprise secured and unsecured assets). James (1991) estimates that losses average 30 percent of the failed bank's assets and that the direct expenses associated with bank closures average 10 percent of assets, making a total of about 40 percent. Seeing that more than 50 percent of interbank loans granted by Belgian banks are secured, it may therefore be realistic to assume a recovery rate of somewhere between 60 and 80 percent (i.e., an LGD between 40 and 20 percent). On the other hand, as domino effects may be considered instantaneous, one could also argue that the time pattern of recovery does not matter and that an LGD of 100 percent should be used to simulate liquidity shocks. Yet the time pattern of recovery may matter, depending on the maturity of the liabilities.

[23]They are, however, available on request.

[24]In a recent paper, Mistrulli (2005) compares the estimated and observed large exposures techniques for Italy and finds that they may differ depending on the level of LGD. In particular, he finds that the observed bilateral exposures generate higher contagion (as a share of total assets) for low LGDs, whereas the opposite holds for large LGDs. In general, it is unclear whether using estimated bilateral exposures leads to overestimation or underestimation. This should, however, not influence our results under the assumption that the potential biases remain constant over time. Note in addition that van Lelyveld and Liedorp (2006) conclude that "the entropy estimation using large exposure data as applied in many previous papers gives an adequate approximation of the actual linkages between banks. Hence this methodology does not seem to introduce a bias." However, they also find that entropy maximization leads to an overestimation of contagion risk.

the failure of 7 Belgian banks whose assets account for 20 percent of total Belgian bank assets. These numbers are considerably higher than those of our simulations with Belgian banks as first domino. The results for the WCS also indicate that, even for an LGD of 40 percent, the default of a foreign bank can have a significant impact on Belgian banks. Note, however, that large differences exist between the median and the worst-case scenarios. For an LGD of 100 percent, only three of the thirteen simulations that involved contagion entailed the failure of banks representing at least 10 percent of the total assets of the Belgian banking system. The next-to-worst-case scenario shows that, for reasonable LGD, contagion is not likely.[25] In addition, all of the foreign banks representing the first domino in the WCS are European banks, and all rank as investment grade, which suggests that actual interbank defaults by these banks, although possible, are not frequent.

Our contagion analysis cannot incorporate indirect effects of the failure of foreign banks, which may be important (i.e., failure of other foreign banks caused by the failure of a given foreign bank). One way to proxy for indirect effects is to simulate the impact of the combined default of several foreign banks coming from the same country. Belgian banks provide a breakdown of their aggregate interbank exposures (the fa_i) by EU countries. The data are available for the last five years. We make the assumption that x percent of the interbank exposures of Belgian banks to banks in a particular EU country are unrecoverable. We use the propagation mechanism explained earlier to measure the impact on the Belgian system. Unreported results show that with the exception of France, the Netherlands, and the United Kingdom, simulations involving defaults on other countries' interbank loans (including Germany and Luxembourg) do not result in significant contagion in the Belgian banking sector at the end of 2002.[26] For example, for an LGD of

[25]This finding was confirmed afterward by van Lelyveld and Liedorp (2006), who found that below an LGD of 75 percent, domestic and foreign contagion was unlikely.

[26]Although the results are quite stable over 1999–2002 (the period over which data are available), with France and the United Kingdom often representing major risks, other neighboring countries sometimes show a higher potential for contagion. These jumps in simulated country impact probably reflect larger interbank positions with those countries. We do not observe any significant increase

100 percent, a simulation of the failure of all German banks shows that Belgian banks losing their entire tier 1 capital represent less than 1 percent of total Belgian bank assets. When we use a lower LGD, only bank defaults in the United Kingdom would yield significant levels of contagion in Belgium. This in fact reflects the United Kingdom's role as a money center and the importance of UK banks as counterparts of Belgian and other European banks. Manna (2004) finds that London is indeed an important nexus for all EMU banks, as UK banks account for more than one-third of their cross-border interbank deposits.

4.2 Evolution over Time: Simulations of Domestic Contagion Based on Aggregate Exposures

4.2.1 Baseline Case

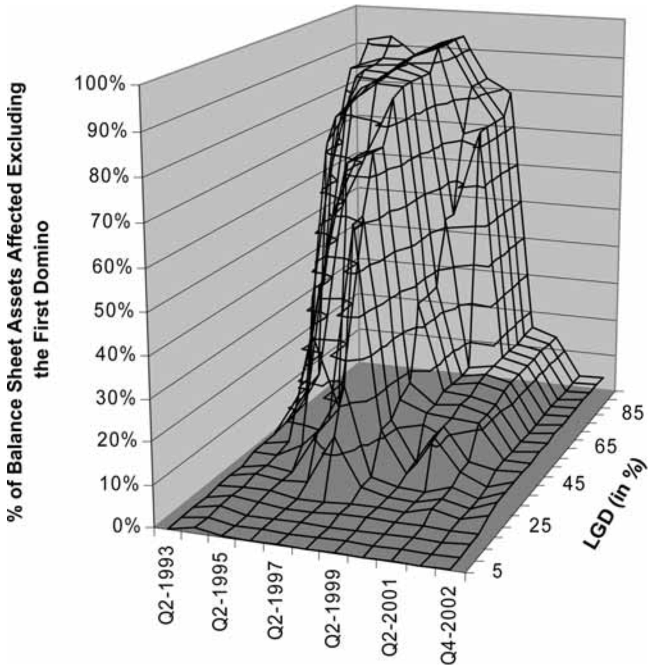
The simulations used to study the evolution of the domestic contagion risk over time cover the period 1992:Q4–2002:Q4. Figure 1 shows the behavior of the WCS over the period 1993–2002 for twenty different LGDs ranging from 5 percent to 100 percent, in steps of 5 percent. Thus, for each quarter, the number of scenarios tested amounts to twenty times the number of banks (between 65 and 112).[27]

Figure 1 shows that, over the last decade, the WCS has been subject to three major evolutions. Between 1993 and 1997, the WCS consistently worsens. Between 1997 and 1999, the WCS affects less of Belgian banking assets; i.e., there is a steep decrease between 1997 and 1999. Finally, between 1999 and 2002, the surface flattens and contagion remains limited, even with high LGDs. Thus, the degree of contagion generated in simulations with data for the last quarter of 2002 appears to be at a record low. These trends are particularly striking for an LGD of 60 percent. In this case, the percentage of total banking assets affected by contagion, excluding the first

in the cross-border contagion risk over 1999–2002. However, such an increase may have taken place earlier, in years in which internationalization of interbank exposures of Belgian banks substantially increased.

