Systemic risk in a netting system revisited

Kimmo Soramäki
European Central Bank
Directorate General Payment Systems

Morten L. Bech
Federal Reserve Bank of New York
Research and Market Analysis Group

DRAFT
Please do not cite!

August 2004

Key words: Payment systems, Fedwire, Systemic risk, contagion
JEL Classifications Codes: E42, G21

Corresponding author: Kimmo Soramäki: kimmo.soramaki@ny.frb.org, tel: (212) 720 8903. While visiting the Federal Reserve Bank of New York for the year 2004.
Contact information: Morten Bech: morten.bech@ny.frb.org. Tel: (212) 720 6935

We would like to thank Kurt Johnson for research assistance.

1. Introduction

Central banks have for the past few decades been concerned about the intraday exposures arising from the settlement of payments. The concerns relate in particular to systemic risk, which in the payment system context can be understood as the impact a failure by a participant in the system may have on other system participants. It is often argued that in a worst case scenario, the losses stemming from exposures taken by participants in the payment system may become contagious and may eventually impede the effective functioning of the payment system or the financial system at large.

During the last decade the risk management techniques used by large-value payment systems have been substantially enhanced, as the risk of contagion in the payment system became better understood. The key developments have been the enhancement of risk management techniques used by the systems themselves, better management of risks by their participants, and the drafting of regulatory standards for payment systems. A major development for payment systems has been the introduction of real-time gross settlement (RTGS). An RTGS system processes payments in real time on a transaction by transaction basis. Hence, it provides instant finality throughout the business day and thus eliminates intraday credit exposures. Systems that continue to operate on intraday exposures have introduced caps, collateralization, loss-sharing rules and other risk management techniques to manage and limit intraday exposures. Also payment system participants have enhanced their internal intraday risk management procedures e.g. by setting bilateral and multilateral limits against their counterparties, and by monitoring their exposures. As a result most systems today employ a wide range of mechanism to mitigate payment system exposures and thereby systemic risk. At the same time the central banks have taken a more active role in overseeing payment systems. The Lamfalussy standards developed by the international Committee for Payment and Securities Settlement (BIS 1990) are a corner stone of risk management standards for payment systems set by central banks. The standard most relevant so systemic risk is number IV. It states that:

> "Multilateral netting systems should, at a minimum, be capable of ensuring the timely completion of daily settlements in the event of an inability to settle by the participant with the largest single net-debit position" (BIS 1990 p. 5) [1]

[1] The standard is reiterated with another wording in the more recent Core Principles for Systemically Important Payment System. Core Principle V: "A system where multilateral netting takes place should, at minimum, be capable of ensuring timely completion of daily settlements in the event of an inability to settle by the participant with the largest single settlement obligation" (BIS 2001 p. 9)

In other words, all systems should be able to withstand the failure of the single largest net debtor without systemic consequences. Central banks generally view this requirement as a minimum standard. Consequently, operators or regulators may impose additional safeguards on a system to ensure that settlement can take place even in the event of multiple failures. Such systems are sometimes referred to as Lamfalussy plus compliant.

Surprisingly little work has been carried out to investigate the two key propositions underlying the Lamfalussy standard. First, are the most severe systemic consequences in fact produced by the failure of the single largest net debtor? Second, how severe are the systemic consequences resulting from multiple simultaneous failures, and are they worse than the failure of a single participant?

In this paper we first explore the extent of intrinsic systemic risk present in our data set, payments originated in the US Fedwire system[2]. We do so by considering the systemic risk if these payments were settled in an unsecured multilateral net settlement system. The results of the simulations show the extent of systemic risk that can be removed by using more secure forms of settlement, such as the RTGS mode that is currently employed to settle these payments. We base our results on simulations where one or more banks are set into insolvency at the end of the day and the impact of the failure is propagated through the system. Using the same methodology we go on to tackle both of the above questions. We are particularly interested on the validity of the assumption that the bank with the largest single settlement obligation causes the worst systemic consequences and on the marginal impact of increasing the number of simultaneous bank failures from one.

The paper is organized as follows. Section 2 presents our methodology for assessing systemic risk. Section 3 explores the data used in the simulations. Section 4 presents and section 5 discusses and summarizes the results.

2. Methodology for assessing systemic risk

De Bandt and Hartman (2000) defines a systemic event as an event where a shock to either a set of financial institutions or markets lead to considerable adverse effects on other financial institutions or markets. A systemic event consists of two parts: the shock and the propagation mechanism. Systemic risk

[2] Fedwire is the large-value USD interbank payment system operated by the Federal Reserve.

is the possibility of losses following such an event. The degree of systemic risk depends on the likelihood of the event and the consequences of it materialization.

Here, we take the set of financial institutions to be participants in a hypothetical unsecured end-of-day net settlement system and define a systemic event as the situation where the failure to settle by one or more participants leads to the settlement failure of at least one other participants. We focus exclusively on the impact of a systemic event and do not try to quantify the likelihood of the event. Hence, our results only provide a partial measure of the systemic risk. Our methodology follows Humphrey (1986) and Angelini et al. (1996). Nevertheless it differs in several respects and we seek to highlight similarities as well as differences below.

Following Humphrey (1986) and Angelini et al. (1996), we consider sudden and unexpected failures of participants. Angelini et al. (1996) simulate the failure of every single bank in the system. Humphrey (1986) considers only banks with the largest net credit position on the day of failure. Kuussaari (1996) and Bech et al. (2002) simulate the failure of the bank with the largest multilateral net debit position on the particular day. As regards single bank failure scenarios, we consider the failure of each bank with a multilateral net debit position in the system. In contrast to prior studies we also consider simultaneous failures of two and four participants in the system.

In our methodology only banks with a negative revised position vis-à-vis the settlement institution can fail. If a participant has a positive net position vis-à-vis the institution, it does not have a payment obligation and its failure need not affect the settlement process. We assume that the system rules stipulate that whenever a participant fails on its settlement obligation, it is removed from the system and its payments are unwound. The failure of a participant is assumed to result in an unwinding of all the payments to and from the failing participant. After unwinding of payments the remaining participants' multilateral net positions are recalculated.

