Contagion Due to Interbank Credit Exposures: What Do We Know, Why Do We Know It, and What Should We Know?

Christian Upper[1]
Bank for International Settlements
CH-4002 Basel
Tel. +41 – 61 – 280 8416
christian.upper@bis.org

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Abstract

Over the last decade, a number of studies have used counterfactual simulations to assess the danger of contagion due to credit exposures in the interbank market. The present paper provides an assessment of this literature. It discusses in detail how interbank exposures can be measured from various data sources, and how this information can be used for simulating contagious defaults. Such simulations show that contagion is an unlikely, but potentially very costly, phenomenon that in some countries may lead to the breakdown of a substantial part of some banking system. The simulations also offer some information on which banks are critical for the stability of the financial system, which could be used to allocate scarce supervisory resources. Unfortunately, few of the studies give anything more than the very basic idea of the probabilities of such scenarios or study how aggregate shocks may increase the danger of contagion, even though both factors can be estimated using Montecarlo simulations. A shortcoming that is more difficult to remedy is the almost complete absence of behavioural foundations of these models, which results in the assumption that banks cannot react to shocks.

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1. Introduction

Interbank exposures provide a channel through which the breakdown of a bank could have an impact on the health of other financial institutions. In the extreme, this could result in cascades of failures triggered by an idiosyncratic shock to a single institution. Such contagion could be purely mechanical, as in the model of Allen & Gale (2000), where banks become insolvent as a consequence of defaults by their (interbank) debtors. Alternatively, contagion may take the form of deposit withdrawals bacause depositors fear that banks will not be able to meet their liabilities because of losses incurred on their interbank exposures (Freixas, Parigi & Rochet 2000).[2] In either case, the scope for contagion depends on the size of interbank exposures relative to capital and on the precise pattern of such linkages. Contagion is less likely to occur in what Allen & Gale (2000) term a "complete structure of claims", in which every bank has symmetric exposures to all other banks. "Incomplete structures", where banks are exposed only to a few neighbouring institutions, are shown to be more fragile. Finally, the scope for contagion in a system with money-centre banks, where the institutions on the periphery are linked to the bank at the centre but not to each other, crucially depends on the precise values of the model's parameters (Freixas, Parigi & Rochet 2000).

Unfortunately, analytical results on the relationship between market structure and contagion can be obtained only for a limited number of highly stylised structures of the interbank markets, which are of limited use when it comes to assessing the scope for contagion in any real-world banking systems. Researchers have therefore increasingly turned to computer simulations. One strand of the literature, mainly by physicists (eg Thurner, Haner & Pichler 2003 and Iori, Jafarey & Padilla 2006) analyse the dynamics of complex artificial networks. Other researchers, mainly those employed at central banks, used data on existing interbank lending to simulate the effect of failures of individual institutions on the stability of the financial system. The present paper surveys this latter strand of the literature.[3] It begins by discussing the various elements of such studies, before turning to the results they have yielded.

Before proceeding, however, it may be helpful to pause a moment on why it is useful to study contagion at all, given that contagious failures have been extremely rare, if they have occurred at

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[2] Contagious failures may also occur if the failure of one institution is perceived as containing information on the health of another institution, for example because it holds a similar portfolio.See de Bandt & Hartmann (2001) and references therein for a discussion of the different channels of contagion.

[3] Another literature studies contagion between markets or currencies, which is not the focus of this paper.

all. Indeed, the vast majority of the systemic crises over the past three decades originated from the simultaneous failure of several financial institutions holding similar portfolios. By contrast, there have been few if any contagious bank failures, or domino effects, triggered by the breakdown of an individual debtor.[4] Even so, it would be premature to dismiss the danger of contagion as a mere theoretical possibility. There has been a substantial number of cases in which the default of large debtors in the interbank market has been prevented by government bailouts, many of which were explicitly intended to prevent contagion to other institutions. For example, almost three quarters of the 104 bank failures considered by Goodhart & Schoenmaker (1995) involved a bailout of one form or another.[5] They argue that "it has been revealed preference of the monetary authorities in *all* developed countries to rescue those large banks whose failure *might* lead to a contagious, systemic failure" (p.352, emphasis in the original). One might add that this suggests that it is important to study contagion as an improved knowledge about the likelihood of contagion may at least somewhat reduce the number of bailouts and the degree of moral hazard associated with them.

Interbank exposures that may open up the possibility of contagion may arise from a variety of sources. This paper concentrates on one type of such exposures, namely loans between banks. It should be borne in mind, however, that exposures from the payments[6] and settlement systems or from OTC derivatives may also provide channels for contagion. Studying these different channels separately has the advantage that it allows the researcher to isolate the precise mechanism of contagion, which is important when deciding on any facilitating remedial action. The drawback is, of course, that it does not give a complete picture and may thus give a wrong estimate of the risk of contagion.

Loans to other banks make up a large proportion of bank's balance sheets in may countries. For example, at the end of June 2005 interbank credits accounted for 29% of total assets of Swiss banks and 25% of total assets of German banks (figure 1). In other countries, the corresponding figures were lower, but, with the possible exception of the United States[7] and Canada, they still exceeded capital. The scope for contagion arising from interbank credit exposures may also be enhanced by

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4 The last time that the failure of a single bank came close to producing a systemic crisis was in 1974, when the breakdown of Bankhaus Herstatt disrupted activity in the international interbank market for several weeks and apparently came close to causing a gridlock in the US payments system (Davis 1995).