[27]For presentation purposes, figure 1 presents the results for Q2 only. Tests reported in subsection 5 show that the trends in the WCS presented in figure 1 are not sensitive to the quarter chosen.

Figure 1. Contagion Effect—Worst-Case Scenario: 1993–2002



Note: The graph presents the evolution of the worst-case scenario for twenty different LGDs over time, from 1993:Q2 to 2002:Q4. LGDs are shown as percentages. The results are based on contagion exercises using matrices of bilateral exposures estimated with the aggregate exposures technique.

domino, varies over the period from 86 percent to 3 percent. We also find that (i) the next-to-worst-case scenario is affected by the same structural changes as the WCS and (ii) the level of the next-to-worst-case scenario is similar to the level of the WCS (unreported).[28]

The WCS is frequently—but not always—generated by the default of a large bank. Actually, an analysis of banks initiating

[28]A potential concern is that the WCS is initiated by sound banks in a particular period and not-very-sound ones in other periods. We find that the bank triggering the WCS persistently belongs to the lowest quartile in terms of capitalization (unreported). This suggests that if the capital ratio is a good proxy for the likelihood of failure, the likelihood of failure of the bank initiating the WCS remained quite constant over time.

the WCS shows that different banks cause the WCS in different years, although some banks tend to do so more often than others. For instance, large banks generate the WCS more often than small banks. In addition, banks initiating the WCS are not only different from year to year but also, to a certain extent, within a given year, depending on the applied LGD. We also find that the default of a large bank is always directly preceded either by the default of another large bank or by the default of a medium-sized bank. Indeed, the tier 1 capital of large banks is never totally absorbed by the combined default of several small banks. However, the default of a small bank may trigger the failure of several small and medium-sized banks and, in turn, of a large bank. Note also that in some cases, no large bank fails, even in the WCS.[29]

The results on domestic contagion suggest that contagion risk in Belgium has evolved over time. Any attempt to compare our results with the results of simulations for other countries must therefore take the time dimension into consideration. A comparison with studies using the same methodology indicates that the simulated failure of a Belgian bank in December 1998 produced smaller contagion effects than the simulated failure of a German bank in the same period, at least for a high LGD (Upper and Worms 2004). Results for the United Kingdom (Wells 2004), which uses data for end 2000, show that the Belgian simulations produced a greater impact of contagion at the same time period. However, contagion occurred in a higher proportion of cases in the United Kingdom. Finally, the simulated impact of contagion for 2002:Q4 is similar in Belgium and in the Netherlands (van Lelyveld and Liedorp 2006). As results for Belgium are broadly similar to results for Germany, the Netherlands, and the United Kingdom at similar time periods, it is impossible to know whether dissimilarities between Germany, the Netherlands, and the United Kingdom are due to structural differences or to general time trends affecting several European countries. We investigate the determinants of domestic contagion in Belgium in section 5.

[29]Since the WCS is a very extreme outcome, we investigate, in unreported exercises, other measures of contagion, i.e., the variations in the percentage of banks intitiating contagion and the propagation mechanisms of contagion (number of rounds). The evolution over time of these indicators is similar to the evolution of the WCS.

4.2.2 Endogenous LGD

Our baseline simulations assume a fixed LGD for all banks. It is not obvious a priori that endogenizing the LGD would deliver additional results, especially as we already test very extreme LGD, ranging from 100 percent to 5 percent. Surprisingly, however, there are some indications that it may do so.

We take two complementary steps to endogenize the LGD. In both steps, the core of the endogenization process is that the LGD of a given bank depends upon the LGD of all the other banks to which it is linked. In a first step, we endogenize the LGD on interbank claims only and apply an exogenous LGD on other "remaining assets."[30] In a second step, we add some admittedly ad hoc assumptions to endogenize the recovery rate on the other remaining assets as well. The LGD is calculated for failing banks only, at each round of the algorithm, in order to assess the value of their remaining assets. The calculation of the LGD for a given bank does not determine whether a bank is bankrupted. It only assesses the value of its assets once it has been declared bankrupted, i.e., the value of the bankrupted bank for its creditors.

We start with the endogenization of the LGD on interbank claims. The LGD on interbank claims of bank i is defined as

$$\theta_i = \left[\frac{\sum_j(\theta_j x_{ij}) + \textit{remaining assets} * \textit{LGDs remaining assets}}{\textit{Total Assets} - \textit{shareholders' equity}}\right],$$

where θ_i is the LGD of bank i, x_{ij} is the gross interbank exposure of bank i to bank j, *remaining assets* represents all the other remaining assets of bank i, and *LGDs remaining assets* stands for the loss rate that bank i has to bear on its assets because of its default. Solving the system of equations for all failed banks simultaneously gives a different endogenous LGD for each failed bank.

