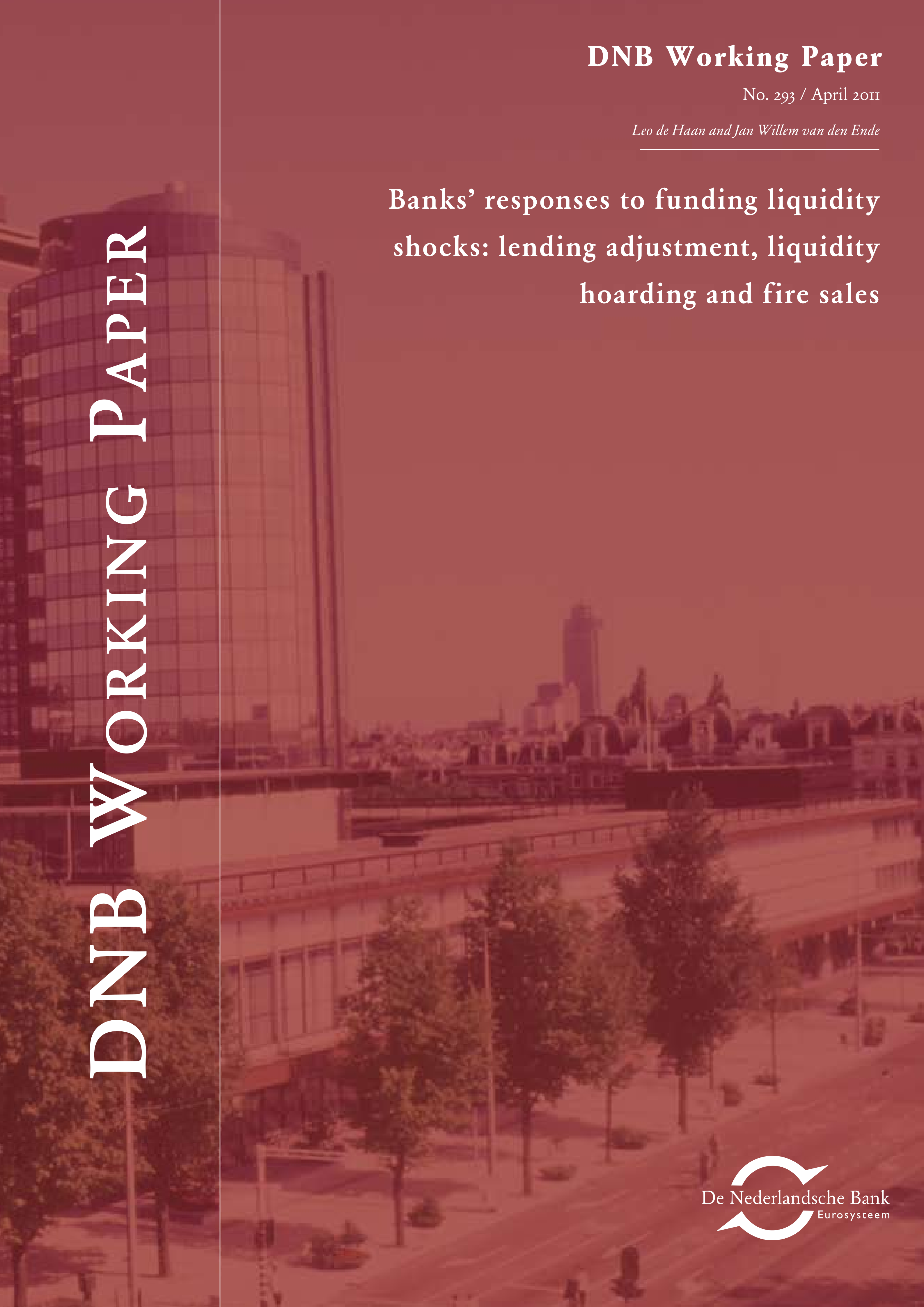

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De Nederlandsche Bank
Eurosysteem

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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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Banks’ responses to funding liquidity shocks: lending adjustment, liquidity hoarding and fire sales

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Abstract

The crisis of 2007-2009 has shown that financial market turbulence can lead to huge funding liquidity problems for banks. This paper provides empirical evidence on banks’ responses to wholesale funding shocks, using data of seventeen of the largest Dutch banks over the period January 2004 to April 2010. The dynamic interrelations among instruments of bank liquidity management are modelled in a panel Vector Autoregressive (p-VAR) framework. Orthogonalized impulse responses reveal that banks respond to a negative funding liquidity shock in a number of ways. First, banks reduce lending, especially wholesale lending. Second, banks hoard liquidity in the form of liquid bonds and central bank reserves. Third, banks conduct fire sales of securities, especially equity. We also find that fire sales are triggered by liquidity constraints rather than by solvency constraints.

Key words: Banks, Funding, Liquidity, Banking crisis

JEL Codes: G21, G32

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1. Introduction

The financial crisis of 2007-2009 has shown that if wholesale funding dries up, banks face huge funding liquidity problems. The freeze of wholesale funding markets was an essential characteristic of the crisis (IMF, 2010). In particular, the part of wholesale funding that is linked to asset markets, i.e. repo funding, issuance of securities and asset-backed finance, was hit hard. This activated the liquidity channel of financial transmission through which funding liquidity shocks are propagated to bank lending and the real economy (BIS, 2011). Evidence on the role of financial markets in the liquidity channel remains scarce. This paper contributes to filling this gap by analysing empirically how banks adjust to a funding liquidity shock originating from financial market volatility, using data on Dutch banks during the financial crisis.

We focus on three types of adjustment on the asset side of the bank balance sheet: (1) reduced lending, (2) liquidity hoarding, and (3) fire sales. Figure 1 shows a stylized bank balance sheet illustrating these three types of responses. If a bank is confronted with a negative shock in wholesale funding (depicted by a downward pointing arrow), it has the following options. First, it can cut down lending, either retail or wholesale. Second, it can sell securities from its investment portfolio, which is known as 'fire sales' if the bank is under pressure to do so. Third, it can borrow from the central bank (thus bringing down its net claims position). If the bank fears that its future access to liquidity is uncertain, it may even borrow extra from the central bank and hold these funds as a buffer in deposit at the central bank. Liquidity buffers could also be strengthened by holding more highly liquid bonds. These two precautionary saving measures can be classified as 'liquidity hoarding' (denoted by the arrows within parentheses in Figure 1).

[insert Figure 1 about here]

Aspects of the above mentioned three behavioural responses to funding liquidity shocks have been addressed in the recent literature, both empirically and theoretically. Theoretically, Diamond and Rajan (2005) stress the interaction and reinforcing effects of banks' liquidity shortages and solvency problems. They explain how aggregate liquidity shortages can emerge and force banks to prematurely foreclose otherwise profitable loans, which can result in banks facing sizable losses that will restrain future lending. Empirically, the response of bank lending to funding shocks has been examined mostly by means of single equation models. For example, Ivashina and Scharfstein (2010) find that a greater volatility of deposits and draws on committed credit lines prompt banks to reduce lending. Cornett et al. (2010) find that US banks with more stable funding sources were better able to continue lending during the crisis. They also find that liquidity hoarding is mostly related to the proportion of illiquid assets and the presence of unused off-balance sheet loan commitments on the bank balance sheet. Acharya et al.'s (2008) theoretical study relates liquidity hoarding to so-called 'predatory behaviour', aimed at the exploitation of urgent funding needs of other market participants. They show that banks with surplus liquidity have an incentive to strategically underprovide liquidity to other banks, to be able to benefit from the latter's forced fire sales of assets against low liquidation prices. Similarly, Diamond and Rajan (2009) show that the expectation of distressed banks being forced to sell assets in the future at fire-sale prices drives healthy banks to hoard liquid funds so as to allow them to take advantage of future investment opportunities. Fire sales as such are mostly captured in theoretical models (e.g. Cifuentes et al., 2005) or in simulation models of central banks (e.g. Aikman et al., 2009). These models consider both liquidity and capital constraints as triggers of fire sales, without specifying which constraint is the most binding.