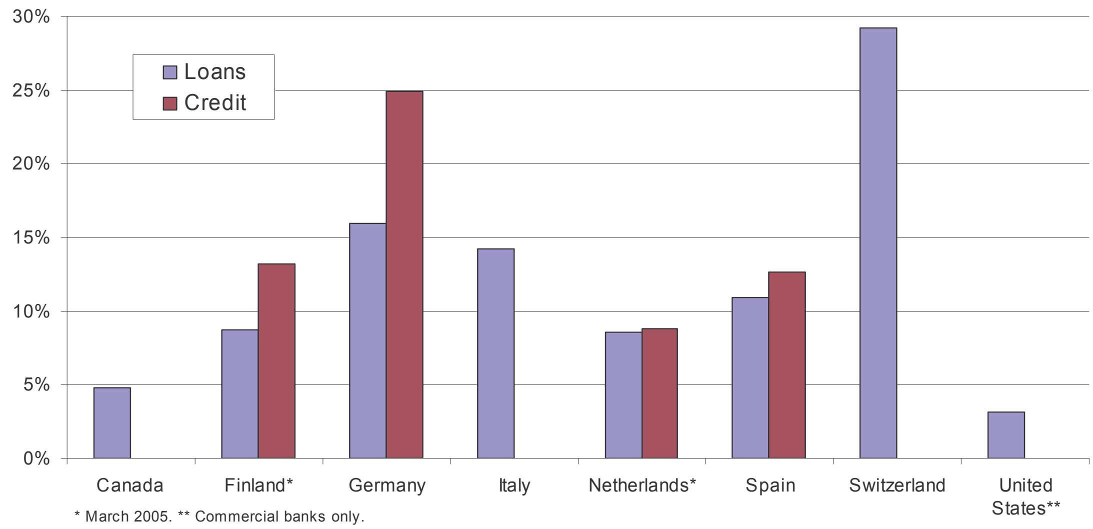
5 Goodhart and Schoenmaker go at lengths to make clear that their list is biased as large banks which are more likely to be bailed out are overrepresented.

6 See Humphrey (1986) and Angelini, Mariesca & Russo (1996).

7 The figures on interbank lending in the United States are not comparable as they do not include lending from the Federal Home Loan Banks, which amounted to $581 billion (equivalent to about 7% of commerical banks' total assets) at the end of 2004. Loans from similar institutions are counted as interbank lending in other countries.

the fact that it is may be much more granular than exposures to non-banks, as it is often exempt from the ceilings on individual exposures.[8]

Figure 1: Interbank lending
as % of total assets, end-June 2005



* March 2005. ** Commercial banks only.
Source: BIS database

The present paper assesses one way to estimate the potential for contagion arising from interbank lending, namely the use of counterfactual simulations. Off course, this is not the only way to test for contagion. Other studies have analysed contagion using to the comovement of banks' equity prices or deposit flows.[9] The different methodologies have their own advantages and disadvantages and thus complement each other. Market prices are available publicly and on a continuous basis, permiting a more precise dating of events and monitoring at higher frequencies than is possible for counterfactual studies, which rely on confidential information for a given point in time. The drawback of studies using market prices is that they usually cannot discriminate between the individual channels of contagion, a precondition for preventive action by regulators. In addition, many studies fail to distinguish between contagion and common exposures. Counterfactual simulations have the advantage that they allow researchers to concentrate on events that have happened before but that are deemed worth looking at. Although unlikely to be very accurate, they provide us at least with some idea of how a given shock would affect the stability of the banking

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8 The risk of contagious failures due to exposures in the interbank market can obviously be eliminated by imposing ceilings on the exposures to any individual bank. However, this may have considerable side effects. For example, it may pose a problem for heavy users of OTC derivatives, who tend to have large exposures to dealers or clearing houses, both of which are banks.

9 See de Bandt & Hartmann (2001) for a survey of the literature focusing on asset price comovements. Hartmann, Straetmans & de Vries (2005) include some more recent references, in particular to studies focusing on large comovements in equity prices rather than normal fluctuations. Schumacher (2000) and Iyer & Perez-Alcalde (2004) analyse deposit flows during banking crises.

system in the absence of public intervention. In addition, they may be used as a tool to identify systemically important institutions and thus contribute to a better allocation of scarce supervisory resources.

The paper is structured as follows: Section 2 presents the relevant literature and discusses in some detail the two main building blocks of such models, namely the matrix of interbank exposures and the simulation methodology, respectively. The following section assesses the usefulness of these models and attempts to give a summary on what they have tought us. Section 4 presents some recent advances in economic theory and discusses how they may be used to incorporate bank behavious into simulations of contagion. A final section draws conclusions and identifies topics where further research is necessary.

2. Counterfactual simulations of contagion

The literature using counterfactual simulations to study the scope for contagion started with the seminal contribution by Sheldon & Maurer (1998) on the stability of the Swiss banking system. Since data on bilateral linkages was not available to them, the authors estimated a matrix of claims between banks from bank balance sheets by spreading the individual interbank exposures as equally as possible. In technical terms, they maximised the entropy (ME) of the matrix. In a second step, they computed the probability of failure of a single bank from profit and loss data and computed the potential knock-on effects on other banks using the matrix of exposures estimated previously.

Subsequent research on this issue can be divided into two broad categories. Papers belonging to the first strand focus on whether or not contagion is possible in a given banking system, in general without saying much about the likelihood of such events. Studies in this vein include Furfine (2003) and Amundsen & Arnt (2005), who used payments data to estimate credit exposures in the US federal funds market and the Danish money market, respectively, and simulated the failure of the largest player in these markets. Upper & Worms (2004) applied a similar simulation approach to a matrix of interbank exposures estimated from German data using a refined version of Sheldon and Maurer's ME method. Wells (2002) and (2004), Degryse & Nguyen (2004) and Van Lelyveld & Liedorp (2004) combined data from credit registers and supervisory reports with ME-estimation to measure the scope for contagion in the British, Belgian and Dutch banking systems, respectively. Finally, the papers by Blavarg & Nimander (2002), Mistrulli (2005) and Lublóy (2005) for Sweden, Italy and Hungary, respectively, simulated the scope for contagion entirely on the basis of direct information on bilateral linkages.

The second strand of the literature is not so much interested in contagion per se but rather attempts to obtain an estimate for systemic risk. Examples are Elsinger, Lehar & Summer (2002) and (2004). In their earlier paper, they estimated a matrix of exposures between Austrian banks from credit register and balance sheet data, and embedded it into a model for market and credit risk that could be used for Montecarlo simulations. In the second paper, they estimated linkages between British banks from market data and undertake a similar analysis. Finally, the paper by Müller (2006) analyses the effect of a generalised unwinding of interbank lending on the health of Swiss banks.