The recalculation of the positions upon the primary failure generally causes some banks' positions to improve and other banks' positions to deteriorate. Humphrey (1986) assumes that a deterioration in a participant's multilateral net position is a principal loss to that participant. The amount of these losses depends on the degree by which the participant has permitted its customers to use funds received from the failing participant and the customer's obligation and ability to return these upon the failure in the final settlement of the funds. If the customer is obliged, and can return the funds, or if the funds were not available to the customer before final settlement, the participant does not experience credit losses. We

take the side of caution and follow Humphrey (1986) in assuming that the full amount is a principal loss to the participant.[3] We implicitly assume a recovery rate of zero for the losses.[4]

If an affected bank has a net debit position and the deterioration of its position exceeds a defined threshold value, we consider that bank to fail on its settlement obligation. It will be removed from the system and payments to and from it will be unwound. This will again lead to a recalculation of the positions. The process is iterated until no new secondary failures take place. Following Bech et al. (2002) we consider a range of different threshold values for the secondary failures. The exact procedure of contagious failures is illustrated via an example in Annex I.

3. Payments, positions and exposures

We use for the simulations interbank payments originated over the Fedwire Funds Service (Fedwire) for January 2003 (21 business days). Participants use Fedwire to handle large-value, time-critical payments, such as payments for the settlement of interbank purchases and sales of federal funds; the purchase, sale, and financing of securities transactions; the disbursement or repayment of loans; and the settlement of real estate transactions. In 2003, an average of 491,158 transfers was originated over Fedwire per day - worth more than $1.7 trillion. Fedwire has more than 9.500 participants.

We include in the simulation only transfers, and thus exposures, between depository institutions. Hence, we ignore transfers to, from or on the behalf of the U.S. Government; Federal Reserve Banks; State and local governments; Federally related agencies; and payments and securities settlement institutions such as CHIPS, CLS and DTCC. For computational convenience we limit our sample to the top 1,000 depository institutions in terms of value of transfers originated. These institutions cover 99% of all transfers originated on Fedwire measured in terms of value.

---

[3] If payments are not irrevocably settled before the failure takes place, the non-failing participants face different demand of liquidity and do not experience a principal loss. In this case banks may still not be able to honor their obligation (i.e. may fail to settle) because of insufficient liquidity. The same methodology can be applied to such an environment, only the interpretation of the results must be adjusted.

[4] For comparison, Furfine (2003) uses recovery rates of 60% and 95%. The first rate is reported by James (2001) to be the typical loss in assets of a failing bank. The second rate is the one recovered from the insolvency of Continental Illinois, as reported by Kaufman (1994). Our results thus depict an unlikely but extreme scenario in this respect.

Moreover, we remove all interbank federal funds overnight loans using an approach similar to Furfine (1999). These loans are used by banks mainly to manage their end-of -day positions vis-à-vis the Federal Reserve and hence serve to manage the interbank exposures created by the payment flows.[5]

The depository institutions in our sample exchange payments to the tune of $1.3 trillion per day. On average, bilateral netting reduces the interbank positions by 76% to $306 billion and multilateral netting implies a further reduction to $56 billion or 96%. Both the bilateral and the multilateral netting effects are fairly stable over the period varying within a narrow 3-percentage point range.

Table 1: Descriptive Statistics of Payment flow, Net Positions and Netting Effect

	Turnover	Bilateral Net Position	Daily Multilateral Net Position	Bilateral Netting Effect	Multilateral Netting Effect	Per bank Capital	Per bank Daily Links
		$billions				$billions	
Mean	1,286.1	305.9	56.0	76%	96%	0.6	63
Median	1,259.9	290.5	56.4	76%	96%	0.1	32
Minimum	1,188.9	274.6	41.0	75%	94%	0.001	1
Maximum	1,509.8	366.5	81.3	78%	97%	56.2	893
St. Deviation	91.7	30.1	11.8	1%	1%	3.2	102

Source: Own Calculations

We use Tier 1 capital numbers from year-end 2002 Call Reports[6]. For foreign institutions we use a U.S. capital equivalency number[7]. The average capital per bank is $600 million but the median only $100 million. The largest institution in terms of capital had in excess of $56 billion where as smallest had less than a million.

In principle, we have 1000*(1000-1)/2 = 499.500 bilateral positions per day. However, not every pair of depository institutions in Fedwire exchanges payments with each other on a daily basis. In fact, over the sample period there were only between 29.000 and 36.000 non-zero bilateral positions on any given day. The average daily number of non-zero bilateral positions (links) per bank was 63 and the median was 32. However, the distribution of bilateral positions with other banks is highly skewed to the left with 95% of

5 See also Furfine (2003)

6 All banks insured by the Federal Deposits Insurance Corporation (FDIC) are required to file consolidated Reports of Condition and Income (Call Report) as of the close of business on the last day of each calendar quarter.

7 If the foreign institution is a financial holding company then the capital amount is 35% of worldwide capital. If the foreign institution has Strength of Support Assessment (SOSA) rating of 1 then the capital amount is 25% of worldwide

banks having less than 228. The most connected bank had an average of 893 links per day. Distributions of the statistics are provided in Annex II.

The average (non-zero) bilateral position is $30.000 and the median is $300. The distribution of bilateral positions is symmetric around zero and 99% of all positions are between ± $77 million. However, the largest bilateral position over the sample period was $14.4 billion. The average bilateral exposure, i.e. positive bilateral position, is $10 million but the median is only $81,000. Less than 5% of bilateral exposures are greater than $20 million and less than 1% are greater than $200 million.

The average multilateral net position is by definition zero and the sample median is a mere $200,000. 99% of the multilateral positions are between -$1.2 and $1.1 billion. The largest position due in the sample is $44.5 billion and the largest position owed is $17.5 billion. The average multilateral exposure, i.e. positive multilateral net position, is $743 million but the median is only $43 million. 5% of the multilateral exposures are greater $3.3 billion and 1% are greater than $11 billion.

4. Simulation results

The results are organized as follows. Section 4.1 analyses the magnitude of intrinsic systemic risk. Section 4.2 analyses the relationship between the net payment obligation of the primary failure and the resulting systemic risk. Both sections are based on simulations where a single bank fails on its payment obligation. Section 4.3 studies the impact of multiple simultaneous failures. All results are first presented for a scenario where the failure threshold equals the capital of the banks. Sensitivity of all results is investigated for several lower failure thresholds.