We first distinguish between liquid and illiquid assets (partial endogenization). We assume a 0 percent LGD on liquid assets. We simulate different LGDs on the remaining illiquid assets. All simulations assume a 60 percent LGD on the first domino. Results are

[30]Note that by LGD on remaining assets, we mean the loss given the default of the bank to which these assets belong. The assets themselves, however, have not defaulted.

reported in panel A.1. of table 5. We present the results for two polar cases in which the LGD on illiquid assets is, respectively, equal to 100 percent and 0 percent, as well as for an intermediate LGD of 60 percent. The latter can be compared to the baseline simulation, which is based on a fixed 60 percent LGD. For each assumed LGD on illiquid assets, the first line presents the WCS, while the second line gives the average implied LGD in the WCS.

We conclude two things from the simulations. Firstly, although the level of and changes in the WCS are broadly similar to the results of simulations that assume a fixed LGD for all assets, the average implied LGD varies substantially within a given year. For instance, in 2002, the minimum LGD—assuming a 100 percent LGD on illiquid assets—was 8.8 percent, while its maximum was 76.5 percent. Thus, endogenizing only the LGD on interbank exposures already suffices to introduce a large heterogeneity between banks, even though it does not affect the general trends. Secondly, although the average implied LGD varies over time, we do not observe a strict correlation between the LGD and the WCS. Because the LGD interacts with other dimensions of the market structure, a higher average LGD does not necessarily generate a higher WCS.

Next, we try to endogenize the LGD on the "remaining assets" as well (labeled "Complete Endogenization"). Besides interbank loans, we distinguish five categories of assets:

(i) Liquid Assets: We assume a 100 percent recovery rate.

(ii) Customer Loans: We assume that the loss rate on a bank's loan portfolio is equal to the average residual maturity of its loan portfolio times its annual loan-loss provisions (as a percentage of its total loans). This amounts to 4 percent on average in 2002. The minimum is equal to 0 percent and the maximum to 35 percent.[31]

[31] As this is a broad measure of the expected losses of the loan portfolio in a going concern, it does not take into account losses resulting from the loss of information that could arise when the loan portfolio is sold. In an unreported test, we assume that the loss on the portfolio is an average between 30 percent and our estimates. The average LGD of commercial loans is indeed approximately 30 percent (see, e.g., Bank for International Settlements 2005). Remember, however, that in our simulations, loans are not in default. This does not qualitatively affect the results.

Table 5. Alternative Scenarios

	1993	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Baseline	3.3%	14.1%	58.5%	73.0%	86.4%	35.7%	13.6%	13.2%	11.5%	2.9%
A. Endogenous LGD										
A.1. Partial Endogenization										
LGD Illiquid 100%	3.8%	76.8%	85.9%	90.9%	91.9%	52.0%	13.6%	14.9%	13.3%	2.9%
Average LGD	*64.8%*	*82.5%*	*85.9%*	*85.0%*	*90.3%*	*86.6%*	*71.0%*	*78.5%*	*76.5%*	*59.3%*
LGD Illiquid 60%	2.5%	13.1%	54.3%	72.9%	75.6%	17.1%	12.4%	13.2%	11.5%	2.8%
Average LGD	*33.5%*	*26.5%*	*27.3%*	*37.9%*	*49.7%*	*43.9%*	*38.1%*	*43.9%*	*38.6%*	*41.0%*
LGD Illiquid 0%	1.9%	1.8%	8.5%	4.5%	10.7%	9.0%	11.6%	9.5%	10.8%	2.8%
Average LGD	*16.2%*	*20.2%*	*9.8%*	*10.0%*	*13.5%*	*14.4%*	*9.0%*	*10.1%*	*9.1%*	*8.7%*
A.2. Complete Endogenization										
LGD First Domino 100%	12.2%	12.5%	32.1%	29.4%	18.7%	15.3%	12.0%	29.1%	12.5%	0.8%
Average LGD	*19.2%*	*19.8%*	*22.1%*	*18.7%*	*20.1%*	*20.2%*	*19.6%*	*21.5%*	*20.4%*	*16.9%*
LGD First Domino 60%	6.2%	6.9%	13.5%	11.6%	17.0%	14.2%	10.4%	9.6%	10.8%	0.6%
Average LGD	*18.4%*	*16.3%*	*18.6%*	*16.7%*	*17.9%*	*18.2%*	*18.2%*	*18.6%*	*18.7%*	*17.9%*
LGD First Domino 5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Average LGD	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*

(continued)

Table 5 (continued). Alternative Scenarios

	1993	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Baseline	3.3%	14.1%	58.5%	73.0%	86.4%	35.7%	13.6%	13.2%	11.5%	2.9%
B. Players' Behavior										
Anticipation	NA	1.9%	29.6%	11.3%	55.9%	8.9%	3.1%	9.7%	8.6%	0.4%
TBTF	3.3%	4.2%	41.2%	10.2%	55.0%	2.4%	3.9%	2.4%	4.1%	0.0%
Coordination	3.3%	14.1%	58.5%	0.0%	0.0%	0.0%	13.6%	13.2%	11.5%	2.9%
Netting	0.7%	2.0%	1.1%	0.6%	0.6%	0.6%	3.3%	1.0%	4.1%	2.8%
C. Correlated Shocks										
Macro Shock	3.7%	75.9%	84.9%	88.6%	87.8%	35.9%	13.6%	14.9%	13.3%	2.9%
Two Failures	31.6%	72.5%	83.1%	84.8%	88.3%	36.1%	30.9%	14.9%	13.6%	3.4%
Three Failures	45.0%	74.0%	83.4%	85.3%	88.5%	55.7%	49.2%	14.9%	13.6%	3.7%
Four Failures	45.4%	75.6%	85.1%	85.3%	88.9%	70.3%	49.2%	14.9%	13.6%	3.7%

Note: Figures are for Q2 of each year. The table presents the evolution of the WCS under alternative assumptions. In the baseline case, a fixed LGD of 60 percent is assumed. Panel A presents results of simulation when the LGD is endogenous. For each assumption, we present both the WCS in the first line and the average implied LGD in the second line. In panel B, assumptions relating to banks' anticipation, too-big-to-fail mechanisms, coordination mechanisms, and netting are modified. In panel C, macro shocks are simulated.

