What determines banks' sensitivity to money market interest rates?

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Abstract

According to the martingale hypothesis, today's overnight rate should equal its expected value for tomorrow, as risk neutral banks should arbitrage away any deviation between the two rates via instantaneous, theoretically infinite shifts of their demand for reserves across days. Most empirical investigations reject this hypothesis and confirm that the interest rate reactivity of the demand for reserves is far from infinite. Several explanations for these findings have been proposed, but never systematically put to test. The present paper performs such tests. In particular, we estimate the interest rate reactivity of the demand for reserves for a cross section of Italian banks, and then study the determinants of these elasticities. Among the determinants suggested by the available theory are fixed or transaction costs, credit constraints, risk aversion, volatility of the end-of-day liquidity shock. Our results indicate that for a large part of our sample the interest reactivity is statistically zero; only for the remaining banks, typically of large dimension, it is significant and negative. The analysis also validates some specific implications of the model of demand for reserves under uncertainty, widely used in the literature on the money market.

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1. Introduction

A well-known simple theory of the interbank market builds on the assumption that reserves are held by banks only to meet the requirement, and hence that banks regard balances held on different days of the averaging period as perfect substitutes. This theory has two strong testable implications. First, the overnight interbank interest rate, typically used by most modern central banks as an operational target, should behave like a martingale – the current value of the rate should be the best predictor of tomorrow's value (see e.g. Hamilton, 1996). Second, the reactivity of the demand for reserves to the overnight rate should be infinite – tiny movements in the rate should trigger shifts in the demand for funds large enough to eliminate predictable patterns in the rate itself. A large literature has focused on testing the first implication, consistently rejecting the martingale hypothesis (see e.g. Hamilton, 1997, Hayashi 2001, Prati *et al.*, 2003 for evidence on the US, Japan and the entire G7, respectively). The evidence concerning the second testable implication is far less abundant, but also strongly rejects the hypothesis that the interest rate elasticity of the demand for reserves is infinite (Hamilton, 1997; Angelini, 2003).

Several explanations have been given for rejection of the theory, all involving a reason why in practice reserves on different days of the maintenance period are not perfect substitutes. These include market frictions such as fixed or transaction costs (Kopecky and Tucker, 1993; Hamilton 1996; Clouse and Dow, 1999; Bartolini *et al.*, 2001), credit line arrangements (Spindt and Hoffmeister, 1988; Hamilton, 1996), generic liquidity benefits of reserves (Ho and Saunders, 1985; Campbell, 1987; Hamilton, 1996), payment system patterns and daily overdraft penalties (Furfine, 2000), risk aversion on the part of banks (Ho and Saunders, 1985; Angelini, 2000), specific features of the monetary policy operational framework (Pérez Quirós and Rodríguez Mendizábal, 2003).

While these explanations are sometimes backed by empirical evidence, they have not yet been systematically put to test. The purpose of the present paper is to perform such test. To this end, we investigate the determinants of the interest rate sensitivity of banks' demand for funds in the interbank market. We proceed in two stages. First, we estimate a reserve demand equation for each of the around 300 Italian banks in our sample, and retrieve a cross-section of estimated interest rate semi-elasticities, one for each bank. If one or more of the elements suggested by the above-mentioned literature are indeed relevant to explain rejection of the martingale hypothesis/of the infinite elasticity of demand, then they should help explain the cross-section dispersion of these elasticities. Therefore, in the second stage we regress the elasticities on a set of explanatory variables suggested by the theory. Are credit constraints, say, rather than (or in addition to) risk aversion, relevant to explain banks' elasticity of demand, and hence the time series patterns found in the overnight rate? Our results shed some light on such questions.

The analysis yields an empirical test of the well-known model of demand for reserves under uncertainty introduced in the sixties by the seminal works by Orr and Mellon (1961), Poole (1968), Baltensperger (1974), and still widely used in the more recent literature.[1] Specifically, the dynamic version of the model, which accounts for the reserve averaging mechanism currently employed in most developed countries, yields particularly sharp predictions about the effect of uncertainty on the interest rate elasticity: higher uncertainty about the end-of-day reserve balance should unambiguously increase the elasticity *at the end* of the averaging period. It should have an opposite effect *during* the period (see e.g. Whitesell, 2003; Pérez Quirós and Rodríguez Mendizábal, 2003). Our daily dataset allows us to split the period and test this prediction.

The following section provides a motivation for the experimental design. Section 3 describes the data; section 4 presents the time series estimates of the demand equations which yield the semi-elasticities of interest. In section 5 the second stage analysis is performed. Conclusions are summarized in the final section. Further details about the data are reported in the appendix.

2. Motivation

This section heavily relies on Pérez-Quirós and Rodríguez Mendizábal (2003), to which we refer for details about the model, and Whitesell (2003). Its purpose is to motivate the specification of the demand for reserves estimated below, and to summarize available theoretical results that suggest determinants of the interest rate reactivity. Consider a banking system populated of a large number of banks. Let a_t be the reserve position held by a representative bank at the beginning of day t, c_t the reserve deficiency (the cumulated difference between the reserve requirement and the amount held) at the beginning of day t, b_t be the amount lent ($b_t>0$) or borrowed in the interbank market during day t. Further, let i_t be the overnight interest rate. The bank is subject to an end-of-day liquidity shock ε_t ($\varepsilon_t > 0$ denoting an inflow of funds), which is realized after the market closes. Assuming a two-day settlement period, consider the final day, denoted by T. At the end of the day, the liquidity position will be $a_T + \varepsilon_T - b_T$. Let $p_T = c_T + b_T$

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[1] See e.g. Guthrie and Wright (2000), Woodford (2000) for static versions, and Furfine (2000), Bartolini *et al.* (2002), Pérez Quirós and Rodríguez Mendizábal (2003), Gaspar, Pérez Quirós and Rodríguez Mendizábal (2004), Whitesell (2003), for dynamic versions; see also Clouse and Dow (1999), Bartolini and Prati (2003).

