Unrestricted

Working paper, draft

xx • 2008

Implicit intraday limits in large value payment systems

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Financial Markets and Statistics

1.6.2008

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1 Introduction

In a modern market economy, payment systems can be considered as one of the necessary basic infrastructures of the society. All the economic transactions in real economy are eventually settled in some form in the payment systems. Therefore soundness and efficiency of payment systems is highly important.

Large value payment systems (LVPS) create the core network of the payment system infrastructure. The most common LVPS structure is real-time gross settlement (RTGS), where transactions are settled in central bank money. All the institutions participating in LVPS's are all called banks in this paper for simplicity.

To enable settlement of transactions, banks in a RTGS system must keep liquidity in their central bank account during the day. The word liquidity is used here for transferable funds. The three possible sources for this intraday liquidity are intraday credit facility of the central banks, where liquidity is typically provided against collateral or with repo transactions, interbank markets and incoming payment from counterparties. Theoretical or computational studies of intraday liquidity management in RTGS systems have shown that banks may have incentive to delay transactions if intraday liquidity is costly. This may cause inefficiencies in the overall level. (see e.g. Angelini 1998, Bech-Garratt 2002 and also Hellqvist 2005). Also some empirical analyses of the payment flows, which are closely aligned to this approach, have been performed. McAndrews and Rajan (2000) analysed the timing and reciprocity of the payments in Fedwire system and found evidence for coordination of timing of submitting payments to Fedwire system. Motivation for such coordination is in decrease in intraday liquidity costs since higher intraday overdrafts are needed for shorter time.

One likely tool for intraday liquidity management is to implement limits for intraday counterparty positions. Such limit would restrict the outflow of payments and liquidity provided for the counterparties unless there are also incoming payments. Some LVPS's have built in features allowing the banks to define bilateral counterparty limits explicitly in the system, like TARGET2 in the euro area and LVTS in Canada[1]. Also some recent proposals for how the efficiency of payment processing could be enhanced in RTGS systems are based on the idea of bilateral limits. (Johnson et al. 2004) If the system does not provide facility to define bilateral limits for liquidity flow, banks can implement

[1] Limits in LVTS system in Canada are due to different basic structure of the system. LVTS is based on extension of credit between system participants instead of immediate transfers of liquidity like in RTGS structure. See Arjani and McVanel (2006).

the limits in their own internal systems. Based on anecdotal evidence, many banks have such systems in place.

Intraday bilateral limits can also be seen as a tool for counterparty risk management. By following the bilateral position intraday, the exposure against each counterparty can be kept within given credit line. Exposure in this context is the deviation of the bilateral position from the expected net position at the end of day. In this study only the position which is aggregated from the settled transactions during the day is considered. Thus the aspect of counterparty risk management is also considered more as a liquidity management issue: if some counterparty is trusted more, a larger exposure vis-à-vis this counterparty can be allowed.

This study presents a methodology for identifying internal intraday counterparty limits of banks empirically from payment system data. If such limits are assumed to be in place, the level of the limits should be possible to observe as implicit constraints for the bilateral balances between the participants, when the real flow of payments is repeated in simulation environment. The analysis is based on transaction data from Finnish LVPS (BoF-RTGS) from years 1997-2007 and the system setup is replicated with Bank of Finland Payment and settlement system simulator[2].

To test the existence of limits, a model is developed where the estimated levels are explained with external market based variables reflecting the use of the limits as a risk management tool. The magnitude of intraday positions is also compared to overnight exposures, which are again identified from the payment system data with commonly used methodology (Furfine 1999). The magnitude of intraday exposures should align with the overnight loans if there are some counterparty credit lines at place.

The presented methodology can be useful in oversight of payment systems. Some possibilities for how it could be utilised are discussed such as monitoring the changes of intraday liquidity usage or identification of free riding participants who may affect adversely on the efficiency of the payment systems.

The paper is structured as follows. Section 2 presents the estimation of implicit limits and data used in this phase, section 3 describes the tests for the validity of the estimated limits and section 4 concludes.

[2] See www.bof.fi/sc/bof_pss/ for more details about the simulator

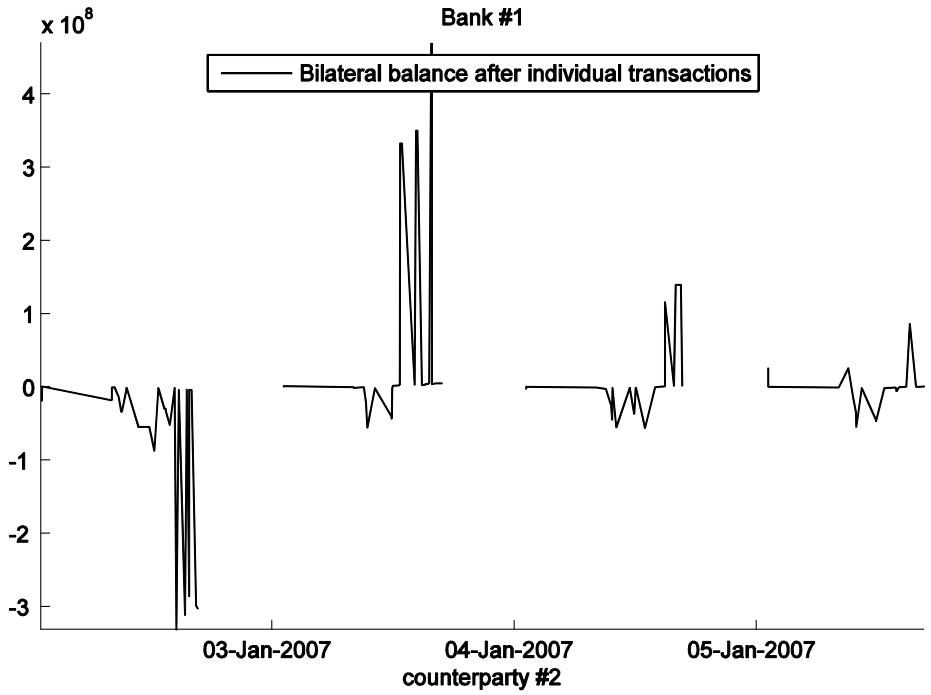
2 Estimation of implicit bilateral limits