In order to understand the uses and limitations of such simulations, it is worth looking at two building blocks of these models in more detail. The first building block is the matrix of interbank claims, which quality of which determines the precision of the results. The second building block concerns the simulation methodology, which determines the scenarios that can be simulated.

2.1 Building block #1: Matrix of interbank claims

An essential ingredient of any study testing a particular mechanism for contagion is a notion of the links along which contagion may take place. In epidemiology, these links may represent physical contact and in international finance trade linkages. In our case, they represent credit exposures in the interbank market. The structure of such relationships can be represented either graphically,[10] or in matrix form. The latter approach turns out to be more useful for simulations of contagion.[11]

Suppose there are N banks that may lend to each other. In this case, the interbank market can be represented as an $N \times N$ matrix

$$\boldsymbol{X} = \begin{array}{c} \\ \\ \\ \\ \\ \\ \Sigma_j \end{array} \begin{array}{c} \left[\begin{array}{ccccc} 0 & \cdots & x_{1j} & \cdots & x_{1N} \\ \vdots & \ddots & \vdots & & \vdots \\ x_{i1} & \cdots & 0 & \cdots & x_{iN} \\ \vdots & & \vdots & \ddots & \vdots \\ x_{N1} & \cdots & x_{Nj} & \cdots & 0 \end{array} \right] \\ \begin{array}{ccccc} l_1 & \cdots & l_j & \cdots & l_N \end{array} \end{array} \begin{array}{c} \Sigma_i \\ a_1 \\ \vdots \\ a_i \\ \vdots \\ a_N \\ \\ \end{array} \qquad (1)$$

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[10] See Boss, Elsinger, Summer & Thurner (2004), Iori et al (2005), Müller (2006) and Lublóy (2005).

[11] The Appendix of Degryse & Nguyen (2004) show how the stylised models of interbank markets considered in the theoretical literature can be shown as graphs and as matrices.

where x_{ij} is the credit exposure of bank i vis-à-vis bank j. The row sums $a_i = \sum_j x_{ij}$ and column sums $l_j = \sum_i x_{ij}$ are bank i's total claims on other banks and bank j's liabilities in the interbank market, respectively. The zeros on the diagonal are due to the fact that banks do not lend to themselves.

How the matrix $\boldsymbol{X}$ is constructed crucially depends on the availability of data, which differs across countries and over time. In some countries, for instance in Italy and Hungary, banks have to report all their bilateral exposures, leaving all elements of $\boldsymbol{X}$ identified. In other countries, credit registers or supervisory reports contain only information on those exposures that exceed a certain threshold (which may be an absolute amount or a fraction of the lender's capital). Using such data may result in an underestimation of contagion for small banks. Other shortcomings of credit registers that may distort the simulation results are the reporting of credit lines instead of actual exposures (in the Netherlands) or the exclusion of off-balance sheet items (in Belgium, Austria, and the Netherlands).

In contrast to credit registers, which identify point-to-point exposures, balance sheets only give information on the aggregate exposure (excluding derivatives and other off-balance sheet items) of the reporting institution vis-à-vis all other banks. Nevertheless, this data can still be used to draw inferences on bilateral exposures, although the researcher has to make assumptions on how banks spread their interbank lending.[12] It is generally assumed that banks spread their lending as evenly as possible as is consistent with the aggregate asset and liability position reported in the balance sheets. In technical terms, this corresponds to maximising the entropy (ME) of interbank linkages. The concept of entropy originates from physics but is also used in information theory, where it denotes the most likely outcome given our a priori knowledge about an event. ME was introduced into the contagion literature by Sheldon & Maurer (1998). Upper & Worms (2004) extended the method by accounting for the zero-elements on the diagonal and by using information on maturities and the types of counterparts. Wells (2002), Degryse & Nguyen (2004) and Van Lelyveld & Niedorp (2004) combined ME with information from credit registers.

There are at least three reasons why ME may not be a particularly good description of reality. First, credit relationships in decentralised markets may involve some fixed costs, eg for screening and monitoring, rendering small exposures unviable. Second, relationship lending may lead to a higher

[12] Balance sheets give N asset positions and N liability positions, corresponding to the row sums a_i and column sums l_i of matrix $\boldsymbol{X}$, respectively. In addition, we know that the elements on the diagonal of $\boldsymbol{X}$ are zero as banks do not lend to themselves. This leaves us with N^2-$3N$ degrees of freedom.

degree of market concentration than that suggested by ME.[13] Finally, maximising entropy results in all banks holding essentially the same portfolio of interbank assets and liabilities, differing only by size and by the fact that no bank has any claims on itself. In the absence of additional information from credit registers or from maturity breakdowns, this would imply that the danger of contagion becomes a function of a bank's total interbank lending relative to its capital. The advantage of ME is that it provides a unique benchmark that is consistent with the data. While there is only one matrix that maximises entropy, there are a large number of possible departures that may be equally plausible, and it is not clear which would provide a better representation of reality.

Assuming ME biases the exposure matrix X towards a "complete structure of claims", to use the terminology of Allen & Gale (2000), and should therefore raise the threshold for a shock leading to contagion. However, if contagion were to occur, it *may* be more severe than in systems with less evenly spread exposures. In particular, ME will never return exposures that are precisely zero unless either the row or the column sums are zero or the element is explicitely constrained to be zero on the basis of outside information (eg that banks do not lend to themselves, which gives rise to the zeros on the diagonal). This means that ME cannot recognise the limits to contagion inherent in disconnected structures. ME, by itself, will also be unable to reproduce money centre systems, where a cluster of small banks forms around large banks.

