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Liquidity Risk and Banks' Bidding Behavior: Evidence from the Global Financial Crisis*

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Abstract
Even in countries that were not directly hit by the global financial crisis and where the banking system had a relatively strong liquidity position, there has been a negative spiral between the market and funding liquidity. We illustrate this on a case study of the Czech banking system. We construct indices of market and funding liquidity using daily market data, including data on banks' bidding behavior in repo operations of the Czech National Bank. We find some evidence of a negative feedback effect between market and funding liquidity, especially after the collapse of Lehman Brothers in September 2008.

1. Introduction

The concept of liquidity has received a renewed attention during the global financial crisis that started in summer 2007 in the U.S. sub-prime mortgage market. Before the crisis, economists and policymakers concentrated on causes and consequences of the global excess liquidity, a macroeconomic concept reflecting a sharp rise in credit and the money stock in 2003–2007. After the turmoil started, the focus shifted to microeconomic and structural concepts of both market liquidity of relevant financial markets and funding liquidity of financial institutions, mainly banks.

We focus on two key dimensions of liquidity: market liquidity and funding liquidity. Markets are liquid if a market participant can trade assets without significantly changing the market price. Funding liquidity denotes a situation where an institution can meet outstanding obligations and is able to raise cash if needed. While conceptually different, the two notions of liquidity are interlinked, a hypothesis corroborated by the evidence from the global financial crisis. Especially in developed financial markets, such as those in the United States, the United Kingdom, and the euro area, there were occasions when liquidity in certain market segments dried out completely and, simultaneously, some financial institutions experienced problems with settling obligations in timely manner.

The aim of this article is to test whether the link between market and funding liquidity exists also in countries that had no or virtually no relevant exposures to the U.S. sub-prime market, and where the banking system had a relatively strong liquidity position. To examine our hypothesis, we select one such country, namely

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the Czech Republic, and construct separate indices of market and funding liquidity, using daily market data.[1] While this is a common practice for market liquidity indices, funding liquidity is usually measured by indicators based on balance sheet data. To construct a market-based funding liquidity index, we apply a slightly modified version of a strategy suggested by Drehmann and Nikolaou (2009), using data from commercial banks' bidding behavior in repo operations of the Czech National Bank (CNB). Subsequently, we show that during the peak of the financial crisis (i.e. in the months that followed the collapse of Lehman Brothers in September 2008), indices of market liquidity and funding liquidity exhibited a high degree of co-movement.

The main contribution of the article consists in showing that the Drehmann and Nikolaou (2009) approach can be used to assess funding liquidity risks even in monetary systems where central bank absorbs liquidity from the markets, i.e. in a setting where banks do not bid for liquidity in market operations of the central bank. Further research could replicate this analysis for other countries. This would require detailed data on balance sheets of individual banks and data related to their behavior in monetary operations, which are not easily available.

The article is structured as follows. Section 2 provides definitions of market and funding liquidity and discusses their possible links that can lead to a downward liquidity spiral. Sections 3 and 4 explain, respectively, the construction of the market liquidity index for Czech financial markets, and the market-based indicator of funding liquidity of Czech banks. Section 5 analyzes the evolution of both indices during the global financial crisis of 2007–2009. Section 6 concludes.

2. Market Liquidity versus Funding Liquidity

Market liquidity can be defined as the ability of market participants to execute financial transactions in assets of a given volume without causing a significant change in their prices.[2] Market liquidity risk can be then defined as the probability that market transactions cannot occur or can take place only with a significant impact on market clearing prices (Kyle, 1985).

Three basic dimensions of market liquidity are usually differentiated in the literature (Kyle, 1985; Fleming, 2003): tightness, depth, and resiliency. Market tightness reflects low costs of unwinding a certain position, meaning that the price at which individual transactions can be undertaken is not very different from the average market prices. Market depth stands for the ability to execute large transactions without excessively affecting the current market prices of an asset. Finally, market resiliency is linked to the speed at which prices recover from a random shock.

Funding liquidity, on the other hand, is a feature of an institution (a bank, usually) rather than a market. There are several definitions of funding liquidity which overlap to some extent. Drehmann and Nikolaou (2009) define funding liquidity as the ability to settle obligations with immediacy. According to the IMF, funding liquidity is defined as the ability of a solvent institution to make agreed-upon payments in a timely fashion (IMF, 2008a). Borio (2000) or Brunnermeier and Pedersen (2007) define funding liquidity as the ability to raise cash at short notice either via

[1] For the discussion of relative strengths of the Czech banking system see CNB (2009).

[2] A detailed definition of a liquid market (as applied to the stock market) can be found in Black (1971).

asset sales or new borrowing. Because the ability of an institution to settle obligations in timely manner is related to the structure of its balance sheet and is usually applied to banks, funding liquidity is often called banking liquidity or balance sheet liquidity.[3]

Drehmann and Nikolaou (2009) also define funding liquidity risk as the possibility that over a specific horizon an institution (a bank) will become unable to settle its obligations with immediacy. They emphasize that it is important to differentiate between funding liquidity and funding liquidity risk. They argue that while funding liquidity is a binary concept (a bank can settle obligations or not) and is associated with a particular point in time, funding liquidity risk can in principle reach infinitely many values and is measured over a particular horizon.[4]

Theoretical and practical research has rationalized strong interactions between funding liquidity risk and market liquidity, especially in periods of crisis (Brunnermeier and Pedersen, 2007; Drehmann and Nikolaou, 2009; Praet and Herzberg, 2008; Frank et al., 2008). Simply put, shocks to funding liquidity can lead to asset sales, and may reduce asset prices. Continuous downward pressure on prices can have considerable consequences for market liquidity. This can lead to a feedback loop if lower market liquidity leads to higher margin calls, which in turn increase funding liquidity risk as outflows rise. As banks always try to remain liquid they launch a new round of asset sales which starts a downward liquidity spiral.