Estimation of implicit bilateral limits is based on exact transaction level data from payment systems. For each transaction, timing, involved participants and naturally the value have to be known. When the processing logic of the system under study is known in detail, the flow of payments and the resulting balances of the participants at all times can be reconstructed and recorded.

In this study Bank of Finland Payment and settlement system simulator was used to replicate the processing pattern of the payment system. It allows including realistic features such as transaction queues and gridlock resolution algorithms into the model, which can significantly impact the liquidity requirement and thus the observed balances. When bilateral limits are included in the simulations the bilateral position is also followed and recorded. When the explicit limits are given large enough values never to be faced, the transaction flow must anyway stay within the bilateral limits set by the participants in their internal systems. This gives possibility to implicitly estimate the approximate level of bilateral limits set by the participants.

Bilateral balance of the participants can be viewed as a stochastic process, where settled transactions change the balance. The value of transactions in large value payment systems is often approximated with lognormal distribution (e.g. Baksys & Sakalauskas 2006). When this is combined by normal payment processing procedures, such as first in first out - rule (FIFO), large transactions can block the process even if the balance is far from the actual limit. This can make identification existing limit values challenging. On the other hand, banks can possibly reorder payment instructions or allow smaller payment to bypass larger ones in their internal queue, if there is not enough liquidity to settle large payment without violating the counterparty limits. If there are assumed to be internal limits and thus willingness to delay at least some transactions, the possibility of reordering the payments and bypassing the FIFO rule is a rather natural addition. This could make it easier to observe the limits if such are used in real systems. One observed realisation of bilateral position between two participants from the data under study is shown in chart 1 below.

Chart 1. Example of bilateral intraday positions between two banks after each individual transaction on the four fist days of year 2007

