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SYSTEMIC RISK IN ALTERNATIVE PAYMENT SYSTEM DESIGNS

by Peter Galos
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In 2005 all ECB publications will feature a motif taken from the €50 banknote.

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2 Barkgårdvägen 10, 77793 Söderbärke, Sweden; e-mail: peter@galos.org, tel: +46 240 650463.

3 Corresponding author: Directorate General Payment Systems and Market Infrastructures, European Central Bank, Kaiserstrasse 29, 60311 Frankfurt am Main, Germany; e-mail: kimmo.soramaki@ecb.int, tel: +49 (69) 1344 7388.

The Public Good Factor in TARGET2

This paper is part of the research conducted under a Special Study Group analysing various issues relevant for the design of TARGET2. TARGET2 is the second generation of the Eurosystem's Trans-European Automated Real-time Gross settlement Express Transfer system, which is planned to go live in 2007. (See http://www.ecb.int/paym/target/target2/html/index.en.html for further details on the TARGET2 project). The Special Study Group operated between spring 2003 and summer 2004. It was chaired by Philipp Hartmann, assisted by Thorsten Koeppl (both ECB). The Group was further composed of experts from the ECB (Dirk Bullmann, Peter Galos, Cornelia Holthausen, Dieter Reichwein and Kimmo Soramäki), researchers from national central banks (Paolo Angelini, Banca d'Italia, Morten Bech, Federal Reserve Bank of New York, Wilko Bolt, de Nederlandsche Bank, Harry Leinonen, Suomen Pankki, and Henri Pagès, Banque de France) and academic consultants (David Humphrey, Florida State University, Charles Kahn, University of Illinois at Urbana Champaign, and Jean-Charles Rochet, Université de Toulouse). Following the completion of the Group's work, the ECB Working Paper Series is issuing a selection of the papers it produced.

Address
Kaiserstrasse 29
60311 Frankfurt am Main, Germany

Postal address
Postfach 16 03 19
60066 Frankfurt am Main, Germany

Telephone
+49 69 1344 0

Internet
http://www.ecb.int

Fax
+49 69 1344 6000

Telex
411 144 ecb d

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CONTENTS

Abstract 4
Non-technical summary 5
1 Introduction 7
2 Interbank exposures and systemic risk 8
3 Methodology and data 10
3.1 Payment and bank capital data 10
3.2 Methodology 12
4 Simulation results 17
4.1 Unsecured end-of-day net settlement system 17
4.2 Secured end-of-day net settlement system 18
5 Discussion 24
References 26
European Central Bank working paper series 27

Abstract

The paper analyses the consequences of an isolated, sudden and unexpected failure of a bank in alternative interbank payment system designs. We assess the exposures and the contagion by a counterfactual analysis assuming that payments currently settled by the pan-European large-value payment system, TARGET, are settled in alternative payment systems: an unsecured end-of-day net settlement system and a secured net settlement system with limits on intraday credit, with collateral and loss-sharing. The results indicate that systemic consequences of one bank's failure on the solvency of other banks can be rather low. If risk management techniques such as legal certainty for multilateral netting, limits on exposures, collateralisation and loss sharing are introduced, the systemic consequences can be mitigated to a high degree. How, and under which circumstances the analyzed failures would render other banks illiquid to meet their payment obligations is outside the scope of the paper.

Key words: Payment systems, Systemic risk, TARGET, Contagion

JEL Classification codes: E42, G21

Non-technical summary

Currently the two main mechanisms for settling interbank claims are the real-time gross settlement systems operated by central banks and systems based on netting operated by the private sector. These systems display different trade-offs between the risks, the speed of which payments can be settled by the system and the cost of liquidity used for settling the payments. The design of the payment system and its rules have a material impact on these costs.

This paper analyses the level of a certain type of systemic risk present in alternative payment system designs, namely that caused by an isolated, sudden and unexpected failure of one or more participants in the system. The systemic consequences are assessed by the means of simulations where one or more banks are set to insolvency during the day and the impact of the failure is propagated through the system. The payment data is identical in all simulations and reflects ten days of individual payments settled in TARGET, the pan-European large-value payment system operated by the European System of Central Banks.

We study two alternative net settlement arrangements; an unsecured end-of-day net settlement system and a secured net settlement system. An unsecured multilateral end-of-day netting does not have any risk controls and payments to and from the failing participant are simply unwound in case of a participant failure. Secured net settlement systems have rules that aim at guaranteeing the settlement of all payments also in the case where one or more participants are unable to deliver their multilateral net dues to the settlement institution. These include limits on intraday credit, collateralisation of intraday positions and loss-sharing.

The results indicate that the systemic consequences of a particular type of systemic event, a sudden and unexpected failure of a bank where contagion is contained to the payment system, can be rather low. As regards unsecured netting, the failure of the vast majority of banks did not cause any systemic consequences. Out of the 1191 simulated single bank failures during the 10-day period, only 96 caused subsequent failures (between 7 and 11 on a daily basis). The results did not change substantially in the case of a simultaneous initial failure of two or three banks. If risk management techniques such as legal certainty for multilateral netting, limits on exposures, collateralisation of exposures and loss-sharing rules are introduced, such systemic consequences can be mitigated to a high degree.

In general, the results are more in line with those found by Angelini et al. [1] for the Italian interbank payment system and Bech et al. [2] for the Danish one, than those of Humphrey [7] on the US CHIPS system. There are, however, a number of caveats and limitations for the applicability of the results that need to be kept in mind when interpreting the results and could be addressed in further research on the topic. These include better measures for bank liquidity, a

wider scope by extending analysis to incorporate other sources of systemic risk to the model and a longer time period of analysis to capture rare but high exposures that might manifest under abnormal market situations.