4.1 Systemic risk in single bank failures

The first study on the magnitude of systemic risks stemming from the payments system was conducted by Humphrey (1986). The paper concluded that systemic risk could be a real threat. In the case of a failure of a major participant in CHIPS, the major US private interbank payment system, a high number of other participants would potentially fail. At the time of the paper 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 failing participant would be unwound and the multilateral positions recalculated. More recent studies on

capital. If the foreign institution has a SOSA rating of 2 then the capital amount is 10% of worldwide capital. If the foreign institution has a SOSA rating of 3 then the capital amount is 5% of worldwide capital

systemic risk in payment systems find that systemic risk in payment systems seems to be low. Angelini, Maresca and Russo (1995) followed Humphrey with some modifications and found out that the interbank settlement exposures in the Italian payment system (BI-REL) were much smaller than the results reported by Humphrey on CHIPS. Similar conclusions have been reached by Kuussaari (1996) on the Finnish interbank payment system, Bech et al. (2002) for the Danish interbank netting system (PBS) and Northcott (2002) for the Canadian Automated Clearing Settlement System (ACSS).

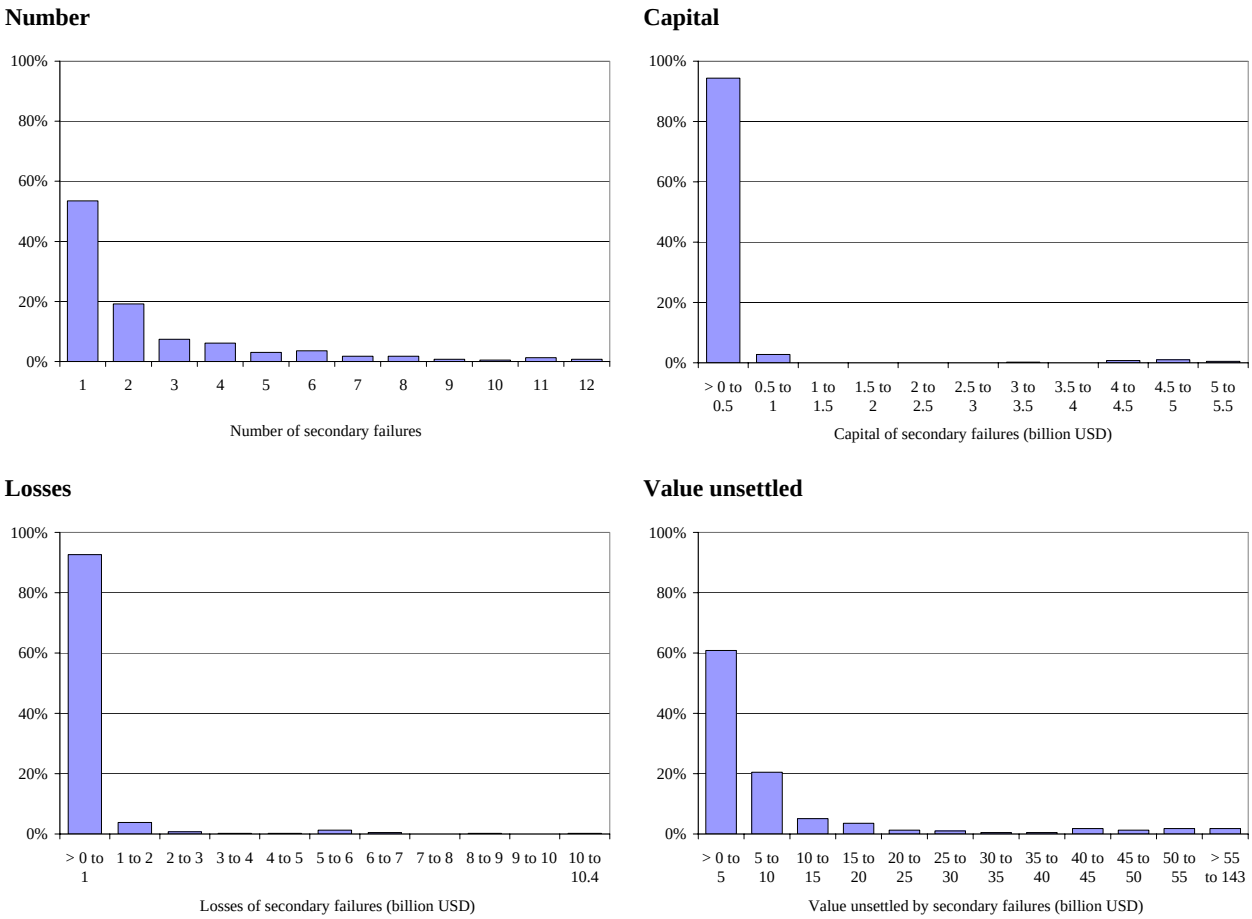
Our results indicate that systemic risk present in Fedwire payment flows seems to be generally rather low. The vast majority of bank failures did not cause any systemic consequences in the simulations. The number of banks causing secondary failures on a given day ranged between 15 and 30.

The systemic consequences of the failure of these banks were also generally modest. In over half of the cases the number of contagious failures was limited to a single additional bank. The median total capital of all secondary failures was $147 million and the median total value of unsettled payments around $2 billion. In contrast to the total capitalization of the banks ($600 billion) and the average daily value of payments ($1.2 billion) these represent negligible shares. The median losses for all banks were $100 million.

On a few occasions the systemic consequences could be higher, however. In the worst case the number of secondary failures amounted to twelve banks. While the total capital of secondary failures never exceeded $5.5 billion (under 1% of total) and the total losses were contained to $10.4 billion (1.7% of total capitalization), the value of payments remaining unsettled could grow higher in relative terms. On the worst day the value of these payments was $143 billion, almost 11% of the day's turnover.