$-\ a_T$. If $p_T - \varepsilon_T > 0$, the bank will have to borrow funds at the marginal lending facility, incurring the cost $i^l(p_T - \varepsilon_T)$. Vice-versa, if $p_T - \varepsilon_T < 0$ the bank will have to resort to the deposit facility, earning $i^d(p_T - \varepsilon_T)$. Thus, expected profits from operating in the interbank market on T are given by:

(1) $$\pi_T = i_T b_T - i^l \int_{-\infty}^{p_T} (p_T - \varepsilon_T) dF(\varepsilon_T) - i^d \int_{p_T}^{\infty} (p_T - \varepsilon_T) dF(\varepsilon_T)$$

Where F is the cdf of the shock ε_t. Maximization of the above expression with respect to b_T yields:

(2) $$i_T = i^l F(p_T) + i^d (1-F(p_T))$$

Consider now day $T-1$. Letting $V_{T\text{-}1}$ denote the value function on $T-1$, the problem for the bank on that day is:

$$V_{T-1} = \max_{b_{T-1}} E_{T-1}(\pi_{T-1} + V_T)$$

Pérez-Quirós and Rodríguez Mendizábal (2003) show that the related first order condition is:

(3) $$i_{T\text{-}1} = i^l F(b_{T\text{-}1} - a_{T\text{-}1}) + i^d[1\text{-}F(p_{T\text{-}1})] + \int_{b_{T-1}-a_{t-1}}^{p_{T-1}} i_T dF(\varepsilon_{T-1})$$

Equations (2) and (3) provide suggestions about an empirical specification of a demand for reserves. Specifically, (2) implies that reserve demand should be negatively related to the overnight rate and positively related to the reserve deficiency. Also, the shape of the CDF of the end-of-day liquidity shock may affect demand. In addition, (3) suggests that that the expected rate should be positively related to the current demand on non settlement days (on the final day of the period no intertemporal arbitrage is possible).

Adopting a normal density with mean zero and variance 2 for ε_t, and a series of numeric values for the parameters, equations (2) and (3) have been used to plot demand curves for days T and T-1, in Chart 1. Similar charts can be found in Whitesell (2003). The curves have been drawn under the assumption that i^l=4, i^d=2, so the relevant portion of the curve is around an equilibrium rate of around 3 percent. The main indications concerning the interest rate elasticity of demand emerging from the figure can be summarized as follows. First, on settlement day a lower variance of the end-of-day liquidity shock reduces the elasticity (panel (a)); this result is reversed on other days, when lower variance is associated with higher elasticity (panel (b)).

Second, if credit limits are binding the elasticity is reduced. Third, the elasticity is inversely related to the width of the official interest rates corridor.[2]

The above model assumes risk neutrality. However, it has been shown that risk aversion can affect both the level of the demand for reserves and its interest rate elasticity (Ho and Saunders, 1985). Specifically, higher risk-aversion should increase the demand for funds and reduce its interest rate elasticity.

Finally, banks' reactivity to interest rates may be influenced by the costs of setting up and running an efficient cash management desk – including compensation of skilled treasurers, hardware, software, rental of space and equipment, etc. While this factor has not been explicitly emphasized in the literature,[3] it seems intuitive that if this cost is substantial, then a small bank may rationally choose a simple rule to manage liquidity. For instance, a computer could be instructed to invest (borrow) at the current overnight rate any amount of liquidity in excess (short) of a target. For such a bank, the interest rate elasticity would be zero, yet this would be consistent with rational behavior. These considerations loosely suggest that the higher a bank's volume of interbank activity, the larger the amount of resources invested in its cash management desk, and the larger the reactivity of its demand for reserves to interest rates.

3. The data

Our daily dataset spans the period 1st January 1999 – 23rd January 2004. It includes various money market rates and several variables at the individual bank level: the reserve requirement and reserve balances held by each Italian bank at the Bank of Italy; measures of payment system activity, based on the Italian real time gross settlement (RTGS) system, and of money market activity, based on the Italian electronic interbank market (*e*-MID). A second part of the dataset includes monthly and quarterly variables at the individual bank level. While most of these data do display some amount of time variability, we mainly use them to measure banks' fixed characteristics (e.g. size) in the second stage of our analysis.

Several observations were dropped in the regression analysis. First, due to its phasing-in features, the first maintenance period, from the 1st of January to the 23rd of February 1999, was

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[2] In our empirical analysis, based on the euro-area framework, this effect cannot be tested, due to insufficient variation of the corridor width over the available sample period.

[3] Bindseil *et al.* (2003) is an exception. They show that the daily cost for keeping a cash management desk open late hours is of the order of 500 euros per day; this could be viewed as a lower bound for the cost of establishing an efficient cash management desk. The role of fixed costs on a per transaction basis has been emphasized in the literature (see. e.g. Hamilton, 1996; Furfine, 2003). While these costs can affect the elasticity of demand, they are likely equal on a cross-section basis, and recorded no time series variation over our sample period. Therefore, they are overlooked in the empirical analysis of the next sections

overlooked. Second, week-ends and holidays were dropped. Third, the first working day of each maintenance period was used to calculate the lagged values of some variables. The full sample period entails around 1,300 working days. However, some banks have fewer observations, due to startups, closures, mergers and acquisitions, etc. Therefore, on a cross-section basis, we decided to overlook banks with less than 300 observations. Also, some banks were excluded because key time series are missing. After these exclusions, the full sample entails 266 banks. Details about the construction of the variables and the filters adopted are in the appendix.