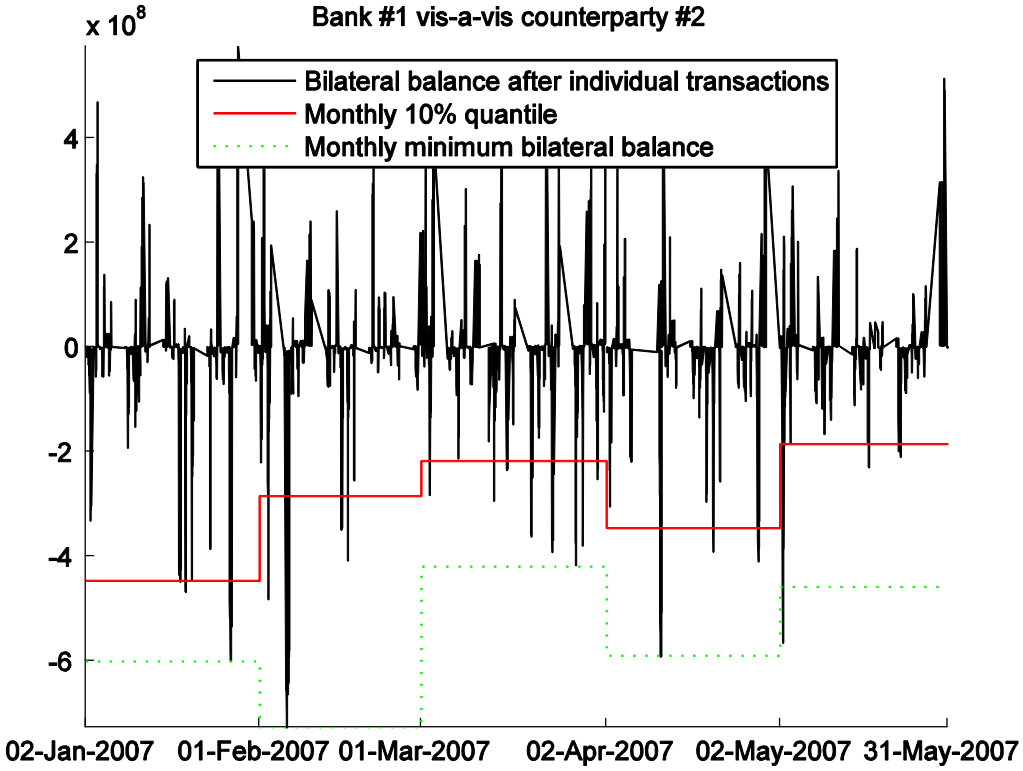


The simplest approach to estimate the bilateral limit is to select a period of time and find the minimum of bilateral position between given participants as the estimated limit value. Discussions with practitioners imply that while there are systems with counterparty limits in place, such limits can also be rather flexibly changed or bypassed by prioritized transactions. This would cause the simple minimums of bilateral balance to become biased estimator for the actual counterparty limit. As an alternative, quantile estimates for the limit were calculated. In quantile estimate, most cases are assumed to stay within a given fixed limit and some small number of transactions is allowed to cause bilateral positions which violate the limit. This decreases the impact of possible outliers or manual changes in the estimated limit. The method is only a coarse heuristic approximation, but since the objective is to capture the magnitude of limits, not their exact value, this is not a problem. Chart 2 shows the bilateral position over a longer period and monthly minimum positions together with monthly 10% quantile estimates of the bilateral limit.

Also alternative method using penalty functions was tested in the study. In that approach the limit was searched with maximization of the limit value and a linear or quadratic penalty term was included in the objective function for each bilateral position violating the limit. The heuristic quantile method

was however used because it was more simple, robust and equally accurate way to estimate the magnitude of the assumed implicit limits.

Chart 2. Bilateral positions for two banks during five months and monthly minimum and 10% quantile estimates of the bilateral limit



The system under study in this paper is BoF-RTGS, the LVPS operated[3] by Bank of Finland. Data consisted of all transactions since July 1997 until end of December 2007, i.e. 2684 days and 126 months. The estimation of counterparty limits was performed in daily and in monthly frequencies with several quantile levels. In total 24 participants were included in the analysis. Total number of account in the system is much higher, but some special participants (e.g. Bank of Finland itself) and account classes were excluded. The data set includes all largest banks operating in Finland.

[3] BoF RTGS was closed in February 2008 when Finland joined the TARGET2 system.

3 Validity of the limit estimates

Estimated counterparty limits were tested in three ways. Two first tests are related to assumption of bilateral limits as a tool or reflection of counterparty risk management. These were a regression analysis against external variables associated with riskiness of the counterparties and secondly a comparison to the magnitude of overnight loans. Third test can be considered as measure for intraday liquidity management use of the limits. There the interaction between the value of transaction flow and observed limit is studied. Each test is presented in detail below.

3.1 Regression for counterparty risk measures

If the bilateral limits of participants are used for limiting intraday counterparty risk, the level of observed limits should correlate with external variables describing the soundness or riskiness of each counterparty. This approach requires also an assumption that the process of setting the intraday limit is independent from other positions between the same participants such as short or long term liabilities or even intraday position in other systems.

Two external variables are used as the description of counterparty's riskiness. First one is a distance to default indicator (DD) calculated from the equity prices and balance sheet data of counterparties based on the option pricing model of Merton (1974). Distance to default or similar indicators are commonly used as a credit risk management tool. Time series for six Finnish publicly listed banks which were included in the current dataset was available for this study based on earlier study at the Bank of Finland. (Lehto 2005) The data of DD indicators cover all the years from 1997 to 2007 for four institutions (Oko, Nordea, Sampo, Ålandsbanken) and part of the period for two other banks (Interbank ending in August 1998 and eQ starting from March 2002).

Second independent variable is the spread between collateralized and uncollateralized three month interbank rates Euribor and Eurepo. The interest rate spread (IS) is used as description of the confidence or lack of confidence between the market participants generally. This time series is available since March 2002, when the Eurepo interest rate was launched.

Third independent variable was the floating average from 20 previous days[4] of daily total incoming transaction volumes (TV) from a given counterparty. It can be considered also partially as a risk management measure, since banks which change many transactions should have good knowledge of their counterparty and trust each other. Even more this variable should be describing the intraday

[4] Time windows of 1,5,10 and 20 days were tested for calculation of floating averages. The selected 20 days was most often a significant independent variable.

liquidity management, since if you expect to receive high value of payments from some counterparty you may be more likely to also send payments to that direction.

Three variations of the two first independent variables were tested. First one was simple face value of DD or IS time series. Second alternative was interaction of DD or IS with the number of sent payments towards a given participant and the third one the interaction with logarithm of the number of sent payments correspondingly. The two last alternatives are motivated by the relatively small transaction volumes. If there are only few transactions it is more likely that the limit is not reached –if such is in place. As a result the estimated value of limit can become smaller than the actual limit in the real system. With larger number of transactions, it is more likely that limit is faced and thus the importance of variables related to riskiness of a counterparty should increase. However, if there are very many transactions and the same limit is still assumed to be binding, increase in transaction number should not have such large impact, which motivates the use of logarithm for transaction volumes. Floating average of the transaction volumes from 20 last days was used in the interaction variables.

All independent variables were available for five counterparties out of 24 for some part of the time period under study. Thus it was possible to test 115 bilateral pairs of counterparties[5]. All regressions were computed both in daily and monthly level time series. Time series with four different quantile levels for the dependent variable were tested[6] in daily level regressions and seven in the monthly time series. With multiple quantile levels it was possible to try which of them is best explained by the independent variables. Stepwise regression with ordinary least squares estimation was used in the analysis.