Figure 1: Statistics on systemic risk in a single bank failure scenario

(α=1, % of simulations with systemic consequences)



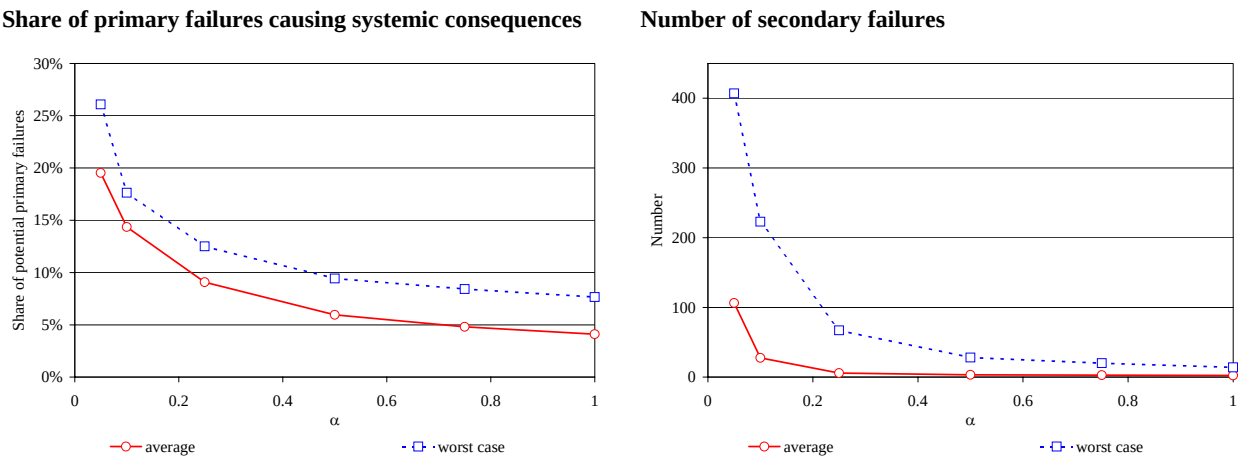
To study the sensitivity of the results we carried out several simulations with lower failure thresholds. We calculated the new failure thresholds by multiplying the capital of the participant with a capital scaling factor α. In general, the relationship between the fragility of the system and systemic risk seems to be convex, for both the likelihood of systemic consequences caused by a primary failure (Figure 2, left graph) and the resulting number of secondary failures (Figure 2, right graph).

When α equaled 0.5 the daily number of primary failures causing systemic consequences ranged between 19 and 37 banks, around double the amount experienced under α of one. Also the magnitude of systemic consequences could grow to be substantially higher. The number of secondary failures was up to 24 banks and the value of unsettled payments up to $688 billion. The latter represented almost 46% of the daily turnover. Generally, however, the systemic consequences were not as severe. In two thirds of the simulations the number of secondary failures did not exceed two banks and the value of unsettled

payments was in nine out of ten simulations below $5.5 billion. The simulations, however, show that already at this level of α low probability but high impact scenarios do exist.

The system seems to be rather robust with only slight increases in secondary failures up to a α equaling 0.25. When α is reduced below this "tipping point", both the average and maximum number of secondary failures increases rapidly. When α was reduced to 0.05, systemic consequences were experienced much more frequently. Depending on the day, 68 to 139 different primary failures caused secondary failures. The level of systemic consequences was multiplied manifold, and on the worst day over 400 secondary failures were experienced.

Figure 2: Relationship between failure threshold and number of secondary failures

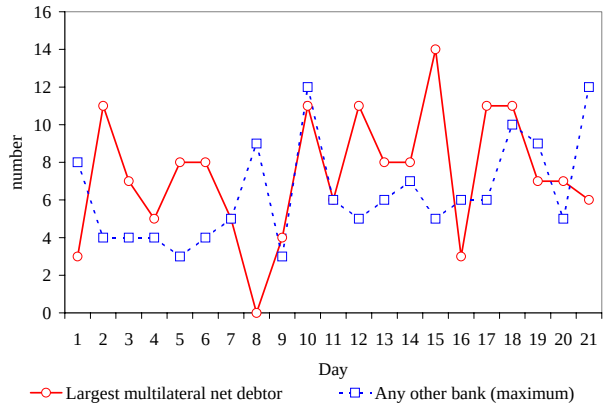


4.2 Systemic risk and net debit position of primary failure

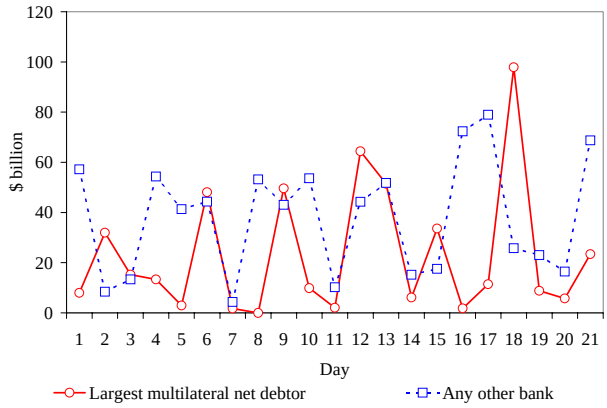
In a payment system with unwinding the initial impact of a failure is driven by the failing participant's bilateral positions vis-à-vis other participants. Therefore it is not a necessity for the participant with the highest multilateral net debit position to cause the most severe systemic consequences. In fact, on 8 of the 21 days a bank other than the largest multilateral net debtor caused the most secondary failures and on 14 days the highest value of unsettled payments. On one of the days the failure of the largest multilateral net debtor did not cause any systemic consequences. The most severe consequences across all days were, however, caused by the single largest net debtor on that day. A time series comparing the impact of the failure of the largest net debtor and the highest impact of any other bank is presented in Figure 3.

Figure 3: Failure of the single largest multilateral net debtor and systemic risk (α = 1)

