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Networks and lending conditions: Empirical evidence from the Swiss franc money markets*

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Abstract

This paper provides an empirical analysis of the network characteristics of two interrelated interbank money markets and their impact on overall market conditions. Based on transaction data from the unsecured and secured Swiss franc money markets, the trading network structures are assessed before, during and after the financial market crisis. It can be shown that banks in the unsecured market are connected to a lower number of counterparties but rely heavily on reciprocal and clustered trading relationships. The corresponding network structure likely favored the exchange of liquidity prior to the financial market crisis but also might have led to a lower resilience of the unsecured market. There is empirical evidence that conditions in both sub-markets were significantly driven by the individual network position of banks. The network topology likely affected the shift observed from unsecured to secured lending and the increase in risk premia for unsecured lending during the financial market crisis. This paper therefore provides further evidence on the functioning of interbank money markets and, especially, on the impact of market participants interconnectedness.

JEL Classification: E42, E43, E58, G01, G12, G21, L14

Keywords: Repo transaction, unsecured interbank money market, financial market turmoil, financial stability, Switzerland.

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1 Introduction

Interbank money markets are a key factor for the efficient allocation of liquidity within the banking system. Broadly speaking, banks exchange central bank reserve balances through interbank money markets. That is, banks with excess liquidity transfer reserves to banks with a liquidity shortage (see, e.g., Heider et al. (2015) or Mancini et al. (2016)). A failing interbank market can lead to an inefficient allocation of money and, consequently, impair the whole financial system as well as the real economy. If the liquidity is, for example, not where it is most efficient to use, the financial intermediation to households and firms can be impaired (see, e.g., Acharya and Merrouche (2010)). Disruptions in the interbank money market can, at an extreme, even lead to bank runs (see, e.g., Afonso et al. (2011)). Interbank money markets can therefore be seen as an important ingredient for the proper functioning of financial markets.

Banks typically exchange liquidity either on a secured basis (in the so-called secured or *repo* market) or on an unsecured basis (in the so-called unsecured market). In the unsecured market, no collateral is involved, while in the secured market, liquidity is exchanged against high-quality securities as collateral. In contrast to secured transactions, unsecured money market transactions do not involve the opportunity cost for the cash taker of the securities involved. That is, the unsecured money market serves as an actual funding source for banks, as no initial endowment is required. However, an unsecured transaction is only concluded if the cash provider trusts in the cash taker that the liquidity will be returned. With increasing risk perception, the price for unsecured borrowing can rise. Secured transactions, in contrast, are considered safer, as the collateral obtained can be liquidated by the cash provider in case of a default of the cash taker. However, to conclude a repo transaction, the cash taker needs to be endowed with unencumbered securities.

It is of particular interest to understand how shocks in the interbank market evolve and whether the interbank market mitigates or amplifies shocks to individual banks or the banking sector as a whole. Likewise, it is important to gain a comprehensive understanding of the drivers of the ability and willingness of market participants to fund themselves in the unsecured or secured market. A comprehensive understanding of interbank money markets is crucial for central bankers, as a well-functioning money market is essential for the effectiveness of the monetary transmission mechanism.

During the financial market crisis of 2007-2009, several interbank money markets across the global financial system were indeed impaired. At the height of the crisis, a strong increase in the risk premia for unsecured loans and, in some jurisdictions, even a freeze in market activity was observed (see, e.g., Hördahl and King (2008)). The US repo market experienced a so-called run on repo, which was characterized by heavily increasing haircuts on repo transactions and, accordingly, the inability to use certain asset classes as collateral (see, e.g., Gorton and Metrick (2012)). Turbulences in the Swiss franc money market were not as severe as in other money markets. However, a significant shift in the market activity from the unsecured to the secured money market was observed, accompanied by increased risk premia for unsecured money market transactions (see Figure 3 and 4 in the appendix).

Presumably, the lack of trust in counterparties led to decreased market activity in the unsecured Swiss franc money market and increasing risk premia for unsecured loans during the financial market crisis (Guggenheim et al., 2011). The interconnectedness of market participants was apparently an important driver for the dispersion of such market tensions. If interconnectedness indeed plays an important role in lending conditions in money markets, the significance of a single market participant cannot be discerned solely by examining an institution in isolation. Instead, it is its position in a web of relationships that has to be considered, especially in times of high uncertainty and lack of counterparty confidence (Gabrieli, 2012). An analysis of network characteristics, therefore, can entail important information on the functioning of relationship patterns within different markets, which in turn can provide information on the dispersion of shocks in the according markets.

The economic literature has shown that trading relationships and the interconnectedness of banks can influence the functioning of interbank money markets. Furfine (1999b), e.g., finds that banking relationships impact the pricing of federal funds transactions, especially for small market participants. Cocco et al. (2009) find evidence that in the Portuguese interbank money market, banks with large imbalances in liquidity reserves, small banks, banks with poor performance and banks with high volatility in liquidity shocks are more likely to borrow funds from banks with which they share a relationship. Furthermore, Kraenzlin and von Scarpatetti (2011) find evidence for price differentiation in the Swiss franc repo market due to different centrality scores and bargaining power of market participants as well as private information. Similarly, Bräuning and Fecht (2012) find that relationship lending can significantly impact the access to liquidity by improving private information about counterparties. Hence, failed relationships can lead to a loss of valuable information and thus hinder access to liquidity for borrowers. Allen et al. (2012) find that market participants in the Canadian dollar market continued to support counterparties with high credit risk during the financial market crisis due to the tight interconnectedness of and hence high contagion risk among Canadian banks. Finally, Gabrieli (2012) examines the Italian unsecured interbank money market and finds evidence that measures of interconnectedness can capture part of the cross-sectional variance in interbank rates.

The goal of this paper is to examine interconnectedness in two different interbank sub-markets. It thus adds to the literature by providing empirical evidence on the influence of market participants interconnectedness across sub-markets by conducting a thorough analysis of the networks in the two interrelated markets and estimating their impact on overall market conditions. In the first step, based on a comprehensive data set consisting of transactions of both the secured and unsecured Swiss franc money market, the network topology of two sub-markets that share a large number of market participants and common institutional features are simultaneously assessed and compared. The characteristics of the networks should tell us, how – according to the theoretical literature – shocks affect the market. In the second step, the impact of network characteristics on market activity and interest rates is analyzed. By running panel regression models, we can test whether network characteristics indeed had an impact on the well-functioning of the money markets. Because the data set ranges from January 2005 to December 2012, the analysis is conducted before, during and after the financial market crisis and, therefore, also allows assessing the impact of the networks structures during various time periods. Moreover, a comprehensive data set from the Swiss payment system and individual bank bond yield spreads allows us to account for the liquidity position and the credit risk of each market participant. Therefore, drivers of money market tensions, which previously had not been evaluated, can be assessed.

The analysis provides evidence that banks in the unsecured market are connected to a small share of potential market participants but rely heavily on a few clustered trading relationships. Through this type of trading relationship, market participants in the unsecured market may have been able to build a so-called social collateral that favored liquidity provision prior to the crisis. According to theoretical models, this type of link pattern can lead to a lower network resilience, as shocks can propagate easily. The econometric analysis reveals that the activity in the two sub-markets is driven by the individual network positions of market participants. The diversification of a bank, measured by its degree-centrality, positively drove turnover and led to lower interest rates for unsecured lending and borrowing. Furthermore, prior to the financial market crisis, the clustering of banks supported turnover in the interbank money markets and led to a reduction in interest rate premia. The reduction in clustered trading relationships accompanied by increasing credit risk of banks likely supported the shift in activity from an unsecured to a secured money market.

The paper is structured as follows. The next section introduces the institutional setup of the Swiss franc money market, provides information on its network topology and draws implications for funding conditions. In section 3, the econometrical analysis is presented. Finally, section 4 offers conclusions.

2 The Swiss franc money markets

2.1 Setup

Repo transactions in Swiss francs are predominantly traded on an electronic trading platform. During the time period analyzed, these transactions were conducted on the Eurex Repo trading platform, which was also used by the Swiss National Bank (SNB) for the implementation of its monetary policy operations[1]. For the collateralization of cash, only high-quality securities are accepted. The automatic settlement of securities is performed in the Swiss security settlement system, SECOM, while the cash leg is simultaneously settled in the Swiss real-time gross settlement (RTGS) system Swiss Interbank Clearing (SIC). For a detailed description of the Swiss franc repo market, see, e.g., Fuhrer et al. (2016).

In the unsecured market, transactions are traded on an over-the-counter basis and are predominantly settled in the SIC system. For more information about the unsecured Swiss franc money market, see Guggenheim et al. (2011).

The main motivation for a cash provider to trade cash against securities as collateral is to lend without counterparty risk. The cash taker, on the other hand, might take advantage of relatively low interest rates compared to unsecured transactions but may also require the availability of (high-quality) securities. Hence, only in the unsecured market can cash takers obtain liquidity without an initial endowment. This might also be a reason why the turnover in the unsecured Swiss franc money market was higher than in the secured market prior to the financial market crisis.

Between January 2005 and autumn 2007, the average daily turnover in the unsecured money market was approximately CHF 8 billion (bn), whereas in the secured market, it oscillated at approximately CHF 5 bn (see Figure 3 in the appendix). With the outbreak of the financial market crisis, the turnover in the unsecured market decreased to a level of CHF 5 bn, while the secured market increased significantly. At the height of the crisis, in autumn 2008, the activity in the unsecured market collapsed to a level below CHF 1 bn a day, while in the repo market, the daily turnover reached a high of approximately 15 bn. Thereafter, the activity in the repo market decreased again but remained at a level above CHF 5 bn and thus far above the level in the unsecured market. Market activity in both markets only dropped significantly after autumn 2011 due to the substantial liquidity provision by the SNB. Overall, a shift in turnover can be observed from the unsecured to the secured interbank money market during the crisis (Guggenheim et al., 2011).

Additionally, a large increase in the spread between unsecured and secured interbank interest

[1] As of 1 May 2014, the SNB conducts its monetary policy operations on the SIX Repo trading platform. Additionally, interbank money market transactions can be conducted on this new platform.

rates during the financial market crisis was observed (see Figure 4 in the appendix). The spread reflects the risk premium for unsecured lending and can be seen as a measure for stress in the unsecured money market. This measure remained at a relatively low and constant level for a long time. However, it suddenly increased in August 2007 and reached a high in autumn 2008. After mid-2009, the spread reached low levels again but remained quite volatile. These facts indicate that, like unsecured money markets in other currencies, the unsecured money market for the Swiss franc exhibited significant stress during the height of the financial market crisis.

2.2 The data

The network structures in the Swiss franc money markets are estimated by analyzing transaction data that stem from two different sources. The first dataset consists of repo transactions between commercial banks concluded on the Eurex Repo trading platform. Between January 2005 and December 2012, approximately 180,000 transactions of 161 banks were settled in the Swiss franc repo market. The second dataset is based on the transaction data from the SIC system. Guggenheim et al. (2011) introduced an augmented Furfine (1999a) algorithm to identify unsecured money market transactions from SIC data. The second dataset contains these transformed data between January 2005 and December 2012 and approximately 365,000 transactions stemming from 241 market participants. In both datasets, information about the cash taker, the cash provider, the interest rate, the maturity and the cash volume is included. Because data from the unsecured market only contains transactions of a maturity of up to 90 days[2], both datasets are limited to transactions with a maturity of up to 90 days.

The transaction data for the purpose of this analysis are favored over the data on interbank exposures collected by the SNB – which is, for example, used in Mueller (2006) – for several reasons. First, in contrast to data that provide balance sheet positions on specific days, the transaction data track every single transaction on every single business day and, therefore, allows a dynamic analysis of the network characteristics. Second, the transaction data provide information on the linkages among all market participants in the SIC system and accordingly in the Eurex Repo trading platform. Due to the open access policy of the SNB[3], foreign banks, which do not need to report their exposure to the SNB, are included in the data set. Therefore, the coverage of the market is assumed to be much broader. Third, the dataset allows one not only to study the exposure among banks but also the prevailing market prices.

Guggenheim et al. (2011) highlight potential drawbacks of the algorithm when used to identify unsecured money market transactions. One important drawback is the missing identification

[2]Robustness checks revealed that the algorithm only allows one to reliably estimate transactions with a maturity of up to 90 days.

[3]In international terms, the access policy of the SNB is relatively liberal, such that foreign banks are also able to participate in SIC and, therefore, in the Swiss franc money markets (see Kraenzlin and Nellen (2015)).

of correspondent banking transactions, as only transactions settled on SIC can be identified by the algorithm. However, it can be shown that the misspecification of network measures due to correspondent banking is expected to be small and that its negative influence on the analysis is limited (see appendix).

The average time to maturity of the relevant contracts in the two markets is roughly 25 days, i.e., a contract will mature, on average, 25 days from today. Hence, on average, the relationships a bank formed during the past 25 days decide whether it is able to renew a contract. In other words, it is reasonable to presume that a bank's network position is determined within the next 25 days before a contract expires and might have to be renewed. To analyze the network structures of the two markets, daily networks, each consisting of transactions of the past 25 days, are computed. Compared to networks only containing transactions of a single day, network statistics are less volatile, and more banks can be related to the different network statistics. Furthermore, it seems reasonable that the network position of a bank is not as volatile as networks based on a single day would suggest.

2.3 Network topology

In the following, the network characteristics of the Swiss franc money markets are illustrated by making use of network theory (also called graph theory in the mathematical literature). Some basic concepts and the measures used in the analysis are explained in Appendix A. In addition to the graphs based on actual data ('actual networks'), so-called random networks are computed that are determined by the densities, i.e., the unconditional probabilities that two nodes in a network are connected, and the number of nodes of the actual networks.[4] The random networks serve as a basis for comparison, as the number of banks, the degree and the density are identical to the actual network, but links are formed randomly. The difference from the random network illustrates the special aspect of the actual networks, which can be explained by the formation of trading relationships. The network characteristics of the actual networks and their random counterparts can be illustrated by the distribution of individual measures at certain points in time as well as by the development of overall network measures over time. Figures 5 and 6 in the appendix illustrate the overall network statistics of the unsecured and secured money markets and their random counterparts for the period from January 2005 to December 2012. Additionally, Figures 7 to 10 in the appendix show particular distributions of individual network measures for selected days and months.

[4]For each day and market, the overall network statistics of the random networks are determined by the mean of one hundred random networks.