There were no significant differences in the outcome of the regressions for different dependent variables with daily data. Reason for this is in the relatively low daily transaction volumes in the system which further on cause only very small differences in the daily time series in different quantile levels used. All the results below are from the regressions with daily minimums as the dependent variable. DD and IS variables were included in the final daily model multiplied by the transaction volume logarithms. Summary of the results of regressions for daily time series is presented in table 1 below.

[5] Distance to default time series for Interbank was not overlapping with interest rate spread time series. 115 pairs are composed from 5 participants against 24 counterparties minus the meaningless bank A vis à vis bank A pairs.

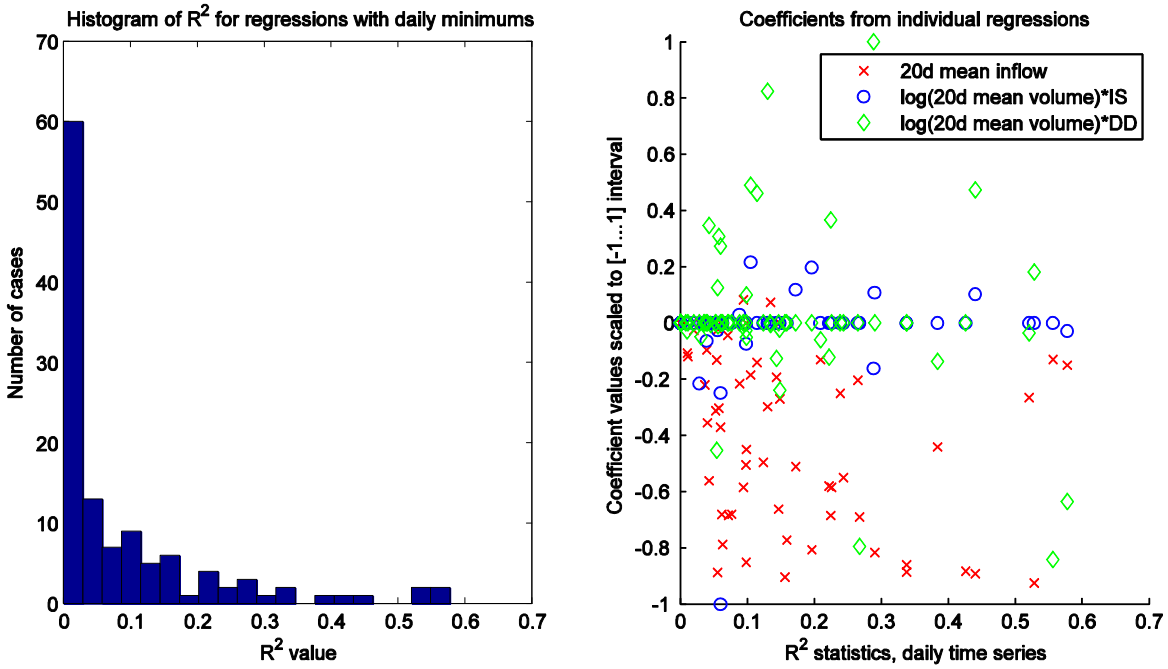
[6] In daily level, minimums and 1%, 2.5% and 5% quantiles for the bilateral position were studied. In monthly level minimums and 0.5%, 1%, 2.5%, 5%, 7.5% and 10% were used correspondingly.

Table 1. Descriptive values of regression with daily time series of bilateral limit estimates and counterparty risk measures

Different independent variables in regressions with daily time series	**Number of times when significant**	**Sign of the coefficient**
Log(20 days mean volume)*Distance to default (DD)	16	?
Log(20 days mean volume)*Interest rate spread (IS)	31	?
20 days mean value, incoming payments (TV)	58	-
Number of significant independent variables	**Proportion of cases**	
0	44%	
1	26%	
2	26%	
3	4%	
R^2 statistics		
Highest individual R^2 value	0.578	

The outcome of the daily regressions is not very convincing. In 56% of the cases there were one or more statistically significant independent variables. Transaction value was the only one with good capabilities for predicting estimated limits. The negative sign of the coefficient is according to intuition, since limits are presented with negative values in data. Results of DD and IS variables were mixed and no clear sign for their impact can be seen. (see Chart 3 below) Estimated coefficients for the independent variables are not reported in the table due to varying results received from independent regressions.This overall picture is well displayed also in histogram of the values of R^2-statistics from all the tested cases and in the values of individual coefficients.

Chart 3. R2 statistics and estimated coefficient for all individual bank pairs from regressions with daily time series.