Number of secondary failures



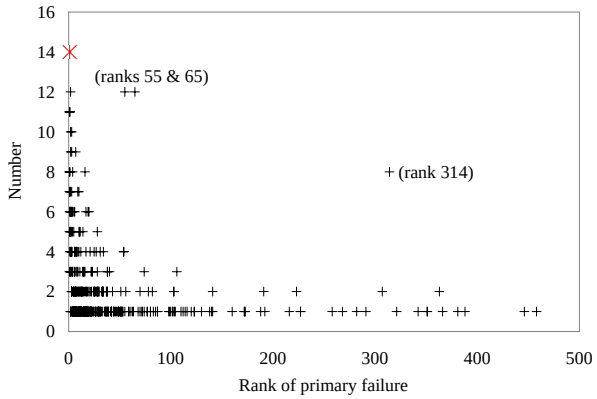
Value unsettled by secondary failures



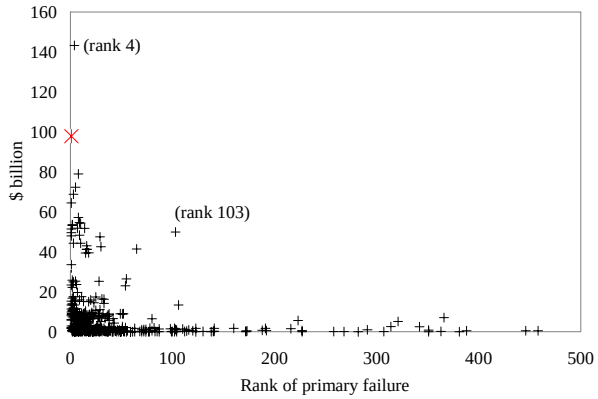
In general there seems to be a downward sloping relationship where banks with lower multilateral net debit positions are less likely to produce higher systemic consequences. There are, however, important outliers as is evident from Figure 4. The failure of banks that were ranked as 55th and 56th largest net debtors in the system produced the second and third highest numbers of secondary failures. Also, the failure of a bank with the 314th largest net debit positions on a particular day was still among the top 10 banks causing the worst impact. Looking only at the failure of the largest net debtor might thus not capture the worst case scenario. In our simulations, the primary failure causing the highest value of unsettled payments among the secondary failures was a bank with the fourth largest multilateral net debt position.

Figure 4: Is there a relationship between systemic risk and size of net debit position?

Number of secondary failures



Value unsettled by secondary failures

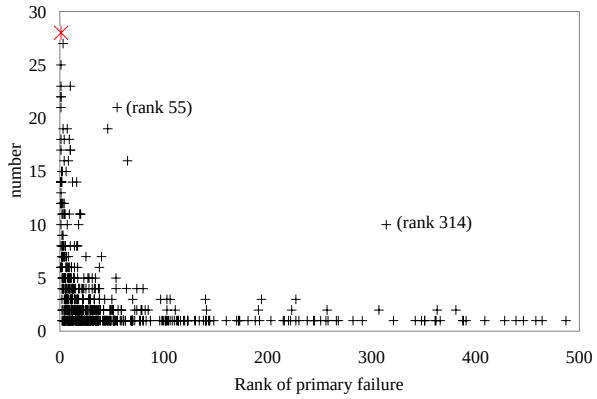


The results are not changed drastically when α is reduced to 0.5. While the failure banks with a higher multilateral net debit positions do not always cause systemic consequences, they are more likely to do so than banks with lower net debit positions.

Figure 5: Sensitivity of results to lower levels of α

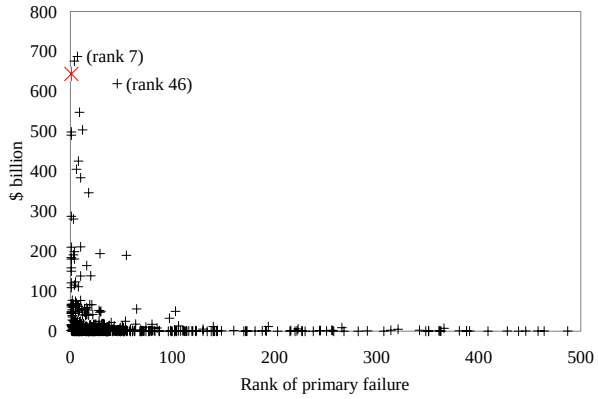
Number of secondary failures

α = 0.5

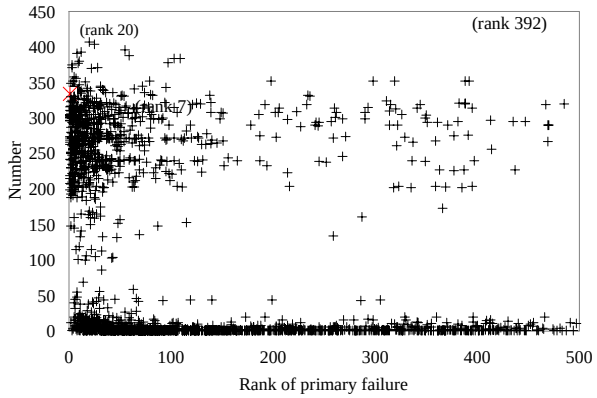


Value of payments unsettled

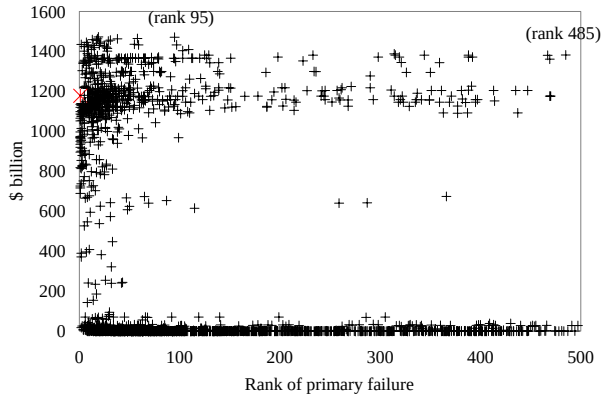
α = 0.5



α = 0.05



α = 0.05



The results change, however, completely when the system becomes extremely fragile i.e. when α is reduced to 0.05. This is, however, an unrealistically low failure threshold as it implies that losses amounting to over only 5% of the current capital of the banks cause the bank to fail. Under this scenarios virtually the failure of any bank, irrespective of its multilateral net debit position, could cause severe systemic consequences. While banks with higher net debit positions are still more likely to cause a high number of secondary failures, a high number of banks with low net debit positions can do so as well. Also, the system tends to end up in two configurations after the contagion process. Either the systemic consequences are contained to a handful of secondary failures (and a few billion unsettled payments) or

around 300 secondary failures (and $1200 billion of unsettled payments) take place. On rare occasions the number of secondary failures could reach over 400, and almost all of the day's payments could end up being unwound. Moderate systemic consequences, however, were missing.

4.3 Systemic risk of multiple bank failures

A sudden and unexpected bank failure is a very rare event. The likelihood of a sudden and unexpected failure of more than one bank is naturally even more remote. It is interesting, however, to analyze how much worse multiple failures can be and what are the dynamics at play when more than one bank is removed from settlement.