To the best of our knowledge, the link between fire sales on the one hand, and liquidity and capital constraints on the other, has not been examined empirically. Hence, another purpose of this paper is to examine the effects of both liquidity and capital constraints on fire sales. For theorists as well as regulators, it is important to know the relative importance of the bank liquidity and bank capital channel as a driver of adjustments on the asset side of banks' balance sheet. We employ a multi-equation framework instead of a single-equation framework, thus taking into account the dynamic interrelations among instruments of bank liquidity management. To investigate bank liquidity management strategies in more detail, our paper uses disaggregated balance sheet data. Spindt and Tarfan (1980), for example, model US banks' liquid assets and liabilities as a system of equations. In their model, liabilities are qualified as (weakly) exogenous and assets as endogenous, based on the idea that banks can determine their investment and lending strategies, while the availability of funding is predominantly given. We adopt similar assumptions in this paper. However, there are several differences between their and our approach. Spindt and Tarfan estimate separate models for five large US money-center banks and then average the coefficients. In contrast, we estimate a multi-equation model while pooling our sample of banks, so that the model represents the banks' average behaviour. Further, we use a panel Vector Auto-Regressive (p-VAR) model, which takes into account the heterogeneity between individual banks by allowing for fixed effects. An advantage of VAR models is that they can be used to generate orthogonalized impulse-response functions, identifying the impact of an isolated shock to one variable to all the other variables in the system.

Our VAR model is estimated using monthly data of 17 of the largest Dutch banks over the period January 2004 to April 2010. This period encompasses the run-up to and subsequent unwinding of the financial crisis. We find that banks respond to an asset market driven funding shock in several ways. First, banks reduce lending, especially wholesale lending. Second, banks hoard liquidity, in the form of liquid bonds and central bank reserves. Third, banks conduct fire sales of securities, especially equity. Finally, our results suggest that fire sales are triggered by liquidity constraints rather than by solvency constraints.

The structure of the paper is as follows. Section 2 introduces the model. Section 3 describes the data and some stylized facts. Section 4 discusses the results. Section 5 presents several robustness checks, after which Section 6 concludes.

2. Model

We use a panel-VAR model, which treats all variables in the system as endogenous and allows for unobserved individual heterogeneity by including fixed effects. The model reads as follows:

$$\begin{bmatrix} X_t \\ Y_{it} \end{bmatrix} = A_i + B(L) \begin{bmatrix} X_t \\ Y_{it} \end{bmatrix} + \varepsilon_{it} \qquad (1)$$

where X_t is a vector containing one market funding cost variable for each month t and Y_{it} is a vector holding a set of balance sheet variables for each bank i and month t. In Section 4 the variables which are included in the respective models are specified. A_i is a matrix of bank-specific fixed effects, $B(L)$ is a matrix polynomial in the lag operator whose order is 3 according to the Akaike transformation criterion. ε_{it} is the error term. The coefficients of the p-VAR are estimated by system Generalised Method of Moments (GMM), using lags of the model variables as instruments.[1] The fixed effects are eliminated by expressing all variables as deviation from their means. Since the fixed effects are correlated with the regressors as a result of the inclusion of lags of the dependent variables, ordinary mean-differencing (i.e. expressing all variables as deviations from their full sample period's means) as commonly used to eliminate fixed effects would create biased coefficients. To avoid this problem, forward mean-differencing, also known as 'Helmert' transformation', is used instead (cf. Arellano and Bover, 1995). This procedure removes only the forward mean, i.e. the mean of all future observations available in the sample and preserves the orthogonality between transformed variables and lagged regressors, so that the lagged regressors can be used as valid instruments for estimating the coefficients by system GMM.

The model variables are chosen for their relevance with respect to our three behavioural hypotheses under consideration (see Appendix A for the definitions of the variables). On the liability side, we distinguish retail funding (*RETDEP*), secured wholesale funding by repurchase agreements (*REPO*) and securities funding (*SECUR*). Next to these balance sheet variables, we include a market funding cost variable, notably the spread on the money market swap rate (*SPR*). *SPR* is the cost of unsecured interbank funding and is usually considered to be an important determinant of banks' deposit and lending rates. For bank lending we consider two main categories, wholesale lending (*WSCR*) and retail lending (*RETCR*). Liquidity hoarding is captured by the asset side variables of highly liquid bonds (*BONDL*) and net claims on the Central Bank (*NCCB*). Both can act as liquidity buffer in times of stress. By relating these two variables to secured wholesale funding (*REPO*) and issued securities (*SECUR*), the link between liquidity hoarding and funding sources that depend on asset markets can be investigated. Negative shocks in the latter two funding sources (*REPO* and *SECUR*) are also assumed to be potential triggers of fire sales of investments in less liquid bonds (*BONDI*) and equity investments (*EQ*), under the assumption that under stressful market conditions banks prefer to sell their least liquid bonds (*BONDI*) first, while holding on to their highly liquid bonds (*BONDL*) for precautionary (liquidity hoarding) reasons. We note that contagion effects between individual banks are not studied explicitly in this paper. However, several of the model variables (for example, *WSCR* and *REPO*) partly measure how much a particular bank lends to c.q. borrows from all other banks. Hence, spill-over effects are captured implicitly by the panel VAR model's coefficient estimates.

[1] For more details we refer to Love and Zicchino (2006), whose Stata code we gratefully used for the estimation.

To examine banks' responses to funding liquidity shocks, we use impulse-response functions that are derived from the p-VAR model. The shocks are orthogonalized, so that the response of one variable to a shock in another variable can be interpreted as the reaction of the former variable to the innovations in the latter variable, while holding all other shocks equal to zero. To orthogonalize the shocks it is necessary to decompose the residuals. The decomposition is conducted by imposing a particular ordering of the variables in the system and attributing any correlation between the residuals of any two elements to the variable that comes first in the ordering. This procedure is known as the Choleski decomposition. The identifying assumption is that variables that come earlier in the ordering affect the following variables contemporaneously, as well as with lags, while the variables that come later affect the previous variables only with lags. In other words, the variables that appear earlier in the ordering are more exogenous than the ones that appear later (or, more formally, in the short run the former are weakly exogenous with respect to the latter). We will perform robustness checks to test the sensitivity of the outcomes for changes in the ordering of the variables.

Since the impulse-response functions are constructed from the model's estimated coefficients, the latter's standard errors need to be taken into account. We calculate the standard errors and generate confidence intervals of the impulse response functions using Monte Carlo simulations. This is conducted by taking random draws of the model's coefficients, using the estimated coefficients and their variance–covariance matrix. We take 1000 draws. The 5th and 95th percentiles of the resulting distribution are used for the 90% confidence intervals of the impulse-responses.

For our model specifications, we generally adopt the following principles with respect to the ordering of the variables. First, we assume that shocks in the cost of wholesale funding have an immediate effect on the balance sheet variables and that the funding cost responds to the balance sheet shocks with a lag. Second, we assume that bank liabilities respond more quickly than bank assets. This assumption reflects the fact that funding depends on market conditions that are often outside the banks' direct control, while banks' asset management in principle is at their own discretion.[2] Third, we assume that wholesale instruments (assets as well as liabilities) respond more quickly than retail items. This takes into account that wholesale instruments usually have shorter maturities than retail instruments and therefore can be more

[2] Access to funding may depend on banks' risk management strategies as well, but most likely with a lag.

easily adjusted. Fourth, we assume that liquid balance sheet items with a short maturity adjust more quickly than less liquid and longer-term items.