1. Introduction

In the last couple of decades the preferred choice of central banks to facilitate interbank or wholesale payments has become the so-called Real Time Gross Settlement (RTGS) systems. In 1985, three central banks had implemented RTGS systems and a decade later the number had increased to 15. However, since the mid-1990s, the adoption of RTGS has rapidly increased. By year-end 2002, 69 central banks had implemented RTGS systems and at least 20 central banks were planning to do so in the near future. Until the late 1990s the system type was largely an industrialised country phenomenon, but since then, both transitional and developing countries have switched to such systems.

An RTGS system processes transactions in real time on a payment-by-payment basis. Hence, it provides instant finality throughout the business day and reduces the risk that settlement will not occur as expected relative to the previously preferred end-of-day net settlement systems. By eliminating credit risks, RTGS systems reduce the risk of a systemic event where the default of a participant on its settlement obligation adversely affects other participants and potentially creates knock-on effects. It has often been argued that in a worst-case scenario, this contagion might impede the effective functioning of the payment system or the financial system at large.

Rochet and Tirole [12] define systemic risk as the propagation of an agent's economic distress to other agents linked to that agent through financial transactions. Systemic risk in financial markets refers to the risk of a disturbance in one section of the financial market that spreads to other parts of the market. The initial disturbance itself can e.g. be severe liquidity problems or insolvency of a bank and its causes varied. The reason of failure may be confided to the single bank (e.g. a rogue trader) or be caused by macroeconomic variables negatively affecting many banks simultaneously (e.g. reduced collateral values). The initial disturbance may become systemic (a systemic event) when it propagates to other participants of the financial system. A systemic event may undermine the confidence in participants of the financial sector and thus propagate through "investor panics" when creditors simultaneously withdraw their claims. A systemic event may materialise as credit losses and/or liquidity problems and may cause other banks to become insolvent or illiquid. A disturbance of systemic nature may weaken the performance of the financial markets and eventually adversely affect the economy as a whole. For an in-depth discussion on the concept of systemic risk, see De Bandt and Hartmann [6].

There are often trade-offs between the exposures that participants of a payment system are exposed to, the speed of which payments can be settled by the system and the cost of liquidity used for settling the payments. If exposures are limited by caps on allowed debit positions, the speed by which payments entered to the system can be settled within the caps will generally decrease. If the exposures are limited or eliminated by collateralisation, the participants of the system face increased costs for the liquidity needed to settle their payments. If the potential risks stemming from the system are too high, systemic consequences may materialise in case a participant in the system becomes insolvent. The design of the payment system and its rules has a material impact on these costs.

The objective of this paper is to analyse the level of a certain type of systemic risk present in alternative payment system designs, namely that caused by an isolated, sudden and unexpected failure of one or more participants in the system. The systemic consequences are assessed by the means of simulations where one or more banks are set to insolvency during the day and the impact of the failure is propagated through the system. The payment data is identical in all simulations and reflects payments settled in TARGET, the pan-European large-value payment system operated by the European System of Central Banks. The results indicate that the systemic consequences of the analyzed scenario, even without any risk management mechanisms, are rather low in relative terms. If risk management techniques such as legal certainty for multilateral netting, limits on exposures, collateralisation of exposures and loss-sharing rules are introduced, the systemic consequences can be mitigated to a large extent.

The paper is organised as follows. Section 2 introduces the topic and reviews prior research on the level of exposures arising from payment settlement and interbank lending in general. In section 3, the data used in the paper and the methodology for conducting the simulations are discussed. Section 4 presents the results from varying the payment system designs. Section 5 presents results and conclusions.

2. Interbank exposures and systemic risk

In the financial markets the main propagation channels for systemic risk are interbank overnight and term loans, credit relations arising from the settlement of foreign exchange and securities trades, and intraday credit exposures arising from the settlement of payments.

The focus of this paper is on systemic risk stemming from the exposures arising from the payment system. Before the introduction of the real-time gross settlement system, the dominant interbank payment system design was Deferred Net Settlement (DNS). Instead of processing each payment individually, payments were accumulated until the end of the processing period (usually a day) when the multilateral net positions for each participant were calculated and the proceedings settled in the books of the settlement institution, such as the central bank. In such systems, payments became final [5] only if all participants could meet their net obligations at the end of the processing cycle. Any negative intraday positions between participants and the system could thus be viewed as credit extended to that participant by the settlement institution or by the community of other participants, and vice versa. Consequently, a participant default on its end-of-day payment obligation could cause a credit loss to the system and/or other participants in the system, depending on its design. As the value of payments settled in such systems grew, these intraday credit relations became substantial.

Humphrey [8] reports that in the case of a failure of a major participant in CHIPS, the major US private interbank payment system, a large number of other participants (37 %) would default. At the time of the paper (1983) CHIPS was operating on an unsecured basis, i.e. in case a participant would fail on its end-of-day payment obligation, all payments from and to the defaulting participant would be unwound and the multilateral positions recalculated.[1]

Angelini, Maresca and Russo [1] follow Humphrey with some modifications and conclude that the interbank settlement exposures in the Italian payment system are much smaller than the results reported by Humphrey on US CHIPS data. Similar conclusions are reached by Bech et al [2] on systemic risk inherent in the Danish interbank netting system. During the last decade the risk management techniques used by large-value payment systems have been substantially enhanced, probably to a large extent due to the central banks' efforts in the area. The Lamfalussy standards [3] set forth several requirements for payment systems and the Core Principles for Systemically Important Payment Systems [5] continued that work. Also the payment system participants have improved their internal risk management procedures e.g. by setting bilateral and multilateral limits against their counterparties and monitoring their exposures. As a result most systems today employ a wide range of mechanisms to mitigate payment system exposures and thereby systemic risks.

Exposures in the payment and settlement arrangements that may lead to systemic risk also arise from the asynchronous settlement of two legs in a securities or foreign exchange trade. In the settlement of foreign exchange trades the risk is also known as Herstatt risk. BIS [4] report that the exposures banks may have in the settlement of FX trades may be manifold to their equity. We are not aware of any studies assessing the exposures arising from the settlement of securities.