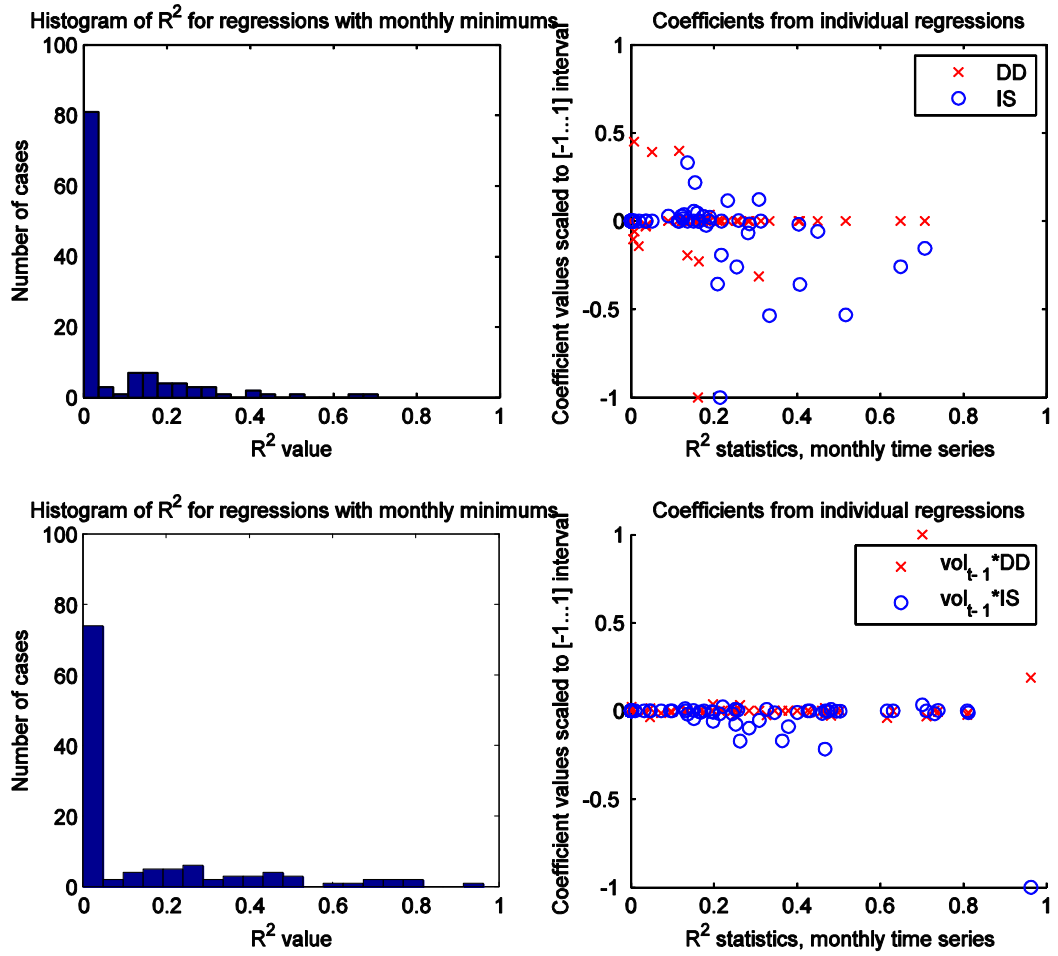


With monthly data, larger scale of possible quantile levels was tried and there are some visible differences in the results with different quantiles. However, when the R^2 values for regressions with different quantile levels are compared with statistical testing[7], there is no evidence for difference between the distributions of R^2 values. This holds for all pairwise tests between the quantile levels and even when only the nonzero R^2 values were used. Thus no such quantile level was found, which would be fit better than others in the independent variables and all results are again reported from regressions with the minimum bilateral balances time series.

With monthly time series the regressions with only DD and IS as independent variables produce higher values for R^2 statistics than with daily time series. On the contrary, number of cases where there is no significant independent variables is also higher. Coefficient values and R2 statistics are shown below (chart 4) from regressions with plain ID and DD series and another case where interaction of the former and transaction volumes from last month (Vol_{t-1}) were used. The results seem to give no clear indication of the correct sign of the coefficients except in individual cases.

[7] Nonparametric Wilcoxon rank sum test was used to test the hypothesis of whether the R^2 values observed in regressions with different dependent variable (see footnote 6) have same distribution.

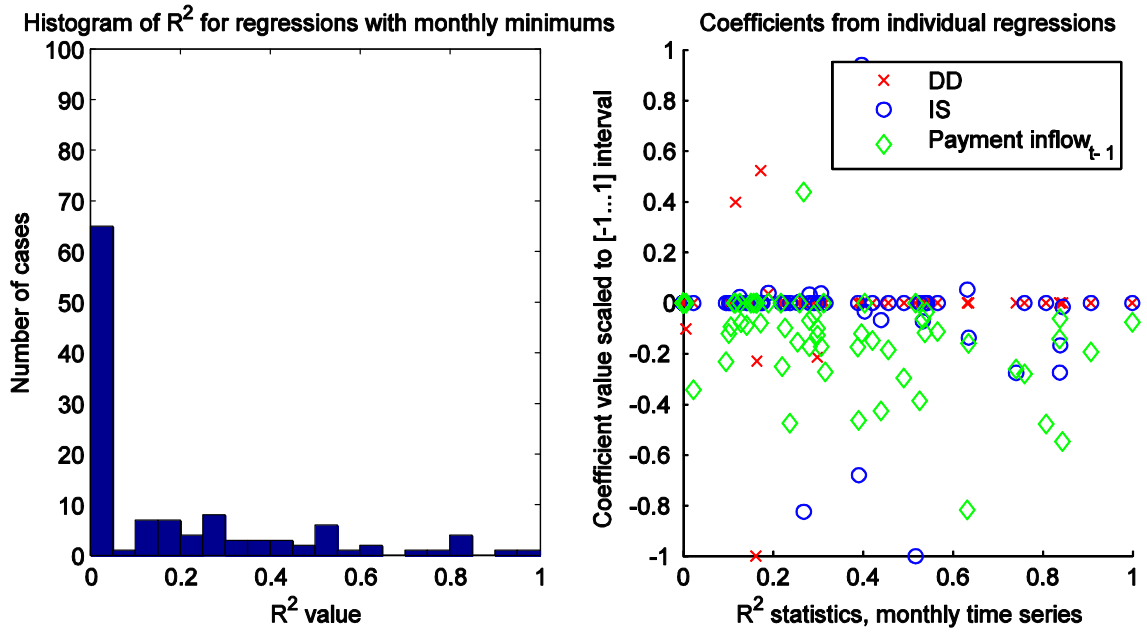
Chart 4. R^2-statistics and coefficients from two set of regression with monthly time series and only external independent variables not derived from payments data