Stylized facts

There are several network measures indicating that banks in the unsecured market are not as well connected to each other as those in the repo market. First, although there are more participating banks in the unsecured market, the average degree (i.e., average number of counterparties) in the repo market is significantly higher. Accordingly, the density in the repo market is much higher, i.e., banks in the repo market trade with a larger share of potential counterparties. Before the collapse of Lehman Brothers, approximately 20% of the possible links are used in the repo market, whereas only approximately 5% are used in the unsecured market. Although the density in the repo market decreases at the end of 2008 to a level of roughly 10%, it remains significantly above the level of that in the unsecured market of 5%. The degree distributions for selected months also reveal that the market participants degrees in the repo market are much more uniformly distributed. In the unsecured market, we can observe a large mass at very low levels and a few outliers with a very high degree. Thus, a large proportion of the market participants in the unsecured market trade with very few counterparties.

Second, in absolute terms, market participants in the repo market are closer to each other. The average path length in the secured market is approximately half of a link shorter than in the unsecured market. However, this is also due to the higher number of market participants in the unsecured market. Between mid-2006 and autumn 2009, the unsecured market even shows a lower average path length than its random counterpart, indicating a short average path length relative to the size of the network. The repo market, on the other hand, exhibits a higher average path length than the random network. Furthermore, the diameter, i.e., the path in the graph that connects the two most distant nodes, is approximately two links longer in the unsecured market. The diameter in the repo market only increases at the end of the observation period, when the market activity in the repo market decreases. Hence, figuratively speaking, market participants in the repo market are more closely connected to each other through links to other banks.

Third, the number of disconnected banks, i.e., banks not connected to the giant component, is very low in both markets until the end of 2008. Afterwards, the average number of disconnected banks in the unsecured market increased greatly and to a level far above that in its random counterpart. The number of disconnected banks in the repo market, on the other hand, remains at a level slightly above zero until autumn 2011. Thus, after 2008, an increasing number of banks in the unsecured market cannot be linked, by transactions, to the large part of the network.

There is evidence that in the unsecured market – in contrast to the repo market – trading relationships with specific counterparties matter greatly. First, banks in the unsecured market rely heavily on clustered trading relationships. The average clustering coefficient (i.e., the probability that two market participants with a common neighbor share a link as well) in the unsecured market lies far above that in its random counterpart, at least until mid-2010. Clustering in the repo market exhibits a very low level in comparison to the level in its random network. The measures remain constant in the repo market until the end of 2008, whereas in the unsecured market, it decreases heavily after August 2007. Moreover, the clustering in the unsecured market is very pronounced at banks with low degrees. Clustering coefficients in the repo market are distributed much more uniformly over the degree. Thus, until August 2007, and to a lesser extent, until mid-2010, it is quite common in the unsecured market for two trading partners to have a trading relationship with a mutual trading partner. Furthermore, many of these market participants only rely on a few specific counterparties.

Second, reciprocity is much higher in the unsecured market than in the repo market. Whereas the share of reciprocal lending in the repo market corresponds to the random network, in the unsecured market, it is ten times as high as in the random equivalent. Thus, for trading on an unsecured basis, market participants more often rely on reciprocal trading relationships. In the unsecured market, 20 to 30% of the transactions are based on reciprocal lending, but in the secured market, only 5 to 10% are based on reciprocal transactions. Moreover, reciprocal borrowing and lending become more important with the evolvement of the financial market crisis. After 2009, banks in the unsecured market increase reciprocal lending and borrowing from roughly 20% to 30%.

Third, banks in the unsecured market depend more heavily on just a few trading partners. The average maximum borrower preference index lies at almost 70%, i.e., banks, on average, borrow 70% of their funds from the same counterparty. In the repo market, this share lies only at around 40% before the start of the crisis, declining to approximately 30% afterwards. In both markets, the indices are much higher than in the random counterparts.

Overall, the illustrations reveal that the networks in the repo and unsecured markets significantly differ from their equivalent random networks and are thus determined by the formation of specific trading relationships. While network measures such as clustering and reciprocity in the unsecured market lie far above the measures of the random network, the respective measures in the repo market do not reach the levels in the random network. This further highlights the importance of the establishment of specific trading relationships in the unsecured market compared to the repo market.

Implications

Market participants in the unsecured market make use of so-called social collateral in order to increase trust and thus facilitate access to liquidity. In contrast to the secured market, in the unsecured money market, no physical collateral is involved to reduce counterparty risk. Thus, trust must be an important factor for the conclusion of transactions, which in turn can be ameliorated by the maintenance of trading relationships. According to the theoretical literature, the establishment of reciprocal and clustered trading relationships can increase trust and thus facilitate access to liquidity. Mobius and Szeidl (2007) and Karlan et al. (2009) propose a game-theoretic model in which a valuable friendship can secure a transaction in a manner similar to physical collateral. They find that "the level of trust equals the sum of the weakest link values over all disjoint paths connecting borrower and lender", and thus, it positively depends on the number of common friends of two agents or put differently on the clustering coefficient. In other words, the network position may serve as social collateral for tomorrow's borrowing and lending activities. The model further reveals that a change in the network structure or social collateral today may have an impact on the lending conditions of subsequent periods. Because the dissolution of a trading relationship today can lead to the breakup of additional relationships tomorrow, a small variation in today's network might have a large impact on conditions tomorrow.

The illustrations of the network characteristics above indeed underline the important role social collateral might play in the unsecured market. Market participants in the unsecured market do not trade with many different trading partners but rely on relationships with specific counterparties as well as clustered and reciprocal trading relationships. This might in turn foster trust between market participants and thus foster the exchange of liquidity in the unsecured market. Because the maintenance of such trading relationships is likely to be costly, market participants might optimize the number of links and therefore only trade with a few counterparties.

In the repo market, market participants do not need to rely as heavily on specific counterparties, as trust plays a minor role due to the inclusion of physical collateral. In contrast to the unsecured market, the diversification of repo market participants is much higher.

The resulting network structure makes the unsecured market more prone to shocks than the secured market. Related literature suggests that a network structure like the one in the unsecured market, characterized by the importance of specific trading relationships and low diversification, makes a market less resilient. Relative to the total number of market participants, banks are relatively close to each other in the unsecured market, which, according to Cohen-Cole et al. (2012), favors a fast spread of shocks. The network of the unsecured market, with its low density, high local clustering and short average path length, resembles a so-called small-world network, as introduced by Watts (1999). According to Georg (2011) and Haldane (2009), such networks are relatively prone to contagion. Also, Allen and Gale (2000) find that financial contagion is favored by chains of overlapping liabilities that allow the losses to move through the network. Consequently, the impact of a liquidity shock is the strongest in an incomplete but connected market[5] with a high

[5]See descriptions in the appendix. Both secured and unsecured markets can be classified as incomplete but connected.

degree of interconnectedness.

Consequently, there are reasons to presume that the network in the unsecured market exhibits a lower resilience to shocks than the secured market. A typical market participant in the unsecured market has a very low degree, has a high clustering coefficient and trades the majority of its liquidity with a few counterparties on a reciprocal basis. These facts indicate a risk for such banks in the sense that shocks can easily flow through overlapping liabilities (high clustering), but the risk of being hit cannot be diversified (low degree). A shock, as for example, banks starting to hoard liquidity, can spread rapidly within a cluster of banks. Because these banks are not diversified, they are unable to obtain liquidity elsewhere in the network. Clustering is not as evident in the repo market as in the unsecured market, and market participants are diversified to a higher degree. Thus, repo market participants are more likely to be able to connect with alternative trading partners in case a shock hits them. Therefore, due to their network structures, one would expect the repo market to be more resilient to shocks than the unsecured market.

Related literature finds that a tipping point can be reached such that the network structure no longer supports access to liquidity but rather favors the dispersion of shocks. Georg (2011) finds that a high degree of interconnectedness in a financial network can amplify access to liquidity in normal times but may intensify shocks and destabilize the system in times of high market stress. Haldane (2009) calls this the ”robust-yet-fragile” or ”knife-edge” property of financial networks. The network can thus serve as a shock absorber up to a certain tipping point, but afterwards, it tends to support the spread of shocks.

The combination of the important role of social collateral and the low resilience of the network structure could have rapidly exacerbated lending conditions in the unsecured market. Due to the existing network structure in the unsecured market, a shock, like evolving mistrust in other participants, could have spread rapidly through the market after the emergence of critical events at the beginning of the financial market crisis.[6] Accordingly, increasing mistrust might have led to a lower willingness of market participants to lend on an unsecured basis. This in turn likely induced a decline in the level of social collateral, which according to Karlan et al. (2009), again worsened subsequent lending conditions[7]. Therefore, the unsecured Swiss franc money market might have exhibited the robust-yet-fragile or knife-edge property, according to Haldane (2009), favoring a stable exchange of liquidity in normal times but also a sudden deterioration in lending conditions in times of stress.

Thus, aside from the fact that unsecured lending is riskier due to the absence of physical collateral, the network structure of the unsecured market tends to be less resilient. Overall, one

[6]Note that shocks do not need to be equated with the default of a market participant. As Cohen-Cole et al. (2012) show, uncertainty, risk or specific behavior can also spread through a network, even without a default.

[7]As proposed by Karlan et al. (2009), a change in today's social collateral can have a strong impact on conditions tomorrow, as a reduction in trading relationships can induce a negative impact on others' social collateral and the dissolution of further trading relationships.

can expect that shocks in the unsecured market instead have a more contagious impact than would be the case in the repo market.

3 Econometric analysis

The econometric analysis aims at assessing whether network characteristics indeed can have an impact on the conditions in the Swiss franc money market. The market turmoil during the financial market crisis provides the opportunity to evaluate the impact of the network characteristics on the activity in the market in times of market stress. Because a comprehensive dataset of transactions in the secured and unsecured money market is available, the network position of each market participant can be assessed. Therefore, it can be tested whether the individual network position had an impact on the individual market activity as well as the interest rates paid before, during and after the market turmoil took place. To test for the impact of network characteristics on conditions in the money market, an econometric analysis is conducted. In the following paragraphs, the choice of potential determinants (i.e., variables) is motivated, the models specified and the regression results stated.

3.1 Determinants of money market conditions

Network variables

The individual network measures that presumably had a major impact on lending conditions, as mentioned above, are taken into account to determine their impact on money market conditions.

The *degree centrality*, defined as the degree of a market participant divided by the total number of market participants in the network, is included in the regressions to account for the relative importance of the number of counterparties of a cash taker and a cash provider. As mentioned above, if a market participant has a higher degree centrality, it is connected to a larger share of the network, is better diversified and is thus able to conduct a money market transaction in case a shock hits the market. The degree centrality should therefore have a positive impact on money market conditions. Hence, the degree centrality is expected to have a positive impact on turnover in the money markets. Moreover, a better-diversified market participant should be able to receive a larger set of offers and to place its price quotations at more banks and therefore be able to pay or receive an advantageous interest rate. Thus, the degree centrality should have a negative impact on the interest rates paid in the money markets. As seen above, market participants in the secured market seem to be better diversified. Hence, the effect is expected to be more pronounced in the secured market.

The *clustering coefficient*, defined as the probability that two trading partners of a market participant are connected to each other as well, is included in the regression to account for the regional interconnectedness of a market participant. As argued above, clustering, or having a common 'friend', can increase trust between two market participants. As in the unsecured money market, no collateral is involved. A certain level of trust might even be essential such that a transaction takes place between two market participants. Clustering is therefore expected to have a positive effect on funding conditions. Hence, a cash provider with a high clustering coefficient is more willing to provide cash or a cash taker with a high clustering coefficient more able to take cash. The same argument holds for the interest rates. A market participant with a high clustering coefficient is able to establish social collateral with trading partners and is therefore able to receive or willing to provide better interest rates. The effect of clustering should be more pronounced in the unsecured market due to the lack of physical collateral. As shown above, clustering – that is, having a common trading partner – can serve as social collateral and foster trust between market participants. In contrast, due to the involvement of physical collateral, trust is expected to play a minor role in the secured market.

Reciprocity, defined as the number of reciprocal links divided by the total number of links established by a market participant, is included in the regression to account for the impact of reciprocal trading relationships on money market conditions. Reciprocity tends to increase trust between two market participant and, thus, to foster a trade relationship. Therefore, specifically in the unsecured market, reciprocity should have a positive impact on funding conditions. Hence, cash providers with many reciprocal trading relationships are expected to be more willing to provide cash or more able to take cash. Analogously, interest rates offered or received by a market participant with a high reciprocity level should be lower than average. Due to the missing physical collateral, the effect of reciprocity should be more pronounced in the unsecured market than in the repo market.

Strength, defined as the net flow of transactions of a market participant, i.e., the value lent net the value borrowed, is included in the regressions to account for the importance of a cash provider and cash taker in the money market during the past observation period. On the one hand, a high measure of strength indicates that a market participant has conducted a high amount of money market transactions as a cash provider. It can be assumed that a strong market participant is generally cash long and a typical cash lender. On the other hand, a low (negative) strength value indicates that a market participant has conducted a large number of money market transactions as cash taker. Strength is thus expected to have a positive effect on cash provision and a negative impact on borrowing.

Control variables

It has been widely recognized in the literature that increasing credit and liquidity risk can lead to disruptions and thus drive the funding conditions in interbank money markets. Several theoretical models suggest that increasing liquidity risk and liquidity hoarding can lead to lending disruptions (see, e.g., Caballero and Krishnamurthy (2008), Allen et al. (2009), Eisenschmidt and Tapking (2009) or Diamond and Rajan (2009)). Therefore, three variables are incorporated to control for the liquidity risk of market participants. First, the net excess reserves according to Fecht et al. (2011) are used. This variable accounts for the balances at the central bank relative to the minimum reserve requirements of a bank[8] and is a measure of the liquidity position of bank i at time t (at the beginning of the settlement day). It can further be seen as a proxy variable for the size of a market participant. Second, current transactions in the Swiss RTGS system SIC are considered as a proxy for current liquidity shocks by including the net value (incoming minus outgoing transactions, excluding money market transactions) of bank i on settlement day t. The variable indicates the size of the liquidity shocks banks have on a specific settlement day. For both liquidity variables, it holds that the higher the value, the better the liquidity position of a participant. Third, the overall value of balances at the central bank is included in the interest rate regressions as a variable for the market liquidity.[9] According to Schwarz (2010), the overall level of liquidity in the market significantly influences the prices in the market.