(iii) Government Bonds: Similarly to Cifuentes, Ferrucci, and Shin (2005), we assume that failed banks liquidate their government bonds portfolio and that their value is inversely proportional to the supply of government bonds in the market. We apply a haircut of 1 percent on the portfolio each time the cumulated sales of government bonds by failed banks amount to 10 percent of the market, defined as the sum of government bonds held by Belgian banks. To ensure comparability, we assume that banks do not mark to market their bonds portfolio so that sound banks are not affected by this decrease. Hence, in our model, government bonds do not constitute an additional direct contagion channel.

(iv) Intangible Assets: We assume an LGD of 100 percent on intangible assets.

(v) Other Assets: We apply an arbitrary LGD of 30 percent on all the remaining assets. The latter is based on James (1991), who finds that loss on assets of failed banks amounts to 30 percent on average. These assets represent, on average, 17 percent of total assets in 2002.

In addition, we apply a fixed cost of bankruptcy amounting to 10 percent of total assets (see James 1991). We also take into account two kinds of privileged creditors—namely, the state and the employees of the bank. By subtracting claims of the latter from both the numerator and the denominator of the LGD ratio, we make the assumption that they are first served in the liquidation process. This increases the LGD applied on interbank claims. As we do not have any other information regarding the seniority of the remaining claims, we assume that the proceeds of the liquidation are shared proportionally.

In panel A.2. of table 5, we present the results using three different levels for the exogenous LGD applied to the first domino. Endogenizing the LGD decreases substantially the level of contagion. Yet, we still observe the same trend over time, with very low contagion indicators in 2002. The average implied LGD amounts to 19 percent. As indicated in section 4.1, this seems to be reasonable, although maybe conservative. A striking result is that the simulations implying an average endogenous LGD of around 20 percent result in more contagion than those with a fixed LGD of 20 percent, in which contagion was inexistent. This is partly due to two effects. Firstly, in two out of the three cases, the LGD of the first domino is assumed to be higher than 20 percent. Secondly, precisely because the LGD is endogenous, we observe heterogeneous LGD with sometimes high levels of losses, helping to propagate contagion. Thus, it is likely that the propagation of contagion is not only determined by the pattern of links defining the market structure but also by the relative strength of each counterpart to which banks are linked.

4.2.3 Robustness

In this subsection, we present some additional robustness checks related to the *behavior of market participants and market rules* and possible *correlated shocks*. The first one relates to *banks' expectations*. Banks may be able to (partly) *anticipate* a bank failure. In the simulation, we assume that banks are able to withdraw the short-term loans granted to all failed banks before the failure occurs. The residual maturity of more than 35 percent of interbank loans granted by Belgian banks at the end of 2002 does not exceed eight days. As we have information on each bank's aggregate short-term bilateral positions only, we assume that the maturity structure of interbank loans granted to each counterpart of a given bank is the same. The results are displayed in the first row of panel B of table 5. Although the WCS is lower than in the baseline case, its evolution over time remains very similar to the evolution of the WCS in the baseline case.

A second assumption relates to the potential presence of a *safety net*. Although interbank loans are not covered by explicit deposit insurance, issues like being "too big to fail" (TBTF) may introduce implicit deposit insurance. To proxy for this possibility, we assume that large Belgian banks would not be allowed to fail.[32] These banks would thus not create initial and additional contagion and could

[32]We define large banks as banks representing more than 10 percent of the total assets of Belgian banks. The TBTF policy is a working assumption made by the authors in order to test the sensitivity of the results. There is absolutely no certainty regarding the effective application of such a threshold or such a policy in case of a large bank failure.

even stop it. The results are displayed in the second row of panel B. Unsurprisingly, a TBTF policy reduces the WCS. Remarkably, however, our simulations indicate that contagion still propagates in 1995 and 1997, despite the safety net. In these two years, contagion effects are caused, in the first instance, by the successive failure of many small and medium-sized banks.

In the baseline simulations, banks do not have the opportunity to *coordinate* in order to avoid liquidation. Leitner (2004) develops a model in which liquid banks bail out illiquid banks because of the threat of contagion. To capture coordination, we will assume that banks may "merge" to avoid failure.[33] An important objection to this procedure is that, in reality, mergers are not observed at such short notice. However, one can view these "mergers" as alternatives to the bailout in Leitner (2004). We address coordination by starting from the WCS in the baseline case. We assume that neither banks nor the regulator know the full matrix of bilateral exposures. Banks only know their direct counterparts. After the initial shock on the first domino, banks observe their losses. At that moment, we assume that banks have time to start "merger discussions" with other banks in order to avoid liquidation.[34] Other banks will accept such a merger if, thanks to this operation, they avoid their own failure. As the matrix of bilateral exposures is unknown to participants, we assume that mergers are only possible between banks failing in the "second round" (subsequently to the first domino) and their direct counterparts, i.e., banks failing in the "third round."

[33]Suppose there are three banks: bank A, bank B (with a tier 1 capital of 2.4 and an exposure of 5 to bank A), and bank C (with a tier 1 capital of 1.9 and an exposure of 4 to bank B). The first domino is bank A. Merging bank B and bank C would give a bank with an exposure of 5 to bank A and a capital of 4.3. Assuming a 100 percent LGD, the failure of bank A triggers the failure of bank B, and the failure of bank B triggers the failure of bank C. Merging both banks would not have an impact on contagion, as the new bank would not be resilient to a loss of 5. With a 50 percent LGD, the failure of bank A triggers the failure of bank B and indirectly of bank C if banks do not coordinate. The merged entity, however, would be able to resist to a shock of 2.5, as it would present a tier 1 capital of 4.3. In this case, merging both banks is optimal, as it allows avoiding domino effects.