4. The demand for settlement balances

We began by estimating the following equation for each bank in our sample. Overlooking bank-specific subscripts:

$$(4) \qquad r_t = \alpha_0 + (1-d^s)(\alpha_1^p \Delta i_t + \alpha_2^p i_{t-1}) + d^s(\alpha_1^s \Delta i_t + \alpha_2^s i_{t-1}) + \alpha_3 \sigma_t$$

$$+ \alpha_4 \omega_{t-1} \bar{r}_{t-1} + \alpha_5 \omega_{t-1} \bar{r}_{t-1} d^e + \alpha_6 r_{t-1} + \eta_t$$

In (4), r_t stands for (log of the) end-of-day reserve balance held by the commercial bank at the central bank, normalized by the bank's current reserve requirement;[4] i_t is the differential between the overnight rate and the fixed/minimum rate for the main refinancing operations of the Eurosystem, and Δ is the first difference operator. The lagged i_{t-1} term is introduced in the regression to test whether interest rate levels play a role in addition, or in alternative, to first differences. The dummy d^s, which equals 1 during the final part of the maintenance period and zero otherwise, is interacted with the interest rate terms to allow the elasticities to decline over the period, as both theory and existing empirical evidence suggest. We experiment with different definitions of "final part" of the maintenance period.

The remaining variables appearing in (4) are mainly introduced to allow for additional flexibility in the specification and avoid biasing the estimates of the parameters of interest, in particular of α_1^i, $i = p, s$. σ_t is a (time-varying) measure of the relevant source of uncertainty, typically a random shock affecting the end-of-period liquidity position. The standard model of reserves demand under uncertainty predicts that if the demand for excess reserves is positive, then an increase in uncertainty should also increase demand; no effect should materialize if the excess demand is zero. Thus, α_3 should be zero or positive. In what follows we proxy σ_t by a conditional standard deviation of net daily payment flows, estimated by fitting an ARCH model

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[4] r_t represents the counterpart of $a_t + \varepsilon_t - b_t$ in section 2. In principle, one would want to use b_t as the dependent variable in (4). However, neither ε_t nor a_t are available in our dataset.

to the series (see the appendix for details).[5] $\bar{r}_{t-1}$ is the cumulated average excess reserve position (the cumulated balance net of the reserve requirement) as a percentage of the requirement, multiplied by the workoff rate ω_{t-1}. This magnitude, which represents the empirical counterpart of the reserve deficiency (c_t in section 2), is crucial in systems featuring averaging mechanisms, such as those in use in the euro area and the US. The sign of α_4 should be negative. The dummy d^e equals 1 when $\bar{r}_{t-1}>0$ and 0 otherwise. Its interaction with $\bar{r}_{t-1}$ allows for an asymmetric response to situations of cumulated reserve deficits or surpluses. Finally, r_{t-1} is the lagged dependent variable.[6]

Equation (4) was estimated with instrumental variables, to account for potential endogeneity problems between the dependent variable and i_t. Specifically, yesterday's tom-next rate was used as an instrument for today's overnight.[7] The monetary policy operational framework adopted by the Eurosystem should be ideal for identifying a demand equation, since the ECB's main interventions, the so-called main refinancing operations (MROs), are conducted on a weekly basis (fine-tuning operations were used only seldom during the sample period). Thus, on any given day other than Wednesday, when MROs are settled, the total supply of reserves changes only because of autonomous factors, which represent exogenous supply shifts and therefore are perfect demand curve identifiers.

Since the regression output for each of the 266 banks in our sample would be rather cumbersome to illustrate, in Table 1 we report the country-wide estimates, obtained as simple or weighted averages of their bank-specific counterparts.[8] Several interesting facts emerge about

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[5] Since σ_t is meant to be a measure of uncertainty faced by the bank, it was computed from the balance stemming from payments originated by clients' transactions. In other words, we omitted payments related to monetary policy and money market operations, which may be viewed as the bank's endogenous reaction to the uncertainty generated by client's demands.

[6] α_5 should be positive, as banks' reaction to surpluses could be milder, given that in principle they are less costly. In the absence of market frictions, α_6 should be zero, as today's demand for funds should be independent from yesterday's end-of-day balance, apart from the contribution of the latter to the cumulated reserve position $\bar{r}_{t-1}$. However, if market frictions are relevant we could expect a positive autocorrelation in end-of-day balances. For example, the bank could wish to work off relatively high balances in t-1 smoothly over subsequent days. Proxies for risk aversion, suggested by the theory reviewed in section 2, are not included in (4) due to the fact that risk aversion is likely to be relatively time invariant at the individual bank level. As a potential determinant of the interest rate elasticity of demand, they are used in the next section, where we can exploit the cross-sectional variability of our dataset.

[7] A buyer of tom-next funds on day t acquires a right to receive the funds on day t+1 and a commitment to reimburse them plus interest on t+2, at the interest rate agreed upon at t; this makes today's tom-next rate a ready-to-use proxy for expectations about tomorrow's overnight.

[8] This aggregation method provides consistent, although inefficient, results (Pesaran and Smith, 1995). Standard errors retrieved via this method are correct as long as parameters are independent across banks. The weights for the weighted average estimates are given by each banks' average share of required reserves over our five year sample period.

our main parameter of interest, α_1, the semielasticity of the demand for reserves to the interest rate. Consider the regression in column (*a'*), where the interest rate elasticities have been allowed to change in the final 5 working days of the maintenance period. For most of the period a 10 basis points change in the overnight rate triggers a 14.8 percent adjustment in the demand for reserves. In the last five days the demand elasticity drops to 1.1 percent. Second, the number of banks for which α_1 is in line with the a priori (negative and significant) is relatively small: barely above one third of the sample in the first part of the period, about one fifth towards the end of the period (last rows of the table). Third, larger banks tend to be more interest rate sensitive, as indicated by the fact that size-weighted average estimates of α_1 are about twice as large than their simple average counterparts in column (*a*). Finally, the coefficient of the lagged interest rate level is also significant; however, it is relatively small in absolute value, indicating that demand behavior is predominantly affected by interest rates changes, rather than levels. The effect of the variability of payment flows is not statistically different from zero. This could be due to the fact that the demand for excess reserves is positive but very close to zero. Overall, the results obtained by focusing on the last 10 working days of the working period remain broadly unchanged.