3. Data and stylized facts

We use monthly data on liquid assets and liabilities of Dutch banks over the period January 2004 to April 2010. This period encompasses both the pre-crisis and the crisis period. Our variables of interest are summed up and defined in Appendix A. All balance sheet variables are scaled by total assets. The forward mean-differencing transformation contributes to the stationarity of the model variables. Panel unit root tests indicate that all series are stationary.[3] The variables for securities holdings (*BONDL*, *BONDI* and *EQ*) have been deflated by a relevant market price index[4], since we are interested in deliberate portfolio adjustments net of revaluation effects.

The data source of the bank variables is De Nederlandsche Bank's (DNB) prudential liquidity report (DNB, 2003). This unique data source contains end-of-month data on liquid assets and liabilities for all Dutch banks (including branches and subsidiaries of foreign banks) under supervision, with a detailed break-down per balance sheet item. Not every item is reported by all banks, since small banks do not have exposures in all categories. For that reason we use data of 17 banks whose average size during the sample period, measured by total assets, falls above the 80th percentile of the full sample's distribution.[5] We also use a sub-sample of the 5 largest banks. These top-5 banks (ING, ABN-Amro, Rabobank, SNS and Fortis-Netherlands, until its merger with ABN-Amro mid-2010) represent around 85% of total assets in the sector. The 17 institutions consist of the top-5 banks, 9 smaller domestic banks and 3 subsidiaries of foreign banks, together accounting for around 95% of the sector.

The asset side of the balance sheets is dominated by retail and wholesale loans (Table 1). On the liability side of the balance sheet, retail borrowing accounts for only a small portion (on average 10% to 15%). This is due to the relatively limited retail savings market in the Netherlands, where banks have to compete with pension funds and insurers (DNB, 2010). Our

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[3] The Levin, Liu and Chu t-test and the Fisher Chi-square-test, respectively, indicate that the null hypotheses of a common unit root process and individual unit root processes can be rejected.

[4] *BONDL* and *BONDI* have been deflated by the FTSE EURO index of AAA rated corporate bonds. *EQ* has been deflated by the MSCI worldwide stock index.

two samples mostly differ with regard to their reliance on asset market related wholesale funding. The largest 5 banks are more dependent on the repo market, with a share of secured wholesale borrowing (*REPO*) in total funding twice as high compared to the average of 17 banks. The smaller banks are relatively more dependent on the issuance of securities (bonds, commercial paper, certificates of deposits, including asset-back securities), as reflected in the average share of *SECUR* of 32.6% for the whole sample of 17 banks versus 22.0% for the top-5 banks.

[insert Table 1 about here]

Before estimating the model, we first describe some stylized facts for our selected model variables. The money market spread clearly depicts the pre-crisis period with a constant and low spread, and the crisis-period beginning in August 2007 with a surging spread. This reflects the drying up of the unsecured interbank market[6] (Figure 2, panel E). The reliance on secured wholesale funding by Dutch banks varied substantially between these two periods. In the years before the crisis, the use of secured wholesale funding relative to retail funding almost doubled (Figure 2, panel A). The benign market conditions and the development of new financial instruments (such as asset-backed securities) stirred banks to expand their wholesale funding rapidly between 2003 and 2007. This trend was driven by the strong growth of secured wholesale transactions. The boom in asset prices in the run up to the crisis boosted financing that was collateralised by tradable securities, particularly repo transactions. During the crisis, this trend reversed dramatically. This illustrates the sensitivity of wholesale funding, repos in particular, for stress in financial markets. Secured wholesale funding declined strongly relatively to retail funding, also because banks increased reliance on retail deposits in their search for more stable sources of funding (ECB, 2009). The issuance of securities fell somewhat back in 2008 but has recovered since 2009, which partly reflects the increased securitisation of assets pledged as collateral at the central bank.

[insert Figure 2 about here]

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[5] The total number of banks under supervision at the end of March 2010 was 81.

[6] Unsecured wholesale funding is captured by the cost variable *SPR* in the model. Unsecured wholesale funding itself is not among our model variables (therefore not shown in the figure). Besides, it was fairly stable during the crisis period, since the strong decline of interbank borrowing and fixed-term deposits was compensated by the growth of demand deposits from other professional money market participants.

Adjustments to lending were concentrated in the wholesale loan portfolio (*WSCR*) of the banks. In terms of total assets it fell from around 35% mid-2007 to 25% in 2010 (Figure 2, panel B). Retail lending (*RETCR*) was more stable. It even increased in 2007 and 2008 and has decreased slightly since 2009.

Liquidity hoarding by Dutch banks was evident by the increased amount of deposits and collateral pledged at the central bank. This outpaced central bank borrowing and as a result net claims on the central bank increased (*NCCB*; Figure 2, panel C). The rising share of highly liquid bonds in the total bond portfolio also indicates that Dutch banks hoarded liquidity in the crisis. The share of liquid bonds doubled between 2007 and 2010 to nearly 10%.

Figure 2, panel D, shows the development of the bond and equity portfolios, adjusted for revaluations. The decline of equity and bond portfolios between mid-2007 and mid-2008 reflects an active scaling down of these exposures, possibly reflecting fire sales.

4. Results

In this Section four p-VAR models are estimated. The first three are designed to capture three types of bank asset reallocation after a shock in funding liquidity, i.e. (1) a cut in lending, (2) liquidity hoarding, and (3) fire-sales. As an encore, a fourth model is estimated designed to test a fourth hypothesis, i.e. whether fire sales are triggered by solvency constraints.

Results are discussed for the sample of 17 banks and for the sub-sample of the 5 largest banks. However, we only display the results for the sub-sample of 5 banks if those are materially different from those of the full sample of 17 banks.

4.1 Response of lending

In the bank lending model, the variables in vectors *X* and *Y* of model (1) are:

$$[SPR \quad REPO \quad RETDEP \quad WSCR \quad RETCR]'$$

For bank lending we consider two main categories, wholesale lending (*WSCR*) and retail lending (*RETCR*). By also taking into account two main funding sources, secured wholesale borrowing (*REPO*) and retail deposits (*RETDEP*), we obtain a rather complete picture of credit management in relation to funding liquidity. With the inclusion of *SPR*, the model incorporates the price of bank funding, which also determines bank lending rates. We allow retail deposits to be immediately affected by the stress in the wholesale funding market, while any feedback effect is assumed to occur only with a lag. The response variable of interest is bank lending, which is split into wholesale lending and retail lending, of which wholesale lending comes first. Robustness checks indicate that changes in the ordering of the variables have no substantial effect on the results.

From the impulse responses (Figure 3) it appears that wholesale lending (*WSCR*) reacts significantly and positively to a shock in secured wholesale funding (*REPO*) and significantly and negatively to a shock in the money market spread (*SPR*). This applies both to the sample of 17 banks and the sub-sample of the 5 largest banks, and is in line with the experience in the 2007-2009 financial crisis that wholesale loans were most vulnerable to funding liquidity risk (ECB, 2010). A sudden rise of interbank spreads and/or constraints in repo funding urge banks to adjust their asset side quickly, both in terms of size and in terms of risk. It is plausible, and evident from the data (Figure 2, panel B), that banks realise this adjustment by changing their wholesale lending rather than their retail lending, since in general the former has a shorter maturity and a higher risk profile than the latter. This outcome is consistent with the theoretical framework of Huang and Ratnovski (2010), who show that negative market signals are an incentive for wholesale financiers to withdraw from lending, especially short-term interbank lending. Liedorp et al. (2010) establish the channel of contagion running from wholesale funding to interbank lending empirically.