The adverse liquidity spiral can also start from market illiquidity. Impaired market liquidity can hit a bank on both sides of its balance sheet. Assets may become unsalable in the extreme case of absolute market illiquidity and due to a lack of trading their value decreases. At the same time, the bank is not able to improve its impaired funding liquidity position through its liability side (by issuing securities or borrowing in the interbank market). When funding liquidity is tight, traders (mostly banks as main market makers starting to hoard liquidity) become reluctant to take on positions (especially in high-margin securities). This lowers market liquidity and in turn increases the risk of funding a trade, thus increasing the margins and funding liquidity risk.

The risk of an adverse liquidity spiral increases with stronger linkages between banks and securities markets. Praet and Herzberg (2008) give a number of reasons supporting the existence of a strong links between banks and markets. First, banks are major issuers of securities (both bonds and stocks). Second, interbank funding have become more dependent on market liquidity, as interbank transactions have been increasingly carried out through repurchase agreements. Third, banks have been increasingly mobilizing their traditional government and corporate bond portfolios to finance less liquid but higher yielding forms of assets that again can be reused as collateral. Fourth, profound changes in liquidity management have been implemented with a view to increase efficiency and manage operational risks. Fifth, banks have been increasingly supplying the market with new securitized products, structuring and repackaging in tranches illiquid assets which they redistributed to investors with corresponding risk preferences. Finally, bank lending has taken on

[3] See Praet and Herzberg (2008) or CNB (2009).

[4] Praet and Herzberg (2008) define banking liquidity risk as the inability of a bank to meet outstanding obligations at a reasonable cost. For the discussion on differences between various definitions of funding liquidity and funding liquidity risk see Drehmann and Nikolaou (2009).

new forms, including direct lending to specialized investors such as hedge funds that are very active market participants. All of these aspects have played an important role in the recent financial turmoil, and contributed to the observed adverse liquidity spiral that followed in developed financial markets especially after the collapse of the U.S. investment bank Lehmann Brothers in September 2008.

3. Construction of a Market Liquidity Index for the Czech Financial Markets

The construction of a market liquidity index for the Czech financial markets follows the methodology applied by major central banks (e.g., Bank of England, 2007, and European Central Bank, 2007). We first look for variables that would capture the three basic dimensions of market liquidity, i.e. tightness, depth, and resiliency, and construct sub-indices for four relevant market segments: money market, bond market, foreign exchange (FX) market, and stock market. Given that the Czech financial markets are much less developed than for instance those in the United Kingdom and the euro area, the range of possible variables capturing the above mentioned basic dimensions is somewhat limited.

Market tightness is measured by the bid-ask spread, i.e. the difference between the (best) prices at which a financial instrument can be bought and sold. If bid-ask spreads are narrow, market liquidity is high, as the price at which individual transactions can be undertaken is only marginally distinct from the average market prices. On the other hand, if market liquidity is tight, bid-ask spreads are large, as the market maker wants to be compensated for the difficulty of realizing a possible prompt sale of an asset. *Table 1* shows bid-ask spreads across the four selected markets.

As regards market depth, a frequently used indicator is the total volume belonging to all bids in the order book. However, the order book or transaction level data are not easily available, so we approximate this dimension by daily turnover volumes. This is based on the notion that a larger turnover makes it more likely that a sizeable transaction can be performed in a short time without a significant shift in market prices. Total volume data are available for all market segments, except for the FX market. For further calculations, the volume data were detrended by subtracting a linear trend.

Market resiliency can be measured by the price impact indicators, which basically express the extent of the price change caused by a given size of order flow. Similarly to market depth, for the calculation of the price change resulting from order flows microstructural data, such as intraday transaction and quotation data are needed, but these are not easily available. Thus, we measure market resiliency by the ratio of the return to the transaction volume (the return-to-volume ratio). It is assumed that in illiquid markets, the price will move more for a given trading volume than in liquid conditions, so the ratio should be higher. Similarly to market depth variables, the data are available for all market segments, except for FX markets.