If the value of payment inflow is included as the third independent variable, more than 50% of cases have some statistically significant independent variables. Several individual cases with high R2 values or almost perfect fit are also found. Correlation of monthly transaction volume and DD time series is relatively high[8]. Also, when the payment inflow was included, it became the only independent variable, for which the sign of the coefficient could be reliably observed (see chart 5 below) .

[8] Correlation coefficient value between monthly DD and incoming liquidity time series was 0.76.

Chart 5. Regression statistics for monthly time series with value of incoming payments included



Based on regression with IS and DD only and the one with payments volume as the third variable, it could be assumed that if interest rate spread (IS) has an impact, the sign of its coefficient is negative. This would mean that higher value of spread between collateralized and uncollateralized interbank credit would make the banks more eager to allow large intraday positions.

3.2 Comparison of intraday positions with overnight lending volumes

Alternative way to test the estimated bilateral limits is to compare their magnitude to overnight loans between the same participants. If the intraday bilateral limits are really used as a limit for the counterparty risk, the level of allowed intraday position should be in line with what is at most accepted in the overnight positions too. This approach avoids some problems of regression between estimated bilateral limits and counterparty risk measures, since the real credit limit against each counterparty including all liabilities should be almost the same during some given day and at the end of the same day.

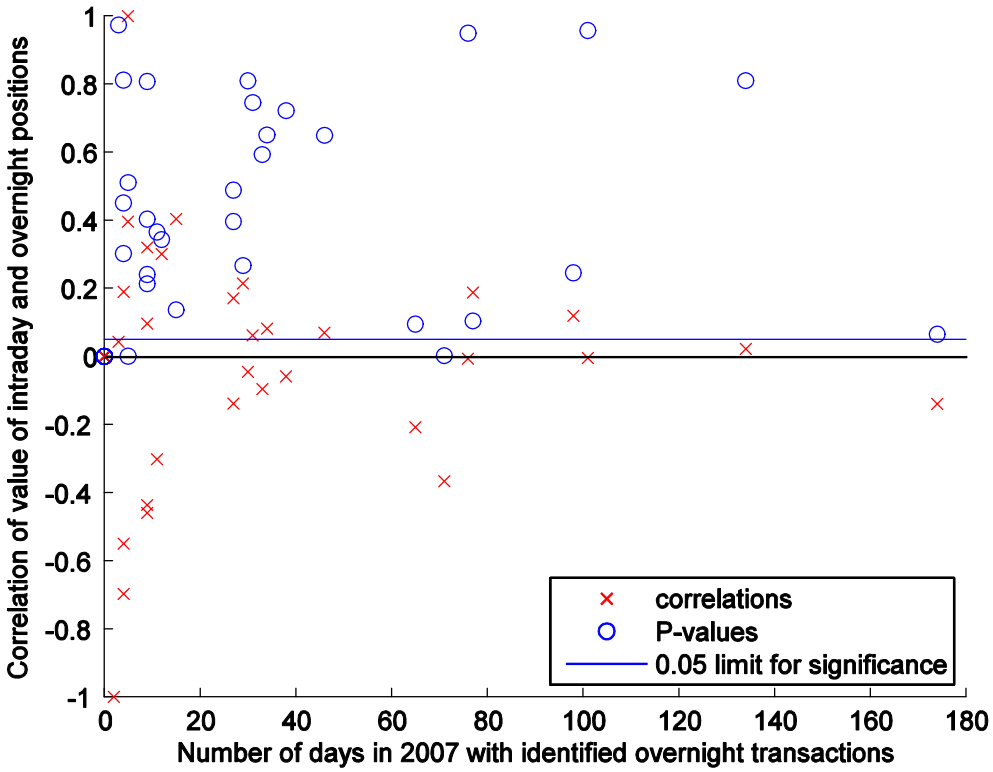
One frequqntly used method for identifying the overnight loans from payment system data has been presented (Furfine 99). The idea is to locate transactions from bank A to B which value is big round number and which has a countering transaction from B to A on the next possible date with principal

and interest closely matching the interbank rate. In this paper, multiples of 10 000 Euros were searched and at most 50bsp difference from the Eonia overnight interest rate was allowed.

For this comparison, overnight loans were searched only from year 2007 data. There were totally 8607 transaction pairs located corresponding to 2,6% of the total transaction volume. Out of these transactions, 2022 were between 12 banks belonging to those 24 banks studied in the regressions. This is not due to limitations of available data, but instead the full picture of the market, which can be observed by the used method.