Moreover, several models emphasize asymmetric information and the increasing level of credit risk. In such a situation, market participants are unable to distinguish between banks with low and high credit risk, and banks start to ration cash provision (see, e.g., Freixas and Jorge (2008) or Heider et al. (2015)). A measure to control for credit risk is included in the regression analysis. Because CDS spreads are only available for a fraction of the participants in the Swiss franc money markets, bond yield spreads are used as a proxy variable for the credit risk of a bank.[10] Bond yield spreads are defined by the volume-weighted yield spread between a set of bonds denominated in Swiss franc with a time to maturity of between 2 and 5 years and the according yield for Swiss confederation bonds, which is assumed to be riskless. Related literature suggests that the bond yield and CDS spreads move together in the long run (see Eisenschmidt and Tapking (2009) and Zhu (2004)). The premium on a specific bond compared to the riskless bond can therefore be seen as a proxy for the credit risk of the according issuer. Data on bonds denominated in Swiss franc are available for approximately 65 banks, allowing their yield spreads to be computed. They account for approximately 85% of the turnover and outstanding volume in the market. Additionally, bond spreads for different groups belonging to the same geographical regions and types of bank are computed.[11] Banks without an individual bond spread are assigned to these artificial group bond

[8] Banks domiciled outside Switzerland do not need to hold minimum reserves at the SNB. Therefore, a value of zero is assumed for their lower bound.

[9] The variable is not included in the turnover regression due to the potential endogeneity problem.

[10] Special thanks goes to Adrian Bruhin and the Financial Stability division of the SNB that provided the codes in R for the calculation of the bond yield spreads.

[11] The following groups are computed: Swiss cantonal banks, Swiss insurances, small banks from Switzerland and banks from Liechtenstein, Belgium, France, Luxembourg, the Netherlands, Great Britain, Scandinavia, Austria, Germany, southern Europe, eastern Europe/Russia, Asia and North America. The majority of banks without an individual bond spread are small, domestic private and regional banks, as well as small, private and regional banks

spreads.

As Eisenschmidt and Tapking (2009) argue, the credit risk of both lender and borrower determines the risk premium. Consequently, in the interest rate regression, the credit risks of both the cash taker and cash provider are included. The collateral basket is included in the interest rate regression.

3.2 Models

To examine the impact of network characteristics on funding conditions in the Swiss franc money markets, two regression models are applied. First, variables accounting for the activity of cash takers and cash providers in the unsecured and secured Swiss franc money markets are regressed on a set of variables considering the individual network measures as well as individual liquidity risk and credit risk ('turnover regression'). Second, variables accounting for interest rate premia in the money markets are regressed on the same set of variable rates ('interest rate regression'). To account for the unobservable individual specific characteristics of the banks, panel and least-square dummy variable (LSDV) regression models are applied.

Turnover regression

In the turnover regression, the determinants of the difference between the individual turnover in the unsecured and secured markets are evaluated, and thereby, the relative importance of the secured and unsecured markets is assessed. The following fixed effects model is estimated:

$$y_{it} = X'_{it}\beta + \alpha_i + \varepsilon_{it} \tag{1}$$

with

$$X'_{it}\beta = \sum_{n=1}^{N} \beta_n NW^n_{it-1} + \sum_{l=1}^{L} \gamma_l LR^l_{it} + \sum_{c=1}^{C} \delta_c CR^c_{it} \tag{2}$$

where NW^n_{it-1} denotes the network measure n at date $t-1$, LR^l_{it} are the liquidity risk variables l and CR^c_{it} is the credit risk component c of market participant i at day t.

In the baseline regression, the dependent variable y_{it} is defined as the spread between the log value (in million (m) CHF) of the turnover in the unsecured market TU_{it} and the log value (in CHF m) of the turnover in the secured market TS_{it} of cash provider i on day t:

$$y_{it} = log(max\{1, TU_{it}\}) - log(max\{1, TS_{it}\}) \tag{3}$$

Regressing the ratio of unsecured and secured turnover on the potential drivers will provide information on the question of whether market participants traded in the unsecured or secured market

from neighboring countries such as Austria, Germany and Liechtenstein. The bond spreads of these groups are also computed based on bonds of rather small private or regional banks. Therefore, it can be argued that the risk profile of these banks should approximately correspond to the credit risk based on the group bond spreads.

due to their network position. The turnovers of market participants as lenders and borrowers are both assessed, and therefore, TU (TS) can be denoted as either the amount of liquidity lending or borrowing of market participant i at time t in the unsecured (secured market). Hence, the relative importance of lending as well as borrowing in the unsecured and secured markets is analyzed. Note that the very few transactions with a value between zero and CHF 1 m are replaced by a value of zero.[12]

As a robustness check, further assessment will be made of whether the potential drivers had an impact on the turnover in the two sub-markets. Therefore, the individual turnover of market participants – as lender and borrower – in the two sub-markets are regressed on the same set of variables:

$$y_{it} = log(max\{1, TU_{it}\}) \tag{4}$$

$$y_{it} = log(max\{1, TS_{it}\}) \tag{5}$$

Interest rate regression

Secondly, the determinants of the interest rate premia in the unsecured money market are evaluated by means of an LSDV regression:[13]

$$\hat{r_{i,t}} = \sum_{n=1}^{N} \beta_n NW^n_{CTUnsec,i,t-1} + \sum_{n=1}^{N} \gamma_n NW^n_{CPUnsec,i,t-1} + \sum_{n=1}^{N} \eta_n NW^n_{CTSec,i,t-1} + \sum_{n=1}^{N} \theta_n NW^n_{CPSec,i,t-1} + \sum_{l=1}^{L} \delta_l LR^l_{CT,i,t} + \sum_{l=1}^{L} \kappa_l LR^l_{CP,i,t} + \sum_{c=1}^{C} \zeta_c CR^c_{CT,i,t} + \sum_{c=1}^{C} \lambda_c CR^c_{CP,i,t} + \sum_{d=2}^{D} \mu_d CT_{i,t} + \sum_{s=2}^{S} \nu_s CP_{i,t} + \alpha_i + \varepsilon_i \tag{6}$$

where $\hat{r_{i,t}}$ denotes the difference between the interest rate of the unsecured transaction iu_i and the Swiss Average Rate for secured contracts S_t in basis points (BP)[14]:

$$\hat{r_{i,t}} = iu_i - S_t \tag{7}$$

The regressions are run separately for transactions with maturities of one day (ON), one week (1W), one month (1M) and three months (3M). $NW^n_{CT(CP)Unsec(Sec),i,t-1}$ denotes the network characteristic n of the cash taker (or provider) of transaction i in the unsecured (secured) market at $t-1$. $LR^l_{CT(CP),i,t}$ stands for the liquidity risk measure l of the cash taker (provider) and $CR^c_{CT(CP),i,t}$ stands for the credit risk component c of the cash taker (provider) of transaction i on day t. Additionally, the indicator variables $CT(CP)_{i,t}$ - equal to one if cash taker (provider) $d(s)$ was involved in transaction i - are included.

[12] Specifically, 0.1% of the transactions worth 0.001% of the total turnover in the unsecured market and none in the secured market.

[13] Standard panel models cannot be applied due to the highly unbalanced dataset. In contrast to turnover regression, missing values cannot be replaced by zeros. Due to the low number of observations for longer maturities, only overnight transactions are considered.

[14] Swiss Average Rates are based on the transactions and quotes concluded or posted on the Eurex Repo trading platform

3.3 Data issues

As outlined in Section 2, the levels of interest rate premia and turnover change significantly during the observation period of the years 2005 to 2012. To account for different time periods and levels in turnover and interest rates, the sample is split into four sub-periods. The first period starts in 2005 and lasts until 8 August 2007, when market turmoil first occurred and unsecured interest rates started to hike[15]. The subsequent period lasts from 9 August 2007 until 14 September 2008, the day before the investment bank Lehman Brothers collapsed. The third period then ranges from 15 September 2008 until 22 April 2010, when the European sovereign debt crisis started to emerge[16]. The subsequent and final period lasts from 23 April 2010 until 2 August 2011. Afterwards, SNB began a major increase in liquidity provision, and activity in both markets nearly came to a halt.

Transactions concluded on the last working day of a minimum reserve requirement period and on the last working day of a month are excluded due to the high volatility in interest rates on such days, as proposed by Kraenzlin (2009) and Mancini et al. (2016). Table 1 in the appendix provides summary statistics for the dependent variables for different time periods.

In the panel regressions, only banks participating in both markets are included. Overall, there are 113 banks participating in both markets between January 2005 and December 2012. However, a number of banks do not participate, either on a daily basis or during the whole sample period, which leads to attrition and, consequently, to a potential bias of the estimates in panel regression models (see, e.g., Baltagi (2005)). Nevertheless, it can be argued that attrition should not lead to a self-selection problem and should not bias the results. In the specifications stated above, the goal is actually to evaluate the difference in total turnover in the unsecured and repo markets, which by definition is only determined by actual transactions. Moreover, missing values can be replaced by zeros, which leads to a perfectly balanced panel data set.

To measure the market activity, the turnover or the outstanding volume in the according market could be measured. As mentioned above, the goal of the regressions is to determine the drivers for funding conditions on a specific day by accounting for individual network positions as well as liquidity and credit risk characteristics. Therefore, turnover is favored over the outstanding volume of market participant i at time t, as its turnover reveals the ability to conclude a new transaction on a specific day. When using the outstanding volume, concluded transactions in the past are considered as well. Depending on the maturities of trades a market participant had completed, the conclusion of trades a long time ago can influence the outstanding volume. Hence, there can be situations where the model would try to explain activity in the money markets a long time ago

[15] On August 8 2007, BNP Paribas had to suspend three funds exposed to the US subprime mortgage market. This event is seen by many economists as the outbreak of the financial market crisis (see, e.g., Acharya et al. (2009))

[16] During April 2010, Greek government bond yields increased heavily, which revealed the unsustainability of Greek fiscal policy. In May 2010, European countries had to agree on the provision of bilateral loans in total of EUR 80 billion (Minka and de Haan, 2013).

based on the current network position of a market participant. Moreover, an endogeneity problem might arise, as simultaneity in the outstanding volume and past network measures might occur through past transactions.

As independent variables, the lagged individual network measures are used, which are based on the network positions between $t-26$ and $t-1$. The dependent variable is based on the current market situation, i.e., the turnover at time t. By regressing current turnover values on past network measures, simultaneity in the dependent and independent variables, and therefore, endogeneity can be ruled out, as proposed in Cocco et al. (2009).

The daily network measures are partially correlated. Specifically, the strength and the degree centrality show a relatively high correlation exceeding 0.5. To avoid multicollinearity, the degree centrality (DC) in the secured (unsecured) market is orthogonalized with respect to the strength (ST) in the secured (unsecured) market:

$$DC_{i,t} = \beta_1 + \beta_1 ST_{i,t} + \nu_{i,t} \tag{8}$$

Thus, the variation in the degree centrality, which is not driven by the strength ($\nu_{i,t}$), is used as an independent variable in the regression model. Due to the orthogonalization of the two variables, the correlation between the degree centrality and the reciprocity can be reduced as well.

Several panel regression tests are computed. Tests for spatial (cross-sectional) and serial correlation are conducted. Höchle (2007) introduces a panel data model with standard errors according to Discroll and Kraay (1989) that are robust to serial and spatial correlation, specifically for panels with a large number of T. If the tests cannot be rejected, these robust standard errors are used. Moreover, a Hausman test is computed to check for random effects. These, however, can always be rejected. Finally, in the LSDV regression, heteroskedasticity-robust standard errors are applied.

3.4 Results: turnover regression

The turnover regressions show the impact of a market participant's network position on its market activity in the unsecured and secured markets, while controlling for its liquidity and credit risk. The regression results can be found in the appendix (see table 3 to 5). In the baseline regression, a positive sign indicates a positive effect on unsecured lending and a negative effect on secured lending, and vice versa. Coefficients in the robustness check regressions with the dependent variables specified in equations 4 and 5 can be interpreted one-to-one, i.e., a positive sign indicates a positive impact on the turnover in the market in question.

The majority of the coefficients are consistent for different specifications, i.e., the sign of the coefficients on the robustness check regression are in line with those in the baseline regressions. The regressions show a goodness of fit between 0.12 and 0.60. The robustness check regressions as well as the regressions with the cash provision as a dependent variable generally show a higher goodness of fit. The majority of the coefficients are statistically significant at least at the 5% level. Hausman tests all indicate fixed effects. Therefore, the results of the fixed effects regressions are reported. Serial and cross-sectional correlation cannot be rejected in all cases. For this reason, robust standard errors according to Höchle (2007) are used in such cases.

The hypothesis regarding the degree centrality stated above can be confirmed: the degree centrality – measured by the network position during the previous 25 business days – has a statistically and economically significant positive impact on borrowing and lending in the unsecured and secured Swiss franc money markets. The baseline regression reveals that the degree centrality in the secured market positively affects turnover in the secured market. Turnover in the unsecured market is affected to a much lower extent. For instance, lending in the unsecured market is only positively influenced by the degree centrality in the unsecured market in the first and last periods. It is likely that diversification in the unsecured market was not high enough to ensure stable market activity. Robustness check regression reveals that the coefficients for the degree centrality are significantly positive in almost all cases. Note that diversification seems to be a more important factor to borrowers than to lenders. Also, the impact on the activity in the secured market is more pronounced.

The hypothesis regarding the clustering of market participants can only partly be confirmed. The baseline regression reveals that the lender's willingness to provide cash is increasing in the clustering coefficients of the corresponding market. The impact tends to decrease over time, especially in the unsecured market. The effect in the secured market is economically stronger and remains significant until the last period. Robustness checks confirm the results from the baseline regression but also reveal that clustering entails a (economically lower) negative impact on borrowing, especially in the repo market. Only in the third period does clustering in the repo market show a slightly positive impact on cash taking in the unsecured market. Thus, the establishment of clustered trading relationships apparently leads to a higher probability of cash lending, whereas it reduces the probability for cash borrowing. These results lead to the conjecture that typical lenders, i.e., cash long market participants, often maintain clustered trading relationships, which might help them increase trust in the counterparties. For typical borrowers, i.e., cash short market participants, trust is less important, as they typically do not rely on clustered trading relationships.