The systemic risk discussion has traditionally focused on explicit interbank lending, in contrast to the implicit lending that may take place in payment systems. In case the loans of the bank are neither collateralised nor insured, the failure may trigger a chain of failures by other credit institutions that have lend it money. However, Furfine [7], using settlement data from Fedwire on unsecured interbank overnight lending, reports that (even with a recovery rate of 0% on the realised credit exposures) the share of the losses to total US commercial banking assets never exceeded 4% of total assets. With a more realistic setting of the recovery rate, contagion remained low.

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[1] Subsequently the system has been substantially improved and settlement is now conditional on pre-funding all resulting exposures on CHIPS account at the Federal Reserve Bank of New York.

Sheldon and Maurer [13] estimate a matrix of interbank loans for Switzerland. They conclude that the interbank loan structure posed little threat to the stability of the Swiss banking system in the period under consideration. Upper and Worms [14] find, using balance sheet information to estimate the matrix of bilateral credit relationships for the German banking system, that contagion is normally confined to a limited number of relatively small banks. On some occasions, however, the failure of a single bank could affect a sizeable part of the banking system.

3. Methodology and data

Payment and bank capital data

The payment data consists of 10 days[2] of payments transferred in TARGET. TARGET opens at 7:00 CET and closes at 18:00 CET, with the last hour reserved for liquidity management (16% of the total value transferred was made during this period). As there is no centralised function to gather payment statistics in TARGET, the payment data were collected by means of a survey from the 15 national TARGET components. The data includes the value, settlement time, sender and receiver of each individual payment processed and some further information that is not used in the study.[3]

During the observed period 1782 banks carried out payments. Due to technical reasons, such as the speed of simulations, only the 625 largest accounts (by transferred value) have been taken into consideration. Over 99% of the total value settled in TARGET was initiated from these accounts. Furthermore, we consolidated the accounts of the same banks/banking groups that were held at different TARGET components. This reduced the number of participants in the simulations to 405. Out of these participants, 269 were commercial banks or banking groups, the remaining being mainly accounts held by central banks, settlement institutions and international financial institutions. As the paper studies only bank failures, we assumed that the latter would not fail - neither as initial failures nor as a consequence of the failure of a bank in the system. These are considered to be rather realistic assumptions for central banks and international financial

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[2] 4-8 February and 18-22 February 2002

[3] Such information includes sending and receiving NCB (in the case of cross border payments) and an indicator whether the payment was originated by a customer or the bank itself. For some TARGET components also the priority of the payment and its economic rationale (e.g. that is related to a foreign exchange trade) is present. There is no standardised way of recording cross-border payment data and each national TARGET component reported its incoming and outgoing cross border payment independently. The two sides were matched on the basis of payment values and time stamps (with a possible time lag added). For cross-border payments sent to Germany, the receivers of 200 000 payments could not be identified. In the simulations, the underlying distribution of successfully matched payments was used to estimate the receiver (there seemed to be no systematic element in the missing payments). In addition, 345 payments that were reported sent from different TARGET components could not be found as received in others. Those were all payments of smaller value (with a total value of 21 million euro) and were removed from the data set.

institutions as well as for settlement institutions, which are also in general well protected against insolvency. Because non-banks do not fail in the simulations, they factually act as shock absorbers mitigating the level of systemic consequences in the simulations.

In the sample, an average of 200,349 payments with a value of 996 million euro was transferred on a daily basis before 17:00 between the participants in the sample. The payments are rather concentrated and the top three banks in terms of payments submitted accounted for 17% of the value of all payments. Banks smaller than the top 100 banks accounted for a very limited amount of the total turnover. As regards to the non-commercial bank entities the concentration was very high. This is explained by the high turnover of the settlement institutions for securities clearing. The top 10 participants in this group accounted for 88% of the turnover in this category, as seen in Table 1.

	banks/banking groups	**other**	**total**
# of participants	269	136	405
value (million euro)	707,081	288,747	995,828
number	161,565	38,784	200,349
share of total payment values			
top 3	17%	55%	18%
top 10	39%	88%	39%
top 50	81%	100%	80%
top 100	92%	100%	92%

Table 1. Payment statistics (daily averages for the 10-day period)

The tier 1 capital of the commercial banks/banking groups in the sample averaged 3.8 billion euro. The variation was, however, high with slightly over half of the banks having less than 1 billion euro capital. The largest 13 banks (i.e. the top 5%) accounted for almost 40% of total capital of all banks. The smallest bank had a tier 1 capital of 19 million euro and the largest bank 57 billion euro. The number of banks, their capitals and daily values of outgoing payments grouped by the size of the bank are summarised in Table 2[4].

capital	**# of banks**		**total capital**		**payments**		**capital / payment**
(billion euro)	number	% share	value	% share	value	% share	
0 - 0.5	106	39%	21	2%	53	7%	40%
0.5 - 1	38	14%	29	3%	26	4%	113%
1 - 2	47	17%	67	6%	39	5%	172%
2 - 5	28	10%	91	9%	53	7%	173%
5 - 10	15	6%	108	10%	97	14%	111%
10 - 20	22	8%	309	30%	201	28%	154%
> 20	13	5%	405	39%	239	34%	169%
total	269		1,030		707		69%

Table 2. Statistics on bank capital and value of payments

[4] The data on the tier 1 capital was collected from the Bankscope database and the June issue of the Banker magazine.

The largest banks in terms of capital were also in general the largest banks in terms of value of payments. The smaller half of banks in terms of capital sent only less than 7% of all payments, while the top 5% in terms of capital submitted over 34% of all payments during the 10-day period. Looking at the amount of capital backed by each unit of payment, we see that in general it is increase by the size of the bank. Although the larger banks sent more payments than the smaller, their levels of capital were in relative terms higher. While each unit of payment for banks with less than 500 million of capital was backed by 0.4 units of capital, each unit of payment for the banks with over 20 billion of capital was backed on average by 1.69 units of capital.