[insert Figure 3 about here]

The impulse responses show a significantly negative response of retail lending (*RETCR*) to a shock in wholesale lending (*WSCR*), Figure 3, panel E. This suggests that, after a shock in the repo market, banks reduce the share of wholesale loans in their loan book in favour of (lower risk) retail loans. This substitution effect is weaker for the top-5 banks, which could reflect the fact that the largest banks have a more diversified asset side and therefore more flexibility to adjust their balance sheets. For both groups of banks, retail lending (*RETCR*) shows a brief but significantly positive response to a shock in retail deposits (*RETDEP*; Figure 3, panel D). This reflects the linkage between both retail items in the asset and liability management of banks. By matching retail lending with retail deposits, banks limit the retail funding gap and thereby their dependence on volatile wholesale markets for funding. Under volatile market conditions, banks shift their funding to more stable retail deposits, as is shown by the significant positive response of *RETDEP* to a shock in *SPR* (Figure 3, panel H). This response is only borderline significant for the top-5 banks, which again underlines that these banks have access to a wider range of non-retail funding possibilities than smaller banks.

4.2 Liquidity hoarding

The variables in the model for liquidity hoarding are:

$$[SPR \quad REPO \quad SECUR \quad BONDL \quad NCCB]'$$

Liquidity hoarding is captured by highly liquid bonds (*BONDL*) and net claims on the central bank (*NCCB*). Both can act as liquidity buffer in times of stress. By relating these two variables to both *REPO* and issued securities (*SECUR*) the link between liquidity hoarding and market dependent funding sources can be investigated. Variable *SPR* takes into account the influence of funding costs on the unsecured interbank market. The funding variables come first in the ordering of the p-VAR. By implication of the ordering, the money market spread has an immediate effect on repo borrowing and the issuance of securities, while any feedback effects are assumed to occur only with a lag. The response variable of interest is liquidity holdings, which is split into highly liquid bonds and net claims on the central bank.

The impulse responses (Figure 4) indicate that liquidity hoarding is evident in response to a shock in repo funding. For both samples of banks *BONDL* shows a (short) significant and negative reaction to a shock in secured borrowing (*REPO*; Figure 4, panels B and H), indicating that a disruption in the secured funding market is followed by an accumulation of highly liquid assets. This is in accordance with the experience during the crisis, when at some point only high-quality collateral was accepted for repo transactions, which stimulated the hoarding of such assets. There is also significant evidence of liquid bond hoarding in response to an upward shock in the money market spread (*SPR*) by the top-5 banks (Figure 4, panel G). We find no empirical evidence for feedback effects running from liquidity hoarding to the money market spread; the response of *SPR* to a shock in *BONDL* is not significant (result not shown in the figure).

The sample of 17 banks also accumulates central bank reserves (*NCCB*) in response to a shock in the money market spread (*SPR*), see Figure 4, panel D. Hence, the price of funding liquidity appears to be an incentive for precautionary savings at the central bank. This is in line with the theoretical model of Gale and Yorulmazer (2011), according to which the price of liquidity is an incentive to hoard liquidity. For the top-5 banks, *NCCB* does not respond significantly to a shock in *SPR* (Figure 4, panel G). This could be related to the tiering of the interbank market during the crisis, as a result of which large banks in general paid lower spreads on unsecured interbank borrowing than small banks. Liquidity hoarding in the form of increasing claims on the central bank (*NCCB*) is also visible in response to a (negative) shock in secured funding (*REPO*) for the sample of 17 bank, see Figure 4, panel E.

The 5 largest banks also seem to be less dependent on the central bank in case of a shock to repo funding; the impulse response in panel K of Figure 4 is not significant. This is not in accordance with the liquidity hoarding hypothesis, which assumes a negative response of *NCCB* to a shock in *REPO* (e.g. decline in repo funding urges banks to hoard central bank reserves, as is the case for the whole sample of banks, see panel E). However, it should be noted that variable *NCCB* is the difference between central bank deposits and borrowings, which implies that a change in *NCCB* could also reflect a change in central bank borrowing. This could explain the positive response of *NCCB* to *SECUR* (which is borderline significant for the top-5 banks, see panel L), since a shut-down of the primary market for securities issuance may stimulate banks to step up their borrowing from the central bank (lowering *NCCB*) by using asset-backed securities as collateral in refinancing operations. During the crisis, such securities were partly created for the purpose of collateralised borrowing at the central bank. The large banks in the Netherlands are particularly active in this field.

[insert Figure 4 about here]

We note that the results on liquidity hoarding are relatively sensitive to the ordering of the variables, especially with respect to the responses of *NCCB* to a shock in *SPR*.

4.3 Fire sales

The variables in the model for fire sales are:

$$[SPR \quad REPO \quad SECUR \quad BONDI \quad EQ]'$$

The first three variables are identical to the ones in the liquidity hoarding model specification. The response variable of interest is securities holdings, which is split into less liquid bonds (*BONDI*) and equity investments (*EQ*). We include *BONDI* instead of *BONDL* (which we used in the liquidity hoarding model), assuming that under stressful market conditions banks prefer to sell their least liquid bonds (*BONDI*) first, while holding on to their highly liquid bonds (*BONDL*) for precautionary reasons.

The impulse responses in Figure 5 do not show a significant response of investment portfolios to shocks in securities issued (*SECUR*; Figure 5, panels B and D), but the significant positive response of equity holdings to a shock in secured wholesale funding (*REPO*; panel C) is consistent with the occurrence of fire sales (this result is robust to changing the ordering of the variables in the VAR, while the sample of the 5 largest banks shows a similar impulse response). The positive relation between equity holdings and secured funding could also reflect the use of equities in repos and securities lending transactions. When these activities are buoyant, banks equity holdings are useful as collateral, while these become less useful when the secured funding market collapses and only high-quality bonds are accepted as collateral. The significant negative response of *EQ* to an upward shock in the money market spread (*SPR*) confirms the risk of fire sales after a shock in wholesale funding (panel F). This finding is in line with the results of Nyborg and Östberg (2010), that tightness in the interbank market for liquidity leads banks to pull-back liquidity, by selling equity portfolios, among other things. They conclude that this could be either due to direct sales of equity holdings by banks or to sales by other stock market investors that are confronted by a reduced liquidity supply of banks.

[insert Figure 5 about here]

Surprisingly, there is a negative response of less liquid bond holdings (*BONDI*) to a shock in secured wholesale funding (Figure 5, panel A), while there is no significant 'fire sales effect' for bonds in response to a shock in the funding spread (panel E). The same result - not shown in the figure - is found when less liquid bonds (*BONDI*) are replaced by highly liquid bonds (*BONDL*), suggesting that banks do not distinguish between liquid and illiquid bonds when they adjust their bond portfolio in response to a funding shock. Apparently, the liquidity hoarding motive (i.e. an increase of liquid bond holdings after a negative funding shock, cf. Section 4.2) dominates the fire sale motive with regard to bond portfolios. A reason for this dominance could be the additional liquidity supplied by the central bank during the crisis, which enabled banks to obtain funding against liquid and less liquid bonds as collateral. By these liquidity operations, central banks aimed to prevent costly fire sales of assets in financial markets by banks with a strong reliance on wholesale funding (ECB, 2010).

As pointed out in Section 1, theoretical models (e.g. Cifuentes et al., 2005) and simulation models (e.g. Aikman et al, 2009) are not clear about the issue whether liquidity or capital constraints are the main trigger for fire sales. Therefore, we also estimate a fourth model that relates securities holdings to both bank capital and the money market spread:

$$[SPR \quad TIER1 \quad BONDI \quad EQ]'$$

Variable *TIER*1 is the ratio of Tier 1-capital to risk-weighted assets. If solvency constraints trigger fire sales of assets, there should be a significantly positive response of *BONDI* and *EQ* to a shock in *TIER*1 (meaning that a deteriorating solvency position urges a bank to offload its investment holdings and vice versa). Figure 6 shows that such a relationship is not evident, neither for bonds nor for equity, while the impulse response of *EQ* is negative and significant with regard to a shock in the money market spread. A similar result is found for the sample of the 5 largest banks. From this we conclude that fire sales of equity are more likely to be triggered by funding liquidity constraints than by solvency constraints.

[insert Figure 6 about here]

Summing up, we find that in times of stress on the wholesale funding markets, banks reduce lending, particularly wholesale lending, hoard liquidity in the form of liquid bonds and sell off part of their investment portfolio, especially equity. We also find that fire sales are more likely to be triggered by funding liquidity constraints than by solvency constraints.