Evidence on how ME affects the findings on contagion is provided by Mistrulli (2005) and Degryse & Nguyen (2004). For Italian data dating from end-2003, it leads to an underestimation of contagion, at least for losses-given-default (LGDs) of up to 0.7 (Tables 3 and 4 in Mistrulli 2005). For higher LGDs, ME leads to too many failures of large banks and too few failures of small banks relative to those obtained from observed exposures. For Belgian data from end-2002, contagion is more severe in simulations using a matrix obtained by ME than in those based on information from the credit register, although this may also have to do with the relatively high cut-off point of 10% of own funds above which banks have to report their exposures. Combining credit register and balance sheet information tends to produce estimates that lie in between these two cases. For very high LGDs, however, combining the two data sources gives a higher estimate for the extent of contagion than either of the two data sets on their own (Degryse & Nguyen 2004). However, notwithstanding the substantial margin of error associated with estimating rather than observing bilateral exposures, there is no case in which one method shows a danger of contagion and the other does not. This is important as it suggests that simulations based on ME may at least provide

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[13] Cocco, Gomes and Martins (2003) show that interbank lending relationships are important in the Portuguese money market.

some rough idea of whether contagion is possible, even if they are not able to quantify exactly the sizes of these effects.

Exposures in the money market can also be estimated from payments data. This approach has been pioneered by Furfine (2003) for the federal funds market. The basic idea is quite simple: For any loan with a maturity of, say, one day, there has to be a transfer of funds from the lender to the borrower on day zero, and a payment of opposite sign on day one. Since loans are usually denominated in round amounts and interest is capitalised at repayment, one simply has to search all the transactions of a large-scale payment system for possible repayments and then identify whether there has been a payment of the same amount minus interest but the opposite sign on the previous day.[14]

The reliability of such estimates depends on whether interbank loans are standardised in a way that allows them to be filtered out of payments data, and on whether they all are routed through the same payment system. In Denmark, all conditions appear to be fulfilled, and Amundsen & Arnt (2005) are able to fully match the exposures that banks reported on a number of business days. In other countries, however, the method may be less reliable. For instance, Demiralp, Preslopsky & Whitesell (2004) find that some US banks split interest rate payments from the repayment of the principal, which introduces a substantial downward bias into Furfine's data. In Germany, the RTGS+ large-scale payment system coexists with several private systems, for which data is not available. Reasearchers at the Deutsche Bundesbank could identify an average of roughly 600 transactions per day, which seems few for to the more than 2000 banks that existed in Germany at the time. Another drawback of payment data is that the method can only be used to identify exposures that have already been paid back, which limits its suitability to the short end of the maturity spectrum. Again, how much this matters depends on which country one looks at.

An advantage so constructing $\boldsymbol{X}$ from payments data is that it gives a daily series of exposures compared to the monthly or quarterly observations at which other data are available. Payments data are therefore not likely to be plagued by window dressing and can be used in event studies which require a precise dating of exposures.

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[14] Starting with potential repayments and working backwards tuns out to be much easier than working the other way around, since there are by an order of magnitude fewer payments of odd amounts than payments of round amounts.

2.2 Building block # 2: Simulation methodology

Once the matrix of interbank linkages is in place, the researcher has to specify the type of shock whose potential for triggering contagion is analysed. Let us begin by considering the sequential, or round-by-round, algorithm for simulating contagion, introduced into the literature by Furfine (2003) and used in most subsequent studies. So far it only has been used to simulate the idiosyncratic failure of a single institutions, although it could easily be extended to analyse multiple failures. The approach involves the following steps:

1. A bank i fails by assumption.

2. Any bank j fails if its exposure versus i, x_{ji}, multiplied by an exogenously given parameter for loss-given-default (LGD), exceeds its capital c_j.

3. A second round of contagion occurs if there is a bank k for whom $LGD(x_{ki} + x_{kj}) > c_k$. Contagion stops if no additional banks go bankrupt.

It turns out that the LGD-parameter is crucial as to whether or not contagion arises. The critical assumption is that losses-given-default are exogenous even in the higher rounds of contagion, even though in principle they could be computed from balance sheet data. The main technical difficulty involved in endogenising LGDs is that it makes it necessary to "revisit" previous rounds as new losses lower recovery rates on past failures.[15]

Endogenising losses-given-default using balance sheet data is appealing, but it requires a series of assumptions that are far from innocuous. They concern (i) the availability (and value) of collateral, (ii) the seniority of interbank relative to other claims, (iii) netting arrangements, (iv) the market value of the defaulting bank's assets as well as the uncertainty associated with it, (v) the time path of and discount rate applied to recoveries, (vi) the administrative costs of bankruptcy, as well as (vii) credit risk transfer through off-balance sheet instruments.

Of these issues, netting agreements and bankruptcy costs are probably the easiest to deal with. Upper & Worms (2004) and Elsinger, Lehar & Summer (2002) performed a robustness analysis using a matrix of net exposures, finding conflicting evidence on the extent to which netting reduces the scope for contagion. In the former study, netting led to a drop in the severity of the worst case of contagion from 76% of total assets to less than 10%, while the second group of researchers

[15] This is done in the algorithm developed by Eisenberg & Noe (2001) that was extended and introduced into contagion analysis by Elsinger, Lehar & Summer (2002).

found the effects to be of little economic significance. Elsinger, Lehar & Summer (2002) also incorporated bankruptcy costs and found that these substantially, and in a non-linear fashion, increase the incidence of contagion.

Incorporating collateral, credit risk transfer and the seniority structure of claims into the analysis has proved to be more difficult, although this is mainly due to a lack of data. Few of the available sources of data on interbank lending distinguish between collateralised and uncollateralised positions. As a consequence, most researchers could no take collateralisation into account, except indirectly through the choice of lower LGDs.

For the same reason they also have left out of the analysis any type of credit risk transfers. In the past, this has problably not affected the results too much, as only a small number of banks have been active in such markets. For example, according to Elsinger, Lehar & Summer (2002) about one quarter of all Austrian banks hold capital against positions in any kind of derivatives, but for all but a few banks such positions were very small. Minton, Stulz & Williamson (2005) found that only about 6% of US banks hold credit derivatives. However, these tend to be fairly large banks, which are likely to be more relevant for contagion than smaller institutions. In addition, the market for credit derivatives and other instruments to transfer credit risk is growing rapidly. According to BIS data, the notional volume of credit default swaps increased from virtually zero at the turn of the millennium to approximately one third of the volume of domestic credit in the G10 countries in mid-2005. This sharp growth makes the assumption that no transfer of credit risk occurs increasingly untenable, even though lack of data means that there is no alternative.