Chart 2 presents the cross-sectional distribution of the individual bank estimates of α_1^p and α_1^s summarized in column (*a*), which we use as dependent variables in the next section. While most of the mass is clustered around zero, the density of α_1^p in panel (a) exhibits the expected asymmetry toward negative values. In some cases the semi-elasticity is even positive and significant.[9] Within the group of interest rate sensitive banks, the absolute value of α_1 lies on average in the range 1.8 – 1.9, with an individual maximum of 5.1. The cross-section distribution of α_1^s in panel (b) is more symmetric and clustered around zero. Although the average remains negative, there is an increase in the number of positive and significant coefficients.

5. The determinants of the semi-elasticity to interest rates

What determines the size of the parameter α_1? According to the theory reviewed in section 2, the absolute value of the elasticity to the interest rate should be inversely related to the bank's degree of risk aversion, and can be reduced by the presence of credit limits. In addition, we saw that the

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[9] Some of these banks result from merger operations towards the end of the sample period. The wrong sign for the elasticity might be due to the few observations available after the merger. According to influence indicators, the other regressions are heavily affected by a few observations, clustered around key sub-periods, like December 31, 1999 (the date changeover) and December 31, 2001 (the euro cash changeover). If these observations are dropped from the sample period, the incorrect elasticity from the regression results is much weaker.

model of precautionary demand delivers particularly sharp predictions about the effect of uncertainty faced by the bank due to its payment system activity. Specifically, lower uncertainty should reduce the elasticity (increase its absolute value) in the initial part of the period, and increase it at the end, when banks can no longer resort to intertemporal arbitrage. Finally, we argued that the payoff from an efficient cash management desk should increase with the volume of interbank activity, and that therefore the elasticity of demand should be related to a bank's size. Indeed, results in the previous section suggest that large banks are significantly more interest rate elastic than average.

In what follows we try to assess the role of these different factors by regressing the estimated coefficients α_1 from equation (4) on a series of bank-specific proxies. As a measure of uncertainty concerning daily net reserve flows we use the unconditional standard deviation of the net daily payments balance, normalized by the bank's reserve requirement.[10] Two proxies were used for the banks' unobservable degree of risk aversion. The first, specifically related to liquidity management activities, is given by the standard deviation of daily cumulated excess reserves normalized by required reserves, computed over the entire sample period. Spindt and Hoffmeister (1988) argue that a risk-averse treasurer will want to keep her balance always close to the requirement, to avoid being exposed to interest rate swings in the remaining part of the maintenance period. Thus, for a risk-averse bank this standard deviation should be relatively small.[11] An alternative measure is given by the (size adjusted) difference between a bank's actual and required capital, according to the Basel Committee definition, based on the hypothesis that higher levels of excess capital may reflect more conservative behavior.

Our dataset contains a direct measure of borrowing constraints. Some Italian banks operate on the money market through other institutions, which typically enforce daily trading ceilings on them. The imposition of a cap on a given bank is revealed in our dataset by an indicator variable (the size of the credit caps is unfortunately not disclosed, nor is there information about the days when they are binding). Under the assumption that the caps are binding for a relevant portion of the sample period, these banks should be characterized by a lower than average interest rate elasticity.

We experimented with various proxies of bank size, including total assets, total managed funds, reserve requirements. We also looked for threshold effects. In the end, we retained the (log of the) trading volume on the overnight segment of the *e*-MID, averaged over the entire

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[10] This was retrieved from the same estimation process as the conditional standard deviation used in equation (4).

[11] One potential problem of this proxy is that it may record high values for a highly risk-averse bank facing large end-of-day shocks, as well as for a risk-neutral bank facing small end-of-day shocks. However, we control for the size of the end-of-day shock by via a measure of the variability of net payment flows among the regressors.

sample period. The proxy is consistent with the assumption, made in section 2, that the volume of interbank trading justifies the costs of setting up an efficient trading desk. Finally, we control mergers and acquisitions operations (M&As). Under the hypothesis that M&A increase efficiency, a bank resulting from such an operation could become more reactive to interest rates. A dummy variable was set to 1 for these banks, and 0 otherwise.[12]

Table 2 summarizes the results of this stage of the analysis. In interpreting the coefficients it must be remembered that variables with a negative sign increase the (absolute value of the) elasticity, and vice-versa. Columns *(a)* and *(a')* report results obtained using in the order α_1^p and α_1^s as the dependent variable when the dummy d^s is set to 1 for the final 5 working days of the maintenance period. Columns *(b)* and *(b')* report results obtained with α_1^p and α_1^s from the corresponding columns of Table 1.

Consider specifications *(a)* first. The coefficient of the variability of payment flows is positive and highly significant: in the first part of the period banks facing relatively high uncertainty about their payment flows appear less ready to react to interest rate movements. The opposite effect prevails in the last days of the period, when the same banks are relatively more reactive: in column *(a')* the coefficient becomes negative and significant. As discussed in section 2, this result is in line with the prediction of the standard model for precautionary reserves. Our first proxy for risk aversion, the standard deviation of daily excess reserves, which should capture liquidity manager-specific characteristics, has a positive and significant effect, in line with some theories (Ho and Saunders, 1985). The effect of the other proxy, bank's excess capital, is not significant. The regression also confirms Hamilton's (1996) intuitive simulation results: credit constrained banks consistently display a lower interest rate sensitivity, at least for most of the maintenance period. The coefficient of our size indicator – money market trading volume – has the expected sign and is significant. Based on the estimates in column *(a)*, each time the bank's turnover on the money market doubles, the absolute value of the semi-elasticity increases by 0.7 basis points. Finally, the coefficient related to the M&As dummy variable is not statistically different from zero. One explanation for this result could be lack of power, as our sample period may be too short for the efficiency gains brought about by mergers to show up.[13]

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[12] Specifically, the daily data of each merged bank were split in an "old" and a "new" time series; the regression (4) was then re-run separately for each. Operations that took place very early or very late in the sample period were dropped, because the time series of the "old" or the "new" bank would have been too short to run the first stage regression.