5. Robustness

In this section we present some robustness tests.[7] First, we re-estimate the models for the 12 smaller banks from our sample of 17 banks, i.e. excluding the 5 largest banks. Concerning the lending model the only notable difference is that retail credit does not significantly respond to shocks in *SPR* and *REPO*, which suggests that credit supply by the smaller banks is less sensitive to developments in wholesale funding markets. The impulse responses for the liquidity hoarding model are in line with the findings for the whole sample. The response of central bank reserves (*NCCB*) to repo funding (*REPO*) and funding cost (*SPR*) shocks is even stronger for the 12 banks than for the whole sample, suggesting that the smaller banks are more dependent on the central bank for liquidity. With regard to the fire sales model, the response of equity holdings (*EQ*) to a shock in the money market spread (*SPR*) and secured wholesale funding (*REPO*) is not found to be significant for the smaller banks (compared to the significant response for the whole sample of banks). One explanation for this difference could be that the smaller banks in the Netherlands hold less equity in their trading books and more equity in the form of participations that can be sold less easily. A shock to the capital ratio has no significant effect on equity or bond holdings, similar to the result for the whole sample of banks.

Second, we re-estimate the models for a sub-period representing the financial crisis (June 2007 to the last month in the dataset, April 2010). The impulse responses for the lending model show some notable differences. The response of wholesale lending (*WSCR*) to a shock in the money market spread (*SPR*) and secured wholesale funding (*REPO*) is stronger for the crisis period. This can be explained by the strong adverse shocks to the wholesale funding market during the crisis. At the peak of the crisis in September/October 2008, the money

[7] For reasons of space, the results are not presented in figures or tables, and are available on request.

market rate increased by more than 2 standard deviations in one month, while repo funding of Dutch banks dropped by almost 1 standard deviation on average for *two* months in a row. For comparison: all impulse response functions show a 1 standard deviation shock during *one single* month. The results of the liquidity hoarding and fire sales models are almost similar for both sample periods.

Third, we introduce a variable to the VAR specifications to test the influence of the default risk of the banks. This risk is reflected in the credit default swap spread (*CDS,* see Figure 7)[8] which replaces the money market spread variable (*SPR*) in the model specifications. In all models, *CDS* is included as the first variable, assuming that market prices are more exogenous to banks than their own balance sheets. In general, the results are similar to those of the original model specifications including *SPR*. A notable difference in the model for bank lending is that the response of wholesale credit to a shock in *CDS* is not significant for the whole sample of banks, while it is significantly negative if *SPR* is included instead of *CDS* (see section 4.1). This suggests that wholesale lending is to a larger extent driven by liquidity risk than by banks' default risk. A similar conclusion can be drawn with regard to the response of equity holdings in the fire sales model, which is significant for a shock in *SPR* (see section 4.3), but not significant for a shock in *CDS* (this difference is specifically due to the largest 5 banks). This is in line with the result found in section 4.3, i.e. that liquidity constraints rather than solvency constraints seem to trigger sales of equity holdings. A difference in the liquidity hoarding model is that the response of net central bank reserves (*NCCB*) to a shock in secured wholesale borrowing (*REPO*) is no longer significant. There is a significantly positive response of *NCCB* to *CDS*, though, suggesting that stress in financial markets (reflected in a higher *CDS*) goes in tandem with increased demand for central bank reserves (reflected in an increase of *NCCB*).

[insert Figure 7 about here]

[8] For the 12 smaller banks CDS spreads are not available. Therefore, for those banks we use the average CDS spreads of the five largest banks.

6. Conclusion

This paper provides empirical evidence on banks' responses to funding liquidity shocks, using data of seventeen of the largest Dutch banks over the period January 2004 to April 2010. The dynamic interrelations among instruments of bank liquidity management are modelled in a panel Vector Autoregressive (p-VAR) framework. Orthogonalized impulse responses reveal that banks respond to a negative funding liquidity shock in a number of ways. First, banks reduce lending, especially wholesale lending. Second, banks hoard liquidity, in the form of liquid bonds and central bank reserves. Third, banks conduct fire sales of securities, especially equity. We also find that fire sales are triggered by liquidity constraints rather than by solvency constraints.

References

Acharya, V.V., D. Gromb, and T. Yorulmazer (2008), Imperfect Competition in the Interbank Market for Liquidity as a Rationale for Central Banking, Working Paper.

Aikman, D., P. Alessandri, B. Eklund, P. Gai, S. Kapadia, E. Martin, N. Mora, G. Sterne and M. Willison (2009), Funding Liquidity Risk in a Quantitative Model of Systemic Stability, Bank of England Working Paper 372.

Arellano, M. and O. Bover (1995), Another look at the instrumental variable estimation of error component models, *Journal of Econometrics* 68, 29–51.

Bank for International Settlements (BIS, 2011), The transmission channels between the financial and real sectors: A critical survey of the literature, Basel Committee on Banking Supervision Working paper 18.

Cifuentes, R. G. Ferrucci and H. S. Shin (2005), Liquidity risk and contagion, *Journal of the European Economic Association*, 3, 556-66.

Cornett, M.M., J. J. McNutt and P. E. Strahan (2010), Liquidity risk management and credit supply in the financial crisis, Working paper, Bentley University.

Diamond, D.W., and R.G. Rajan (2005), Liquidity shortages and banking crises, *Journal of Finance* 60(2), 615-647.

Diamond, D.W., and R.G. Rajan (2009), The credit crisis: Conjectures about causes and remedies, *American Economic Review* 99(2), 606-610.

DNB (2003), Regulation on Liquidity under the Wft (www.dnb.nl).

DNB (2010), Overview of Financial Stability in the Netherlands, 12, November 2010.

ECB (2009), EU banks' funding structures and policies.

ECB (2010), Report on deleveraging in the EU banking sector.

Gale, D. and T. Yorulmazer (2011), Liquidity Hoarding, Federal Reserve Bank of New York Staff report 488.

Huang, R. and L. Ratnovski (2010), The dark side of bank wholesale funding, IMF Working Paper 10/170.

IMF (2010), Systemic liquidity risk: improving the resilience of financial institutions and markets, Global Financial Stability Report, October 2010.

Ivashina, V. and D. Scharfstein (2010), Bank Lending During the Financial Crisis of 2008, *Journal of Financial Economics* 97, 319-338.

Liedorp, F.R., L. Medema, M. Koetter, R.H. Koning and I. van Lelyveld (2010). Peer monitoring or contagion? Interbank market exposure and bank risk, DNB Working Paper 248.

Love, I. and L. Zicchino (2006), Financial development and dynamic investment behaviour: Evidence from panel VAR, *Quarterly Review of Economics and Finance* 46, 190–210.

Nyborg, K.G. and P. Östberg (2010), Money and liquidity in financial markets, Centre for Economic Policy Research, Discussion Paper 7905.

Spindt, P.A. and V. Tarfan (1980), Liquidity adjustment behaviour of large money center banks, *Journal of Money, Credit and Banking* 12(2), 198-208.

Appendix A

Variable names and definitions

Name	Definition
Assets [1]	
NCCB	Net claims on central bank (deposits minus borrowing)
BONDL	Liquid bond holdings (Tier 1 assets according to previous ECB list)
BONDI	Less liquid bond holdings (non-Tier 1 assets according to previous ECB list)
EQ	Equity portfolio
RETCR	Retail credit (households and companies)
WSCR	Wholesale credit (secured and unsecured, professional counterparties)
Liabilities [1]	
SECUR	Securities issued (bonds, CPs, CDs, etc.)
REPO	Secured wholesale borrowing (repos and securities borrowing)
RETDEP	Retail deposits (households and smaller companies)
Capital	
*TIER*1	Ratio of Tier 1 capital to risk-weighted assets
Financial markets	
SPR	Money market spread (Euribor 3 month rate minus EONIA swap index), in basis points
CDS	Credit default swap spread, in basis points

[1] Ratios to total assets.