We saw in the previous section that the worst systemic consequences on a particular day can be produced by the failure of virtually any bank in the system, especially when the system is very fragile. Likewise virtually any combination of multiple failures is a potential "worst case" scenario. It is, however, computationally not possible by enumeration to find the set of banks causing the most severe systemic consequences – especially when the number of simultaneous failures exceeds two banks.[8] To select the combination of banks that produce the worst impact we would therefore need information that is present in the payment and bank data that would tell us which combinations to try. Currently we do not possess such information.

While the bank with the largest multilateral net debit position did not always produce the worst systemic consequences, these banks were more likely to produce severe consequences than banks with lower net debit positions. We therefore select our primary failures from the top 10 banks with the highest multilateral net debit positions. We simulate in addition to a single failure, also the failure of two and four banks. For a given failure threshold this gives us 945 observations (45 combinations for 21 days) for the simultaneous failure of two banks and 4410 observations for the failure of four banks. For comparative reasons the simulations presented here for the single failure scenario are based on the failure of the same 10 banks.

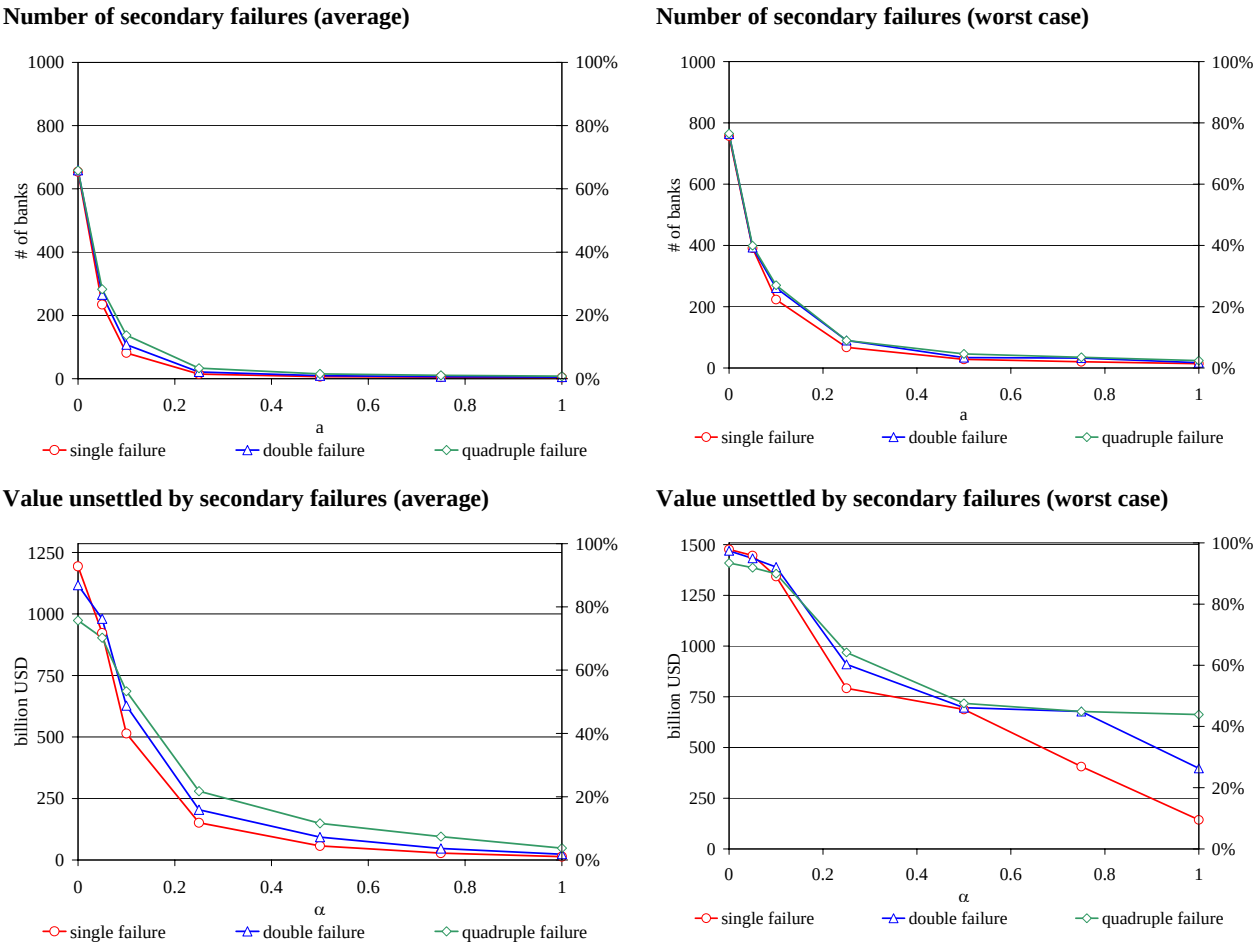
As expected, a higher number of primary failures result in a higher number of secondary failures. The differences are, however, surprisingly small. The curves representing the number of secondary failures at given failure thresholds are very close to each other irrespective of the number of primary failures,

---

[8] With 1000 banks the number of combinations for any two banks is approximately half a million, three banks 166 million, and four banks 41 billion.

especially at low and high levels of α. The number of primary failures seems therefore, to be a less decisive factor for systemic consequences than the failure threshold used. This is true for both the average impact and the worst-case scenario. The value of unsettled payments was, on the other hand, substantially higher in the multiple failure scenarios than in the single failure scenario, especially at high levels of α and in the worst case scenario.

Figure 6: The impact of multiple failures



Why do not multiple failures cause more severe systemic consequences than present in the simulations? One possible explanation is that the losses are distributed to a higher number of banks. When looking at the number of banks with a deterioration in their multilateral net debit position caused directly by the primary failure we found that the number of these banks increases substantially when more than one bank fails. While in the single failure scenario an average of 267 banks were affected, the number for double and quadruple failure scenarios was 434 and 465 banks respectively. Another explanation could be that the losses caused by the first failure are offset by gains from a second, third or fourth failure. It could,

however, also be that the results are driven by our choice of primary failures. We simulated the failure of the largest banks in terms of their multilateral net debit positions. If these banks transfer heavily payments with each other, a multiple failure could mainly results in exposures between these banks where another set of simultaneous failures could be more severe from a systemic risk perspective.