Given that measuring the individual dimensions of market liquidity involves approximation using relatively aggregate measures in the case of a lack of order book data, supplemental variables that are linked to market liquidity can be used (ECB, 2007). We included a proxy for liquidity premium and the market volatility index. The liquidity premium can be understood as a form of compensation demanded by an investor for the potential risk of having to abandon the position associated with

Table 1 Dimensions and Variables for the Calculation of Market Liquidity Index

Dimension	*Description*	*Money market*	*FX market*	*Bond market*	*Stock market*
Tightness	Bid-ask spreads	O/N, 1W, 2W, 1M, 2M, 3M (spread PRIBOR vs PRIBID)	CZK exchange rate to USD, EUR, GBP, CHF	31 government bond reference prices	13 individual stocks making up the index PX
Depth	Daily turnover*	Czeonia volume		All government bonds trading on the Prague Stock Exchange	Index PX
Resiliency	Return-to-volume ratio	Daily change in Czeonia index/daily turnover		Daily changes of 31 individual government bond prices/ /daily turnover	Daily changes of 13 individual stock prices/daily trunover
Liquidity premia	Spreads between alternative assets with different degrees of liquidity	2W PRIBOR and CNB 2W repo rate		IRS and benchmark government bond yields (2Y, 3Y, 4Y, 5Y, 10Y, 15Y)	
Volatility	30-days historical volatility	Czeonia index	CZK/EUR	10Y benchmark bond yield	Index PX
Indicator		MM_indicator	FX_indicator	GB_indicator	SM_indicator
		Market liquidity indicator			

Notes: O/N = overnight, W = week, M = month, Y = year, PRIBOR (BID) = Prague InterBank Offered (Bid) Rate, Index PX = main stock price index of the Prague Stock Exchange, IRS = interest rate swap, CZK = Czech Koruna, USD = United States Dollar, EUR = euro, GBP = sterling, CHF = Swiss franc, Czeonia = CZEch OverNight Index Average,

* the daily volume is always de-trended

Source: authors

uncertain future market conditions. In calculation of the liquidity premia, we have been limited by the lack of relevant data as the Czech financial system is not so extensive in all its segments. However, for two markets (money and government bond), we gauged two possible indicators of the liquidity premia: for money market, the difference between the two-week interbank rate and two-week CNB repo rate[5] and for government bond market, the difference between bond yields and interest rates swaps (so-called asset swap spread) with the same maturity (*Table 1*). It is expected that the wider spreads between the rates are, the higher liquidity premia are demanded and the less liquid markets are.[6]

The volatility index is used as a supplementary indicator of market resiliency. Consistent with the theory and practice, highly volatile market prices are likely to reflect low liquidity, as the price reacts too much to every trade given the lack of possible counterparties in the order book prepared to trade for the last price. We include this variable for each market segment (*Table 1*).[7]

[5] The CNB repo rate is the main instrument of Czech monetary policy.

[6] The spreads calculated in the above mentioned way include also other risk premia, mainly the credit/ /counterparty risk premium.

[7] We are aware of the fact that higher volatility does not always reflect lower liquidity, but we still see some merit in including it among the variables used to construct the market liquidity index given its relatively high correlation with market liquidity measured by other variables.

For each relevant market, all time series entering the calculation were first normalized (using the mean and standard deviation of the whole available time span) and then averaged within each of the five dimensions presented in *Table 1*. Each dimension represents an equal part of the compiled sub-indices for the four individual market segments, which are subsequently smoothed using the Hodrick-Prescott filter (MM_indicator, FX_indicator, GB_indicator and SM_indicator). Finally, the overall market liquidity index is calculated as a simple (unweighted) average of the four (smoothed) sub-indices.[8] Given that the underlying values are normalized, the units in which the index is expressed are standard deviations from historical average. We smoothed the individual sub-indices to more clearly indicate the trend in the market liquidity. The smoothing was applied at the level of the sub-indices (rather than at the level of the overall market liquidity index) to enable clear assessment of liquidity trends in individual market segments.[9]

The five dimensions and the four market segments were given equal weights in the composition of the sub-indices and the aggregate index, respectively, as it is ex ante difficult to assess overall relevance of the individual dimensions and segments. For example, for banks, stock market liquidity is probably less relevant than money market liquidity, but this may not hold for other market participants including for example households investing in stock markets through mutual funds.

Clearly, our market liquidity index is only a proxy for overall market liquidity. It is impossible to eliminate from the index certain temporary investors' behavior that is not necessarily related to market liquidity, such as speculation on changes in monetary policy rates.

For other countries in the Central and Eastern European region, we are aware only of the Hungarian financial market liquidity index compiled by the Hungarian National Bank (Páles and Varga, 2008), which uses a very similar methodology. They calculate sub-indices for the three basic dimensions (across relevant market segments, which exclude the stock market but include the FX swap market), followed by a calculation of an overall index.[10]

4. Construction of a Market-Based Funding Liquidity Indicator for Czech Banks

Funding liquidity is usually measured by indicators based on balance sheet data, such as the ratio of variously defined liquid assets to total or short-term liabilities, or the deposit-to-loan ratio. These are available usually at monthly frequency. However, funding liquidity may deteriorate very quickly over a few days, so ideally a more frequent (daily or weekly) indicator of funding liquidity risk would be appropriate to monitor the liquidity situation in financial institutions.

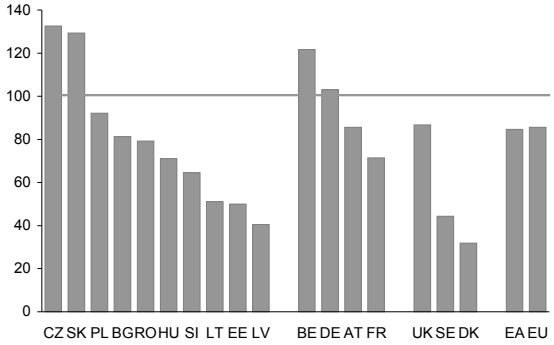
Drehmann and Nikolaou (2009) suggested a way to derive an indicator based on data from banks' bidding behavior in open market operations of the European

[8] This index is available from 2000, although until end-2001 it excludes the government bond market, for which data are available only from 2002 (see Section 5).