Figure 1. Stylized bank balance sheet: Possible asset side responses to a shock in wholesale borrowing

Net claims on Central Bank	↓(↑)	Retail deposits	
Retail credit	↓	Wholesale borrowing	↓
Wholesale credit	↓	Capital	
Securities holdings	↓		
- of which: Liquid securities holdings	(↑)		

Note: A downward (upward) pointing arrow denotes a decrease (increase).

Table 1. Summary statistics, January 2004 – April 2010

	All 17 banks			Top-5 banks		
	Mean	Median	Standard deviation	Mean	Median	Standard deviation
Assets						
NCCB	0.011	0.004	0.037	0.007	0.004	0.025
BONDL	0.062	0.046	0.057	0.066	0.048	0.044
BONDI	0.063	0.016	0.089	0.077	0.082	0.061
EQ	0.010	0.000	0.018	0.441	0.356	0.224
RETCR	0.492	0.549	0.299	0.441	0.356	0.224
WSCR	0.328	0.234	0.286	0.341	0.340	0.200
Liabilities						
SECUR	0.326	0.233	0.292	0.220	0.164	0.158
REPO	0.111	0.000	0.196	0.225	0.225	0.166
RETDEP	0.106	0.049	0.126	0.154	0.153	0.089
Capital						
*TIER*1	0.192	0.139	0.197	0.129	0.102	0.060
Financial market						
SPR	31.2	6.3	38.2	31.2	6.3	38.2
CDS	54.2	16.2	60.7	54.2	16.2	60.7

Note: Variable definitions are given in Appendix A.