[34]Such a period could be due, for instance, to a lag between the failure of the first domino and the realization of losses, due to an arbitrary decision of the regulator, or due to bankruptcy procedures such as chapter 11.

We simulate the consequences of each possible merger involving one or more banks that would have failed in the second round and one or more banks that would have failed in the third round.[35] We identify the merger that minimizes the assets of the failing banks. The third row of panel B of table 5 presents the results assuming coordination. We observe that in some cases coordination would prevent contagion from taking place. Successful mergers involve relatively small banks, as the implied increase in the Herfindahl index never exceeds 58 points. This happens exactly in periods when the WCS affected a large proportion of total banking assets and when contagion was slow to propagate, affecting firstly small banks (i.e., 1996–98).

The baseline simulations started from a matrix of gross bilateral exposures. To the extent that legislation allows for bilateral setoff—*netting*—of interbank positions,[36] we performed contagion simulations based on "netted" matrices of domestic bilateral exposures (i.e., $x_{ij} - x_{ji}$). These simulations assume that all the interbank claims are covered by bilateral netting agreements. The results are displayed in the fourth row of panel B of table 5. Netting substantially reduces contagion toward very low levels and this for all years.[37] Furthermore, the WCS assuming netting becomes flat over the entire period 1992–2002, in contrast to the baseline case. However, our distributional assumption may partly drive the results, as

[35] The total number of mergers involving at least one bank that failed in the second round and one bank that failed in the third round is equal to the number of possible combinations of banks that failed in the second round times the number of possible combinations of banks that failed in the third round. For instance, in 1997, in the WCS, two banks fail in the second round and one in the third round. In total, there are thus three different possible mergers. The total number of potential mergers ranges from 3 in 1997 to 65,025 in 1999.

[36] The European Directive 2002/47/EC on financial collateral arrangements obliges all EU member states to recognize closeout netting arrangements. In the Belgian law, netting arrangements are accepted provided they have been concluded before the opening of the insolvency procedure. In case of bankruptcy, a claim that is not protected by a netting agreement is generally treated as a normal claim and is reimbursed, proportionally to the value of recovered assets, after privileged creditors have been served.

[37] Note, however, that netting may also present some drawbacks. For instance, Emmons (1995) shows that netting of interbank claims shifts the bank default risk away from interbank claimants toward nonbank creditors; i.e., the risk is transferred to the banks' creditors who are not included in the netting agreement.

we assume a complete matrix of bilateral exposures. In other words, we assume that each bank is both debtor and creditor of all the other Belgian banks. Bilateral netting with a given bank becomes effective once this bank is both debtor and creditor, which in practice may represent a limited number of cases.

While our baseline simulations assumed idiosyncratic initial shocks, the initial shock could also be common to several banks or the whole banking system. We address the impact of correlated shocks in two complementary ways. First, we simulate a macro shock in combination with an idiosyncratic shock. In order to simulate a macro shock, we assume that each bank loses 10 percent of its tier 1 capital. The results are displayed in the first row of panel C, table 5. The WCS remains relatively similar over the entire 1993–2002 period. Second, we simulate the consequences of multiple simultaneous failures (two, three, or four banks). The WCS results of each possible joint default of two, three, or four banks are shown in rows 2–4 of panel B. Although allowing for multiple failures increases the level of the WCS, its level remains very low in 2002.

5. Interbank Market Structure and Domestic Contagion

Because nearly all our contagion indicators tend to follow a regular time pattern, they are more likely to be caused by trends in the organization of the interbank market than by exceptional events. For instance, although the Russian crisis as well as the LTCM failure could have influenced the pattern of contagion in 1997, it is difficult to ascribe the whole evolution of contagion indicators over time to these two events. Rather, the combination of two main trends in the banking landscape could explain the changes in our simulation results over the period 1993–2002. First, the estimated matrix of bilateral exposures went through some structural changes. As described earlier, large banks now seem to show an increased tendency to operate as multiple money centers. Freixas, Parigi, and Rochet (2000) show that, for certain parameter values, a single-money-center structure could reduce the contagion risk, as banks at the periphery no longer trigger contagion. A multiple-money-center structure will also reduce contagion provided the exposures between banks at the center are such that they do not propagate contagion.[38] Second, following consolidation and international financial integration, (large) Belgian banks have further increased their cross-border interbank exposures.[39] Consequently, the bilateral interbank exposures between the large Belgian banks could be such that they would no longer propagate contagion.

In order to test for the respective impact of interbank market structure and internationalization on contagion risk, we estimate OLS regression models of the form

$$WCS_t = \beta_0 + \beta_1 LB_t + \beta_2 DOM_t + \beta_3 CAPDUMMY_t * LB_t + \beta_4 CAP_t + \sum_{i=5}^{9} \beta_i \, Control\ variable_{it} + u_t$$

for WCS, calculated employing several LGDs and using quarterly data from 1992:Q4 to 2002:Q4.[40]

Table 6 provides definitions and descriptive statistics for the variables employed in the regression.[41] *LB* captures the interbank market structure. It measures the domestic interbank exposures of large banks as a fraction of the total domestic exposures. In a money center, *LB* should be equal to 1 since small banks are not linked together and all interbank transactions transit through the money center. In a complete structure, we expect *LB* to be smaller, as small banks have

[38] Of course, the reverse causation, although unlikely, cannot be entirely ruled out. Banks may adopt a given market structure in reaction to a perceived increase in the risk of contagion. However, we believe that the interbank market structure is determined by business rationales rather than by systemic concerns.

[39] Although the share of international interbank loans has always been high for large banks, it has increased over the last decade. In December 1992, the interbank loans granted by large Belgian banks to foreign banks accounted for 79 percent of total interbank loans. This proportion reached 89 percent at the end of 2002.