Methodology

We study two alternative net settlement arrangements for payments currently settled in TARGET. These are an unsecured end-of-day net settlement system and a secured net settlement system with limits on intraday credit, with collateral and with loss-sharing.

In the scenarios we assume that all payments transferred currently through TARGET (until 17:00) would be settled using either one of the alternative systems.[5] TARGET would be used only to settle the end-of-day positions stemming from these systems and for end-of-day liquidity management (in TARGET between 17:00 and 18:00). As the intraday credit exposures in TARGET are fully collateralised and the credit risks are borne by the central bank, the payment system itself does not create any credit exposures between participants. Systemic risk stemming from a TARGET type of system is only contained to liquidity effects. To study the effects of bank failures in the alternative systems, we let each participant and combination of two and three participants default on their settlement obligation. We call these initial failures and consider them to be exogenous to the model.

An important parameter for assessing the exposures is the rate at which the losses can be expected to be recovered by the non-failing participants from the failing ones. The paper by Furfine [7] on systemic risk in interbank lending uses recovery rates of 60% and 95%. The first rate is reported by James [10] to be the typical loss in assets of a failing bank and the second is the one recovered from the insolvency of Continental Illinois, as reported by Kaufman [11].

[5] In reality it is unlikely that all current participants would move to a private settlement system. Private systems are normally organized as clubs where only the largest banks in the economy participate. The current largest private settlement systems are CLS, CHIPS and EURO1 - all of which have under 100 participating banks.

We use a recovery rate of 0% losses experienced in the system. It depicts an unlikely but extreme scenario that gives us the maximum systemic consequences. In the simulations[6], an affected bank is set to default in case its exposure exceeds its tier 1 capital. The approach is thus similar to e.g. Humphrey [8], Angelini et al. [1] and Upper and Worms [14]. We denote any bank that fails due to the initial bank/banks failing as a *direct failure*. The failures of banks directly affected by the *initial failure(s)* may again affect further banks. These are set to default by the same rule, taking the additional losses from direct failures into account. We call banks that fail through this contagion as *secondary failures*. These could be banks without any business relationship with the initially failing participant. The process is repeated until no new secondary failures take place. Illiquid but solvent banks are assumed to be able to acquire sufficient liquidity from the market or from the central bank and we do not look at the cost element of liquidity problems.

The exposures from the payment system are only one source of systemic risk. As the paper concentrates on systemic risk present in the payment system we need to isolate it from other sources of systemic risk that may in reality manifest simultaneously. This is equivalent to making the assumption that all exposures from interbank lending are collateralised and that securities and foreign exchange trades are settled on a payment versus delivery and delivery versus delivery basis, respectively. Thus the only source of contagion is assumed to be the exposures arising from the settlement of payments. The detailed methodology for assessing credit exposures in the two alternative systems is explained below.

1. Unsecured net settlement system

We call a system with multilateral end-of-day netting, without any risk controls and with the unwinding of payments processed to and from the failing participant in case of a participant failure, as an unsecured net settlement system.

The methodology used for simulating failure in an unsecured net settlement system is as follows. Let n denote the number of banks participating in the netting system. Let z_{ij} denote the gross (end-of-day) amount to be paid from bank i to bank j. The matrix

$$\underset{nxn}{\mathbf{Z}} = \begin{bmatrix} 0 & z_{12} & \cdots \\ z_{21} & 0 & \\ \vdots & & \ddots \end{bmatrix} \tag{1}$$

will then represent all the gross settlement obligations. Let B denote the matrix of bilateral net positions between bank i and bank j.

[6] Part of the simulations were carried out with the BoF-PSS2 simulator. For a description of the simulator, see Leinonen and Soramäki [9]

$$\underset{nxn}{\mathbf{B}} = \mathbf{Z} - \mathbf{Z}' = \begin{bmatrix} 0 & z_{12} - z_{21} & \cdots \\ z_{21} - z_{12} & 0 & \\ \vdots & & \ddots \end{bmatrix} = \begin{bmatrix} 0 & b_{12} & \cdots \\ b_{21} & 0 & \\ \vdots & & \ddots \end{bmatrix} \tag{2}$$

The multilateral net positions are given by

$$\underset{nx1}{\mathbf{d}} = \mathbf{B} \cdot \mathbf{1} \tag{3}$$

where **1** is a unit vector. If $d_i > 0$ then bank i owes funds to the settlement institution whereas bank i will receive funds from the settlement institution if $d_i < 0$. The position of the settlement agent is zero, i.e. $\mathbf{d'1}=0$.

Systemic events can result from one or more participants, k, failing on their settlement obligations. Specifically, we assume that $z_{kj} = 0 \ \forall \ k,j$ and that all other participants can unwind on their obligations towards this/(these) bank(s), i.e. $z_{ik} = 0 \ \forall \ i,k$. The resulting bilateral and multilateral net positions are calculated using equations (1), (2) and (3).

The failure of a participant will, in general, change the multilateral net positions of each of the failing bank's counterparts who will face a different demand for liquidity in order to settle their remaining payments. If the bank has considered its incoming payments from the failing bank as final and credited the amounts to its customers, the bank will face a credit risk on those amounts. If the bank has considered all payments pending until the final settlement, it will only face a liquidity effect as its multilateral net position and final payments are different from expected.

In the simulations we will consider the failure of each single bank (with a multilateral end-of-day net debit position) and each combination of two and three of these banks. We will assume that any negative changes in the multilateral net positions for the other banks, after recalculating the settlement obligations, are credit losses to the banks.