Reciprocity hardly exhibits any effect in the baseline regression. The hypothesis, however, cannot be rejected, because in the robustness check regressions, the coefficients reveal a statistically significant, although economically weak, impact. In the unsecured market, a statistically significant effect on both cash provision and cash taking in the third period can be observed. Additionally, reciprocity in the unsecured market exhibits a positive impact on secured borrowing in the third period. Hence, at the height of the crisis, market participants in the unsecured market seem to increasingly have maintained reciprocal trading relationships to conclude money market transactions. Therefore, in addition to maintaining clustered trading relationships, reciprocity might have supported the access to liquidity by fostering trading relationships.

The strength of a market participant, especially in the unsecured market, significantly influenced the borrowing in the secured and unsecured market. Secured borrowing is increasing in the strength of the market participants in the unsecured market. That is, net cash lenders in the unsecured market also borrow funds in the secured market. The coefficients are statistically and economically significant in the first two periods. The effect diminishes afterwards. Furthermore, the borrowing in the secured market is increasingly influenced by the strength of the repo market in the third and fourth periods. Hence, market participants seem to have borrowed cash on a secured basis and lent it on an unsecured basis in the first two periods, which is potentially associated with earning a spread. With the evolvement of the crisis, these trade patterns changed, and market participants instead traded as cash takers and providers only within the repo market. Thus, there is evidence that market making across the two sub-markets was reduced by strong market participants.

The effects of the control variables are in line with expectations. On the one hand, banks experiencing positive cash shocks preferably provide cash on a secured basis. On the other hand, banks with a negative liquidity shock are more able to obtain liquidity in the secured market. The credit risk has an ambiguous effect on turnover in the two markets. Market participants with a higher credit risk are more likely to lend and borrow cash in the unsecured market at the beginning of the sample period. After the first period, however, market activity in the unsecured market is significantly decreasing in the credit risk. Furthermore, in the second period, the market activity in the secured market is significantly increasing in the credit risk. The switch can be ascribed to the fact that market participants with a high credit risk were able to borrow on a secured basis, and cash providers became more risk averse due to precautionary reasons and lent cash in the secured market.

3.5 Results: interest rate regressions

The interest rate regression shows the impact of a market participant's network position on the interest rate premia paid in the unsecured money market, while controlling for its liquidity and credit risk. A positive sign indicates a positive effect on the premia or an increasing unsecured rate. Put differently, a positive sign indicates that a cash taker is worse off and a cash provider better off than average.

Most coefficients, including those for bank-specific dummy variables, are statistically significant at least at the 5% level. The goodness-of-fit varies between 0.14 and 0.48 and is the highest in the third period, when the interest rate premia increased heavily. The regression results can be found in the appendix (see table 6 to 9).

As in the turnover regression, the economic impact of the degree centrality is the highest among all regressors. The degree-centrality seems to be the most important driver of price differentiations, as the economic and statistical significance is the highest among all independent variables. The hypothesis regarding the degree centrality can partly be confirmed. Interest rate premia generally decrease with the degree-centrality of cash takers and cash providers. Only during the second period, for a maturity of one day and one week, do interest rate spreads increase in the degree centrality of cash takers. Moreover, during the second and third periods (especially in the overnight and one week segment), cash providers with a high degree centrality were able to take advantage of higher interest rates. Therefore, with a few exceptions during the financial market crisis, diversification seems to have reduced the risk premia in the unsecured market.

The hypothesis regarding the clustering of market participants cannot be rejected either. The interest rate premia in the unsecured market is decreasing in the clustering coefficients of market participants. However, compared to the degree centrality, the economic effect is less pronounced. Generally speaking, interest rate premia are decreasing in the clustering coefficient of cash takers. Nonetheless, there is evidence that cash providers that established clustered trading relationships granted rebates in the overnight market during the second and third periods. Thus, cash providers with a high clustering coefficient in the unsecured market not only provided more liquidity but also offered better interest rates to their counterparties.

The hypothesis regarding the impact of reciprocity only holds during the second and third periods. The results reveal that interest rates are increasing in the reciprocity of market participants. This might be for two reasons. First, cash takers with high reciprocity rely heavily on a specific counterparty, which might increase the bargaining power of the cash provider. Moreover, if the counterparty is unable to provide funds, it might be more difficult to find an alternative counterparty to conclude a transaction. Note, however, that in the second period, reciprocity entails a significant negative impact on the interest rate premia in the overnight unsecured market. Hence, reciprocal relationships can lead to a reduction in interest rate premia in times when market participants increasingly rely on trust to conclude a transaction.

The strength of a market participant has an ambiguous effect on interest rate premia. Interest rates are increasing in the strength of the cash provider. This is likely due to the fact that strong cash providers (i.e., net lenders) have a higher bargaining power and can thus demand higher interest rates. On the other hand, interest rates are also increasing in the strength of cash takers, especially after the first period and in short-term contracts. Strong cash takers previously had provided a relatively large amount of liquidity, making them sensitive to unexpected liquidity shocks. In the case of such shocks, they would have to fund themselves again in the interbank market, which is likely to be done on a short-term basis. Because they might be in an immediate cash need, their interest rates are likely to increase. The regression results indicate that such unexpected shocks with a price impact likely occurred with the evolvement of the financial market crisis.

The impact of liquidity risk is ambiguous and in most cases has low economic explanatory power. Credit risk, on the other hand, shows a statistically and especially economically significant positive impact on interest rate premia in the second and third periods. While in the first period, even a slight negative effect is observed, during the financial market crisis, premia are increasing in the credit risk of both cash takers and cash providers. Moreover, the positive impact increases with the maturity of the contract. This finding is in line with the reasoning of Eisenschmidt and Tapking (2009), who argue that the credit risk of cash providers negatively affects unsecured lending due to high uncertainty regarding refunding conditions.

4 Conclusion

The network topology of the secured and unsecured Swiss franc money markets significantly differs from so-called random graphs and is thus determined by the formation of specific trading relationships. The network topology reveals that market participants in the unsecured market are less diversified but locally more interconnected than in the secured market, i.e., banks trade with only a small fraction of potential counterparties and rely heavily on a few reciprocal and clustered trading relationships. There is indication that market participants in the unsecured market establish social collateral in order to increase trust and facilitate the exchange of liquidity.

The regression results indicate that the interconnectedness or network position of market participants indeed influences their ability to obtain and willingness to provide liquidity in the interbank market. Furthermore, interest rates are affected by the individual network positions. It can be shown that the turnover in the interbank markets is increasing in the degree centrality, especially in the repo market, where diversification by market participants is much higher. The degree centrality accordingly reduces interest rate premia. Clustering fosters the trading relationship of two banks and can thus support – to an economically lesser extent than the degree centrality – the exchange of liquidity and the reduction of interest rate premia. Although clustering in the secured market is lower than in the unsecured market, the impact on turnover is more pronounced in the former, especially after the first period. This might, however, also be due to a reduction in the number of clustered trading relationships in the unsecured market during the crisis. Instead, market participants in the unsecured market seemed to have increasingly maintained reciprocal trading relationships to conclude money market transactions at reduced risk premia. This, in turn, might have reduced the social collateral between market participants and increased the dependency on specific counterparties. In contrast, in the repo market, the impact of the network position remained quite stable and seemed to have continued supporting the exchange of liquidity. Finally, regression results indicate that strong market participants reduced cross-market market making, which might have reduced turnover in the unsecured market.

Another important finding of the regressions is that the network positions in both sub-markets influenced the conditions. This result can certainly be ascribed to the fact that the markets are closely related. It nonetheless gives rise to the interpretation that even the interconnectedness of market participants in other market segments can affect market functioning.

In addition to network characteristics, credit risk affected money market conditions. After the outbreak of the financial crisis, turnover in the unsecured market was decreasing and interest rate premia increasing in the credit risk of market participants. The increasing credit risk likely contributed to the shift of turnover towards the secured market and the increased risk premia for unsecured lending at the height of the crisis.

Network theory has proven to be a useful tool for analyzing the effects of interconnectedness in financial markets. This network analysis reveals that interconnectedness in unsecured money markets can be accentuated by heavy local clustering and reciprocity, which supports access to liquidity through social collateral. By their nature, markets such as the unsecured money market have to rely on trust or on social collateral. In normal times, such behavior is certainly favorable, both for an individual bank and for the system as a whole, as it supports access to liquidity. In times of high market stress, it turns out that the resulting network structure can make the market prone to shocks, which may lead to reduced market activity and increased interest rate premia.

Although the perception of credit risk has decreased during the last couple of years, activity in the unsecured market has not yet picked up. This is certainly also due to the vast liquidity available in the market, which makes a redistribution of liquidity less necessary. Moreover, with the new regulatory initiatives, it is doubtful whether the market activity in the unsecured Swiss franc money market will start to increase again in times of lower overall liquidity in the system. Finally, it might also be questionable whether a network structure that allows for a stable a level of market activity in the unsecured Swiss franc money market can be reached again. In this respect, a nearly nonexistent unsecured money market might be a probable scenario in the future. What this might mean for the well-functioning of the financial system will be left open for further research.

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A Network concepts

For a long time, network theory was primarily used in fields such as applied mathematics, physics and biology. Economic and financial literature has only recently started to apply network theory. The following paragraph provides a short introduction to network concepts.

In the mathematical literature, networks are represented as graphs. A graph can be described by two types of elements: the *nodes* (sometimes called *vertices*) and the connections between them, the *links* (sometimes called *edges*). The links between the nodes can either be directed or undirected. In contrast to an undirected link, a directed link reveals the direction of a link (see Figure 1). A network where all nodes share a link with each other is called a *complete* network (see Newman (2003) and Soramäki et al. (2007)).

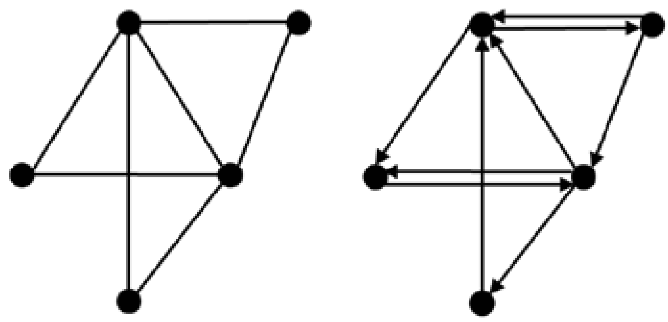

Figure 1: Undirected (left) and directed graph (right)

A network can be mapped into a so-called *adjacent matrix* $G(g) = \{g_{ji}\}$, which is a square matrix that keeps track of the direct connections in the graph. If a node i has a direct connection to node j, then g_{ji} =1 and $g_{ji} = 0$ otherwise. Two nodes with a direct link are called neighbors. Nodes can also be connected by a path through indirect links. The path length then defines the number of links one has to take in order to reach node j from node i. Therefore, the path length is equal to one for neighbors and larger than one otherwise. In a *connected* network, every node can be reached by a path. Otherwise, the network is called *disconnected.* A disconnected graph can be divided into two or more components. In a *component*, every node can be reached again by a path. The largest sub-network or component in a graph is called the *giant-component* (Gabrieli, 2011).

There are three main types of networks mentioned in the literature. Erdös and Rény (1959) introduce the classical random graph model, where in a network with n nodes, each pair of nodes is connected with probability p. It can be shown that the resulting network has a Poisson degree[17] distribution. Hence, the random graph is sometimes called the "Poisson random graph". Furthermore, the so-called small-world networks introduced by Watts (1999) are characterized by

[17] The degree of a node is defined by the number of its neighbors.

a low density, a high clustering and a small average path length, which makes them a priori more vulnerable to contagion than random networks. Finally, Barbasi and Albert (1999) describe the so-called scale-free network, which exhibits a degree distribution following a power-law distribution. Thus, there are a few very heavily connected nodes. New nodes entering the network in this model preferentially connect to these nodes that are already well connected.

There are measures taking into account the characteristics of the network as a whole and measures displaying the individual position of each bank in a network. Below, the most important measures used in the analysis are described[18]. Most of these measures can be computed for directed and undirected networks. For the empirical analysis above, network measures of the directed networks are used, except for path-based measures, in which the direction of the connections does not matter. Furthermore, if the undirected network is disconnected, path-based statistics are calculated based on the undirected giant component.[19]

Individual network measures:

- In-degree, out-degree and degree: defined by the sum of cash providers of a market participant, the sum of cash takers of a market participant and the sum of cash takers plus cash providers of a market participant, respectively.
- Degree-centrality: defined as the degree of a market participant divided by the total number of market participants in the network.
- Strength: defined as the net flow of transactions of a market participant, i.e., the value lent minus the value borrowed.
- Average shortest path: defined as the average number of links to reach any other bank in the network on the shortest path.
- Clustering coefficient: measures the probability that two market participants with a common neighbor share a link as well. Technically, it is defined as the number of transitive triads divided by the number of total triads to which a market participant is connected (see Figure 2).

[18] Whenever possible, terminology related to interbank money markets is used. See also Gabrieli (2011), Newman (2003) or Soramäki et al. (2007) for a detailed description of the measures.

[19] The undirected networks in the two markets are connected most of the time. After mid-2009, there is an increasing number of disconnected graphs, especially in the unsecured market (see section 2.3). The measures thus have to be computed based on the giant component. Nonetheless, most banks can be caught in the analysis, as, on average, 94.6% (98.3%) of the participants can still be assigned to the giant component in the unsecured (repo) market after mid-2009.

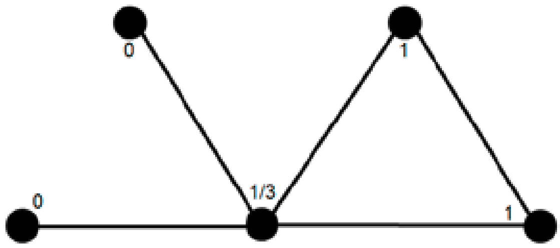

Figure 2: A triad (left) connected to a transitive triad (right), and the clustering coefficients of the nodes (in brackets).

- Closeness: defined as the inverse of the average shortest path, i.e., it is a measure of the proximity of a market participant to every other market participant.
- Maximum borrower/lender preference index: defined as the maximum share of turnover of a market participant with a specific lender and borrower, respectively, as proposed by Cocco et al. (2009).