Concerning the seniory of interbank claims, Elsinger, Lehar & Summer (2002) and (2004) assume they are junior to claims by non-banks. However, conversations with bank supervisors in Germany have shown that at least for that country this is a less reasonable assumption than an equal sharing of losses among all creditors. The situation in other countries may be different, but it will probably be difficult to reach any general conclusions.

A more substantial problem, and one that cannot be solved with more and better data, is the uncertainty associated with the market value of collateral, banks' assets more generally and the time path of recovery. Computing LGDs from balance sheet data implicitly assumes that book values can be realised under conditions of stress. This assumption has been criticised by Cifuentes, Ferruci & Shin (2005), who argue that fire sales will depress asset prices, providing a further channel of contagion. A related, also implicit, assumption is that recoveries are instantaneous. Anecdotal evidence suggests that this is not the case, and that merely looking at the ex post costs is misleading. For example, the Frankfurter Allgemeine Zeitung published an article in 1999 saying that the Herstatt's creditor banks had by then obtained 72% of their claims, but this was 25 years after the failure! In the case of BCCI, press reports at the time suggested that creditors expected to lose almost all of their exposures, but in the end recovered about half of them. Not allowing for lags in recovering loans and the uncertainty surrounding the value of the failing banks' assets may lead to an underestimation of the scope for contagion. However, this issue could be addressed by assuming very high LGDs, as in the short-run scenario of Elsinger, Lehar & Summer (2002), which provides an upper bound for the impact of uncertainty on the scope for contagion.

But even in light of the difficulties associated with endogenising losses-given default, doing so seems useful, as it provides some cross-sectional dispersion of LGDs. This is illustrated by the fact that although the median LGD of 35% obtained from the simulations of Elsinger, Lehar & Summer (2002) is no far from the losses incurred in previous bank failures,[16] there are enormous variations around this value. For example, the 10% quantile of the LGD distribution is 7%, and the 90% quantile is 100%.

2.3 Contagion due to idiosyncratic shocks

After having discussed in some detail the matrix of interbank linkages and the simulation methodology, this section reviews the results of counterfactual studies of contagion following the failure of individual banks (figure 2).

Given the differences in the structure of the banking systems of the various countries and differences in the methodologies used, it is not surprising that few clear-cut results emerge. A first glance at figure 2 suggests that the danger of contagion is greatest in Germany and the Netherlands, where it may destroy institutions accounting for as much as three quarters of the banking system's total assets (Upper & Worms 2004, Van Lelyveld & Liedorp 2004). However, a closer look reveals that both scenarios actually have a probability of zero and therefore devoid of any practical relevance. In the Dutch case, the "bank" triggering these catastrophic results actually represents the aggregated banking system of Europe (except the Netherlands).[17] In Germany, the financial safety net in place at the time (end-1998) rendered the worst case scenario impossible.

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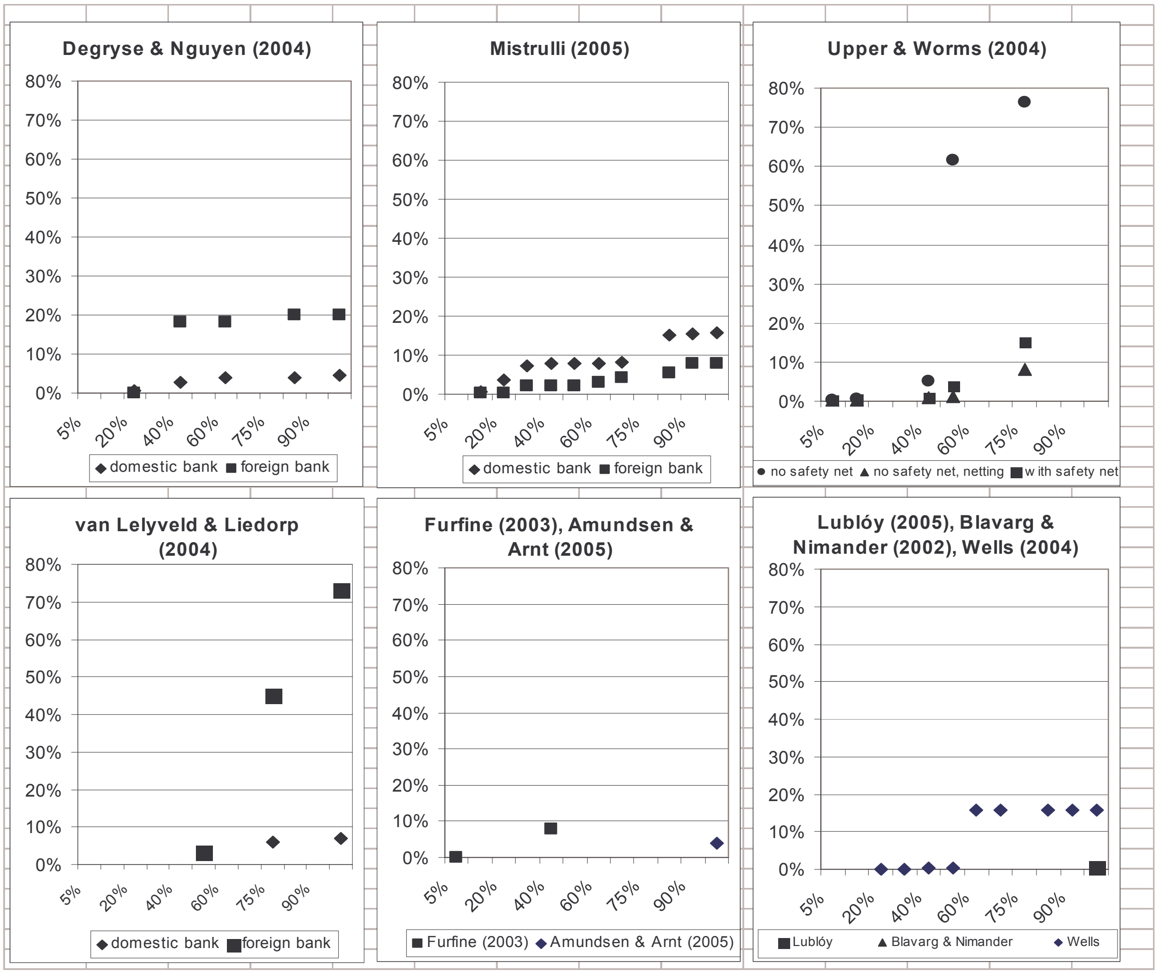
[16] James (1991) found that the average loss realised in bank failures in the mid-1980s United States was 30% of the book value of the bank's assets. In addition, creditors had to bear administrative and legal costs of a further 10%. Kaufman (1994) argues that the losses to creditors of Continental Illinois would have been a mere 5% of the face value of their loans, had the bank not been bailed out.