2. Secured end-of-day net settlement

The system is called a secured net settlement system when its rules aim at guaranteeing the settlement of all payments also in the case where one or more participants are unable to deliver their multilateral net dues to the settlement institution. A secured net settlement system can be configured in many ways. In the simulations, we take the design of EURO1[7] as a reference system for a secured net settlement system. We start our analysis with a design with least amount of elements to secure settlement, and subsequently add elements present in EURO1 to analyse the

[7]EURO1 is the largest private euro payment system. At the time period under study it had 72 participating banks from 15 EU countries and 5 non-EU countries. Payments in EURO1 are processed individually on a continuous basis throughout the day but finality is achieved only after settlement of the resulting net positions in TARGET normally between 16:00 and 17:00.

reduction in systemic risk. The elements to secure the system includes limits on exposures, collateralisation of the exposures, and two different loss-sharing rules to cover for the shortfall of funds in case of one or more banks fail on their net debit obligations.

EURO1 has two different limits on intraday credit: bilateral and multilateral. The bilateral limits are set by the participants of the system against each other and consist of a mandatory and a discretionary part. The mandatory bilateral limit (L_m) is currently set to 5 million euro. The discretionary bilateral limits (L_i) may range between the mandatory lower level of 5 million and a maximum upper level of 30 million euro. The bilateral exposures can thus vary between 5 and 35 million euro. The net debit positions of a single participant against the system may never exceed the multilateral limit. It is currently set to 1 billion euro.

If all TARGET payments were to be settled by a similar settlement system, the bilateral and multilateral limits would need to be adjusted as the value of payments processed by TARGET is approximately eight times as high as that of EURO1.

In EURO1, the amount of collateral posted must equal the multilateral intraday credit limit. The collateral consists of a liquidity pool deposited at the European Central Bank, which will be used to complete settlement if, at the end of the settlement process, one or more short banks fail to settle. The collateral pool is set so that EURO1 is able to complete settlement even in the event of the failure to settle by the largest net debtor in the system. The presence of collateral does not reduce the losses experienced by system participants in case of a failure: it only guarantees that settlement can be completed without any secondary effects to the extent that the losses are less than the collateral employed (i.e. that all participants can cover their initial loss shares).

The simulations are done using two levels of collateral. Initially the system with no collateral present is simulated, followed by the one with collateral amounting to the single highest net debit position experienced during the sample (15.15 billion euro). In simulations with collateral, systemic consequences may thus only arise in the case of multiple bank failures as the failure by the first bank is always covered by the collateral pool.

Secured net settlement systems usually employ some type of loss-sharing rules (to complement any collateral available) in order to complete settlement of all payments even in the case of the failure by one or more participants to cover their net debit positions. If two or more participants in EURO1 fail to settle their obligation the liquidity shortage to complete settlement will be funded in the following way:

(i) the defaulting participant's share in the cash collateral pool will be transferred to the EBA settlement account;

(ii) obligations related to loss-sharing will be calculated for the surviving banks. The loss-sharing rule is as follows. In an event of up to three participants defaulting (k=1,2,3) on their net debit positions, the loss share (LS) borne by each non-defaulting participant (i) equals:

$$LS_i = \sum_{d=1}^{k}\left(L^m + \frac{L_i^d}{\sum_{j=1}^{n-k} L_j^d}\big((D_d - C_d) - L^m(n-k)\big)\right) \tag{4}$$

where L^m is the mandatory bilateral limit against any participant, $L^d{}_i$ the bilateral limit set by participant *i* against the defaulting member *d, D* the defaulted amount, *C* the collateral held by defaulting member, and *n* the number of participants in the system.

The loss share of non-failing participants thus consists of the mandatory bilateral limit (L^m) and a proportion of the losses that exceed the sum of the mandatory limits by all non-failing participants. The proportion of the losses is calculated on the basis of the discretionary bilateral limits that were granted to the failing participants.

As the system is of a "survivors pay" type, the share of losses increases when more banks fail after the failure of more than one participant. The loss share of an individual bank is also dependent on the discretionary bilateral limits. The higher a bank has set these limits in comparison to other banks, the larger its share of the total losses.

The amounts calculated on the basis of the loss-sharing rules must be paid by the surviving banks on the day of settlement. If a participant is not able to pay its loss share amount, the method below (5) is used to distribute the losses to the remaining participants:

$$ALS_i = \sum_{d=1}^{s}\left((LS_d - C_d) * \frac{L_i^d}{\sum_{j=1}^{n} L_i^d}\right) \tag{5}$$

If further participants fail to cover the additional loss-sharing amounts, the process is repeated. As the level of bilateral limits that banks would set against each other if all TARGET payments were settled in a secured multilateral net settlement system are unknown to us, we use the following simplified rule to mimic loss-sharing rules like those employed in EURO1. We group the participants of the system in three groups on the basis of their capital; small, medium and large. We assume that the small banks have set minimum bilateral limits against all other participants of the system, that medium banks have set bilateral limits that are halfway between the minimum and maximum and that large banks have set maximum bilateral limits against all other participants of the system. The loss share for any bank is then defined as

$$LS_G = \frac{B_G}{B_S(n-F_S)+B_M*(n-F_M)+B_L*(n-F_L)} \quad (6)$$

where $G=[S,M,L]$, i.e. small, medium or large, B is the bilateral limit, n the number of all banks and F the number of banks that has failed (in each group G). If we use the relation of bilateral limits in EURO1 (i.e. 5, 20, and 35 million euro) we get initial individual loss shares (assuming the failure of a large bank) 0.1% of total loss for small banks, 0.4% for medium, and 0.7% for large banks. We will run the simulations with two loss-sharing rules. In the first one the losses are distributed equally among all banks, and in the second one they are distributed mimicking the loss-sharing rule of EURO1 as described above.