Figure 2. Development of model variables

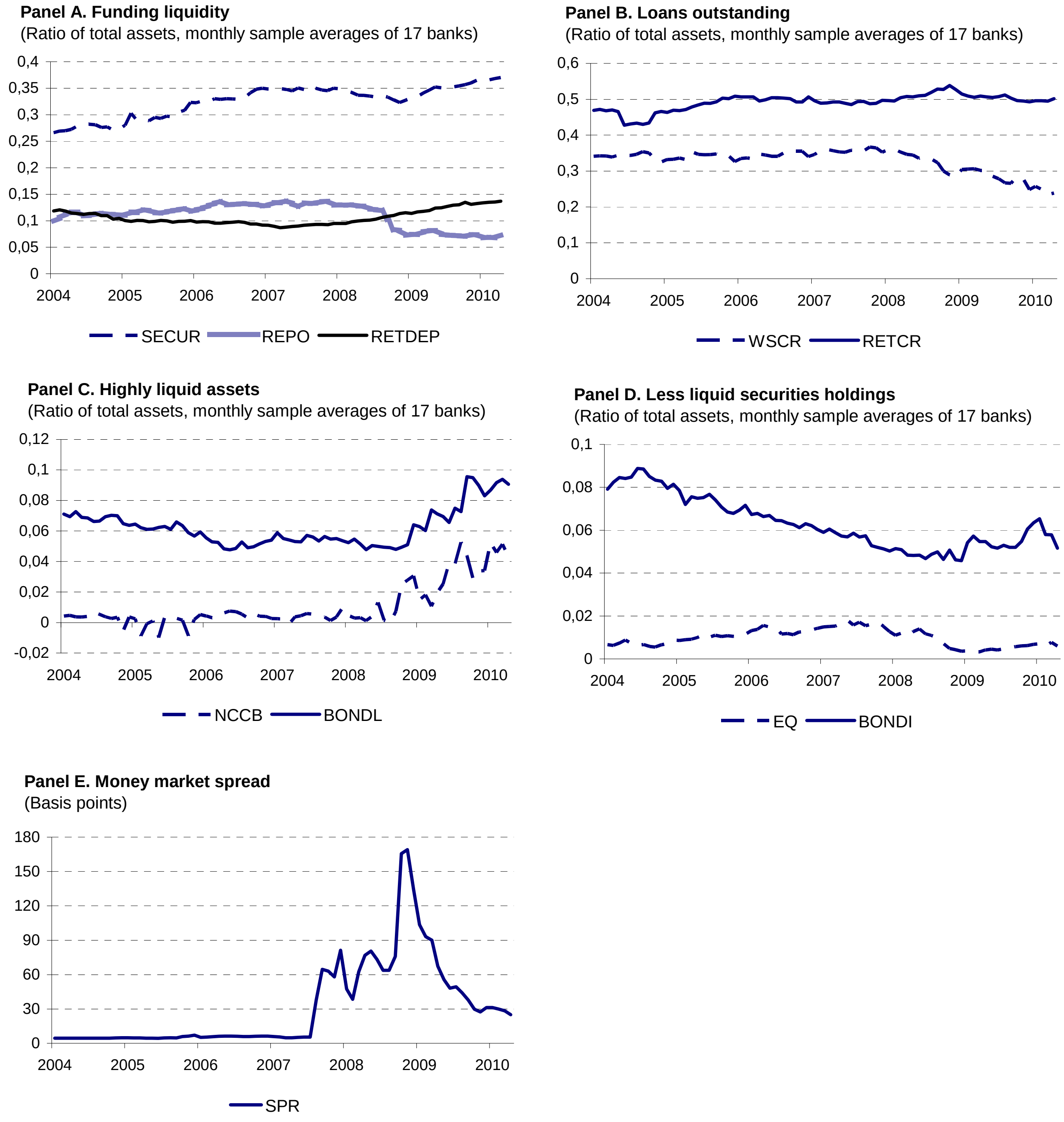


Figure 3. Adjustment of lending, sample of 17 banks

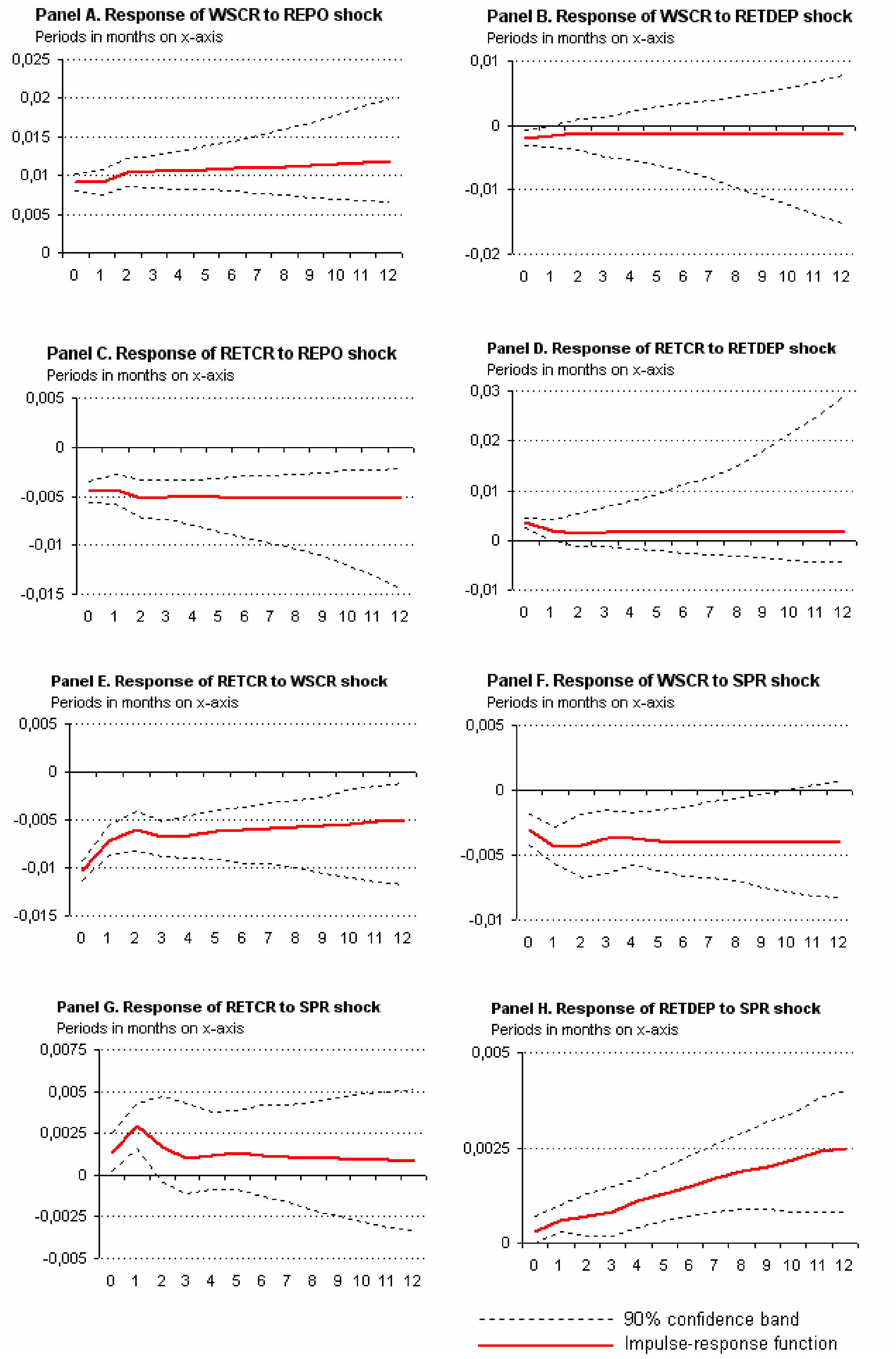


Figure 4. Liquidity hoarding

I. Sample of 17 banks

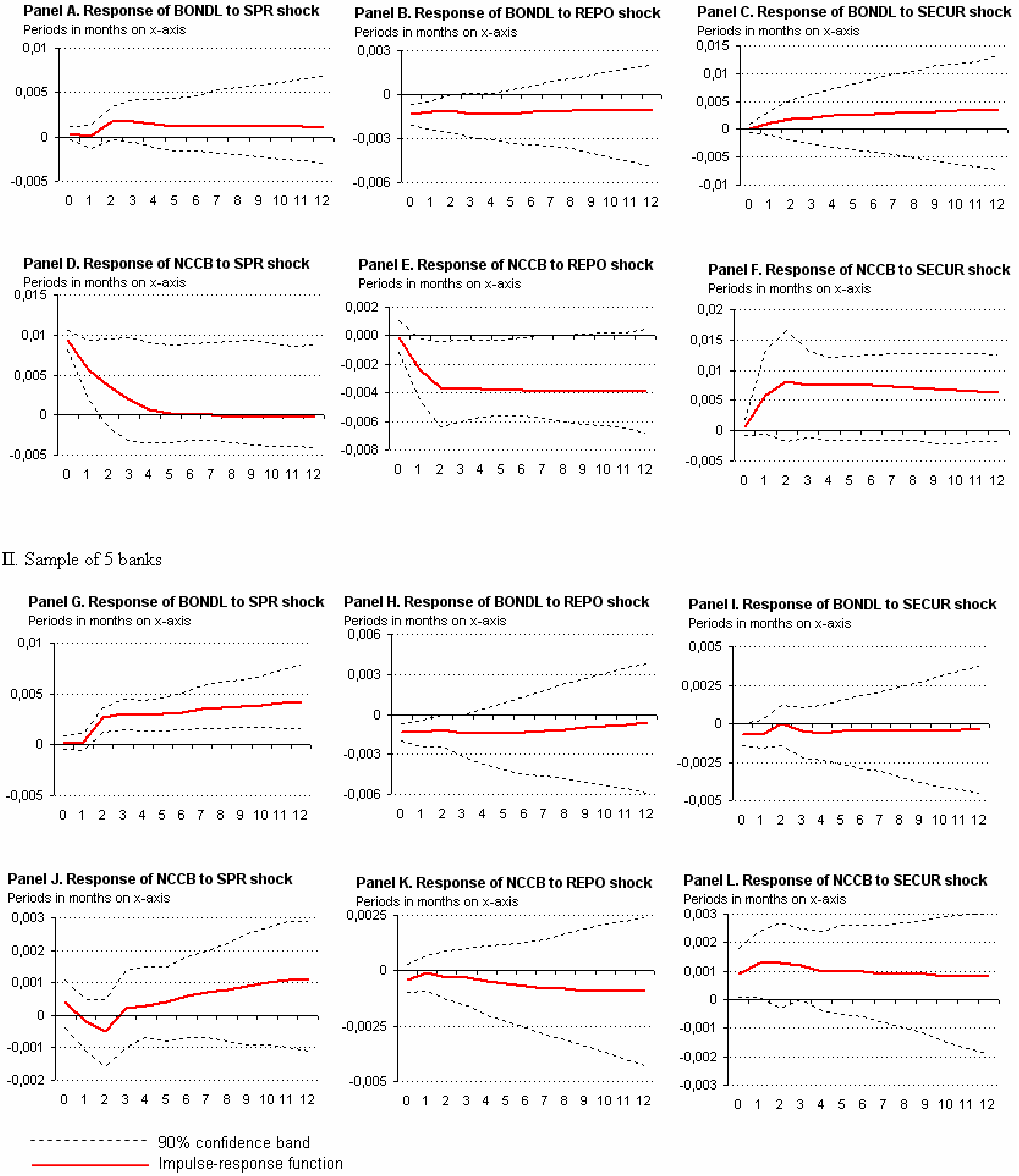


Figure 5. Fire sales, sample of 17 banks