[17] By contrast, contagion due to the failure of a domestic institution (foreign institutions are aggregated by regions) may affect at most 7% of total assets.

Figure 2: Contagion due to idiosyncratic shocks



% of total assets of the banking system

Allowing for guarantees from the state and from other banks reduces contagion in the worst-case scenario to 15% of the German banking system. This is of a similar order of magnitude as the results obtained by Degryse & Nguyen (2004) for Belgium (20% of total assets), Mistrulli (2005) for Italy (16%), and Wells (2004) for the UK (16%). These numbers are substantial by any standard, especially if one considers that most surviving banks loose a substantial proportion of their capital.

By contrast, little scope for contagion was found by Blavarg & Nimander (2002) for Sweden[18] and Sheldon & Maurer (1998) for Switzerland. Furfine (2003) and Amundsen & Arnt (2005) also report only a limited scope for contagion, but their samples are limited to overnight transactions and hence do not provide a full picture of interbank lending.

2.4 Contagion due to aggregate shocks

The studies reviewed so far have implicitely assumed that the shock triggering contagion has no effects on the health of the other banks except through losses on their exposures to the failing institutions. This may not be a bad assumption in the case of fraud or if the bank hit by the shock has a completely different risk profile than other banks. While such cases are not unheard of,[19] they represent only a small number of all bank failures. By contrast, the available evidence suggests that the vast majority of failures result from shocks that hit several banks simultaneously.[20] Such shocks may weaken the resiliency of the remaining banks and may thus increase the risk of contagion.

Failures due to common shocks could in principle be handled by the same tools as the ones used to analyse the effects of idiosyncratic shocks. Lulbóy (2005) follows this approach when calculating the effect of losses on Hungarian banks' FX exposures. An alternative was suggested by Elsinger, Lehar & Summer (2002), who embed a matrix of interbank linkages of the Austrian banking system in a risk management model covering both market and credit risk. They then draw from the distributions of the risk factors and compute the effect on each bank's capital. If banks become insolvent, they test for the scope for contagion to other institutions, which may already be weakened by the shock to their remaining assets. In contrast to simulations of idiosyncratic failures, their approach provides estimates of the probability in addition to estimates on the severity of contagion.

The results of their model suggest that contagious failures are extremely rare compared to failures due to losses on loans to non-banks or securities ("fundamental failures"). That said, if contagion does happen, it could affect a large part of the banking system. An earlier version of the paper reports that the worst case of contagious defaults affected 37% of the banking system, measured by the failing banks' share in total assets. Moreover, fundamental failures and contagion are not independent, as contagion is much more likely in an environment where banks have been weakend by common shocks.

In a second paper, Elsinger, Lehar & Summer (2004) perform a similar analysis using a multivariate Merton-type model of default risk. They find that ignoring the correlation structure of

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[18] None of the four major banks considered failed due to contagion after the failure of a major debtor, although there was one instance where a bank lost all its tier I capital following losses on FX settlement.

[19] Examples are the failures of Baring and BCCI, respectively. The former was brought down by losses piled up (and hidden) by a single trader in Singapore, while the latter had a very different business model and organisational structure than other banks.

[20] Caprio & Klingebiel (1996) provide an extensive list of financial crises and their causes. See also Basel Committee on Banking Supervision (2004).

the processes driving the banks' distance to default and interbank linkages results in a "considerable underestimation of the probability of a systemic crisis"(p.x). However, their simulations suggest that it is more important to take into account correlations in the banks' market values than exposures in the interbank market.

2.5 Insolvency and illiquidity

So far contagion occurred only if banks became insolvent. The liquidity of banks entered the models only through the back door, via its effect on losses-given-default. However, illiquidity may not only amplify contagion, but may even cause it. An interesting simulation by Müller (2006) considered the effect on solvency and liquidity of a complete unwinding of all interbank lending. Although all banks were solvent ex ante, some institutions found that they did not have enough liquid assets to fully repay their obligations and defaulted. These defaults led then to the insolvency of creditor banks. In an extension of her base scenario, Müller then analysed how the ability to draw on credit lines affected the scope for contagion. In fact, they did offer a source of liquidity and reduced the likelihood of banks not being able to meet their commitments, thus leading to fewer contagious failures.[21]

Drawing on credit lines is only one of many actions that banks may take when confronted with the failure of a debtor. Perhaps the most obvious action is to sever as many of the links to the failing institution as possible, assuming that there is some time between the moment a bank learns about a failure and the moment claims are frozen. Most simulations rule such behaviour out by assuming that contagion is instantaneous, ie without any warning period.[22] Degryse & Nguyen (2004) test for the potential of contagion using interbank exposures arising from exposures with maturities of 8 days or more. Quite surprisingly, this does not affect the results very much, despite the dominance of short-term lending in the Belgian interbank market. However, while this approachs solves one problem, it opens up another, namely that the unwinding of short-term lending may itself lead to contagion, as in Müller (2006).