[9] See for example CNB (2009, p. 34).

[10] Market liquidity indices exist for some emerging markets outside the Central and Eastern European region, usually constructed by the central banks to facilitate their financial stability monitoring. Examples are the stock market liquidity index for China (Lee and Wong, 2009) or market liquidity index for Chile (Banco central de Chile, 2007, p. 25).

Figure 1 Deposit-to-Loan Ratios in Selected EU Countries
(%; 2008; resident loans and deposits; non-bank institutions)



Notes: EA = euro area; EU = average for all EU countries; CZ = Czech Republic; SK = Slovak Republic; PL = Poland; BG = Bulgaria; RO = Romania; HU = Hungary; SI = Slovenia; LT = Lithuania; EE = Estonia; LV = Latvia; BE = Belgium; DE = Germany; AT = Austria; FR = France; UK = United Kingdom; SE = Sweden; DK = Denmark.

Sources: European Central Bank; authors' caluclations.

Central Bank (ECB). Open market operations conducted by the ECB in weekly frequency serve to provide short-term liquidity (central bank money for a given maturity of one week) to banks in exchange for sufficient collateral.[11] Within the operations, individual banks submit bids (volume and price) for the central bank money provided that the bid rate cannot be lower that the minimum bid rate set by the ECB Governing Council. The auction is price-discriminating, i.e. each successful bidder pays for his bid. On the marginal rate, bids may be rationed if the total demand for central bank money is higher than the planned allotment.[12]

Theoretical findings by Nyborg and Strebulaev (2004) suggest that a bank needing to raise cash to settle obligations will bid more aggressively in such an auction, i.e. submit higher bid rate and larger volume, especially if it cannot get liquidity in the interbank market. Using these findings, Drehmann and Nikolaou (2009) build an indicator that is based on the difference between the bid rate and the policy rate (adjusted by the relative share of each bank in the total allotted volume). The higher bid rate and the larger volume demanded by a bank (relative to the total allotment) reflects higher funding liquidity risk of that particular bank.[13]

The Czech banking system features relatively high balance-sheet liquidity due to the exceptionally high deposit-to-loan ratio in comparison to both new EU countries as well as other selected EU countries or the euro area (*Figure 1*). The liquidity surplus of the banking system is absorbed by the CNB via its open market operations in the form of repo tenders. The tenders are harmonized with the ECB tenders.

[11]There are also some other less frequent fine-tuning operations and tenders with the maturity of 3 months.

[12] This description was valid only until 7 October 2008 when the ECB changed the operations to a fixed rate tender procedure with full allotment at the policy rate to satisfy any demand for short-term liquidity provided the bank had sufficient collateral. For details, see:
http://www.ecb.int/mopo/implement/omo/html/index.en.html.

[13] To construct an aggregated indicator of funding liquidity risk, Drehmann and Nikolaou (2009) sum the indicator across all banks for each auction.

The only differences are that the CNB tenders have a two-week maturity (rather than one), are used to absorb rather than provide liquidity to the banking sector, and are organized three times a week.[14]

At the first sight, it seems that the liquidity-absorbing nature of the CNB's repo tenders prevent us to apply the Nyborg and Strebulaev (2004) logic to construct a funding liquidity risk indicator out of the bidding behavior of Czech banks. However, because a bank gives up liquidity in the repo operations for two weeks, it is reasonable to assume that the bank's bidding behavior will also reflect an assessment of its own liquidity needs and thus the funding liquidity risk. We thus start by assuming that a bank's behavior in a tender (i.e. both the volume bid and the rate bid) is a function of its balance-sheet liquidity.

In systems where banks traditionally demand liquidity from the central bank (e.g. in the euro area), banks with deteriorating balance-sheet liquidity will bid higher amounts more aggressively at an interest rate which is further from (higher than) the set (minimum) limit rate. In the Czech Republic, where the CNB traditionally absorbs liquidity from banks, banks will be less willing to deposit their liquidity with the CNB for two weeks in the case of deteriorating balance-sheet liquidity and will do so only at the maximum (limit rate).

The construction of the market indicator of funding liquidity risk (MIFL) is based on a modification of the approach used by Drehmann and Nikolaou (2009). We first calculate the so-called "adjusted bid" (*AB*) for each bank *i* and each day of tender *t* according to the equation below, which combines information about the spread between the maximum (limit) repo rate and the bid rate and about the relative bid volume to the total liquidity absorbed, i.e.[15]

$$AB_{it} = \frac{(repo\_rate_t - bid\_rate_{it}) \cdot volume_{it}}{total\_volume_t}.$$

The bid volume must be weighted by the total volume absorbed to capture factors leading to a change in the bid volume that are not caused by a change in the perceived balance-sheet liquidity risk and are common to all banks (e.g. a change in the repo rate or generally lower tender volumes). The main difference to the adjusted bids constructed by Drehmann and Nikolaou (2009) is the opposite interpretation of this variable that arises from the liquidity-absorbing nature of CNB operations, i.e. lower (rather than higher) values of *AB* stand for higher funding liquidity risk. The highest funding liquidity risk corresponds to a situation where a bank is bidding at the maximum (limit) rate, thus the *AB* is equal to zero. This behavior is interpreted as increased concern about a lack of liquidity on the part of the bank.