4. Simulation results

Unsecured end-of-day net settlement system

Exposures arising in the system

In a multilateral end-of-day unsecured net settlement system exposures arise when the payments sent or received by the failing bank are unwound. These exposures equal the difference between the original multilateral net positions and the resulting positions when the settlement is unwound. Table 3 shows the combined negative changes in the positions for all other banks.

	average	average daily peak	peak over period
Single failure	1.6	19.2	30.2
Double failure	3.0	29.0	40.7
Triple failure	4.8	39.7	54.0

Table 3. Exposures arising in the unsecured net settlement system (billion euro)

The exposures caused by a single bank averaged 1.6 billion euro during the observation period. With two banks failing simultaneously the impact was approximately doubled, and with three banks tripled. The peak exposures caused were substantially higher, ranging between 30 billion for a single bank failure and 54 billion euro in the case of a removal of three banks in the system.

The impact of bank failures

The failure of the vast majority of banks did not cause any systemic consequences. This is also reflected in the low exposures arising from the failure of an average bank. Out of the 1191 simulated single bank failures during the 10-day period, only 96 caused subsequent failures (between 7 and 11 on a daily basis). The number of banks causing systemic consequences during the whole period was 48, i.e. such banks were not always the same ones on each day.

For the observed 10 days and out of the simulations causing further failures, an initial single bank default would on average have caused the resulting exposures to exceed the capital of 1.2 other banks. The affected banks were rather small and their combined tier 1 capital amounted to only 220 million euro on average. In the worst-case scenario four banks failed. One of these banks failed as a result of the direct failures.

The results did not change substantially in the case of a simultaneous initial failure of two or three banks. Here, the worst-case scenario with three simultaneous initial failures caused seven other banks to fail. The combined capital of these banks was 4.8 billion euro, i.e. less than 5% of the total capital of all banks in the sample. These results are summarised in Table 4.

	single failure	double failure	triple failure
# of total runs*	1,191	70,530	2,768,914
# of runs causing failures*	96	10,914	617,210
share of runs causing failures	8%	15%	22%
... out of runs causing failures			
average impact			
# of failures	1.2	1.2	1.3
- of which direct	1.2	1.2	1.3
- of which secondary	0.0	0.0	0.0
capital of failing banks (million euro)	220	232	244
worst case scenario			
# of failures	4	6	7
- of which direct	3	5	7
- of which secondary	1	1	0
capital of failing banks (million euro)	3,804	4,383	4,759

* over the 10-day period, only banks with short multilateral net debit positions were failed

Table 4. Impact of bank failures in an unsecured net settlement system

Secured end-of-day net settlement system

<u>Exposures arising in the system</u>

In a multilateral secured net settlement system with loss-sharing, exposures to participants arise when the losses are shared according to the rules of the system. Table 5 shows the exposures arising in such a system, i.e. the multilateral net debit positions of the banks.

	average	average daily peak	peak over period
Single failure	0.5	11.4	15.2
Double failure	1.0	16.5	20.4
Triple failure	1.5	20.7	24.6

Table 5. Exposures arising in secured net settlement (billion euro)

On average the exposure caused by a single bank was around half a billion euro. The peak exposure caused by a single bank, however, amounted to over 15 billion euro. The combined net debit positions of two banks could be as high as 20.4 billion euro, and that of three banks almost

25 billion. The peak exposures were in general around half of those arising from unsecured net settlement.

The impact of bank failures

To study the impact of banks failing in a secured multilateral netting system, simulations with banks failing at their end-of-day positions were carried out. As secured net settlement systems can have many different risk control mechanisms, we employed two different levels of collateral (no collateral and collateral to cover the single highest end-of-day net debit position), and two loss-sharing rules (losses shared equally and on the basis of bank size).

We let the bank(s) fail and distribute the losses (minus collateral, if present) to the remaining participants of the system. If the loss share of a bank exceeds its capital we assume that the bank fails on its net debit position (if any), and the losses would be shared among the remaining banks. The procedure is repeated until all remaining banks are able to cover their loss share.

The results for simulations without collateral and with equal loss-sharing are presented in Table 6. The vast majority of bank failures did not cause any systemic consequences. Out of the 1191 runs where a single bank was set to default, in only 20 the loss share allocated to each participant exceeded their tier 1 capital. In these simulations the average number of further bank failures was 6.2. In the worst-case scenario, caused by the failure of the single largest net debtor on the last day, 13 further banks failed. Those banks were naturally the smallest banks in the sample in terms of capital. An average failing bank had a capital of 26 million euro. Virtually all of the banks failed directly as a consequence of the initial failure and secondary failures were limited to a single bank in the worst case.

The systemic consequences increase only marginally with the initial simultaneous failure of two or three banks. The worst-case scenario with the initial failure of three banks caused the failure of only 23 banks (out of 269). The Tier 1 capital of these banks amounted to 1.16 billion euro (out of 1030 billion euro).

Compared to unsecured settlement, systemic consequences of bank failures in this type of secured settlement system were less common. When these took place the number of banks failing was, however, somewhat higher but their size (in terms of capital) smaller.

# of total runs*	1,191	70,530	2,768,914
# of runs causing failures*	20	2,504	159,906
share of runs causing failures	2%	4%	6%
... out of runs causing failures			
average impact			
# of failures	6.2	6.5	6.7
- of which direct	6.0	6.3	6.4
- of which secondary	0.2	0.2	0.3
capital of failing banks (million euro)	164	178	186
worst case scenario			
# of failures	13	21	23
- of which direct	12	18	20
- of which secondary	1	3	3
capital of failing banks (million euro)	387	793	1,164

* over the 10-day period, only banks with a short multilateral net debit positions were failed

Table 6. Impact of bank failures in a secured net settlement system without collateral and equal loss-sharing