[13] Focarelli and Panetta (2003) show that efficiency improvements of mergers and acquisitions in a sample of Italian banks tend to show up in the data about 2 years after the operation.

Regression *(a')*, in which α_1^s was used as the dependent variable, has a very low explanatory power. Whereas some of the effects showing up in specification *(a)* are lost, the coefficient of bank size remains negative and significant. The coefficient of our second proxy for risk aversion becomes negative and statistically significant. This is at odds with our a priori, and may deserve further analysis. The regressions in columns *(b)* and *(b')*, derived from the elasticities estimated with the alternative split of the sample period, broadly confirm the findings from columns *(a)* and *(a')*.

6. Conclusions

The hypothesis that the short-term interbank interest rate should behave like a martingale, and the ancillary hypothesis that the interest rate sensitivity of the banks' demand for funds should be infinite, have been rejected by a large body of empirical literature for the main international money markets. This paper tests some of the theoretical explanations that have been put forward for these findings. In the first stage of the analysis, estimates of the interest rate elasticity of demand are derived by running time series regressions for each bank in our sample. Next, using the cross-section dimension of the data, these elasticities are regressed against a series of proxies of the explanatory factors suggested by the available theory. The main conclusions can be summarized as follows.

First, the aggregate elasticity of demand for reserves, computed as an average of individual estimates for each bank, is found to be finite and significant: over the first three working weeks of the maintenance period a 10 basis points change in the overnight rate triggers a 15 percent adjustment in the demand for reserves. In the last five days of the period the elasticity drops to 1 percent. Second, substantial heterogeneity of behavior is detected across banks in our sample: for about 65 to 70 percent of them, typically of small-medium size, the elasticity is statistically zero even in the initial part of the period. The banks displaying a nonzero elasticity are generally large. This finding helps explain the low values of the elasticity often detected in empirical work relying on aggregate time series. Third, the demand for reserves does not seem to be directly affected by the degree of uncertainty concerning exogenous net payment flows.

The second stage of the analysis confirms some of the theoretical explanations of a low interest rate reactivity of the demand for reserves, with a few qualifications. We find that banks facing borrowing constraints (credit caps) in the interbank market tend to be less interest rate sensitive. Second, a bank's interest rate sensitivity tends to grow nonlinearly with its size. While not emphasized thus far in the theoretical literature, this finding can be rationalized via effects generated by the costs of setting up and running a high quality cash management desk. Third, based on our proxies for banks risk attitude, there is some evidence that higher risk aversion is associated with lower interest rate reactivity, in line with some of the theoretical literature (e.g. Ho and Saunders, 1985). Finally, we find that the effect of uncertainty on the interest rate reactivity changes sign over the maintenance period: in the final days, higher uncertainty concerning end-of-day net reserve flows increases reactivity, whereas for most of the period the opposite effect prevails. This finding is in line with recent dynamic versions of the classic Orr-Mellon-Poole model of reserve demand (see e.g. Pérez Quirós and Rodríguez Mendizábal, 2003; Whitesell, 2003). To our knowledge, this result represents the most clearcut empirical confirmation of this model available in the literature.

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Table 1: Dependent variable: log of end-of-day reserve balance, r_t

(Instrumental variables estimates of equation (4))

		"End of period" defined as last 5 working days		"End of period" defined as last 10 working days	
		Simple Averages	Weighted Averages	Simple Averages	Weighted Averages
		(a)	*(a')*	*(b)*	*(b')*
Constant		–0.03**	–0.16	–0.04**	–0.20
		(0.02)	(0.14)	(0.02)	(0.15)
Δi_t *(1st part of period)*	α_1^p	–0.64**	–1.48**	–0.67**	–1.58**
		(0.01)	(0.10)	(0.01)	(0.10)
Δi_t *(end of period)*	α_1^s	–0.08**	–0.11*	–0.12**	–0.23**
		(0.01)	(0.06)	(0.01)	(0.05)
i_{t-1} *(1st part of period)*	α_2^p	–0.20**	–0.46**	–0.23**	–0.61**
		(0.01)	(0.04)	(0.01)	(0.05)
i_{t-1} *(end of period)*	α_2^s	0.02**	0.08*	–0.02**	0.03
		(4.4e–3)	(0.04)	(3.7e–3)	(0.03)
σ_t		–6.2e–4**	–5.6e–4	–5.3e–4**	–2.7e–4
		(1.4e–4)	(1.1e–3)	(1.4e–4)	(1.1e–3)
$\omega_{t-1}\bar{r}_{t-1}$		–0.14**	–0.10**	–0.14**	–0.11**
		(1.8e–3)	(0.01)	(1.7e–3)	(0.01)
$d^e\omega_{t-1}\bar{r}_{t-1}$		–0.09**	–0.20**	–0.09**	–0.19**
		(2.5e–3)	(0.02)	(2.5e–3)	(0.02)
r_{t-1}		0.32**	0.29**	0.32**	0.28**
		(1.4e–3)	(0.01)	(1.5e–3)	(0.01)
No. of regressions		266		266	
Avg. No. obs. per regression		960		960	
Avg. adjusted R^2		0.29		0.29	
Share of banks with negative and significant α_1 at 5% level		34.6 % (1st part of period) 18.4 % (end of period)		33.8 % (1st part of period) 20.7 % (end of period)	

Notes

r_t is the log of the ratio between the end-of-day balance held by each bank at the central bank and the bank's current reserve requirement. The values in the table are obtained by estimating regression (4) in the text for each individual bank in the sample, and by taking simple and weighted averages of the estimated coefficients and heteroskedasticity robust standard errors (in brackets). Weighted averages are computed using each bank's share of the reserve requirement, averaged over the sample period. Each equation was estimated with instrumental variables, using the previous day's tom-next as an instrument for the current overnight (Eonia). Daily data; sample period: February 24, 1999 – January 23, 2004. One or two asterisks denote significance at the 5 and 1 percent level, respectively.