Correlations were calculated for the daily time series of estimated intraday bilateral limits total value of overnight loans for each pair of banks. The values of correlations are plotted below against the number of days from which the value of overnight loans could be identified for the pair of banks in question. The correlation coefficients are shown in chart 6, which thus includes again all individual pairs of banks.

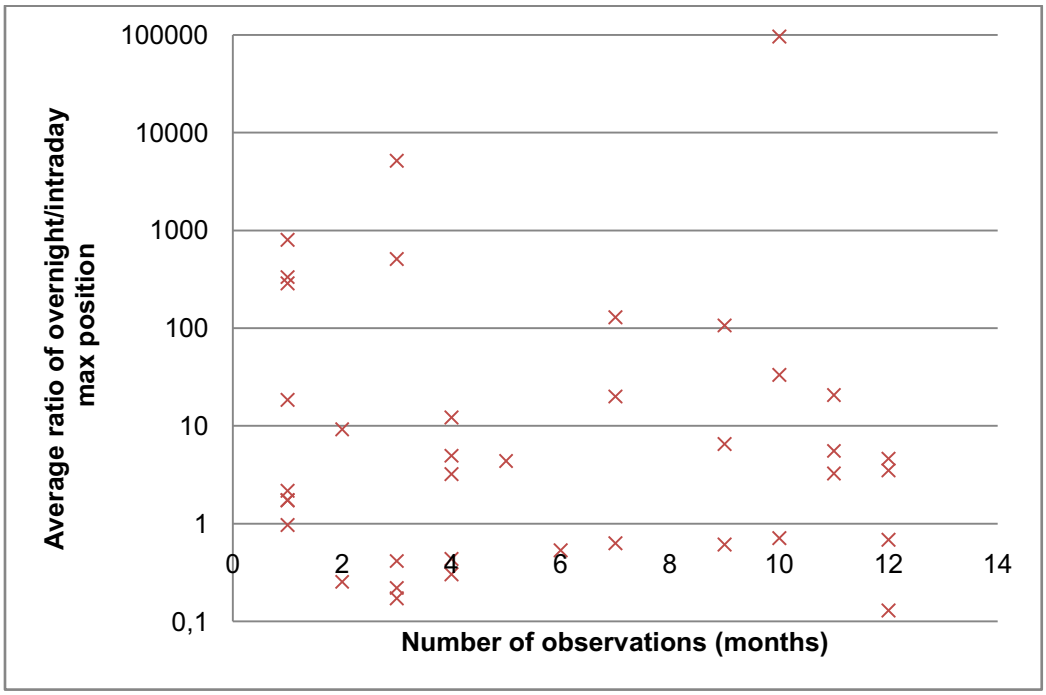
Chart 6. Correlation of daily time series of value of overnight loans and value of minimum bilateral positions intraday calculated independently for each pair of banks. X-axis presents the number of observations i.e. the number of days with some identified overnight loans for the given pair of banks. P-values for the test of nonzero correlation are also displayed.



No clear sign for the correlation can be seen and the three cases out of 56 with P-value smaller than 0.05 are likely to be just random noise.

The overall magnitude of intraday and overnight positions can also be compared. Minimum bilateral positions for each month were compared to average daily overnight loan positions or maximum daily overnight position from the same month and for each bilateral pair of banks. Below in chart 7 the average of these ratios from the numbers of year 2007 are shown as a function of the number of months for which the ratio was available for given pair of banks.

Chart 7. Average ratios of the magnitude of monthly minimums of intraday position and overnight position between individual pairs of banks. Relation is plotted on logarithmic scale as a function of number of observations for each pair of banks



The scale of ratios is very large. Smallest average values are 0.1 meaning ten times bigger intraday exposures than overnight exposures against the same counterparty while the largest individual ratio, average over ten months, was overnight exposures one hundredth thousand times the smallest intraday position. The high level of variations is also visible within the ratios of individual banks; the same bank may have very small ratio of overnight vs. intraday positions against a counterparty and high against another.

4 Summary and discussion

Transaction from Finnish large value payment system BoF-RTGS were used to identify assumed internal bilateral limits for the intraday counterparty positions. Data consisted of all transactions settled in BoF-RTGS between August 1997 and December 2007.

Regression analysis was performed between the estimated intraday position limits and independent variables related to counterparty risk and value or volume of the transaction flow. Explanatory power of the independent variables related to counterparty risk was weak. If internal bilateral limits are used by Finnish banks, it is more likely they are used as a method for intraday liquidity management. There is clearly no common practice among all participants to adjust or set bilateral intraday limits for counterparties based on counterparty risk management measures.

One possible observation from this study is that the difference between the uncollateralized and collateralized interbank interest rate may have positively correlated with the size of allowed intraday positions. Thus higher uncertainty could cause wider intraday limits. This could be understood as unwillingness to show any kind of liquidity problems to counterparties if the confidence between market participants is low. This observation is related to the recent period of liquidity turbulence, since before August 2007 there was practically no significant difference between the Euribor and Eurepo interest rates. However, a deeper study would be needed to confirm the hypothesis.