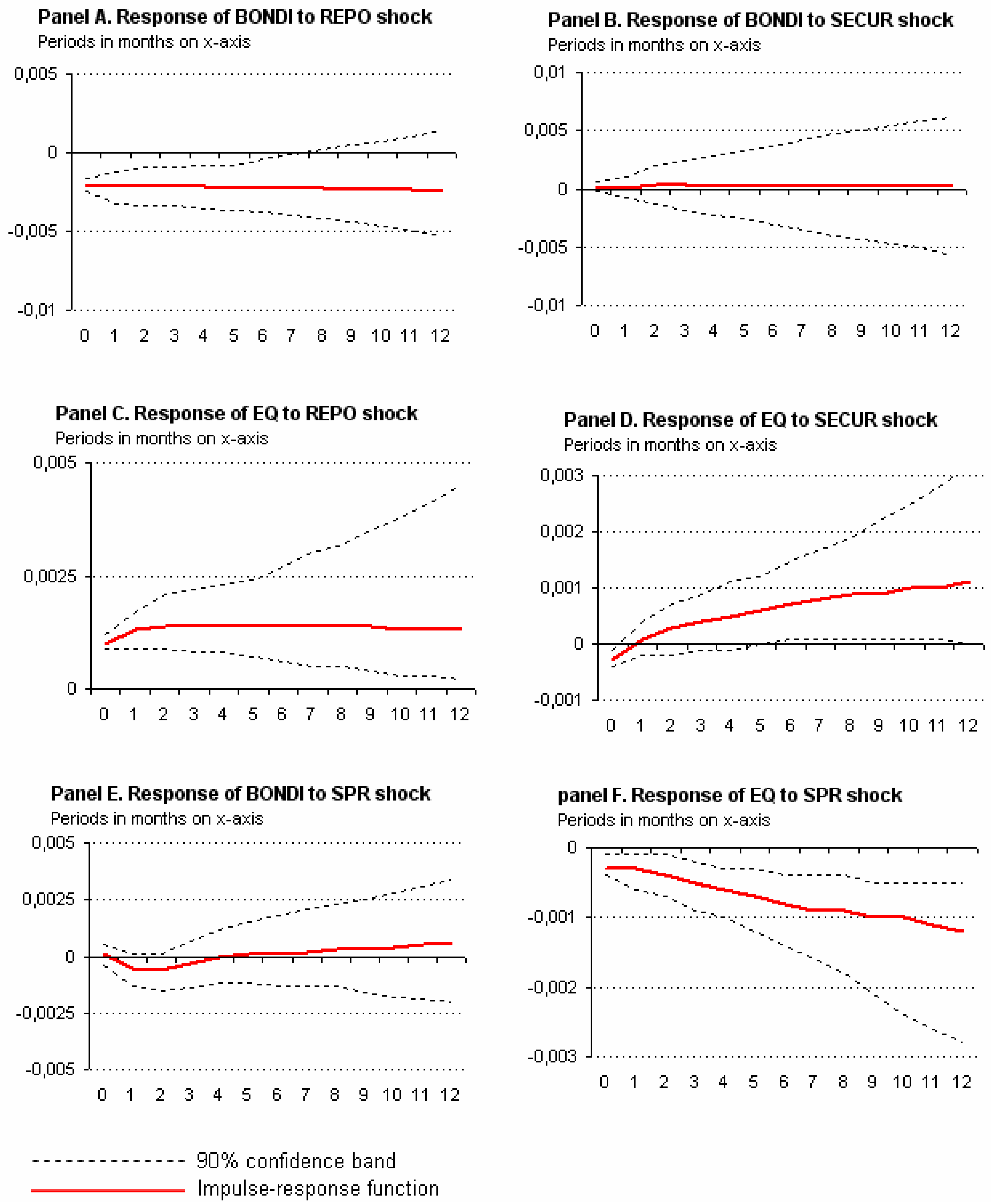


Figure 6. Fire sales and solvency, sample of 17 banks

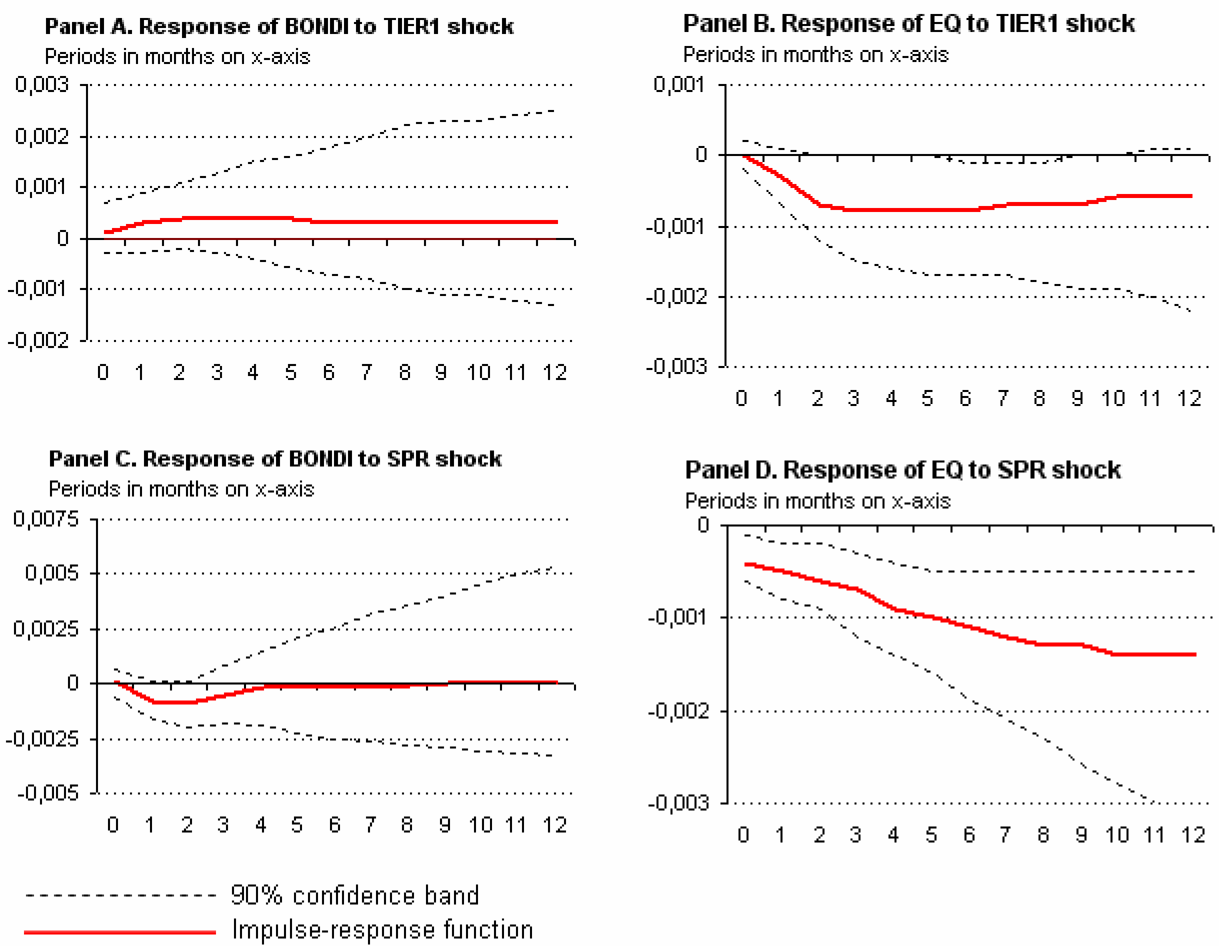
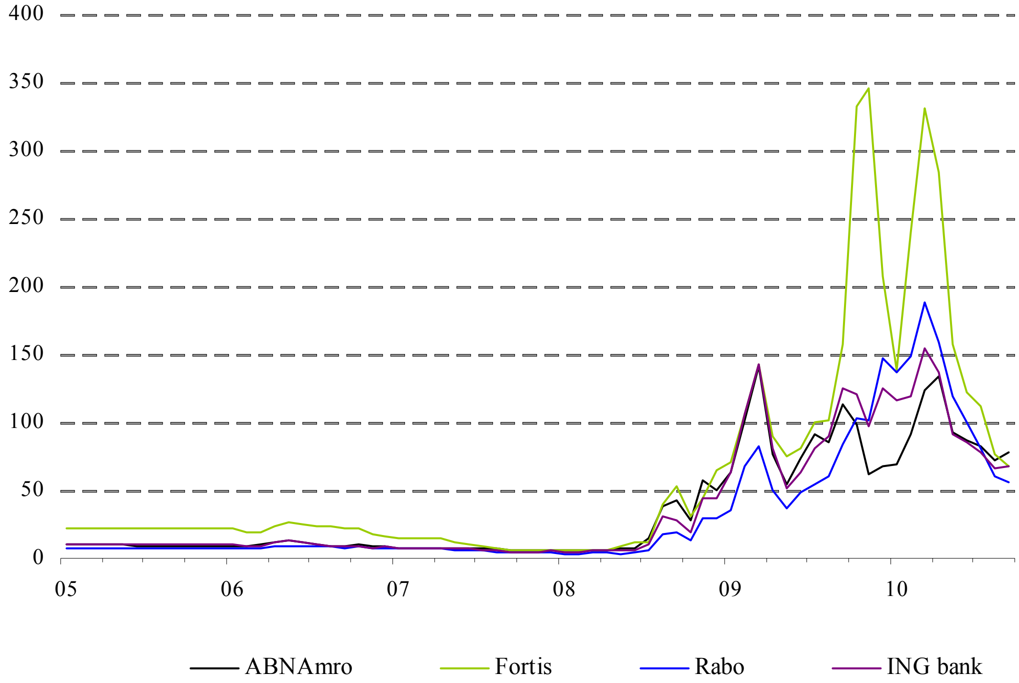


Figure 7. Credit default swap spreads of the largest Dutch banks
Montly averages, basis points



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