Table 2: Dependent variable: estimated semi-elasticities to interest rates

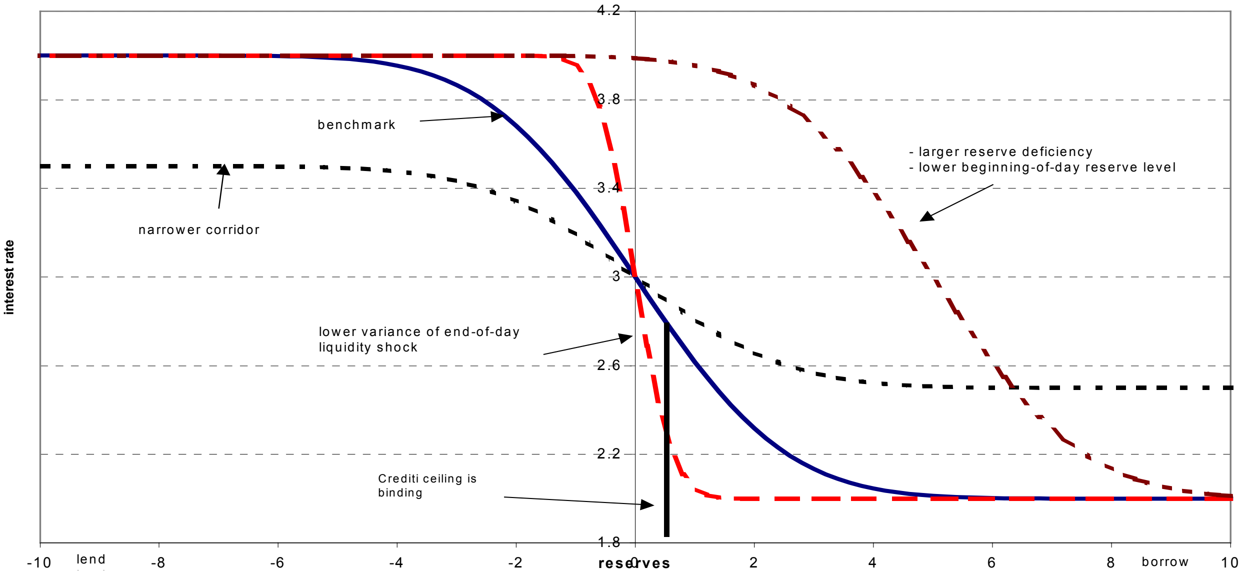
	“End of period” defined as last 5 working days		“End of period” defined as last 10 working days	
	Dependent variable:			
	α_1^p	α_1^s	α_1^p	α_1^s
	(a)	*(a’)*	*(b)*	*(b’)*
Constant	–0.31**	–0.02	–0.32**	–0.04*
	(0.06)	(0.02)	(0.06)	(0.02)
Net payment flows variability	5.7e–5**	–2.7e–5**	6.2e–5**	–1.8e–5*
	(2.0e–5)	(9.6e–6)	(2.0e–5)	(8.0e–6)
Risk aversion				
Treasurer’s behavior	0.11**	–0.03	0.13**	–0.02
	(0.04)	(0.04)	(0.04)	(0.03)
Bank’s excess capital	4.9e–3	–2.1e–2**	3.5e–3	–1.8e–2**
	(0.01)	(6.8e–3)	(0.01)	(6.6e–3)
Credit caps	0.51*	–0.02	0.52*	0.06
	(0.20)	(0.05)	(0.24)	(0.05)
Bank size	–7.3e–3**	–8.0e–4*	–7.6e–3**	–1.2e–3**
	(1.3e–3)	(3.7e–4)	(1.4e–3)	(3.7e–4)
Mergers & acquisitions (0/1 dummy)	–0.05	0.05	–0.05	0.03
	(0.06)	(0.03)	(0.06)	(0.02)
Dependent mean	–0.16	–0.03	–0.17	–0.04
Number of observations	266	266	266	266
Adjusted R^2	0.08	0.03	0.09	0.03

Notes

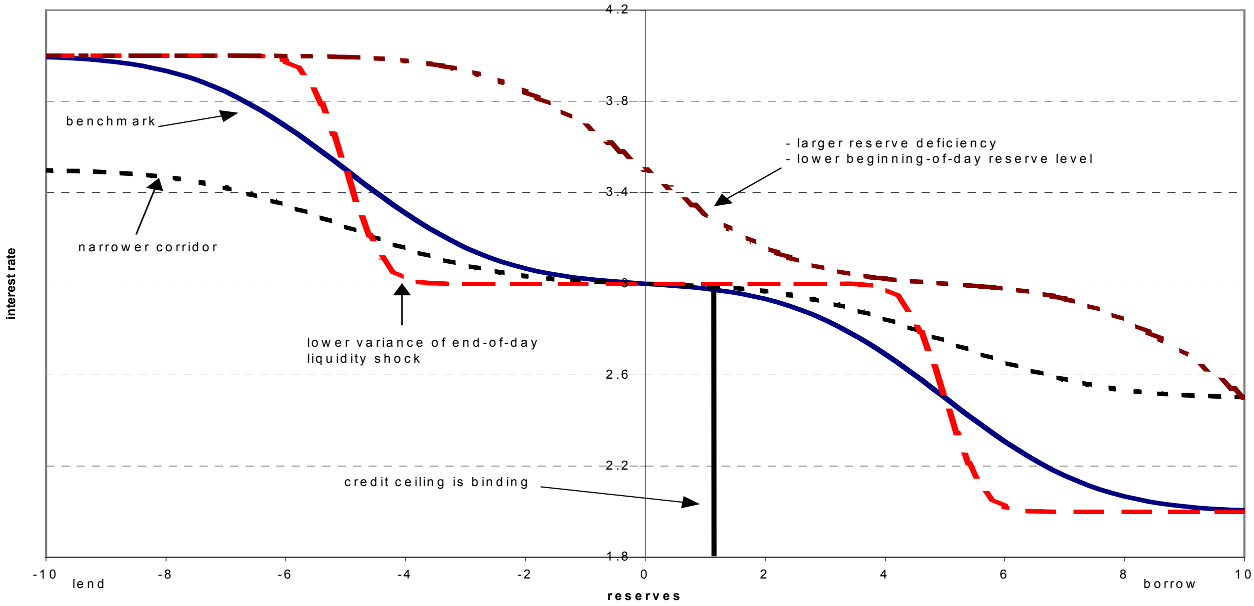
Cross-section regressions of the individual bank semi-elasticities, α_1^p (first part of the maintenance period) and α_1^s (end of the period) from equation (4) in the text (summarized in Table 1), on the set of explanatory variables listed in the first column. See the appendix for the definition of the regressors. The regressions have been estimated by weighted least squares, where the weight of each observation is inversely proportional to the standard error of the estimated α_1. The dependent variable mean is weighted accordingly. Heteroskedasticity robust standard errors are reported in brackets. One or two asterisks denote significance at the 5 and 1 percent level, respectively.