Overall network measures:

- Average degree: defined as the mean of the degree across all market participants.
- Density: defined as the total number of established links divided by the number of possible links in the network.
- Average path length: defined as the mean of the average shortest path.
- Diameter: defined as the number of links between the two most remote banks in the network.
- Number of disconnected banks: defined as the number of banks not connected to the giant component.
- Average clustering coefficient: defined as the average local clustering.
- Reciprocity: defined as the number of reciprocal links divided by the total number of established links in the network.
- Average maximum borrower/lender preference index: defined as the mean of the maximum borrower/lender preference index.

B Correspondent banking in the unsecured money market

A number of market participants do not have direct access to SIC and have to rely on large Swiss banks such as UBS, Credit Suisse and Zürcher Kantonalbank ("large banks") for the settlement of unsecured money market transactions. The resulting transactions are captured in the dataset as payments between the large banks. The data reveal that large banks are responsible for a disproportionate share of the turnover in the SIC system and presumably settled a high number of correspondent banking payments. This could potentially exert a bias on the network analysis. However, the misspecification of network measures is expected to be small and its negative influence on the analysis to be limited, as demonstrated below.

There are three types of transactions in the payment system identified as unsecured money market trades:

1. Transactions between two large banks, consisting of a) trades between the two actual counterparties (as registered in the payment system), b) trades between a large bank and a correspondent bank of another large bank (not observable in the payment system) or c) trades between two correspondent banks of the large banks (not observable in the payment system).

2. Transactions between a large bank and non-large banks ("others"), consisting of a) trades between the actual counterparties (as registered in the payment system) and b) trades between others and a correspondent bank of a large bank (not observable in the payment system).

3. Transactions between others without any participation of the large banks (as registered in the payment system).

A bias in network measures can be due to transactions of type 1b), potentially leading to an underestimation of the network measures of the large banks (e.g., in- and out-degree) and 1c) possibly leading to an overestimation of network measures of the large banks. Furthermore, a bias could evolve through trades of type 2b), which would conceivably lead to an underestimation of network measures of others and an overestimation of measures for large banks.

However, the bias due to transaction type 2b) is limited. The market share of such transactions is similar in both markets (39% in unsecured and 33% in secured markets). Because correspondent banking is not feasible in the repo market, the bias due to transactions of type 2b) cannot be large. Moreover, the over- and underestimation due to transactions of type 1b) and 1c) can be netted. For example, the in-degree is underestimated due to 1b) transactions but is overestimated again by 1c) transactions. Assuming an equal share of 1b) and 1c) transactions, therefore, completely eliminates the over- and underestimation due to transactions of type 1). Therefore, a misspecification of network measures due to correspondent banking is expected to be small and its negative influence on the analysis to be limited.

C Figures and tables

C.1 Developments and network topology in Swiss franc money markets

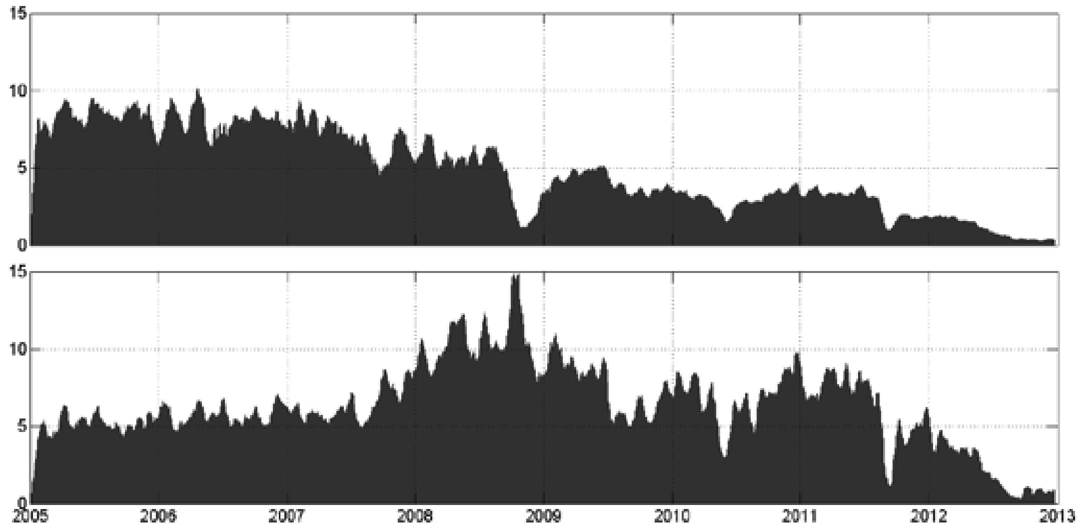

Figure 3: Turnover in the unsecured (top) and secured (bottom) money markets in bn. CHF, day-to-day up to 3 months maturity, 15-day moving average.

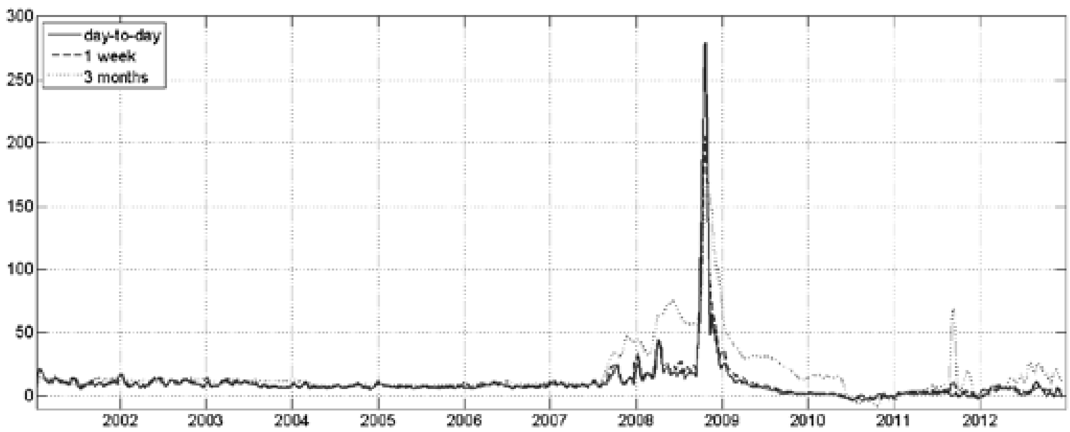

Figure 4: Unsecured money market risk premia, defined by the spread in interest rates between unsecured and secured lending (Libor rates - Swiss average rates) in base points (BP) for day-to-day, 1 Week and 3 months maturity, 15-day moving average.

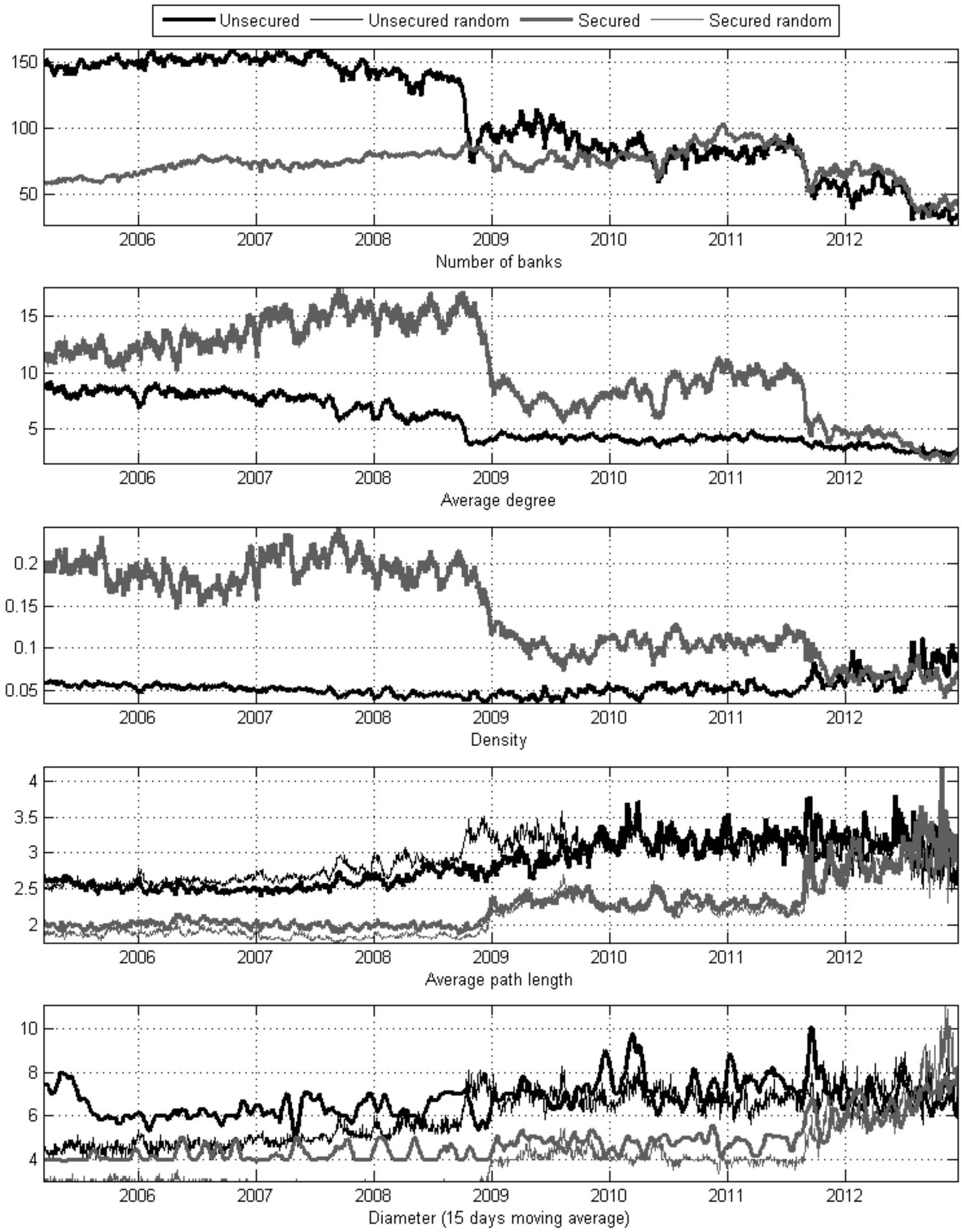

Figure 5: Network characteristics of Swiss franc money markets, Jan. 2005 to Dec. 2012

The illustrations show the development of selected network characteristics of the unsecured and secured Swiss franc money markets as well as their random counterparts. The network measures are computed on a daily basis. Random networks are computed based on the number of nodes and the density of the actual networks. For each day and market, the network statistics of the random networks are determined by the mean of 100 random networks.

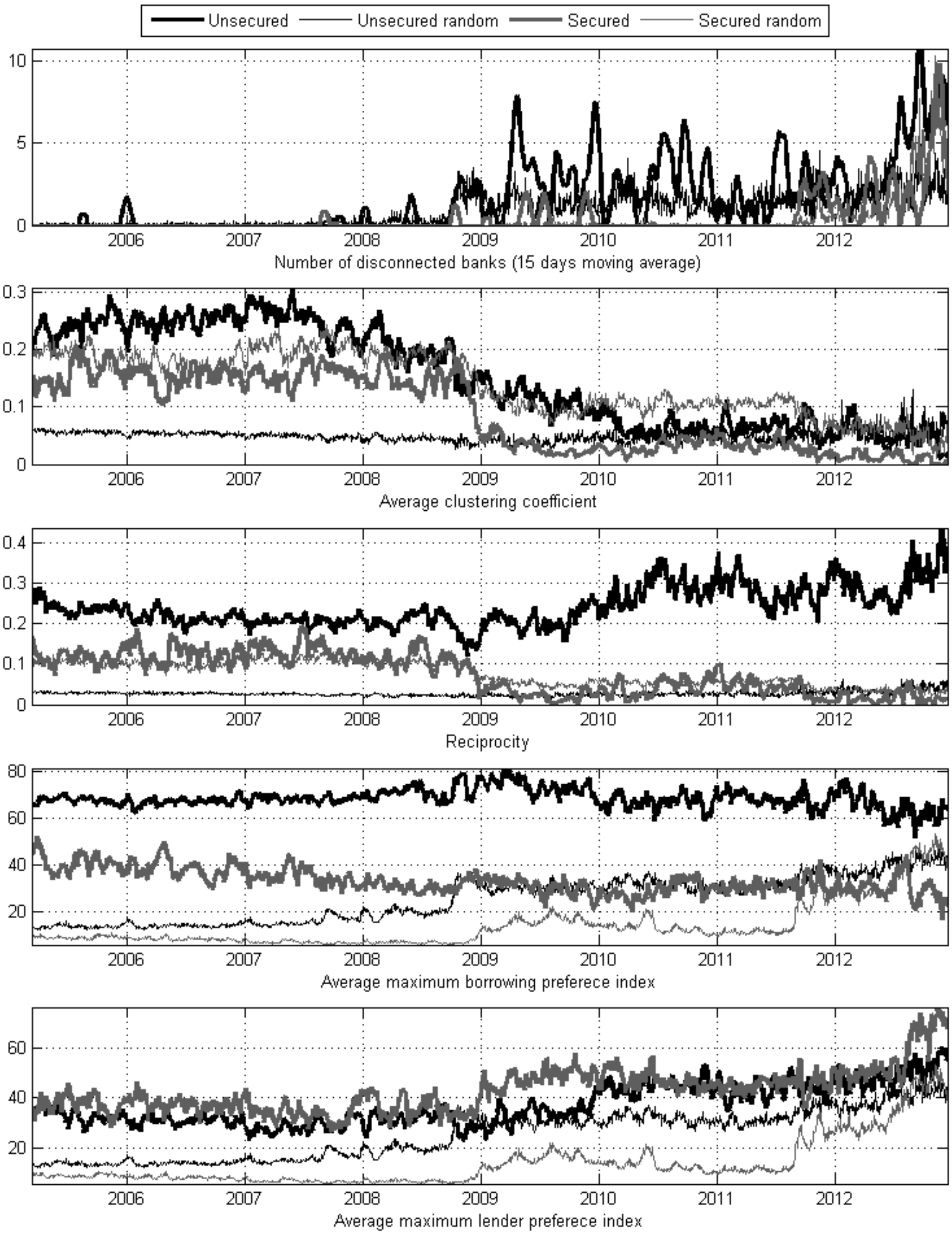

Figure 6: Network characteristics of Swiss franc money markets, Jan. 2005 to Dec. 2012

The illustrations show the development of selected network characteristics of the unsecured and secured Swiss franc money markets as well as their random counterparts. The network measures are computed on a daily basis. Random networks are computed based on the number of nodes and the density of the actual networks. For each day and market, the network statistics of the random networks are determined by the mean of one hundred random networks.