5. Summary

Our results seem to indicate that systemic consequences in a single bank failure scenario are rather modest, especially when the failure threshold is set to levels that are more realistic. This does not, however, mean that they can not be severe. Although the results are in line with more recent studies on the topic, results with other data sets or longer time series could be different. Severe contagion may be a low probability but high impact event. In an unsecured net settlement system no limits for exposures exist. Even though the exposures present in our data did not grow high enough to cause widespread disruptions when realized, they can do so. Therefore it is difficult to assess using real payment data the extent by which risk reduction methods such as RTGS or secured net settlement systems reduce systemic risk.

Our second research question related to the common wisdom and the assumption underlying the Lamfalussy standard IV that the largest single net debtor in the system causes the most severe systemic consequences. The simulations showed that for an unsecured net settlement system this may not always hold. While participants with larger net debit positions are more likely to cause more severe systemic consequences, virtually any other bank can do so as well. These results were very sensitive to the level of failure threshold used. If the net positions are binding and the system has ways of covering these, e.g. though collateralization, the assumption, however, holds.

Our results indicated that the systemic consequences increase surprisingly little as a consequence of multiple simultaneous failures. As it is not possible via enumeration to simulate all combinations of multiple banks it might be the case that our results do not exhibit the worst-case scenario. Research on the drivers of systemic risk, e.g. on the basis of network topology could shed light on this question.

References

Angelini, P., Maresca, G. and Russo, D. (1996). Systemic risk in the netting system. Journal of Banking and Finance 20, pp. 853-69.

Bech, M, Madsen, B. and Natorp, L. (2002). Systemic Risk in the Danish Interbank Netting System, Danmarks Nationalbank working paper, No. 8.

BIS (1990). Report of the Committee on Interbank Netting Schemes of the Central Banks of the Group of Ten countries, prepared by the Committee on Payment and Settlement Systems. No 4.

BIS (2001). Core Principles for Systemically Important Payment Systems, prepared by the Committee on Payment and Settlement Systems. No 43.

De Bandt, O. and P Hartmann, Systemic Risk: A Survey, Working Paper no. 35, European Central Bank, 2000.

Furfine, C. (2003). Interbank Exposures: Quantifying the Risk of Contagion, Journal of Money, Credit, and Banking 35. Issue 1, pp. 111-129.

Humphrey, D. (1986). Payments Finality and Risk of Settlement Failure, In: Saunders, A., White, L.J. (Eds), Technology and the Regulation of Financial Markets: Securities, Futures, and Banking. Heath, Lexington, MA, pp. 97-120.

James, C. (1991). The Losses Realized in Bank Failures, Journal of Finance 46, pp. 1223-42.

Kaufman, G. (1994). Bank Contagion: A Review of the Theory and Evidence, Journal of Financial Services Research 8, pp. 123-50.

Kuussaari, H. (1996). Systemic Risk in the Finnish Payment System: An Empirical Investigation, Discussion Paper 3, Bank of Finland.

Northcott, C.A. (2002). Estimating Settlement Risk and the Potential Contagion in Canada's Automated Clearing Settlement System, Working Paper 2002-41, Bank of Canada.

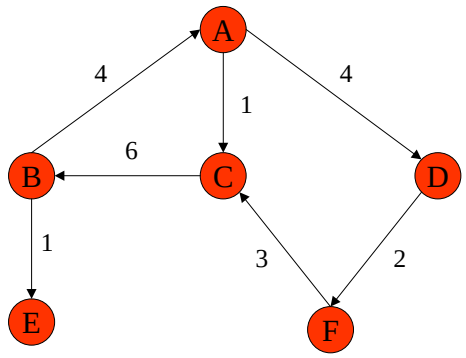
Annex I: Illustration of the methodology

Let us consider the following example to illustrate the methodology and to introduce some terms.

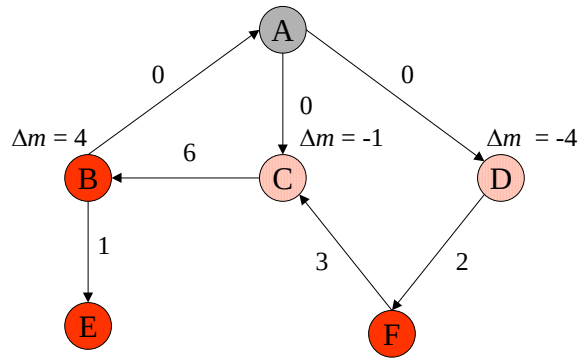
The system consists of six participants that have exchanged payments during the day. The end-of-day bilateral net debit positions vis-à-vis each participant are presented below. The arrows represent the direction of the debt relation, e.g. Bank A owes four units to Bank D . The threshold values for triggering failures are in the example the following: banks B=C=D=3, and banks E=F=1.

1. We let bank A fail and calculate the changes in multilateral net positions when payments from and to bank A are removed from settlement (unwound). Bank A is the *primary failure*. As this is the first step in the process of contagion, we call this round *generation 1*. As a result of the primary failure, Bank B experiences a positive change (+4) in its multilateral net position, and banks C (-1) and D (-4) a negative change. As discussed before we consider Bank D's loss to equal the negative change in its multilateral net position (-Δm). Bank C's threshold value for failure (3) is higher than its loss (1) and therefore it continues to participate in the system. The loss of bank D (4), however, exceeds its threshold value (3).

0

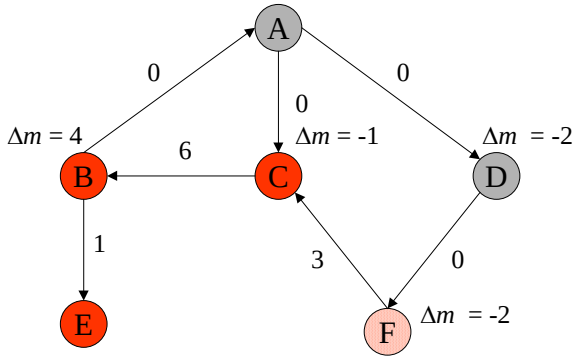


1

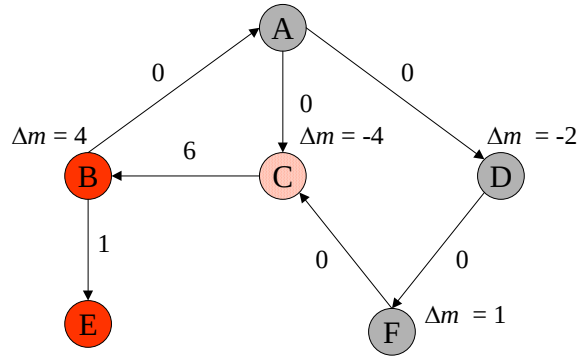


2. As a consequence, Bank D is removed from the system and the multilateral net positions are recalculated. The recalculation of the positions moves the contagion process to the second generation. Bank D is the only direct secondary failure. The failure of bank D causes a negative change (-2) in Bank F's multilateral net debit position.
3. Bank F fails, as its loss is higher than its threshold value for failure (2>1). Bank F is the first *indirect secondary failure* and the only failure in the third generation.