Chart 1: A theoretical demand for reserves

(a) Settlement day (equation (2))



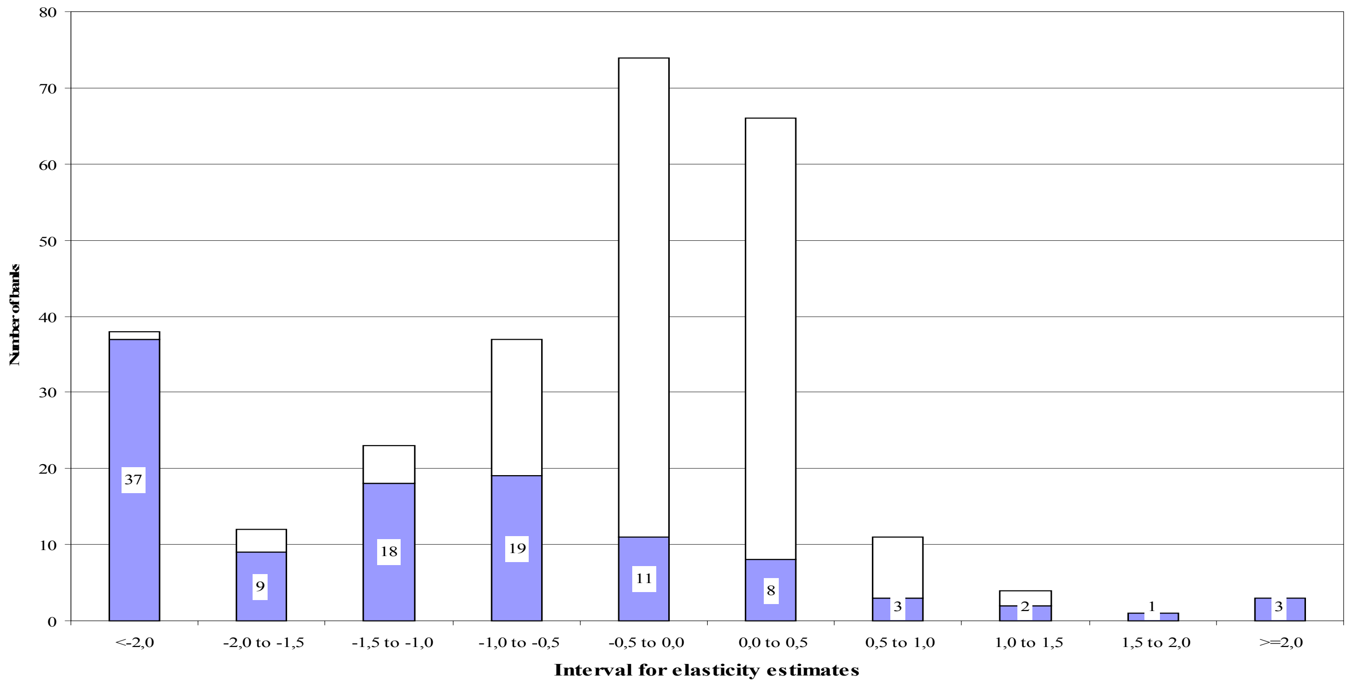
(b) non settlement day (equation (3))