A second test for the estimated levels of bilateral intraday limits was performed by comparing them with the overnight positions between the same participants. These were similarly identified from the payment data with a commonly used methodology. No statistically significant correlation could be found with the current data between the value of overnight positions and the value of estimated bilateral limits.

Overall level of intraday positions was noticed to vary very much when it was compared to overnight loan positions. The observed ratios can in practice mean two things. First possibility is that the structure of overnight lending markets and intraday payment flows is very different and thus those banks which are used for overnight credit are not the same as those to whom most payments are sent intraday. The second alternative is that banks have limits for their intraday positions after all, and with these limits the intraday position against some counterparties are kept small enough for the high value of ratios to emerge. The latter case would mean that limits were mainly in intraday liquidity

management use. Analysis of the network structure of the intraday payment flows and overnight exposures would be needed to find out the reason for the observed ratios.

4.1 Discussion of the approach and possible improvements

There are some known shortcomings in the current analysis. Only transaction taking place in one LVPS are considered. In real life banks may have intraday positions against each other also in many other systems such as securities settlement systems, foreign exchange settlement, retail payment systems and private large value payment systems or even other central banks RTGS systems. If there exist an in-house system for intraday positions and limits, it should ideally cover all these positions. In this study only the data from Finnish LVPS was used with the assumption that it should contain the relevant part of the value of intraday positions between Finnish market participants.

In real systems banks may or may not include the operations performed on behalf of their customers in their bilateral positions controlled by the bilateral limits. If the use of the limits is for counterparty risk management, performing payments for the bank's customers should not perhaps be limited. However, if the limits serve primarily in intraday liquidity management purpose, then it may be irrelevant, what is the original reason for a payment.

One basic assumption in this study is that bilateral limits are stable and fixed at least for each day or even for each month. Based on anecdotal evidence this is perhaps not the case at all, but instead the limits may be rather flexibly changed and for example starting with small limits, which is then gradually relaxed can be even a rule. The approach used in this study did allow outlier transactions to bypass the rigid limits, since quantile estimates were tested, which increases flexibility. Also the assumption of the more stable or fixed level of intraday limit can be understood as the final level to which the real and possibly variable limit can be extended. Such "backbone" limit should indeed be based on more stable variables such as perceptions of the counterparty riskiness or overall intraday liquidity capacity.

In this study all the pairwise regressions were managed as one homogenous group. In real world, the practices and thus the results for individual institutions are likely to be different. Filtering or grouping the regressions based on the sender bank would allow the analysis of practices of individual banks against all of their counterparties. This more detailed analysis is left for future studies.

One way to improve the regressions could be to use operational reputation of the counterparty, "probability of liquidity sink", instead of distance to default indicator. This measure could be much more relevant for intraday liquidity management. Participants operating in systems with high transaction flow could collect such indicators for their counterparties based on observed longer than

average outages in the transaction flow. One such analysis of the existence of operational incidents in Fedwire system and their implications on money market is presented by Klee, (Klee 2007). Also in some simulation studies of operational failures in payment systems, the reactions of other market participants have been described as a quick stopping of payments to failed participant. (Bedford et al. 2005) Such behaviour requires in practise close monitoring of payment streams and facilities like bilateral intraday limits and thus it supports both the use of operational reputation indexes as independent variable and the whole idea about the use and existence of internal limits.

Transaction volume in large value payment system is not very high. This can make the estimation of bilateral limits more difficult, because larger number of observations would "draw the image" of the estimated implicit limit more clearly. This idea could also be used to test the estimated limits. First, it should be assumed that there is a given binding limit for the bilateral position between banks A and B set by the bank A. The bilateral position after each transaction can be considered to be random walk which will hit the limit more likely, when there is more steps i.e. high volume. Thus the observed value of limit should increase when the transaction volume is low and increases. After some level, which is the actual real limit, the increase in volume no longer has an impact on the expected value of observed limit.

Advantage of this alternative test compared to the two ones used in this study is that full length of observation period can be utilized. Also this approach can be seen as a test for the use of bilateral limits as an intraday liquidity management tool because the idea is based on the process of liquidity flows and no external variables are needed. However, the test has to be performed for each participant pair separately and for some pairs there is not real high volume days available. Also, a rather large sample size is needed and because of this it will not be easy to track changes in the limit levels.

4.2 Possible usages of the methodology

Transaction data from the payment systems is quantitative data with high accuracy and high frequency and it can be used for identification of the positions and actions of the participants in payment systems. Although this study did not find clear rationales for the observed intraday positions, which would be based on counterparty risk measures, the methodology can provide some valuable insight for oversight purposes.

Comparison of the intraday and overnight positions of the participants should tell how large positions the counterparties have in different time scales or maturities. Also the analysis can reveal if there are any implicit limits in the systems or are there changes in the levels of these limits for example due to changes in market conditions or market structures.

Analysis of intraday behaviour of payment system participants would also reveal any participants which repeatedly use more than average incoming payments to fund their intraday liquidity needs. If such free riding is observed, some policies for safequarding the efficienfy of liquidity circulation in the system can be considered. Possible examples could be changes in the settlement logics, which make the process more efficient and give fewer incentives for delaying payments.

Finally, the findings presented in this paper will depend on each system of the market practices or market specific features in that particular system. Thus results from one system should not be generalized without critical assessment or own estimation to other setups.

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