One dimension of bidding behavior that is not captured by the *AB* is a bank's decision not to participate in the CNB tender on a given day at all. This would correspond to an increase in funding liquidity risk as the bank prefers to hold money (for example in the form of an O/N deposit at other banks or at the central bank) and pay

[14] Before May 2006, the CNB repo tenders were conducted daily.

[15] If a bank made more than one bid in a single tender or if more than one tender took place in a single day, the bids were averaged.

the opportunity cost in the form of foregone interest. Thus, we sum the *AB* either across several tender days (for example in a month) for each bank or across banks for each day of the tender.

The last step involves a transformation of the summed AB (either for a bank or for a day) to enhance interpretation and presentation. The final MIFL was calculated as a logarithm of the inverse of the summed *AB*s to achieve "higher MIFL higher risk" relationship. However, as the *AB* often equals zero and so may the sum of *AB*s, before creating the inverse the sum of *AB*s was adjusted by a very small constant ε that is ensuring the existence of an inverse value for any number (including zero). Thus, a bank's MIFL for a given time span (for example a month) was calculated as

$$MIFL_i = \log\left[\frac{1}{\sum_{t=1}^{T} AB_{it} + \varepsilon}\right]$$

while a day's (or tender's) MIFL was calculated as

$$MIFL_t = \log\left[\frac{1}{\sum_{i=1}^{I} AB_{it} + \varepsilon}\right]$$

where *I* corresponds to the number of participating banks in the given tender.

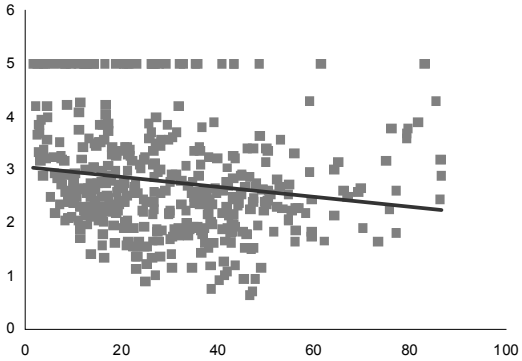
Higher MIFL indicates a greater risk of an outflow of balance-sheet liquidity, while lower MIFL indicates a low funding liquidity risk. We set the constant ε to 1E-5, so that the resulting MIFL ranges between 0 and 5. It takes the highest value of 5 if a bank (or banks for the day's MIFL) enters repo tenders with the CNB at the limit rate, i.e. the highest possible rate. The data for all 23 participating banks were available for the period May 2007 to March 2009[16] and thus cover the most important period of the global financial crisis for the Czech Republic, including the increased risk aversion towards the Central and Eastern Europe between December 2008 and end-February 2009 (CNB 2009).

Figure 2 shows the banks' monthly MIFL for as a function of the average traditional balance-sheet liquidity indicators (the ratios of quick liquid assets to assets, to liabilities and to deposits) lagged by one month to capture the fact that the bidding behavior is to some extent influenced by the liquidity position in the previous period.[17] The figure suggests that there is a negative correlation between the ratios and the MIFL (of around -20%; the slope coefficient in *Figure 2* is - 0.01 and is

[16] The Czech banking sector consists of 36 banks including branches of foreign banks and specialized savings buildings societies. The 23 banks that participate in the repo operations with the CNB are the most important banks in the country (in terms of both size and activity on the markets), and represent almost 90% of the banking sector assets.

[17] We also compared the results using banks' balance-sheet ratios and MIFL of the same month and they do not differ.

Figure 2 Relationship between the "Ratio Indicators" of Funding: Liquidity and the Market Index of Funding Liquidity (MIFL)
(x-axis: average ratios of banks in different months;
y-axis: MIFL of banks in the following month)



Sources: Czech National Bank; authors' calculations.

significant at 1% percentage level) and supports the hypothesis that banks with weaker funding liquidity position tend to bid more aggressively (in the sense of biding at the maximum limit rate).

The clustering of observations at MIFL = 5 is due to many banks bidding in some months at the maximum limit rate. The visible "gap" between MIFL values around 4 and 5 is due to selected level of ε and is kept intentionally to emphasize the "terminal" value of 5.[18]

5. Liquidity and the Global Financial Crisis of 2007–2009

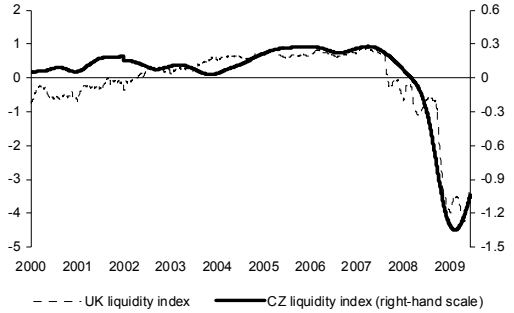
The Czech financial system has not been severely affected by the global financial turmoil (CNB 2008, 2009). Reflecting mainly their strong focus on retail banking in the as yet unsaturated Czech market, Czech financial institutions had low exposures to toxic assets. The stability of the domestic banking sector in times of financial market turbulence has also been fostered by banks' high balance-sheet liquidity and thus minimum dependence on interbank markets, funds from foreign markets or parent companies.