If we further secure the system and make collateral equalling the largest single net debit position available to cover the losses, the impact of bank failures is largely mitigated (Table 7). Collateralising the largest net debit position enables the system naturally to withstand the failure of the single largest participant, without recourse to further loss-sharing. Only the failure of a single combination of two banks during the 10-day period caused the resulting loss share to exceed the capital of one further bank. In the case of a failure of the three largest banks, only 171 out of the possible 2.7 million combinations caused systemic consequences. With the simultaneous failure of three banks, the peak number of further bank failures was 9. In this run, the loss share stemming from the initial loss share exceeded the capital of 8 banks, whose failure further caused the newly calculated loss shares to exceed the capital of one bank.

	single failure	double failure	triple failure
# of total runs*	1,191	70,530	2,768,914
# of runs causing failures*	0	1	171
share of runs causing failures	0%	0.0014%	0.0062%
... out of runs causing failures			
average impact			
# of failures	0	1	2.5
- of which direct	0	1	2.4
- of which secondary	0	0	0.1
capital of failing banks (million euro)	0	19	51
worst case scenario			
# of failures	0	1	9
- of which direct	0	1	8
- of which secondary	0	0	1
capital of failing banks (million euro)	0	19	202

* over the 10-day period, only banks with a short multilateral net debit positions were failed

Table 7. Impact of bank failures in a secured net settlement system with collateral and equal loss-sharing

In the scenarios discussed above it was assumed that the losses stemming from the system are shared equally among all participants. This is likely to be unrealistic. In EURO1 the losses are shared on the basis of bilateral limits that participants have set against the failing member. This enables the participants to manage their exposures on the basis of their risk-taking capability. We simulate this type of loss-sharing both with and without collateralisation of the single largest position.

When losses are shared on the basis of bank size, as explained under section 3.3, and when no collateral is used, we find that the results are very similar to the ones where collateral was used and where the losses were shared equally among surviving banks (Table 8). In the case of the failure of a single bank, no further failures took place. In the case of the simultaneous failure of two banks, only one further bank failed on the peak day. In the worst-case scenario for the simultaneous failure of three banks, only 4 further banks failed. Sharing the losses according to the size of the banks also removed all secondary failures.

	single failure	double failure	triple failure
# of total runs*	1,191	70,530	2,768,914
# of runs causing failures*	0	1	191
share of runs causing failures	0%	0.0014%	0.0069%
... out of runs causing failures			
average impact			
# of failures	0	1	1.2
- of which direct	0	1	1.2
- of which secondary	0	0	0
capital of failing banks (million euro)	0	19	23
worst case scenario			
# of failures	0	1	4
- of which direct	0	1	4
- of which secondary	0	0	0
capital of failing banks (million euro)	0	19	82

* over the 10-day period, only banks with a short multilateral net debit positions were failed

Table 8. Impact of bank failures in a secured net settlement system without collateral and loss-sharing by size

Finally, we simulated a system where we combined collateralisation of the single highest net debit position with loss-sharing according to the size of the bank. We found that none of the simulations caused any systemic effects.

Intraday exposures

In addition to end-of-day exposures, we also investigated exposures that arise during the day. The peak intraday net debit position for a single bank was around 16 billion euro and was found at 15:57. The combined positions of two and three banks were 28 and 35 billion, respectively. These peaks took place right after 11:00. Compared to end-of-day positions (or the average intraday positions), the intraday positions were almost 10% higher for a single bank and almost 40% higher for the combined positions of two and three banks.

The intraday variation in the peak positions (which may be a different bank or a combination of banks at each point of time) was rather modest. For the system as a whole, the exposures were on average highest at 11:01. Figure 1 shows the maximum intraday net debit positions for a single bank and the peak combined debit positions of any two/three banks. The sum of all debit positions in the sample is also depicted as reference.

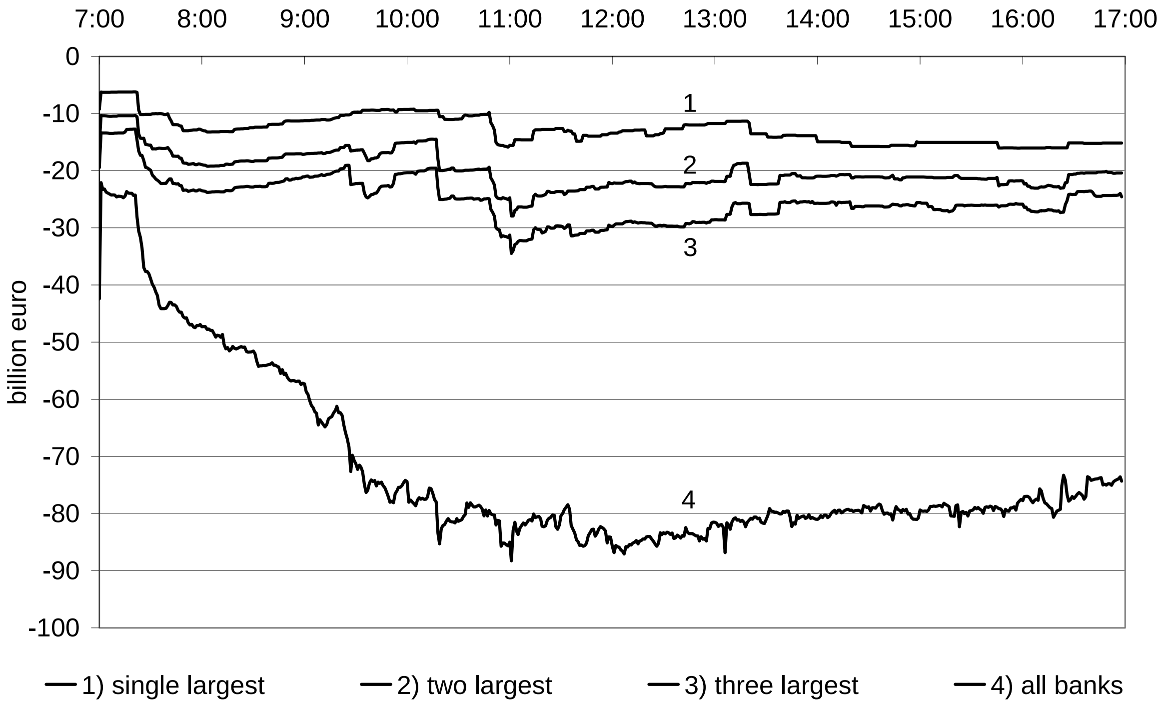

Figure 1. Peak intraday credit during the day (over 10 days)

In the final simulations we let the bank(s) fail at the time of the peak intraday net debit position vis-à-vis the system day. We assumed that payments after this time point would remain unsettled and calculated the positions of all banks until the defined time. The results are summarised in Table 9.