[40] In order to isolate contagion from other simulated effects, we use the baseline WCS.

[41] For each variable, we performed Phillips-Perron tests to test for unit roots. The series appear stationary. We can reject the hypothesis of a unit root at a 10 percent level for all the dependent and explanatory variables, with exception of the WCS for an LGD of 80 percent and 60 percent, and *DOM* and *CAP*. Although we cannot formally reject the null hypothesis of unit roots for these series, there is a strong economic rationale to reject it, as they are, by construction, constrained between 0 and 1.

direct links. *DOM* is a proxy for the degree of internationalization and is defined as the total domestic interbank exposure of Belgian banks as a fraction of their total interbank exposures. A ratio equal to 1 would represent a "closed" system, relying only on the domestic interbank market. A ratio equal to 0 would represent a fully internationalized system. Our regression analysis also contains some control variables. Two variables are included to control for bank-capital cyclical patterns. *CAPdummy* aims at identifying periods in which large banks are well capitalized. It is a dummy variable equal to 1

Table 6. Definition of Explanatory Variables

Variable	Definition	Rationale	Min	Max	Median
Dependent Variables					
WCS100	Worst-case scenario assuming a fixed LGD of 100%		0.033	0.964	0.874
WCS80	Worst-case scenario assuming a fixed LGD of 80%		0.032	0.931	0.747
WCS60	Worst-case scenario assuming a fixed LGD of 60%		0.009	0.918	0.158
Variables Capturing the Hypotheses					
LB	Domestic interbank exposures of/to large banks as a percentage of the total domestic exposures	Proxies for the type of interbank market structure. In a money center, this ratio should be equal to 1 since small banks are not linked together. To the extent that the structure moves to a complete structure, this ratio decreases.	0.636	0.941	0.700
DOM	Domestic interbank exposures as a percentage of the total interbank exposures	This ratio indicates the level of internationalization of interbank positions. A ratio equal to 1 would represent a "closed" system relying only on the domestic interbank market. A ratio equal to 0 would represent a fully internationalized system.	0.147	0.373	0.297

(continued)

Table 6 (continued). Definition of Explanatory Variables

Variable	Definition	Rationale	Min	Max	Median
Variables Capturing Other Structural Changes					
CAP	Nonweighted average of the ratio tier 1 capital of Belgian banks on assets of Belgian banks	A higher capitalization of banks should increase their resiliency to shocks and decrease indicators of contagion.	0.075	0.109	0.089
CAPdummy	Dummy variable equal to 1 when the tier 1 capital ratio of large banks exceeds its long-term average and 0 otherwise	Used in combination with *LB* as an interaction variable measuring to what extent the money centers need to be well capitalized to reduce contagion.	0	1	
Variables Capturing Macroeconomic Evolution					
GDP	Quarterly GDP growth	Banks' profits should increase when the GDP growth is high, as the quality of their assets improves.	−0.041	0.058	0.017
INT	Term spread of the interbank interest rate (Bibor before 1999 and Euribor from 1999 onward)	The term spread of the interbank interest rate represents the difference between the one-year and the one-month interbank interest rate. A high spread will constitute a positive environment for banks whose interbank liabilities are short term and whose interbank assets are long term (which is, to a certain extent, the position of Belgian banks). A low spread, on the other hand, will constitute a negative environment for these banks.	−0.016	0.019	−0.002
Other Control Variables					
Q2, Q3, Q4	Dummy variables identifying quarters	Control for seasonal effects			

Note: The table presents the variables used in the regression analysis. The first column gives the name of the variable, the second column gives its definition, and the third column gives the rationale for including each of the variables in the analysis. The remaining three columns give, respectively, the minimum, maximum, and median value over the observation period.

when the average tier 1 capital ratio of large banks exceeds the long-term average of the ratio and 0 otherwise. *CAPdummy* is used in interaction with *LB*. This interaction variable captures the extent to which a change in the structure, combined with a higher capitalization of money centers, effectively reduces contagion. We also control for the leverage of banks (*CAP*). In addition, we control for the macroeconomic environment with the GDP growth rate (*GDP*) and the term spread of the interbank interest rate (*INT*), defined as the spread between the one-year and the one-month interbank interest rate.[42] Finally, we also introduce quarterly dummies (*Q2, Q3, Q4*) to control for potential seasonal effects.

Table 7 displays the results of our regression analysis. The three panels report the results for the levels of LGD at 100 percent, 80 percent, and 60 percent, respectively.[43] For each LGD, *LB* and *DOM* are significantly different from 0, and both have the expected sign. That is, a move toward a money-center structure (an increase in *LB*) and a higher internationalization (decrease in *DOM*) reduces the WCS. For example, a 10 percent increase in *LB* would lead to a decrease of 23 percent, 29 percent, and 14 percent of the WCS for the 100 percent, 80 percent, and 60 percent LGD, respectively. Similarly, a 10 percent decrease in *DOM* would lead to a decrease in the WCS of 38 percent, 41 percent, and 23 percent for the 100 percent, 80 percent, and 60 percent LGD, respectively. However, in some regressions, coefficients of *LB* and *DOM* are not significant when entered jointly, pointing to potential multicollinearity problems.[44] Mistrulli (2005) uses simulations keeping the tier 1 capital-to-asset

[42] We control for macroeconomic conditions, as they might affect the ability/willingness to take or grant interbank loans and might influence the behavior of interbank players.

[43] The results using the 40 percent LGD and the 20 percent LGD are less significant. This is not too surprising, as changes over time in the WCS are much more important for an LGD of 100 percent than for an LGD of 20 percent, where little or no contagion at all is observed.

[44] The correlation between the variables *LB* and *DOM* is −0.76. This high negative correlation is not too surprising. Indeed, an increase in *LB* goes together with an increase in concentration as large banks become more important. In small countries, a higher concentration may lead to a higher degree of internationalization. Technically, the relatively high correlation might prevent us from obtaining statistically significant results when including these variables jointly in a regression framework.