The global financial crisis nonetheless to some extent affected the liquidity on Czech financial markets, as illustrated by the market liquidity index (*Figure 3*). The index signaled declining market liquidity in late 2007 and early 2008, followed by a sharp drop during the peak of the global financial crisis in the months that followed the collapse of Lehman Brothers in September 2008. Nevertheless, when compared to the development of similar indices for the U.K. financial markets (*Figure 3*),[19] the euro area (ECB 2009) or global financial markets (IMF 2009), liquidity

[18] Higher levels of ε such as 1E-4 would not produce such a big gap, but there would be a risk of having the same value of MIFL for situations with all banks bidding at marginal rate and situation where for example one small bank bids with a positive AB.

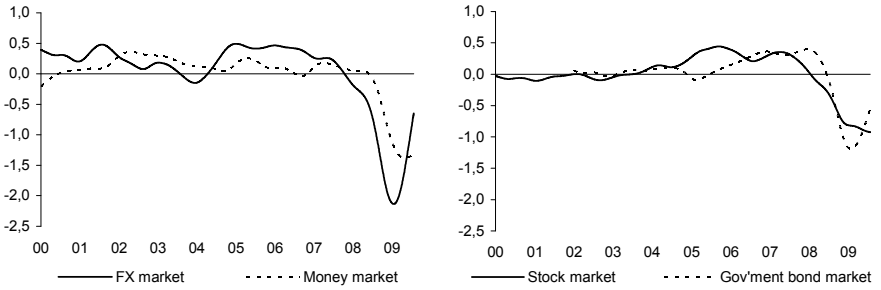
[19] The UK market liquidity index is constructed as a simple unweighted average of nine liquidity measures, normalised on the period 1999–2004. The series shown is an exponentially weighted moving average (Bank of England, 2007).

Figure 3 Overall Market Liquidity Indices for the Czech and the U.K. Financial Markets
(in standard deviations from historical average)



Sources: Czech National Bank; Bank of England; Bloomberg; authors' calculations.

Figure 4 Partial Market Liquidity Indices for the Czech Financial Markets
(in standard deviations from historical average)



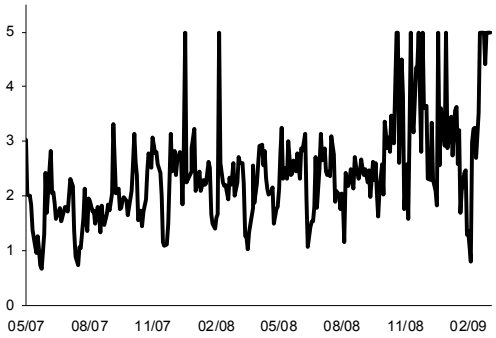
Sources: Czech National Bank; Bloomberg; authors' calculations.

on the Czech financial market was not impaired that much. Hungarian liquidity index followed the same direction as the other indices. The largest decline was evident after the fall of Lehman Brothers and at the beginning of this year. The Hungarian index is currently higher, but below pre-crisis values (MNB 2009, p. 32, Chart 2-11).[20]

The decline in overall market liquidity index was due to a decline in all market liquidity sub-indices for individual market segments (*Figure 4*). While in the FX market the decline in liquidity was driven by a combination of wider spreads and a sudden increase in volatility, in the money market it was driven by several simultaneous factors. Bid-offer spreads widened at all maturities from 10 basis points to around 30 basis points, all interbank rates with longer maturities started significantly exceeding the monetary policy rate, trading decreased at maturities longer than one week, and activity was concentrated mostly in the overnight segment. Trading activity decreased and bid-ask spreads widened also in the stock market.

[20] A comparison with the euro area, the U.K. and global market liquidity indices reveals that while the pattern is similar, the global, euro area and the U.K. indices increased much more in the „good" times of low risk aversion and global excess of liquidity in the years 2003–2007 and decreased much more during the global financial crisis 2007-2009 (ECB, 2009, p. 65, Chart 3.1.; Bank of England, 2009, p. 5, Chart 1; IMF 2009, p. 5, Figure 1.4).

Figure 5 Market Index of Funding Liquidity (MIFL)
(tender's MIFL, range between 0 and 5)



Sources: Czech National Bank; authors' calculations.

Market liquidity problems were also observed in the Czech government bond market. In mid-October 2008, in a situation of excess government bond supply on the market, particularly on the part of foreign institutional investors,[21] market-makers' bid-offer spread widened from the usual 20 basis points to about 300 points. This wide spread temporarily almost paralyzed trading in this market via market-makers (CNB, 2009).[22]

As a whole, the Czech banking system recorded no major balance-sheet liquidity difficulties. There were no bank runs, panics or large withdrawals of liquidity from bank accounts by households and firms.[23] However, the deterioration in market liquidity led to concerns about fund availability, and decreased confidence in financial institutions. This stimulated liquidity hoarding, leading to an increased concentration of liquidity in a small group of banks. Thus, as a result of declining market liquidity, the funding liquidity risk increased. This has been reflected in the decrease in the overall liquidity withdrawn in the CNB two-week repo tenders.