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[21] Similar credit lines have been advocated for emerging market governments by the IMF, although the suggestions has not really been taken up in practice.

[22] Alternatively, one may assume that contagion takes place on the same day, ie before overnight loans could be recalled.

3. What are these models good for?

To be sure, counterfactual simulations of contagion are based on very restrictive assumptions that may compromise the accuracy of the results. Some of these assumptions (summarised in table 1) could in principle be solved by collecting better data, although addressing others would require a fully microfounded model that is not yet available.

Table 1: Potential sources of bias

Source of bias	Direction of bias		Potential remedies (and their side effects)
	Incidence	Severity	
Maximum entropy	-	+	Better data
Reporting floors for credit register data	0	-	Better data
No netting	+	+	Use net exposures (may lead to underestimation)
No information on collateral	-	-	Better data
No bankruptcy costs	-	-	Incorporate into model
No credit risk transfer	+/-	+/-	Better data
Interbank claims junior to claims from nonbanks	+	+	Better data
No uncertainty about asset values	-	-	Microfounded model
Immediate recovery	-	-	Assume 100% LGD (leads to overestimation of effects)
Constant LGDs (accross rounds and banks)	?	?	Endogenises
Failures are not anticipated, banks cannot react	?	?	Exclude short-term assets, incorporate credit lines (only partial solution, does not address deposit withdrawals) Microfounded model
No safety net	+	+	Incorporate guarantees (potential overestimation if guarantees are not fully covered, underestimation if guarantees lead to contagion)

+ overestimation, - underestimation, 0 no significant bias, +/- can go both ways, ? not clear

Given these shortcomings, how should regulators react to the findings of such simulations? It would be too easy to simply shrug off the result that contagious bank failures could occur in many modern banking systems, and attribute it to some of the restrictive assumptions on which the models are based. While simulations may not be very reliable, they are at least based on real data on the structure of interbank markets, whereas any alternative would have to rely on anecdotal evidence (which anyway could be incorporated into the models) or on theoretical reasoning on the basis of a highly stylised structure on interbank linkages. In addition, counterfactual simulations provide much more information than merely stating whether contagion may or may not occur. They also could be used for identifying potentially critical institutions or market structures, and thus contribute to a more eficient allocation of supervisory resources and to more comprehensive cost-benefit analysis before introducing regulations. This section reviews some of these uses in more detail.

3.1 Identifying critical banks

Complex networks usually feature a comparatively small number of critical nodes that are essential for the stability of the system as a whole. In the context of interbank markets, these are banks whose breakdown is likely to lead to contagious failures. The importance of such nodes is illustrated in figure 3 (figure 6 in Upper & Worms 2004), which shows how the pattern of contagion across rounds switched for different LGDs (be aware of the different scales!). What is interesting is that while most contagion occurs in rounds one and two for low LGDs, this does not hold for the worst cases of contagion. Instead of petering out after a few rounds, the process of contagion gains momentum and suddenly spreads to a large number of banks after the failure of some critical institutions.

The criticality of a bank does not directly depend on its size. Rather, it is determined by the magnitude of its interbank liabilities, its exposure to other banks, its capital position and, crucially, on its precise location in the interbank network. It is on this latter point that simulations could yield information that is not available from other sources.

[Measures of centrality, etc. using graph methods, Iori et al (2005), Boss et al (2004)]

[Evidence from rank correlations between #of failures and a) size of bank, b) share in total interbank liabilities.]

3.2 The structure of interbank markets and the scope for contagion

Interbank markets are in constant flux and their structure has changed over the years. This may be due to the adoption of new technologies, the appearance of new financial instruments, regulatory changes or historical events such as European monetary union. Counterfactual simulations can be used to assess how changes in the structure of interbank loan markets affect the risk of contagion. Such knowledge could, for instance, be used in cost-benefit analyses before the introduction of pieces of legislation that affect the structure of interbank markets.

The relationship between market structure and contagion has been explored by Degryse & Nguyen (2004) and by Mistrulli (2005) by exploiting the time-series dimension of their respective samples. Both Italy and Belgium have shifted from a comparatively diversified system towards a structure with multiple money-centre banks. In Belgium, this appears to have led to an reduction in the severity of contagion, whereas in Italy the effect have gone into the opposite direction.[23] An additional piece of evidence is provided by Wells (2004), who found that a money-centred structure (obtained by restricting the ME-estimator to yield zero exposures between small banks) is associated with more severe cases of contagion than a more diversified structure.

So far, there has been no attempt to exploit cross-country variations in the severity of contagion to study the link between structure and fragility. This is mainly because the datasets used are confidential, thus limiting cooperation between researchers. Any attempt into this direction would therefore have to take the form of a meta-analysis, which relates the findings of the individual papers to a common set of system characteristics.

3.3 Crisis resolution

Despite their stylised nature and the lack of behavioural assumptions, counterfactual simulations may provide some new results on the resolution of financial crises. The first lessons concerns the importance of efficient resolution procedures. For example, Elsinger, Lehar & Summer (2002) show that the danger of contagion is highly sensitive to the level of bankruptcy costs. In particular, they found a critical value for such costs, above which contagion becomes both much more likely and more severe.[24] Brining down these costs and speeding up resolution should therefore be one of the highest priorities of regulators.

The other result concerning crisis resolution is also due to Elsinger, Lehar & Summer (2002) and concerns the funding required for lender-of-last-resort operations. They found that Euro 51 million

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[23] Degryse & Nguyen's findings may be distorted by the increased capitalisation of the Belgian banking system, which may override a potential negative effect of the change in interbank market structure.

[24] In one of the simulations, the threshold is actually very close to the average bankruptcy cost of 10% of total assets that have been recorded by James (1991).

would be enough to prevent contagious defaults in 99.9% of the cases even if losses-given-default are 100%. This figure seems low by any standards.