Table 7. Regression Results for the Worst-Case Scenario

Intercept	*LB*	*DOM*	*LB* CAPdummy*	*CAP*	*GDP*	*INT*	R^2	*DW*
LGD 100%								
2.69 (6.66)***	−2.28 (−4.69)***			−3.41 (−0.58)	2.03 (0.87)	0.88 (0.10)	0.61	1.26
1.65 (5.91)***	−0.97 (−2.85)**		−0.58 (−7.61)***	−0.83 (−0.23)	−3.25 (−0.63)	−0.22 (−0.15)	0.86	2.82
−0.01 (−0.01)		3.80 (6.82)***		−4.26 (−0.96)	6.06 (0.92)	1.74 (0.89)	0.73	1.35
0.56 (0.96)	−0.89 (−1.76)*	3.02 (4.33)***		−0.69 (−0.15)	1.59 (0.84)	1.79 (0.26)	0.76	1.62
1.23 (2.69)**	−0.78 (−2.05)**	0.78 (1.14)	−0.51 (−5.13)***	−0.45 (−0.13)	−0.05 (−0.04)	−2.50 (−0.48)	0.87	2.72
LGD 80%								
3.23 (8.47)***	−2.87 (−6.27)***			−4.92 (−0.89)	−1.04 (−0.47)	−9.98 (−1.24)	0.73	1.04
2.41 (7.36)***	−1.84 (−4.62)***		−0.46 (−5.17)***	−2.87 (−0.69)	−13.26 (−2.19)**	−2.83 (−1.67)	0.85	2.17
0.30 (0.54)		4.10 (6.79)***		−9.15 (−1.90)*	−1.26 (−0.18)	−1.15 (−0.54)	0.75	1.24
1.36 (2.35)**	−1.65 (−3.33)***	2.66 (3.89)***		−2.52 (−0.54)	−1.42 (−0.77)	−9.18 (−1.37)	0.81	1.49
1.83 (3.44)***	−1.57 (−3.57)***	1.07 (1.35)	−0.36 (−3.14)***	−2.35 (−0.57)	−2.59 (−1.54)	−12.23 (−2.03)*	0.86	2.11

(continued)

Table 7 (continued). Regression Results for the Worst-Case Scenario

Intercept	*LB*	*DOM*	*LB*CAPdummy*	*CAP*	*GDP*	*INT*	R^2	*DW*
LGD 60%								
2.58 (6.09)***	−1.36 (−2.66)**			−13.33 (−2.17)**	0.74 (0.30)	−10.28 (−1.15)	0.59	1.09
2.50 (5.10)***	−1.27 (−2.12)**		−0.04 (−0.30)	−13.15 (−2.11)**	−10.57 (−1.16)	0.58 (0.23)	0.59	1.11
0.91 (1.52)		2.35 (3.58)***		−13.43 (−2.57)**	−7.48 (−0.96)	0.53 (0.23)	0.64	1.41
1.21 (1.67)	−0.46 (−0.74)	1.95 (2.28)**		−11.57 (−1.99)*	0.46 (0.20)	−9.70 (−1.15)	0.65	1.31
−0.32 (−0.72)	0.53 (1.44)	2.42 (3.64)***	0.26 (2.73)**	−8.69 (−2.51)**	3.39 (2.40)**	11.22 (2.22)**	0.54	1.53

Note: Dependent variable is the worst-case scenario, measured as the percentage of total assets accounted for by failed banks (*WCS*). Explanatory variables are *GDP*, *INT*, *CAP*, *LB*, *DOM*, *LB*CAPdummy*, and three dummy variables for the quarters (not reported). Definitions are provided in table 6. Each cell displays the *t*-statistic for the OLS coefficient. For each OLS estimation, the *R* and the Durbin-Watson (*DW*) are given. The sample comprises forty-one observations (one per quarter between 1992:Q4 and 2002:Q2). The first panel of the table assumes an LGD of 100 percent, the second panel an LGD of 80 percent, and the third panel an LGD of 60 percent. Significance level of the *t*-tests: (***) at the 1 percent level, (**) at the 5 percent level, and (*) at the 10 percent level.

ratio at the sample mean. He reports that contagion has increased by moving from a complete structure toward a multiple-money-center structure. His analysis, however, does not control for the documented decrease in the degree of internationalization. As the Italian interbank market has become more domestic over time—in contrast to many other European countries—this reduction in internationalization may actually have caused the greater domestic contagion. In addition, because he keeps the tier 1 capital-to-asset ratio at the sample mean, he may fail to capture changes in bank capitalization that would constitute responses to higher contagion risk.

In regressions where both *LB* and *LB*CAPdummy* are used, both are negative and statistically significant (except for the 60 percent LGD where *LB*CAPdummy* is negative but not significantly different from 0). The mitigation effect of money centers is thus reinforced when money centers are well capitalized. *CAP*, the proxy for the capitalization of the whole banking system, also has a negative coefficient and is economically relevant. However, its coefficient is only statistically significant when the LGD is not too high. Thus, during the periods in which banks were holding more capital, contagion was less likely for lower LGDs. The impact of capitalization is also economically relevant: based on the first regression for an LGD of 60 percent, an increase in *CAP* from its lowest level to its highest level (i.e., from 0,075 to 0,109) reduces the WCS by 45 percent. In most cases, the unreported coefficients of the quarterly dummy variables are insignificant. The macroeconomic variables are also generally not significantly different from 0.