The market index of funding liquidity (MIFL) calculated across all banks for each day of the tender measures the risk of an outflow of balance-sheet liquidity for the banking sector as a whole. *Figure 5* shows that this risk increased primarily in 2008/Q3 and early 2009, when banks' interest in entering tenders with the CNB decreased, and if they did enter them it had to be at a price close to the maximum rate (i.e. the *AB* equals 0 and thus the MIFL equals 5). The spikes in December 2007 and early 2008 correspond to days where there have been some frictions already in the global markets, the December one partly explained by end-of-year effects.

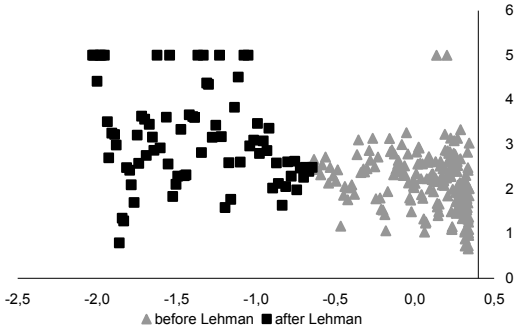
The MIFL indicator supports increased concerns regarding a shortage of liquid funds on the market and the hoarding of liquid funds by banks in response to the worsening market situation following the September 2008 events. We can docu-

[21] Excess market supply of government bonds may have been partly related to a change in the range of collateral accepted by the ECB for operations in the Eurosystem. As the demand for eligible collateral accepted by the ECB increased, the supply of other high-quality securities, including Czech government bonds, increased in parallel.

[22] The trading volume on the secondary government bond market did not fall, however. Trades continued to be carried out through the system of brokers instead of market makers.

[23] However, there was a temporary increase in currency in circulation, see CNB (2009).

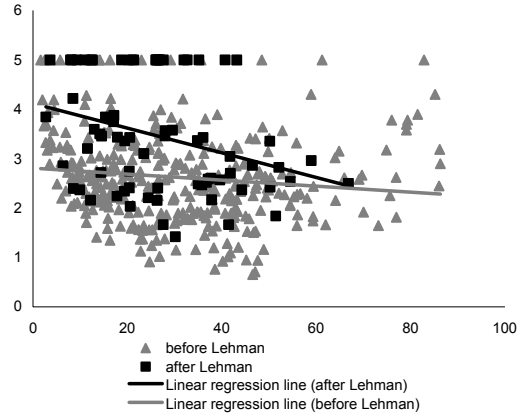
Figure 6 Relationship between Market Liquidity and the MIFL
(x-axis: market liquidity index; y-axis: tender's MIFL)



Notes: The individual points are the tender dates (total of 283 points) ranging from 2 May 2007 to 2 March 2009. As the tenders were organized three times a week, the number of the data points is lower than what would correspond to daily frequency.

Sources: Czech National Bank; Bloomberg; authors' calculations.

Figure 7 Relationship between the "Ratio Indicators" of Funding Liquidity and the MIFL in Two Different Periods of the Crisis
(x-axis: average ratios of banks in different months;
y-axis: MIFL of banks in the following month)

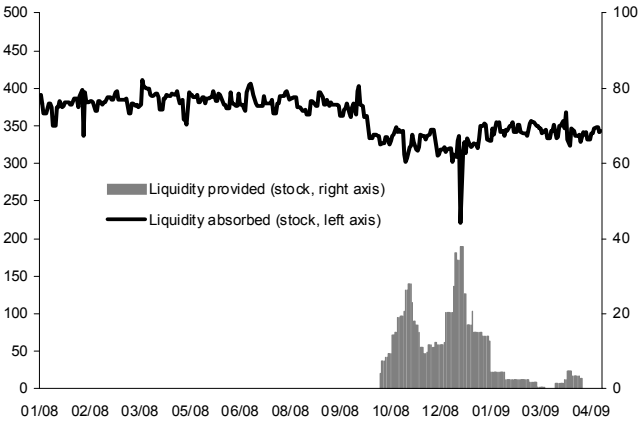


Sources: Czech National Bank; authors' calculations.

ment a downward spiral between funding liquidity risk and market liquidity by juxtaposing the MIFL for each day and the market liquidity index. *Figure 6* confirms some correlation between market and balance-sheet liquidity risk perceived in the whole banking sector (as measured by the MIFL) of around -53% (statistically significant at 1% level) and shows that the risk of an outflow of balance-sheet liquidity increased in the Czech Republic after the collapse of Lehman Brothers in September 2008, a period in which the market liquidity declined as well.