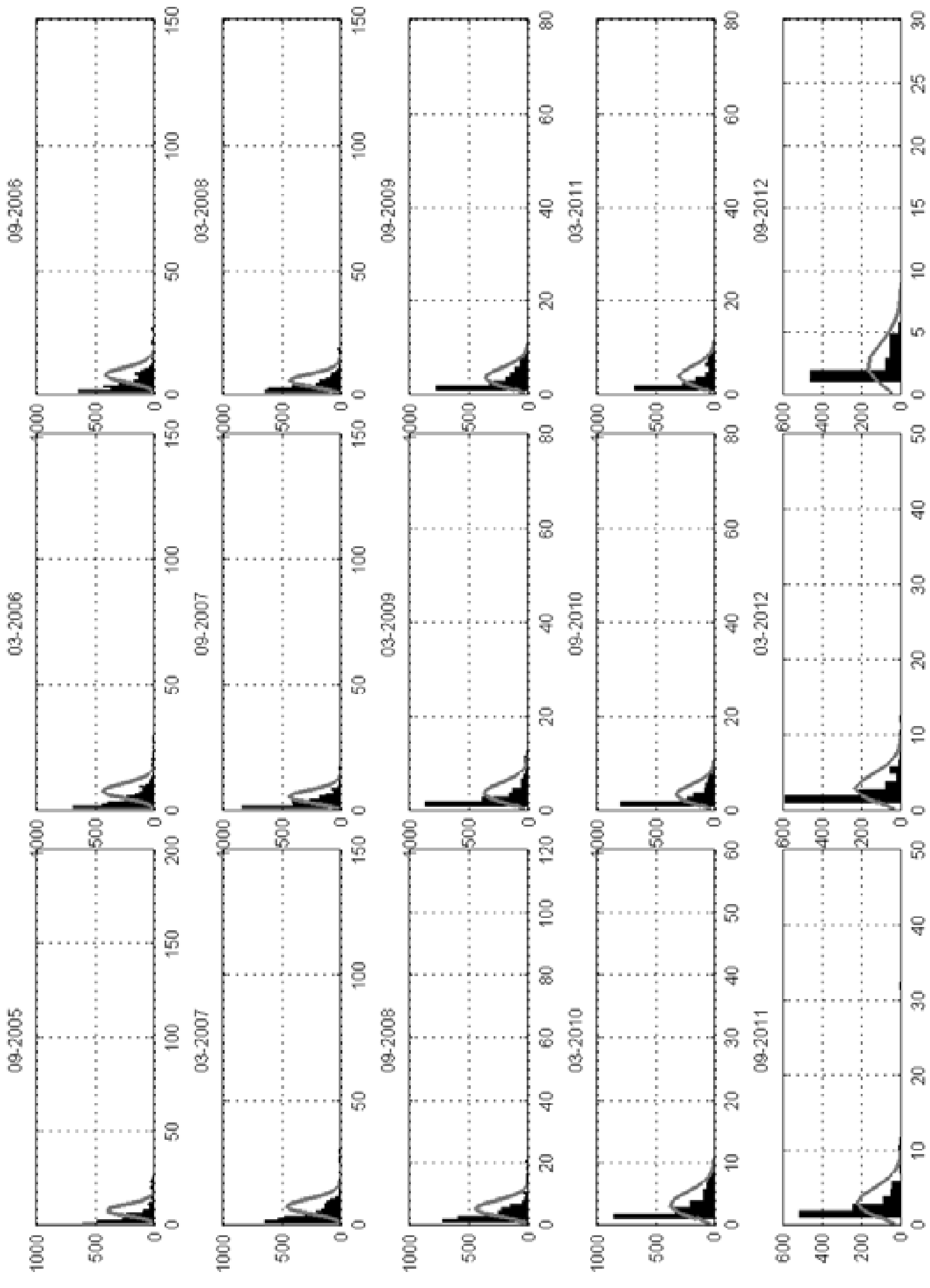

Figure 7: Degree distribution unsecured market

The illustrations show histograms of the degrees of unsecured market participants for selected months. The degree distribution of a random graph follows a Poisson distribution. To compare the empirical distribution, a Poisson density function is fitted based on the empirical value of λ. Note that the range of the x-axis is determined by the maximum degree observed in the data.

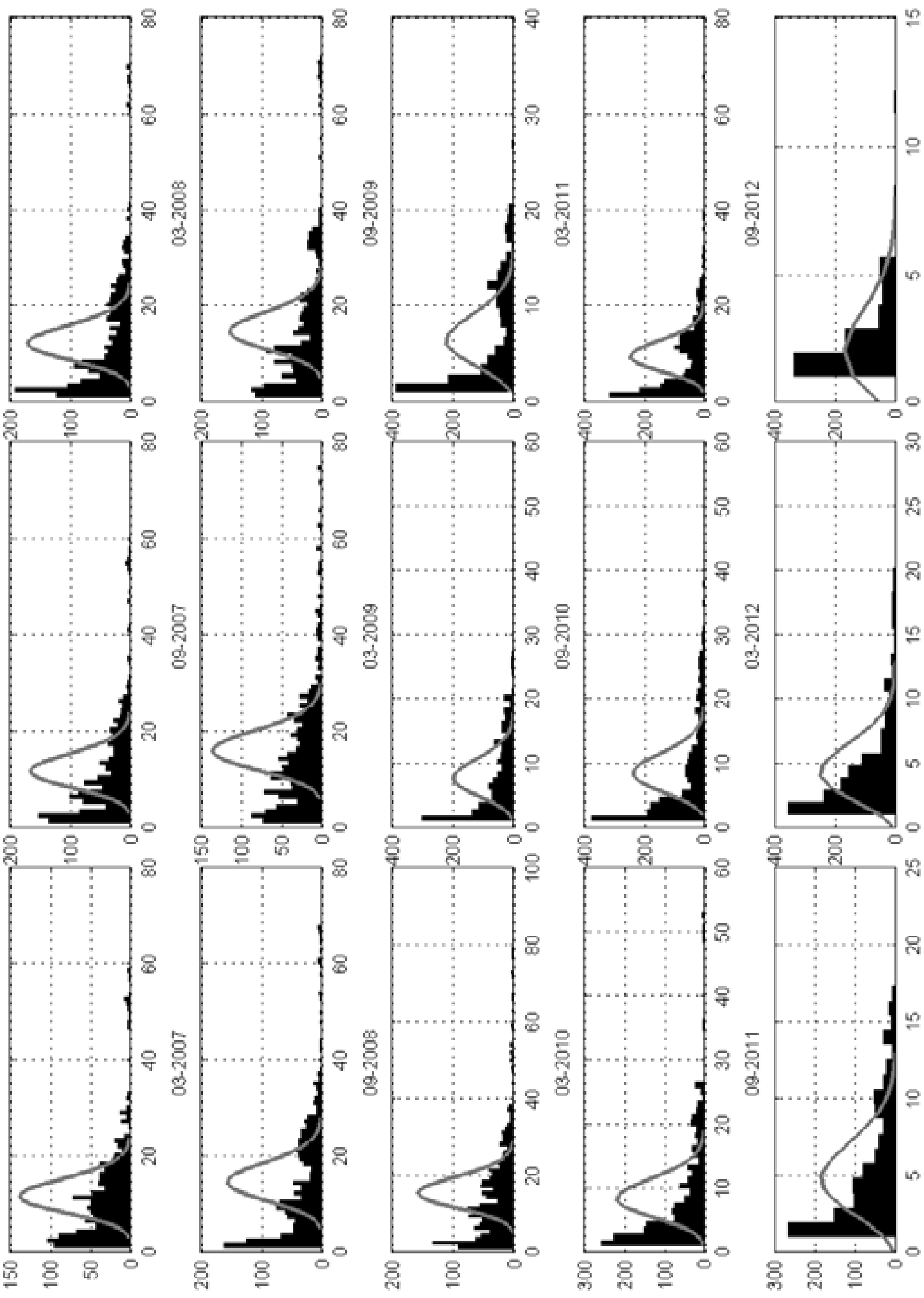

Figure 8: Degree distribution secured market

The illustrations show histograms of the degrees of secured market participants for selected months. The degree distribution of a random graph follows a Poisson distribution. To compare the empirical distribution, a Poisson density function is fitted based on the empirical value of λ. Note that the range of the x-axis is determined by the maximum degree observed in the data.

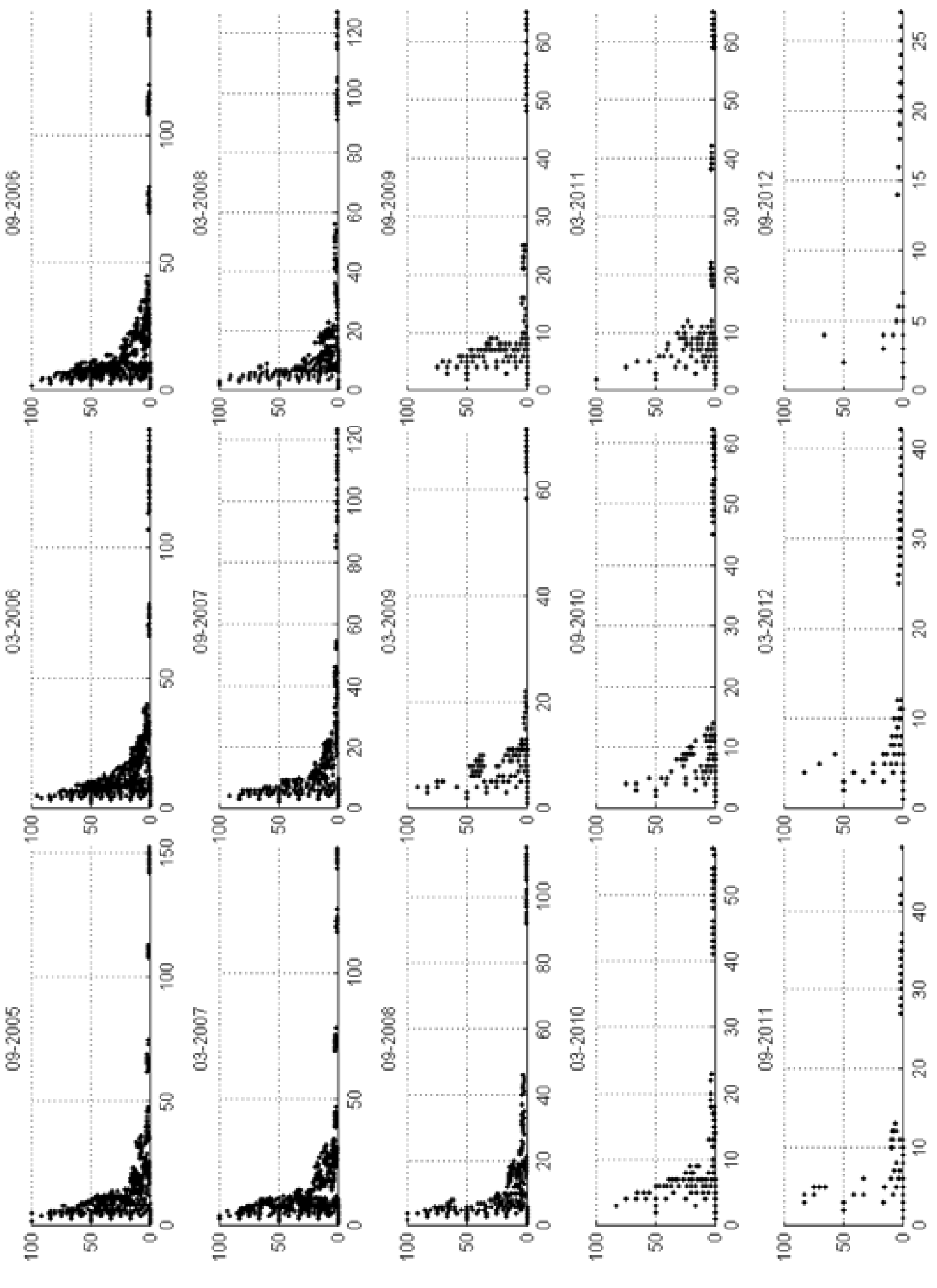

Figure 9: Degree vs. clustering coefficient, unsecured market

The illustrations show scatter plots of the degree (x-axis) and corresponding clustering coefficient (y-axis) of market participants in the unsecured market for selected months.