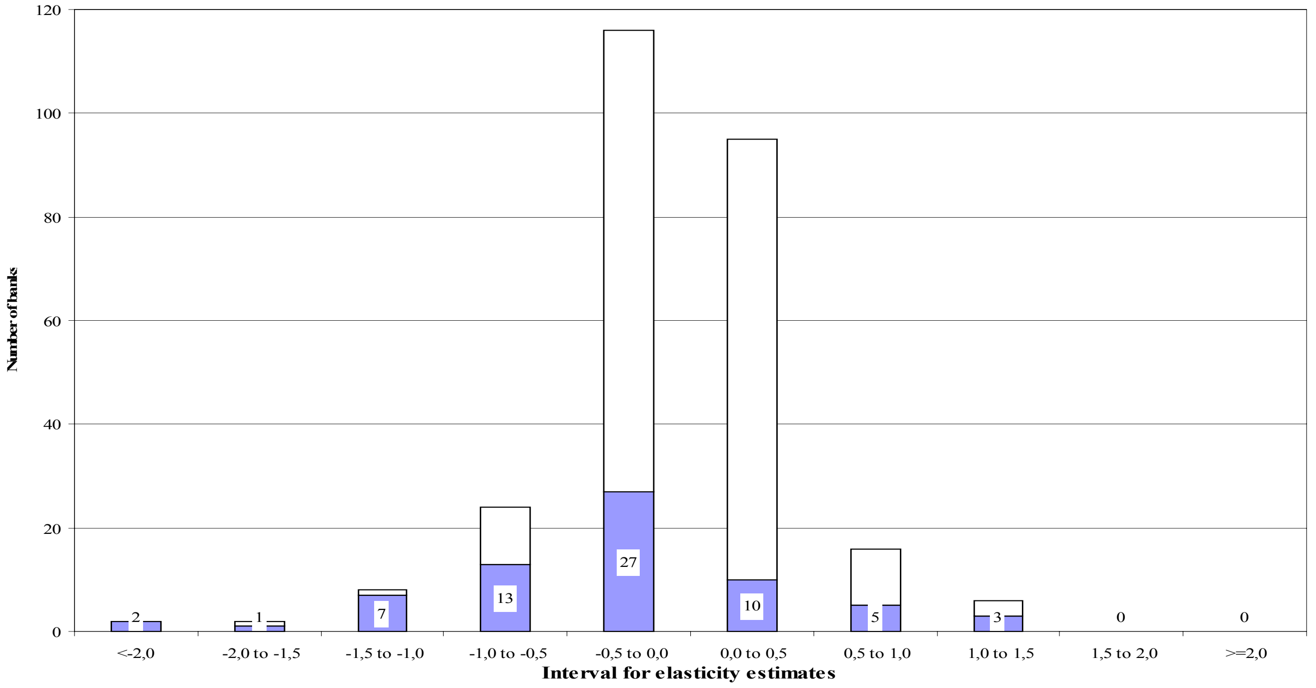
Note: The curves are drawn using equations (2) and (3) in the text, under the assumption that the liquidity shock ε_t is normally distributed with mean zero. For the benchmark curves, we use the following numerical values for the parameters: $\sigma_\varepsilon^2=2$, $i^l=4$, $i^d=2$, $a_t=5$, $c_T=5$ in equation (2) and $c_{T-1}=10$, $i_T=3$ in equation (3). For the "narrower corridor" curve we set $i^l=3.5$, $i^d=2.5$. For the "lower variance" curve we set $\sigma_\varepsilon^2=.5$.

Chart 2: Frequency distribution of estimated interest rate elasticities

(a) α_1^p (first part of the maintenance period)



(b) α_1^s (end of the maintenance period)



Note:
The chart is based on the estimates of α_1 summarized in Table 1, column (a). The shaded areas and the related figures within the histograms refer to the number of banks for which the estimated α_1 is statistically significant at least at the 5 percent level.

Appendix

1. Sample definition

We considered the set of Italian banks that over the period from 24 February 1999 to 23 January 2004 had a non-zero reserve requirement, held a current account at the central bank, and participated directly in the Italian real time gross settlement system Bi-rel. This selects a set of 428 banks, about 50 percent of the universe of Italian banks in terms of number and over 99.5 per cent in terms of the reserve requirement. Most of the banks excluded are cooperative credit banks which fulfill their reserve requirement through an intermediary or are too small to have a requirement in excess of the deductible. Next, we dropped banks with less than 300 time series observations. These are mainly due to startups, cessations, or banks that at some point in time decided to fulfil the requirement through another bank, and therefore closed their account at the central bank (or those that did the opposite). Also, we dropped banks whose time series displayed unaccountable structural breaks. This reduces the number of banks to 266.

2. Variables definition. - For each bank, variables are calculated as follows.

Daily time-series regressions in section 4:

r_t log of the ratio: End-of-day balance on the current account held at the central bank/Reserve requirement over the relevant period.

i_t Eonia (Euro overnight index average) rate minus the fixed/minimum rate on main refinancing operations (MRO), the main policy rate of the Eurosystem (over the period 1 January 1999 – 25 June 2000 MROs were allotted at a fixed rate; subsequently the auction mechanism was changed into a variable-rate tender, with a minimum bid rate). In the instrumental variables estimation, the t-1 tom-next (computed as a volume-weighted average; source: Italian electronic interbank market *e*-MID) was employed as an instrument for i_t.

ω_{t-1} workoff rate, $\omega_{t-1} = 1/(T - t + 1)$, where T is the length of the maintenance period and t is the number of days from the start of the period. See Spindt and Hoffmeister (1988).

$\bar{r}_{t-1}$ cumulated excess reserve position: $\bar{r}_{t-1} \equiv \left[\frac{1}{t-1} \sum_{i=1}^{t-1} (R_i - RR_i)/RR_i \right]$, where R_i and RR_i are the end-of-day balance and the reserve requirement on day i, respectively.

σ_t conditional standard deviation of the ratio: net payment flows/reserve requirement. Only payments originated by clients' transactions and sent on the Italian real time gross settlement system were considered; payments originated by the bank, such as those related to money market or monetary policy operations, were overlooked. σ_t was retrieved by estimating an ARCH model for each bank. Weighted average estimates (using the average reserve requirement over the sample period) are as follows: Intercept: –3.31; AR(1): +0.20; AR(2): +0.09; ARCH(1): +0.28; Avg. No. of observations: 706 (further details are available from the authors).

Cross-section regressions in section 5:

Payment flows variability. It is the analogue of σ_t, as it is the unconditional variance retrieved from the AR(2)–ARCH(1) model estimated for each bank.

Risk aversion – Treasurer's behavior. It is equal to minus the standard deviation of $\bar{r}_t$ over the sample period.

Risk aversion – Bank's excess capital. Ratio (Actual capital – Required capital, according to the Basel Committee rules)/Risk weighted assets, derived from quarterly bank reports; average over the sample period.

Multilateral caps (0/1). The variable is 1 for the subset of Italian banks that work on the *e*-MID via another bank, and are therefore subjected to volume caps.

Bank size – Money market trading volume. Log of the sample period average of the daily gross volume (lending plus borrowing) of overnight contracts on the *e*-MID.