We investigate the *robustness* of our regression results by performing some additional tests. First, we employ instrumental variables for *LB* and *DOM*. We use instrumental variables to control for the fact that the same data set is used to generate simulations and to partially construct *LB* and *DOM*. As instrument for *LB*, we employ the Herfindahl index based on total assets (concentration in a money-center structure will tend to be higher than in a complete structure, as the money-center bank tends to be larger than banks at its periphery), and to instrument *DOM*, we compute an index of bank internationalization based on total assets. A second set of instruments uses lagged *LB* and *DOM*. Finally, we also test alternative specifications for the money-market structure such as the average of the ratio (exposure of bank i to small and medium-sized banks/exposure of bank i to large banks) over all small and medium-sized banks. The (unreported) results confirm our analysis.

The results hold when we run regressions for other characteristics of the distribution. For instance, the signs of the coefficients of the regression with the median value remain unchanged although, in some specifications, they are not statistically different from 0. In regressions where *LB* and *DOM* are taken separately, both coefficients remain significant for the 100 percent and 80 percent LGDs. A further issue is that our results may suffer from a potential censoring bias, as knock-on effects of foreign banks to Belgian banks are disregarded. We investigate this issue by using the WCS after one round (*WCS1r*).[45] Although the *WCS1r* suffers less from this censoring bias, it only measures the direct exposures of the banking sector to a given bank and, by construction, does not capture the whole contagion process. Therefore, if the market structure is an important driving factor of the second and further rounds of contagion, we may not observe any significant link between market structure and *WCS1r*. In unreported regressions, we find that *LB* and *DOM* are not significant, as *WCS1r* does not present sufficient heterogeneity. This paradoxically shows that the market structure strongly affects contagion propagation in second and further rounds.[46]

6. Concluding Remarks and Policy Implications

This paper exploits a unique time-series data set on interbank exposures in Belgium to study the determinants of interbank contagion. In our simulations, we track the consequences of nonrepayment of (a fraction of) interbank loans on the equity capital of other banks,

[45] *WCS1r* is defined as the maximum percentage of total banking assets accounted for by failing banks after one round of contagion.

[46] In unreported robustness exercises, we find that the results for the two other indicators of contagion, the percentage of banks initiating contagion and the "propagation mechanisms of contagion (rounds)," are similar to those of WCS. Namely, a change to a money-center structure leads to a decrease in the number of cases of contagion in the simulations. Although the proportion of banks capable of triggering contagion decreases when a multiple-money-market structure is adopted, the structure may become more risky if the probability of default of these banks, precisely because of the structural changes, increases.

including any further domino effects. The exercise provides insights on the potential impact of "stress" situations on the Belgian financial system, which may be representative for many other small countries due to the high degree of internationalization of its interbank market, the economic significance of its large banks, and the similarities in the structure of its interbank market.

We find that the risk of contagion due to domestic interbank defaults varies substantially over time: it increased over the period 1993–97, decreased afterward, and flattened out at a very low level at the end of the sample period (end of 2002). This is important, as existing studies focus on a single point in time. Our results reveal that the interbank market structure, the overall bank capitalization, and the degree of internationalization are important in explaining the time-series behavior of contagion. In Belgium, the structure of the interbank market has moved over time from a complete structure à la Allen and Gale (2000) toward a multiple-money-center structure. If large money centers are robust and can set off obligations against each of their counterparties, or if they are too big to fail, this move results in a de facto multilateral netting agreement for small banks. Simulations indicate that bilateral netting agreements dramatically reduce contagion indicators.

Interbank exposures between Belgian banks currently represent only 15 percent of total Belgian interbank exposures, suggesting that the potential contagion risk stemming from foreign interbank exposures is more important. We find that the failure of some foreign banks could have a sizable effect on Belgian banks' assets. Cross-country analyses could deliver additional results on the relationship between the interbank market structure and the risk of contagion, but to the best of our knowledge, there exists no database that covers interbank exposures in a region such as the European Union. In addition, since in some regions in the European Union, clear geographical segmentation remains, making the assumption of maximal dispersion of interbank loans and deposits would not be correct, while it is acceptable in a domestic context.

Existing methodologies assume a fixed LGD. When we endogenize the LGD, we find not only that the LGD interacts with other determinants of contagion such as the market structure but also that contagion effects are more important when cross-sectional variations in LGD are introduced than they are with the corresponding average

LGD. Assuming a fixed LGD may thus lead to an underestimation of contagion risk.

The findings of the paper highlight some specific regulatory issues. First, though the risk of contagion is currently low—the analysis shows that contagion is a low-frequency event—interbank exposures at some time periods may constitute a devastating contagion channel. This kind of event is particularly relevant for banking supervisors. As contagion risk evolves over time, supervisory practices should include not only a frequent monitoring of interbank large exposures but also a regular assessment of the interbank market structure. Yet, interbank contagion risk should not be monitored in isolation of other risks.

Second, to the extent that large money centers are resilient, we should not observe significant domestic contagion processes. Supervisory efforts to control propagation processes will thus be more successful if they are focused on large banks. In addition, although small banks may trigger some limited contagion effects, they do not cause a systemic crisis if large banks are resilient. Analyzing the different propagation channels will allow supervisors to distinguish nonsystemic contagion effects from real systemic crises.

Third, the default of some large foreign banks has the potential to trigger significant domino effects in Belgium. This suggests that it is important for regulators to monitor cross-border sources of interbank systemic risk. However, domestic regulators do not have any control over these banks. Fostering international regulatory cooperation is thus essential. To this extent, European initiatives such as the Committee of European Banking Supervisors or bilateral or multilateral memoranda of understanding agreed upon by regulators in different countries constitute significant progresses.

Finally, the current structure and characteristics of the Belgian interbank market reflect several changes that have taken place over the past decade. Integration of money markets at the European level, increased recourse by banks to secured interbank exposures, and several major mergers between Belgian banks have resulted in a trend toward market tiering and appear to have reshaped the risk of contagion. In the coming years, changes in the microstructure of interbank markets may further alter the structure of interbank markets, thus keeping alive the debate about interbank contagion risk.

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