We can also document that those banks that had weaker funding liquidity as measured by the traditional ratio indicators were bidding even more aggressively in the CNB repo tenders after the Lehman Brothers collapse (*Figure 7*). The linear re-

Figure 8 CNB: Absorbed versus Provided Liquidity
(in CZK billion, as stock)



Source: Czech National Bank.

gression line which shows the relationship between ratio indicators of funding liquidity and the banks' MIFL has steepened in the period between September 2008 and March 2009.[24]

In October 2008, as a reaction to the evolving adverse liquidity spiral that manifested itself in frictions in the interbank and the government bond market, the CNB introduced a liquidity-providing facility in the form of a fixed rate tender procedure with full allotment at the policy rate plus margin. This new type of operation allowed government bonds to be accepted as collateral (in addition to short-term bills). This helped ease market participants' concerns regarding the potential illiquidity of these securities. This proved useful especially for smaller banks that were lacking liquidity and were unable to find it in the dysfunctional interbank market or secondary government bond market. However, the amounts of the central bank money provided within this facility is much smaller that the volumes that are withdrawn (*Figure 8*). This can be interpreted along two different veins, both positive. First, relatively small amounts of liquidity injections (when compared to liquidity absorbed) were sufficient to improve the liquidity situation. Second, the banking system as a whole was rather resilient to the liquidity problems.

6. Conclusions

Global financial crisis has brought a renewed attention to the liquidity risk and the relationship between market and funding liquidity in banks. The so-called negative liquidity spiral, i.e. situation where declining market liquidity leads to an increase in the risk of funding liquidity outflow, which in turn reinforces the declining trend in market liquidity, emerged to some extent even in countries which were not directly hit by the global financial crisis.

[24] The slope of the relationship changed from -0.006 in the pre-Lehman period to -0.025 in the post-Lehman period. The Chow breakpoint test (F = 23.9, prob. F(2,414) = 0.000) rejects the null hypothesis of no break in the time series in the month of Lehman failure.

In this article, we documented the existence of a negative feedback effect between market and funding liquidity in the Czech Republic. We constructed a market-based funding liquidity index using data from banks' bidding behavior in the repo operations of the Czech National Bank and market liquidity index of Czech financial markets using traditional indicators of market depth, resiliency and tightness. We argue that an assessment of banks' liquidity situation based on selected aggregated ratio indicators should be ideally complemented by some microeconomic analysis that uses individual banks' behavioral data.

The results of the analysis show that in the peak of the financial crisis (i.e., in the two quarters that followed the collapse of Lehman Brothers in September 2008), the indices of market liquidity and funding liquidity showed a significant degree of co-movement. However, as the Czech Republic' banking system has a strong balance-sheet liquidity position, the magnitude of the adverse liquidity problem was of much lesser extent than in the countries where the crisis originated. To prevent possible further deepening of the adverse liquidity loop, the central bank has reacted by introducing a new liquidity-providing facility which stabilized the markets.

At the same time, it should be emphasized that although there were some signs of adverse liquidity loop, the effect on the banking system was only marginal. The Czech Republic's banking system is one of the strongest in the EU as regards funding liquidity. Czech banks are not dependent on foreign funding and continued to show decent profitability over the whole period of global financial crisis.

REFERENCES

Banco central de Chile (2007): *Financial Stability Report*.

Bank of England (2007): *Financial Stability Report*. October.

Bank of England (2009): *Financial Stability Report.* June.

Banque de France (2008): *Financial Stability Review – Special issue on liquidity*, no. 11.

Black F (1971): Towards a Fully Automated Stock Exchange. *Financial Analysts Journal*, 27(6).

Borio C (2000): Market Liquidity and Stress: Selected Issues and Policy Implications. *BIS Quarterly Review*, November: 38–51.

Brunnermeier M, Pedersen L (2007): Market liquidity and funding liquidity. *CEPR DP*, no. 6179.

Bank for International Settlements (1999): Market Liquidity: Research Findings and Selected Policy Implications. *Committee on the Global Financial System Publications*, no. 11.

CNB (2008): *Financial Stability Report 2007*.

CNB (2009): *Financial Stability Report 2008/2009*.

Drehmann M, Nikolaou K (2009): Funding Liquidity Risk: Definition and Measurement. *ECB WP*, no. 1024.

ECB (2007): *Financial Stability Review*. December.

ECB (2008): *Financial Stability Review*. June.

ECB (2009): *Financial Stability Review*. June.

Frank N, González-Hermosillo B, Hesse H (2008): Transmission of Liquidity Shocks: Evidence from the 2007 Subprime Crisis. *International Monetary Fund Working Paper*, no. 08/2008.

International Monetary Fund (2008a): *Global Financial Stability Report.* April 2008.

International Monetary Fund (2008b): *Global Financial Stability Report.* October 2008.

Kyle A (1985): Continuous auctions and insider trading. *Econometrica*, 53(6).

Lee J, Wong A (2009): Impact of Financial Liberalisation on Stock Market Liquidity: Experience of China. *Hong Kong Monetary Authority, Working Paper,* no. 03/2009.

Magyar Nemzeti Bank (2009): *Financial Stability Review, November 2009*.

Nyborg KG, Strebulaev IA (2004): Multiple Unit Auctions and Short Squeezes. The *Review of Financial Studies*, 17(2):545–580.

Páles J, Varga L (2008): Trends in the liquidity of Hungarian financial markets – What does the MNB's new liquidity index show? *MNB Bulletin.* April.

Praet P, Herzberg V (2008): Market liquidity and banking liquidity: linkages, vulnerabilities and the role of disclosure. *Banque de France: Financial Stability Review – Special issue on liquidity*, no. 11.