4. Towards an optimising model of contagious failures

Section 2.5 discussed attempts to extend the mechanical framework to introduce at least some kind of bank behaviour in order to loosen the assumption that contagion takes place instantaneously and banks have no time to react. This assumption rules out circumstances in which the default triggering contagion has been anticipated by more than one business day (the time it takes to obtain repayment on overnight loans), which is usually the case in the presence of aggregate shocks such as recessions or declines (but not jumps) in asset prices, which tend to unfold over time and give the banks some time to adjust at least some of their exposures.

While allowing for credit lines and the repayment of short-term loans are important improvements on the complete passivity of banks assumed in the other papers, they are rather ad hoc and fall short of a truly behavioural model. In part, this has been due to a lack of guidance from the theoretical literature. More recently, however, two models have examined more closely how bank behaviour could interact with domino effects and open up additional channels for contagion. Iyer & Peydro-Alcalde (2005) find that the threat of withdrawals by small depositors may force banks to reduce their exposures to the counterparts of a failing institution (ie the banks in the first line of contagion). These counterparts are therefore faced with two different types of shocks: losses on their exposures to the failing bank as well as deposit withdrawals by their creditor banks. For a certain parameter region, such withdrawals force banks into liquidation, even though in their absence they would have survived the losses on their interbank assets. Note that this additional channel of contagion is likely to run along the same lines as direct contagion, ie the graph of interbank exposures.

The second paper by Cifuentes, Ferrucci & Shin (2005) describes yet another channel of contagion in addition to direct losses. Internal or external risk-based capital constraints may force banks to sell liquid assets after incurring losses on their interbank deposits. This could put pressure on asset prices, which in turn force other banks to write down the value of their assets. Contagion due to interbank exposures may thus result in contagion on the asset side.

The additional channels of contagion brought forward by Iyer & Peydro-Alcalde (2005) and Cifuentes, Ferrucci & Shin (2005) have, to my knowledge, not yet been quantified by empirical estimates. To the extent that they are of any economic significance, existing simulations of contagion would only provide a lower bound for both the probability and the severity of contagion.

5. Conclusions and suggestions for further research

Counterfactual simulations of contagion may be plagued by a series of shortcomings, but they provide as yet the only way of estimating the potential for contagious defaults in a real-world banking system that can distinguish between different channels of contagion. Although the models have improved considerably since the first of such studies was undertaken approximately ten years ago, there is still much room for improvement. In part, this concerns the data input into the simulations. So far they have not been able to fully account for some features of real-world interbank markets such as collateralisation, differing seniorities and the transfer of credit risk. Better data would allow researchers to capture their effects, thus rendering the estimates much more reliable. A second area in which improvements could be made is the specification of the scenarios leading to contagion. Most studies, with the prominent exception of those by Elsinger, Lehar & Summer (2002) and (2004), have focused on the failure of single banks for idiosyncratic reasons. This is not the scenario that is of most relevance for supervisors. Instead, future work should consider the effect of common shocks on the stability of the banking system. In addition, any use of such models in policy work would require measures of the probability of the scenarios that may lead to contagion. It is difficult to justify costly remedial actions unless there is some information on the expected benefits.

A more fundamental problem is the absence of optimising banks. However, some recent work reviewed in section 4 could provide some guidance on how microfoundations could be introduced into models that can be used for simulation. What is necessary, though, is that microfoundations should not lead to stylised representions of the structure of the interbank market.

Finally, contagion is only one side of the coin. The contagion literature has nothing to say on the benefits of interbank lending. It explicitly does not provide a cost-benefit analysis of interbank lending. This should be kept in mind when drawing any policy conclusions.

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Appendix: Papers on contagion in the interbank market

	Country	Date	Interbank exposure matrix obtained from	Consolidated data	Exposures included	Losses-given-default	Measure of capital		Extensions
Amundsen & Arnt (2005)	Denmark		Large-scale payment system		Overnight (?) loans between domestic counterparts with maturity of one year or less				
Blavarg & Nimander (2002)	Sweden	Sept. 1999 to Sept. 2001	Supervisory report on 15 largest exposures of top 4 banks	yes	(i) Deposits, securities and derivaties (ii) FX settlement exposures	Exogenous	Tier 1		
Degryse & Nguyen (2004)	Belgium	(i) 2002/12 (ii) 1992/12-2002/12	(i) ME and credit register on large exposures (ii) ME	No		Exogenous	Tier 1		Time series analysis, bailout of largest bank
Elsinger, Lehar & Summer (2002)	Austria	2001/9	ME and credit register		Loans to domestic banks	Endogenous			Montecarlo analysis, bankruptcy costs
Elsinger, Lehar & Summer (2004)	United Kingdom								
Furfine (2003)	United States	1998/2-1998/3	Fedwire payments	No	Fed funds transactions	Exogenous	Tier 1		Effect of illiquidity

Lublóy (2005)	Hungary	50 days in 2003	Supervisory reports	?	Uncollateralised	Exogenous	Tier 1		
Mistrulli (2005)	Italy	1990/12-2003/12	Supervisory reports	No	All on-balance sheet exposures excl. equity	Exogenous	Tier 1		Time series analysis
Müller (2006)	Switzerland		Supervisory report of			Endogenous			Graphical analysis, effect of credit lines
Sheldon & Maurer	Switzerland		ME for bank categories (not individual banks)	No	Loans to domestic banks	Exogenous			Prob. of failure
Upper & Worms (2004)	Germany	1998/12	ME, using breakdown by maturity and type of counterpart	No	Loans to domestic banks	Exogenous	Book capital		Netting, safety net
Van Lelyveld & Liedorp (2004)	Netherlands	2002/12	ME, large exposures, supervisory reports for largest ? banks	No?	On-balance sheet exposures (also securities?), foreign banks grouped by regions	Exogenous	Tier 1		
Wells (2004)	United Kingdom		ME and supervisory reports on largest 20 exposures	Single bank, adjusted for intragroup lending	Large exposures include off-balance sheet instruments, ME for on-balance sheet exposures to domestic banks	Exogenous	Tier 1		