# of failing banks	single failure	double failure	triple failure
No collateral, equal loss sharing	15	30	42
No collateral, loss sharing by size	0	5	7
With collateral, equal loss sharing	0	9	17
With collateral, loss sharing by size	0	0	0
Total capital of failing banks (billion euro)			
No collateral, equal loss sharing	0.6	2.0	3.7
No collateral, loss sharing by size	0	0.1	0.2
With collateral, equal loss sharing	0	0.2	0.7
With collateral, loss sharing by size	0	0	0

Table 9. Impact of bank failures on intraday peak position (single worst-case scenario)

We find that the worst-case impact of bank failures at peak intraday positions is not substantially different than a failure at the end of the day. Overall the systemic effects remain rather moderate. At worst, the number of banks failing almost doubles (from 23 to 42) in the system without collateral and equal loss-sharing. Adding collateral and loss-sharing by size of the bank remains an efficient method for reducing systemic effects. When both of these methods were used, the systemic impact could be wholly eliminated during the simulated days.

5. Discussion

The results indicate that the systemic consequences of a particular type of systemic event, a sudden and unexpected failure of a bank where contagion is contained to the payment system, can be rather low. If risk management techniques such as legal certainty for multilateral netting, limits on exposures, collateralisation of exposures and loss-sharing rules are introduced, such systemic consequences can be mitigated to a high degree.

There are, however, a number of caveats and limitations for the applicability of the results that should be mentioned and could be addressed in further research on the topic.

First, the failure of a bank rarely takes place in isolation of its environment. Our methodology did not take into account related events such as a spill over of loss of confidence from the failing bank to other banks, or deteriorated future expectations that would reduce collateral and other asset values.

We also assumed that no exposures are present outside the payment system, e.g. in the interbank money market, in interbank term loans or from exposures arising from the asynchronous settlement of the two legs in FX (i.e. Herstatt risk) or securities settlement. The risks taken by banks in these other areas are likely to be manifold to those arising from the payment system. In a scenario where a bank fails on its obligation across all these segments, the systemic consequences are likely to be much higher.

We also did not analyse the impact of bank failures on ancillary systems. The central bank RTGS systems are in many countries used for the final settlement of funds related to securities settlement and foreign exchange settlement systems. Credit or liquidity problems experienced in the main system are likely to negatively affect these systems as well. We also only studied credit events, leaving any liquidity problems banks may encounter aside. From the perspective of a smooth functioning of the payment system, these are, however, highly relevant.

The alternative settlement arrangements may have different performance characteristics under other type of systemic events or when the whole settlement system is studied, i.e. when links to other settlement arrangements are taken into consideration.

Second, a number of assumptions on the sequence of events in a failure scenario were necessary to carry out the simulations. Two of the most critical assumptions were that banks can withstand credit shocks up to their capital before becoming insolvent, and that solvent but illiquid banks will by default get liquidity either from the market or from the central bank to cover the shortfall. While widely used in previous research, capital of a bank is only a proxy for the bank's ability to withstand financial shocks. Other measures, such as available collateral or other proxies could be better. Market conditions may also worsen in conjunction of a failure, or the timing of the failure may be such that the markets are not open. These could make it difficult also for solvent banks to cover their liquidity shortfall from the market. Unless properly collateralised, the central bank may not be particularly willing to lend to the market either. Carrying out simulations with various failure threshold levels would provide more information on the impact of these aspects.

Third, the data used in the study reflected the normal pattern of payments sent and received by the participants. The time period was also rather short due to the limited availability and difficult accessibility of the payment data. The exposures may occasionally be substantially higher than those experienced during the period under study. This may especially be the case during crisis times when also the likelihood of settlement failure tends to be higher. Banks may hesitate to submit payments to the system in order to save liquidity, as they are not sure whether their counterparts will submit theirs. If only a portion of banks do so, the imbalances in liquidity and the exposures may be much higher than under normal operating conditions. A great part of the payments processed are also linked to the delivery of another currency (FX trading) or securities (securities trading). Uncertainty by the banks on their counterparties' ability to deliver the other leg may also change the amount and pattern of payments they submit to the system. Furthermore, banks are likely to change their behaviour with regards to payment submission when operating in a system of different design than TARGET. We did not try to capture these changes and the simulations simply present the mechanical settlement of payments in alternative environments.

While the initial failures were rather large, the contagion was in all scenarios very limited and affected mainly the smaller banks. One reason for the limited contagion may be the European market structure where banks mainly interact with their local counterparts instead of large euro area banks towards which many other banks have high exposures. In general, the results are more in line with those found by Angelini et al. [1] for the Italian interbank payment system and Bech et al. [2] for the Danish one, than those of Humphrey [8] on the US CHIPS system. The results show that collateralisation of the peak positions in the payment system in general reduce the systemic consequences substantially. Collateral, however, comes at a cost. If the amount of collateral available to banks is overall limited, the collateral used in the payment system may be better used for the collateralisation of exposures outside it, i.e. an important question in this regard is where the collateral is most efficiently used to mitigate systemic consequences. The liquidity available for an individual participant in such an unsecured system is restricted to the amount of collateral posted.

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