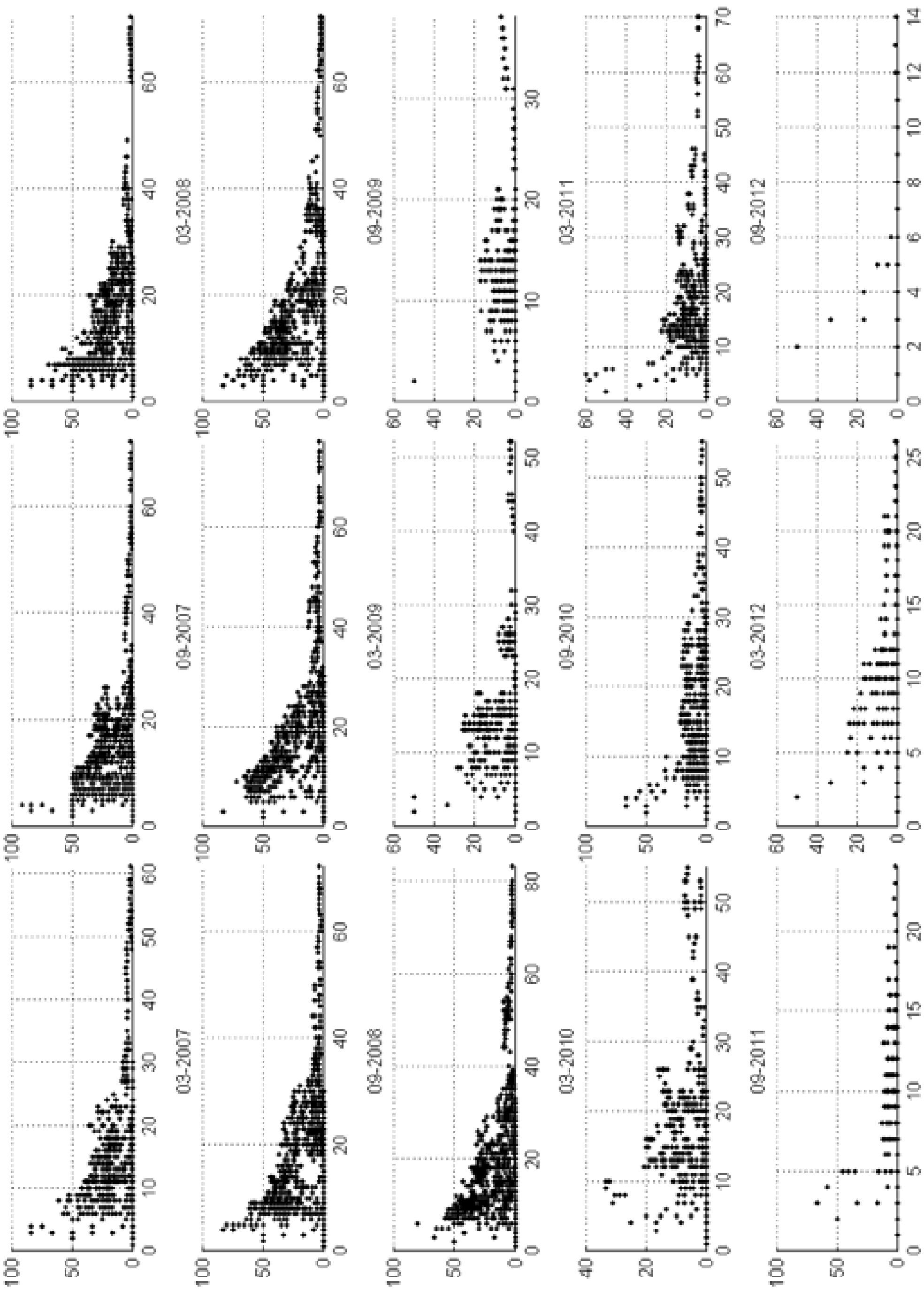

Figure 10: Degree vs. clustering coefficient, secured market

The illustrations show scatter plots of the degree (x-axis) and corresponding clustering coefficient (y-axis) of market participants in the secured market for selected months.

C.2 Tables regression results

Table 1: Summary statistics turnover regression

	P1					P2					P3					P4				
	Mean	Stdev	p10*	p50*	p90*	Mean	Stdev	p10*	p50*	p90*	Mean	Stdev	p10*	p50*	p90*	Mean	Stdev	p10*	p50*	p90*
Turnover																				
TU	59.29	188.53	0.00	0.00	140.30	44.24	171.33	0.00	0.00	97.90	29.03	159.23	0.00	0.00	30.00	26.23	166.53	0.00	0.00	10.00
TS	46.75	163.60	0.00	0.00	114.00	78.21	256.95	0.00	0.00	210.00	67.90	249.46	0.00	0.00	150.00	55.68	230.60	0.00	0.00	100.00
Network position unsecured market																				
DC	5.67	12.64	0.00	2.01	13.61	4.51	11.07	0.00	1.45	9.85	3.09	8.97	0.00	0.98	6.41	3.15	8.97	0.00	0.00	7.32
CL	17.71	24.19	0.00	1.98	52.38	15.06	22.90	0.00	0.00	50.00	7.14	16.92	0.00	0.00	38.10	3.66	11.72	0.00	0.00	8.33
RP	8.49	17.80	0.00	0.00	27.27	7.23	17.45	0.00	0.00	25.00	4.65	14.66	0.00	0.00	18.75	6.04	18.03	0.00	0.00	25.00
ST	0.13	3.99	-1.48	-0.02	0.21	0.07	2.45	-1.08	-0.00	0.08	0.00	1.53	-0.33	0.00	0.04	-0.00	1.01	-0.15	0.00	0.10
Network position secured market																				
DC	10.96	17.39	0.00	1.69	31.75	12.72	18.30	0.00	4.00	35.00	7.34	11.73	0.00	1.45	22.08	7.24	10.78	0.00	2.33	22.22
CL	8.37	15.86	0.00	0.00	33.33	9.27	16.35	0.00	0.00	35.56	3.00	8.37	0.00	0.00	10.53	2.17	5.95	0.00	0.00	8.33
RP	3.14	7.89	0.00	0.00	13.79	3.34	8.01	0.00	0.00	13.89	1.25	5.66	0.00	0.00	0.00	1.20	4.29	0.00	0.00	4.35
ST	-0.02	3.36	-1.39	0.00	0.69	-0.09	4.29	-2.58	0.00	1.77	-0.05	5.36	-2.60	0.00	1.18	0.03	4.40	-1.49	0.00	1.50
Liquidity and credit risk																				
NE	0.06	0.35	-0.02	0.02	0.23	0.07	0.48	-0.08	0.02	0.33	1.18	7.39	-0.07	0.08	1.80	0.90	5.96	-0.05	0.08	1.40
PS	0.02	0.24	-0.04	0.00	0.07	0.02	0.28	-0.05	0.00	0.10	0.03	0.39	-0.06	0.00	0.10	0.02	0.33	-0.05	0.00	0.10
BS	29.53	15.69	11.91	26.26	51.24	70.21	31.01	39.31	64.89	105.56	135.41	95.61	61.28	114.02	210.92	80.60	34.21	36.95	82.58	117.05

* 10%, 50% and 90% percentile

TU = Turnover unsecured market, TS = Secured market DC = Degree centrality, CL = Clustering coefficient, RP = Reciprocity, ST = Strength, NE = Net excess reserves, PS = Liquidity position payment system, BS = Bond-spreads

This table reports summary statistics for the turnover, risk premia, and network positions as well as the liquidity position and credit risk in the secured and unsecured Swiss franc money markets between 1 March 2005 and 2 August 2011. Statistics for the turnover and network positions as well as the liquidity position and credit risk are based on the panel data structure, including all market participants that exhibited turnover in both markets; hence, on 67,687 observations in the first period 30,510 in the second period, 44,183 in the third period and 35,482 in the fourth period. In each period, 113 banks are included.

Table 2: Summary statistics interest rate regression

	ON					1W					1M					3M				
	Mean	Stdev	p10*	p50*	p90*	Mean	Stdev	p10*	p50*	p90*	Mean	Stdev	p10*	p50*	p90*	Mean	Stdev	p10*	p50*	p90*
Interest rate premia unsecured market																				
RP	8.90	17.19	-2.20	5.80	22.00	4.31	13.89	-4.70	1.00	15.50	9.34	18.76	-4.30	4.40	29.00	19.76	27.21	-2.00	10.00	54.40
Network position unsecured market																				
DC (CT)	56.72	32.72	6.80	69.93	94.04	59.89	28.89	9.20	69.29	93.10	64.28	28.58	14.48	72.55	94.52	61.99	29.05	8.84	71.33	93.24
DC (CP)	37.95	35.13	2.04	18.29	90.91	37.09	34.33	0.68	22.86	80.52	39.93	34.73	1.98	39.85	87.86	49.24	34.78	2.05	61.54	91.89
CL (CT)	2.51	5.73	0.54	0.88	5.36	1.71	3.97	0.52	0.88	2.38	1.53	3.59	0.55	0.84	2.04	1.84	4.73	0.51	0.84	2.61
CL (CP)	14.27	22.02	0.56	1.51	50.00	10.54	20.02	0.00	0.98	50.00	13.71	21.90	0.53	1.27	50.00	8.71	18.13	0.45	0.93	40.00
RP (CT)	23.95	11.77	11.27	24.32	33.33	25.80	11.70	15.00	25.23	35.29	25.30	9.97	15.63	25.00	33.96	25.85	12.12	15.66	25.23	35.16
RP (CP)	19.52	15.81	0.00	21.43	33.33	19.14	17.45	0.00	21.74	35.56	19.72	14.91	0.00	22.22	34.29	21.50	14.00	0.00	23.75	34.29
ST (CT)	12.84	13.80	-1.06	12.26	32.36	11.47	14.22	-4.80	9.00	32.32	12.45	13.43	-3.28	13.60	30.53	11.76	13.42	-3.14	12.12	30.34
ST (CP)	6.17	12.43	-3.36	-0.08	26.76	3.51	11.00	-7.24	-0.17	20.85	6.13	11.85	-3.16	0.00	25.16	8.56	12.65	-2.73	1.74	27.42
Network position secured market																				
DC (CT)	54.93	36.59	0.00	70.00	95.83	51.31	35.39	1.37	45.71	94.92	58.10	34.59	3.03	75.00	95.59	56.32	35.80	1.33	71.43	96.05
DC (CP)	35.15	36.14	0.00	23.29	91.03	27.49	31.91	0.00	15.71	85.90	35.68	35.55	0.00	24.69	91.03	45.55	37.31	0.00	37.97	94.37
CL (CT)	2.64	5.09	0.00	1.50	5.00	2.62	4.56	0.00	1.52	5.71	2.57	4.25	0.00	1.64	5.26	2.62	4.75	0.00	1.66	5.04
CL (CP)	3.65	8.18	0.00	0.91	9.48	2.45	6.34	0.00	0.00	5.77	4.29	9.58	0.00	1.14	11.20	3.30	7.41	0.00	1.41	7.05
RP (CT)	11.61	9.70	0.00	12.50	23.64	11.08	9.44	0.00	11.54	22.86	12.88	9.19	0.00	13.79	24.19	12.51	9.50	0.00	13.73	24.14
RP (CP)	7.58	9.36	0.00	0.00	21.15	6.58	8.95	0.00	0.00	19.64	8.71	9.45	0.00	6.25	21.67	10.63	9.81	0.00	10.53	23.44
ST (CT)	7.33	13.23	-5.32	2.14	26.14	5.39	13.10	-7.87	1.09	24.32	8.04	14.47	-6.63	2.83	28.51	6.83	13.89	-6.77	1.92	26.48
ST (CP)	3.55	11.04	-5.01	0.00	20.11	1.77	9.70	-6.58	0.00	13.78	3.16	11.00	-6.07	0.00	19.63	5.03	12.48	-5.99	0.00	23.78
Liquidity and credit risk																				
NE (CT)	5.11	27.17	-1.31	0.24	8.48	11.14	41.18	-1.02	1.01	26.36	8.93	38.23	-1.30	0.75	18.74	10.85	43.23	-1.10	0.85	24.68
NE (CP)	4.97	26.83	-0.50	0.07	8.01	11.31	43.09	-0.26	0.12	26.36	8.34	39.22	-0.35	0.15	16.41	9.35	39.77	-0.70	0.34	20.06
PS (CT)	0.12	1.20	-1.12	0.00	1.50	0.12	1.28	-1.19	0.00	1.52	0.06	1.40	-1.48	0.00	1.60	0.10	1.42	-1.35	0.00	1.65
PS (CP)	0.07	0.98	-0.68	0.00	1.00	0.05	1.06	-0.75	0.00	0.93	0.05	1.07	-0.84	0.00	1.06	0.08	1.26	-1.11	0.00	1.41
ML	17.58	37.89	3.76	4.81	45.95	30.17	51.67	3.94	5.31	63.02	24.53	49.55	3.87	5.08	57.08	29.63	58.28	3.88	5.14	62.98
BS (CT)	0.53	0.65	0.00	0.32	1.26	0.69	0.73	0.00	0.49	1.56	0.59	0.64	0.00	0.36	1.34	0.66	0.71	0.00	0.47	1.47
BS (CP)	0.53	0.60	0.00	0.35	1.22	0.67	0.68	0.00	0.49	1.46	0.58	0.61	0.00	0.40	1.27	0.64	0.68	0.00	0.48	1.36

* 10%, 50% or 90% percentile

RP = Spread to Swiss Average Rate, DC = Degree centrality, CL = Clustering coefficient, RP = Reciprocity, ST = Strength, NE = Net excess reserves, PS = Liquidity position payment system, ML = Market liquidity, BS = Bond-spreads, CT = Cash taker, CP = Cash Provider

This table reports summary statistics for the turnover, risk premia, and network positions as well as the liquidity position and credit risk in the secured and unsecured Swiss franc money markets between 1 March 2005 and 2 August 2011. Statistics are based on the transaction data structure; hence, 205,074 observations for the ON (overnight) segment, 42,281 observations for the 1W (on week) segment, 34,210 for the 1M (one month) segment and 25,701 for the 3M (three months) segment.
30,510 in the second period, 44,183 in the third period and 35,482 in the fourth period.

In the following, the results of the turnover and interest rate regressions are presented. The models are computed for four time periods. The first period lasts from 1 Mar 2005 to 7 August 2007 (marked 'P1' in the tables); the second continues from 8 August 2007 to 15 September 200 ('P2'); the third lasts from 16 September 2008 to 22 April 2010 ('P3'); and the final period lasts from 23 April 2010 to 2 August 2011 ('P4'). To quantify the economic effect, standardized coefficients are illustrated.

While for the liquidity and credit risk variables, the value on the settlement date t of the transactions are used, for the network variables, the values on the previous date $t-1$ are used.