2

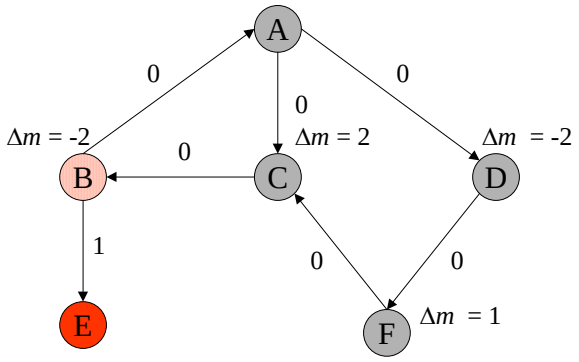


3

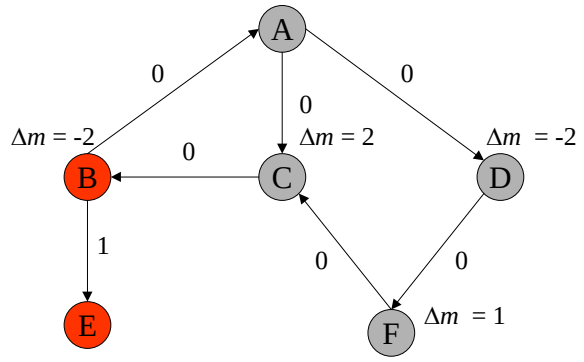


4. The failure propagates in the system. The deterioration of Bank C's multilateral net debit as a result of the failures of A, D and F is more than its threshold value for failure. Bank C is removed and the positions recalculated for the fourth time. Bank C is the second indirect secondary failure and the third indirect failure in total. The combined deterioration caused by the failure of banks A and C on bank B's positions is two - less than its capital.
5. The contagion ends at generation five as no new failures take place.

4

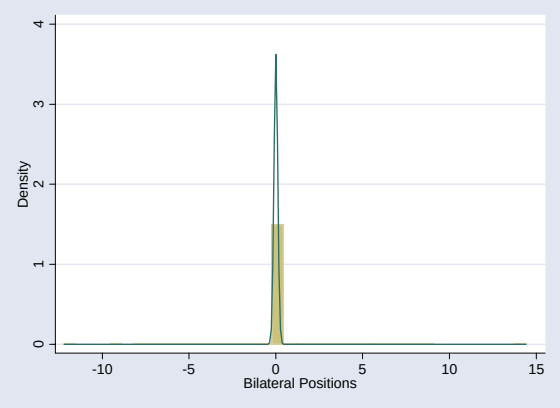


5

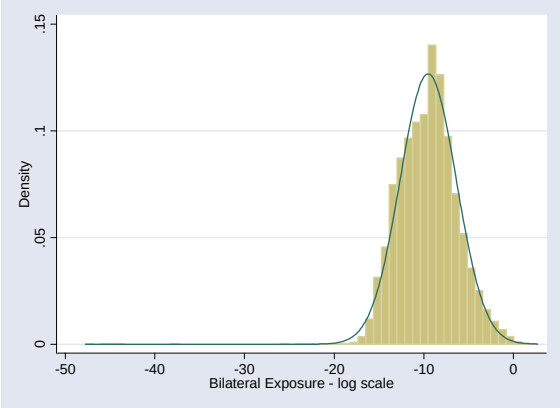


Annex II: Payment statistics ($ billion)

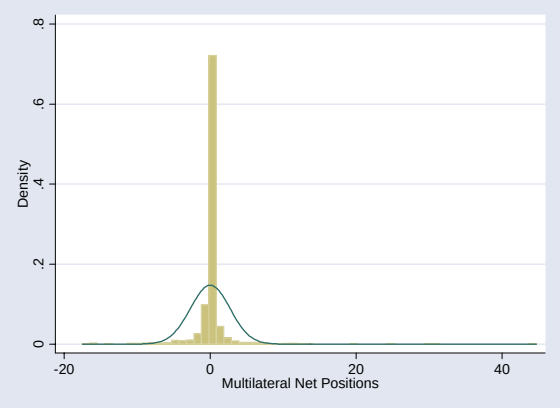
Bilateral Net Positions



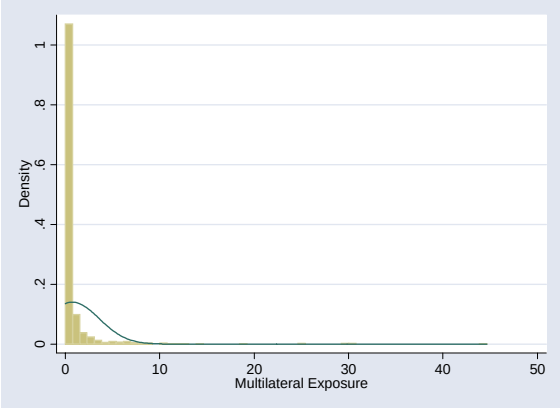
Bilateral Exposure (log)



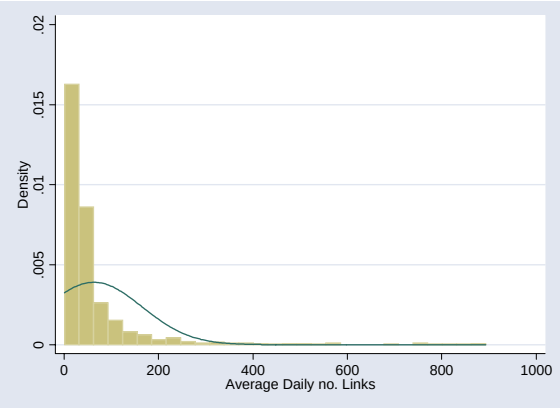
Multilateral Net Positions



Multilateral Exposures



Average Daily Number of Links



Tier 1 Capital