Table 3: Turnover regression (y_{it} based on (3))

	Lending				Borrowing			
	P1	P2	P3	P4	P1	P2	P3	P4
***NW* unsecured market**								
DC	0.15***	0.075	0.04	0.11*	0.035	-0.015	-0.15***	-0.019
CL	0.063***	0.031***	0.028**	-0.019	-0.033***	-0.020*	0.0025	-0.013
RP	-0.0062	-0.0037	0.00055	-0.0068	0.0019	0.007	-0.012	-0.017
ST	-0.19***	-0.027	-0.077***	-0.058**	0.11**	0.043	-0.046*	0.081**
***NW* secured market**								
DC	-0.14***	-0.046	-0.27***	-0.15***	-0.28***	-0.28***	-0.40***	-0.24***
CL	-0.13***	-0.12***	-0.13***	-0.053***	0.039***	0.048***	0.054***	0.018***
RP	-0.014**	-0.01	-0.00066	0.0048	0.0064	0.0019	-0.0039	0.01
ST	0.21***	0.062***	0.20***	0.22***	-0.015	-0.077***	-0.22***	-0.25***
LR								
NE	-0.092***	-0.13***	-0.0081	-0.0047	0.11***	0.18***	0.024***	0.023**
PS	-0.11***	-0.11***	-0.061***	-0.072***	0.11***	0.13***	0.082***	0.10***
CR								
BS	0.041***	-0.031**	0.0014	0.028*	0.023***	-0.065***	-0.026**	-0.0098
Const.	0.21***	0.068	-0.090***	-0.18***	-0.026	-0.11**	-0.18***	-0.20***
R^2	0.37	0.35	0.35	0.36	0.22	0.33	0.15	0.24
N. of obs.	67687	30510	44183	35482	67687	30510	44183	35482

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; coefficients are standardized
DC = Degree centrality, CL = Clustering coefficient, RP = Reciprocity, ST = Strength
NE = Net excess reserves, PS = Liquidity position payment system, BS = Bond-spreads
P1 = 1.3.05-7.8.07; P2 = 8.8.07-15.9.08; P3 = 16.9.08-22.4.2010; P4 = 23.4.10-31.7.11

Table 4: Turnover regression unsecured market (y_{it} based on (4))

	Lending P1	P2	P3	P4	Borrowing P1	P2	P3	P4
***NW* unsecured market**								
DC	0.30***	0.093*	0.22***	0.23***	0.33***	0.28***	0.18***	0.28***
CL	0.096***	0.043***	0.056***	0.0041	-0.042***	-0.038***	-0.018***	-0.027***
RP	0.0046	0.012	0.024**	0.013	0.0036	-0.003	0.020*	-0.016
ST	-0.019	-0.069	-0.062***	-0.097***	0.41***	0.36***	0.12***	0.033**
***NW* secured market**								
DC	0.091***	0.067*	0.050*	0.16***	0.21***	0.12***	-0.038*	0.19***
CL	0.0059	0.014	0.0038	0.011	-0.010*	-0.016**	0.012***	-0.0091*
RP	-0.005	-0.0056	-0.0089	-0.0095	-0.0014	-0.013*	-0.016*	-0.0052
ST	0.11***	-0.01	-0.011	0.038***	0.094***	-0.029***	0.011*	0.017*
LR								
NE	0.13***	0.17***	0.023**	-0.00015	-0.12***	-0.17***	-0.027***	-0.033***
PS	0.13***	0.13***	0.060***	0.068***	-0.11***	-0.13***	-0.095***	-0.11***
CR								
BS	0.028***	-0.012	-0.0032	0.004	0.0068	-0.028**	-0.035***	-0.024**
Const.	0.60***	0.49***	0.26***	0.20***	0.36***	0.32***	0.21***	0.26***
R^2	0.45	0.12	0.39	0.52	0.60	0.60	0.47	0.54
N. of obs.	67687	30510	44183	35482	67687	30510	44183	35482

* p < 0.05, ** p < 0.01, *** p < 0.001; coefficients are standardized
DC = Degree centrality, CL = Clustering coefficient, RP = Reciprocity, ST = Strength
NE = Net excess reserves, PS = Liquidity position payment system, BS = Bond-spreads
P1 = 1.3.05-7.8.07; P2 = 8.8.07-15.9.08; P3 = 16.9.08-22.4.2010; P4 = 23.4.10-31.7.11

Table 5: Turnover regression secured market (y_{it} based on (5))

	Lending P1	P2	P3	P4	Borrowing P1	P2	P3	P4
***NW* unsecured market**								
DC	0.12***	-0.007	0.12**	0.054	0.30***	0.22***	0.30***	0.22***
CL	0.017***	0.00085	0.01	0.024*	-0.010*	-0.01	-0.015*	-0.006
RP	0.013**	0.014***	0.018***	0.017*	0.0017	-0.0087	0.028**	0.0071
ST	0.24***	-0.029	0.041*	-0.0071	0.31***	0.24***	0.13***	-0.064**
***NW* secured market**								
DC	0.29***	0.11**	0.35***	0.29***	0.48***	0.35***	0.43***	0.40***
CL	0.19***	0.15***	0.15***	0.066***	-0.049***	-0.056***	-0.053***	-0.026***
RP	0.014**	0.0069	-0.006	-0.012	-0.0077	-0.011*	-0.0072	-0.015
ST	-0.17***	-0.082***	-0.24***	-0.22***	0.11***	0.049**	0.26***	0.29***
LR								
NE	0.13***	0.17***	0.023**	-0.00015	-0.12***	-0.17***	-0.027***	-0.033***
PS	0.13***	0.13***	0.060***	0.068***	-0.11***	-0.13***	-0.095***	-0.11***
CR								
BS	-0.027***	0.026***	-0.004	-0.028*	-0.016***	0.038***	0.005	-0.0064
Const.	0.40***	0.42***	0.35***	0.38***	0.39***	0.43***	0.39***	0.45***
R^2	0.54	0.48	0.53	0.43	0.52	0.57	0.36	0.39
N. of obs.	67687	30510	44183	35482	67687	30510	44183	35482

* p < 0.05, ** p < 0.01, *** p < 0.001; coefficients are standardized
DC = Degree centrality, CL = Clustering coefficient, RP = Reciprocity, ST = Strength
NE = Net excess reserves, PS = Liquidity position payment system, BS = Bond-spreads
P1 = 1.3.05-7.8.07; P2 = 8.8.07-15.9.08; P3 = 16.9.08-22.4.2010; P4 = 23.4.10-31.7.11

Table 6: Interest rate regression (ON)

	P1	P2	P3	P4
***NW* unsecured market**				
DC (CT)	-0.19***	0.31***	-0.15***	-0.21***
DC (CP)	-0.20***	0.087	-0.039	0.035
CL (CT)	-0.018***	-0.016	-0.0029	-0.0021
CL (CP)	-0.013	-0.045**	-0.070***	0.025
RP (CT)	0.015**	-0.088***	-0.01	-0.0038
RP (CP)	-0.0046	-0.060***	-0.0041	0.052***
ST (CT)	-0.37***	0.17***	0.13***	0.062*
ST (CP)	-0.35***	0.051	0.14***	-0.0081
***NW* secured market**				
DC (CT)	-0.15***	0.26***	0.30***	-0.13**
DC (CP)	-0.13***	0.17***	0.15***	0.072
CL (CT)	-0.0084	0.015	0.033***	-0.0028
CL (CP)	-0.008	-0.0052	0.011	0.01
RP (CT)	0.025***	-0.044***	0.080***	-0.00056
RP (CP)	0.024***	-0.029**	0.048***	0.012
ST (CT)	0.054**	0.15***	0.21***	0.067*
ST (CP)	0.078***	0.11***	0.060***	-0.017
LR				
NE (CT)	0.13***	-0.00074	0.015**	0.030**
NE (CP)	0.12***	-0.012	-0.016***	0.026*
PS (CT)	0.046***	-0.035***	-0.023*	0.062***
PS (CP)	0.045***	-0.019*	-0.019*	0.059***
ML	0.17***	0.32***	-0.011	-0.0069
CR				
BS (CT)	-0.028***	0.11***	0.12***	0.0081
BS (CP)	-0.045***	0.047***	0.071***	-0.085***
Const.	-2.599	-23.60***	2.65	6.21***
R^2	0.15	0.221	0.482	0.143
N. of obs.	68278	23470	17802	12268

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; coefficients are standardized
DC = Degree centrality, CL = Clustering coefficient, RP = Reciprocity
ST = Strength, NE = Net excess reserves, PS = Liquidity position payment system, ML = Market liquidity, BS = Bond-spreads
P1 = 1.3.05-7.8.07, P2 = 8.8.07-15.9.08,
P3 = 16.9.08-22.4.2010, P4 = 23.4.10-31.7.11

Table 7: Interest rate regression (1W)

	P1	P2	P3	P4
***NW* unsecured market**				
DC (CT)	0.025	0.25*	-0.056	-0.24**
DC (CP)	-0.049	0.37***	0.30***	-0.24***
CL (CT)	-0.04	0.00	-0.037***	0.092**
CL (CP)	0.00	0.03	0.02	-0.090***
RP (CT)	0.00	-0.04	-0.020*	-0.089***
RP (CP)	0.02	-0.02	0.048***	0.059*
ST (CT)	-0.044	0.27*	0.22***	0.15**
ST (CP)	0.13**	0.089***	0.31***	0.18***
***NW* secured market**				
DC (CT)	-0.25**	0.18	-0.05	-0.50***
DC (CP)	-0.18**	0.26*	0.19***	-0.35***
CL (CT)	0.03	-0.06	0.03	0.03
CL (CP)	0.00	-0.03	0.050**	0.01
RP (CT)	-0.0046	-0.051	-0.067***	0.0062
RP (CP)	0.037*	0.012	0.081***	0.038
ST (CT)	-0.36**	0.28	0.22***	0.13**
ST (CP)	-0.12	0.081***	0.23***	0.32***
LR				
NE (CT)	0.0038	-0.082***	0.023*	-0.0085
NE (CP)	-0.038**	-0.070***	-0.014	0.013
PS (CT)	0.022*	-0.050**	-0.024	0.029
PS (CP)	-0.0037	-0.0013	-0.028	0.013
ML	0.11***	0.20***	-0.026	0.02
CR				
BS (CT)	0.067**	0.17***	0.094***	-0.061*
BS (CP)	-0.02	0.17***	0.055	0.01
Const.	-0.012	-0.0026	0.026	-0.24***
R^2	0.216	0.316	0.602	0.23
N. of obs.	9305	3211	5979	3340

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; coefficients are standardized
DC = Degree centrality, CL = Clustering coefficient, RP = Reciprocity
ST = Strength, NE = Net excess reserves, PS = Liquidity position payment system, ML = Market liquidity, BS = Bond-spreads
P1 = 1.3.05-7.8.07, P2 = 8.8.07-15.9.08,
P3 = 16.9.08-22.4.2010, P4 = 23.4.10-31.7.11

Table 8: Interest rate regression (1M)

	P1	P2	P3	P4
***NW* unsecured market**				
DC (CT)	-0.23***	-0.59***	-0.13***	-0.24**
DC (CP)	-0.19***	-0.34***	0.077*	-0.24***
CL (CT)	-0.01	0.01	-0.01	0.092**
CL (CP)	0.022*	-0.00	0.058***	-0.090***
RP (CT)	-0.00	0.01	-0.048***	-0.089***
RP (CP)	0.049***	0.00	0.089***	0.059*
ST (CT)	-0.20***	-0.75***	0.024	0.15**
ST (CP)	-0.11*	0.019	0.27***	0.18***
***NW* secured market**				
DC (CT)	-0.1	-0.59***	-0.072	-0.50***
DC (CP)	-0.12*	-0.34**	0.11***	-0.35***
CL (CT)	0.028*	-0.14***	-0.047*	0.03
CL (CP)	0.02	-0.03	0.030*	0.01
RP (CT)	-0.0077	-0.066**	-0.058***	0.0062
RP (CP)	0.054***	0.023	0.047*	0.038
ST (CT)	-0.20*	-0.93***	0.071*	0.13**
ST (CP)	-0.0065	-0.018	0.24***	0.32***
LR				
NE (CT)	0.031**	0.084***	0.0087	-0.0085
NE (CP)	-0.00058	0.068***	0.0048	0.013
PS (CT)	0.040***	0.038*	-0.026	0.029
PS (CP)	0.0081	0.011	-0.032**	0.013
ML	0.076***	0.021	-0.14***	0.02
CR				
BS (CT)	-0.0044	0.12***	0.11**	-0.061*
BS (CP)	0.031	0.16***	0.18***	0.01
Const.	-0.033**	0.021	0.11	-0.24***
R^2	0.209	0.25	0.772	0.23
N. of obs.	10795	4475	3444	3340

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; coefficients are standardized
DC = Degree centrality, CL = Clustering coefficient, RP = Reciprocity
ST = Strength, NE = Net excess reserves, PS = Liquidity position
payment system, ML = Market liquidity, BS = Bond-spreads
P1 = 1.3.05-7.8.07, P2 = 8.8.07-15.9.08,
P3 = 16.9.08-22.4.2010, P4 = 23.4.10-31.7.11

Table 9: Interest rate regression (3M)

	P1	P2	P3	P4
***NW* unsecured market**				
DC (CT)	-0.35***	-1.17***	-0.076***	-0.67***
DC (CP)	-0.23***	-0.85***	0.11***	-0.47***
CL (CT)	-0.01	-0.03	-0.026*	-0.02
CL (CP)	-0.01	0.07	0.02	-0.05
RP (CT)	-0.01	0.11***	-0.16***	-0.03
RP (CP)	0.03	0.16***	0.090***	0.088**
ST (CT)	-0.22***	-1.12***	-0.13***	0.19**
ST (CP)	-0.27***	0.10***	0.27***	0.25***
***NW* secured market**				
DC (CT)	-0.33***	-1.18***	-0.087*	-0.37**
DC (CP)	-0.21***	-0.89***	0.11**	-0.26**
CL (CT)	0.01	0.03	0.02	0.065*
CL (CP)	-0.020*	0.03	0.053***	-0.03
RP (CT)	0.022	0.11***	-0.089***	0.0078
RP (CP)	0.035*	0.14***	0.027	0.11***
ST (CT)	-0.41***	-1.42***	-0.077***	0.064
ST (CP)	-0.21***	0.045**	0.28***	0.23***
LR				
NE (CT)	0.037**	0.052***	0.00036	0.011
NE (CP)	0.018	0.053***	0.005	-0.0034
PS (CT)	0.019	0.031*	-0.0062	-0.037
PS (CP)	0.016	0.022	-0.00013	-0.061*
ML	0.038***	0.029*	-0.11***	-0.044
CR				
BS (CT)	-0.022	0.28***	0.15***	0.0011
BS (CP)	-0.024	0.29***	0.12***	0.01
Const.	-0.03	-0.035	-0.20***	-0.041
R^2	0.158	0.422	0.881	0.14
N. of obs.	8520	4545	2504	2481

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; coefficients are standardized
DC = Degree centrality, CL = Clustering coefficient, RP = Reciprocity
ST = Strength, NE = Net excess reserves, PS = Liquidity position payment system, ML = Market liquidity, BS = Bond-spreads
P1 = 1.3.05-7.8.07, P2 = 8.8.07-15.9.08,
P3 = 16.9.08-22.4.2010, P4 = 23.4.10-31.7.11

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