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ARE BANKS RISK-AVERSE? A NOTE ON THE TIMING OF OPERATIONS IN THE INTERBANK MARKET

by Paolo Angelini (*)

Abstract

The paper presents a simple theory of intraday behavior in the interbank market. The timing of borrowing and lending operations depends on the available information on two key variables: the end-of-day balance from the clearing system and the short-term interest rate. When the former is the relevant source of uncertainty, risk-averse banks should tend to operate close to the end of the business day, when the balance becomes observable; conversely, when the interbank rate is relatively more volatile, operations should be shifted to the early morning, when the balance is not observed but the rate is. Tests based on the Italian interbank market support the hypothesis of risk-averse behavior by banks, an issue on which little empirical evidence is available.

Contents

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1. Introduction[1]

It is seldom realized that most financial operations, such as those in foreign exchange, bonds, equities and derivatives, trigger a flow of interbank payments whereby funds are transferred from the accounts of the buyers to those of the sellers. In turn, at the end of each day these flows determine a net debtor or creditor balance, which must be offset by bank treasurers to meet their end-of-day liquidity targets. The main instrument for the redistribution of liquidity is the interbank market, where banks demand and supply loans for maturities ranging from overnight to several months. While this market is often used as a permanent source of financing by banks facing a demand for loans larger than that for deposits, a significant share of the activity stems from the need to meet temporary cash shortages or to invest excess funds.

The individual components of this picture have been thoroughly analyzed. The literature dealing with the various aspects of financial markets is too abundant to need mention. The demand for reserves has been analyzed as a special case of the optimal demand for inventories under uncertainty, and theoretical models are readily available to describe banks' end-of-day demand for funds in the interbank market.[2] Much

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1 The initial idea for this paper came out of a conversation with Subir Lall. Useful comments on earlier drafts were provided by Giovanni Ferri, Fabio Fornari, Subir Lall, Marco Martella, Massimo Massa, David VanHoose, Giorgio Zen, an anonymous referee for Temi di Discussione, and participants in a seminar organized by the Research Department of the Banca d'Italia. I also thank Ginette Eramo for preparing the dataset, and Cinzia Chini and Roberto Felici for editorial assistance. The usual disclaimer applies.

2 See, among others, Orr and Mellon (1961), Grossman (1965), Miller and Orr (1966), Poole (1968). Full-fledged models of the interbank market are in Ho and Saunders (1985), Spindt and Hoffmeister (1988), Griffiths and Winters (1995).

less is known on the interrelationships among the various facets. In particular, the connections between financial markets, interbank payment systems and the interbank market have received little attention.[3] And, while some studies have dealt with the intraday behavior of operators in the stock and derivatives markets[4] and in the foreign exchange markets,[5] little is known on banks' behavior in the interbank market during the day.

These issues are relevant for several reasons. First, the interbank market is the environment in which monetary policy has its most direct impact, before affecting the other financial markets. In addition, better understanding of banks' intraday behavior is increasingly important in the light of recent or incipient reforms of interbank payment systems at the EU level and in several G10 and Eastern European countries.[6]

The purpose of the present paper is twofold. First, using a simple model of demand for liquidity under uncertainty, it explains the timing of the operations in the interbank market during the day as the outcome of banks' optimizing behavior; within this context, the existence of an informational link between financial markets, the interbank market and the interbank payment system is highlighted.

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3 See Stigum (1990), Folkerts-Landau and Garber (1992), VanHoose (1992), Lall (1995), Angelini (1994).

4 See the contributions of Kyle (1985), Glosten and Milgrom (1985), Admati and Pfleiderer (1988), Brock and Kleidon (1992). See also French and Roll (1986), Stephan and Whaley (1990), Lockwood and McInish (1990), Chan, Chan and Karolyi (1991), Yadav and Pope (1992).

5 See, among others, Ito and Roley (1988), Mueller et al. (1990), Bollerslev and Domowitz (1993).

6 See, among others, Board of Governors of the Federal Reserve (1988), Committee of Governors of EC Central Banks (1993).

Second, it tests the hypothesis of risk-averse behavior by banks, exploiting the fact that risk aversion is a key feature of the model.

In this model, unlike others dealing with intraday behavior in financial markets, no heterogeneity of agents is required (all operators are liquidity traders), bid-ask spreads play no role, and risk aversion and competitive behavior are assumed (there is no strategic interaction among agents). Banks target an end-of-day liquidity position, which depends on two factors: the clearing balance, resulting from payments on behalf of clients, and the amount of funds borrowed or lent in the interbank market, which banks choose so as to offset the flow of funds generated by the clearing balance. To this end, banks optimize on the basis of available information, which concerns essentially two stochastic variables: a short-term interbank interest rate, and the end-of-day clearing balance itself. The basic idea of the paper is that the gathering of information on these two sources of uncertainty is characterized by a trade-off: if banks choose to operate early during the business day, they face small interest-rate uncertainty, as the interbank rate prevailing at the moment is directly observable, but large uncertainty concerning the clearing balance. Conversely, waiting until the end of the business day allows banks to observe both the balance and the interest rate; however, the latter may have changed substantially since the morning, so waiting entails relatively higher interest-rate uncertainty.

In short, postponing operations to the afternoon amounts to trading information on the interbank rate for information on the clearing balance; accordingly, banks decide the timing of interbank operations based on an optimizing decision along this trade-off. This theory can be tested by exploiting the fact that on "reserve" days - i.e. once a month, at the end of the reserve requirement holding period - the intraday volatility of the interbank rate is substantially higher than during the rest of the month. If the theory holds, on those days the share of interbank operations performed in the early morning hours should be significantly larger than on other days. The empirical evidence presented in the paper is in line with this prediction, and confirms the results in Ratti (1980), who finds that banks are risk-averse.

Section 2 describes the intraday behavior of the overnight rate, trying to verify whether stylized facts analogous to those often mentioned in the literature dealing with speculative markets also hold for this market. In Section 3 a simple model illustrates how uncertainty concerning the interest rate affects the intraday pattern of interbank operations, and the main underlying assumptions are pointed out; Section 4 reports the main results, and Section 5 provides supporting empirical evidence based on data from the Italian interbank market. Some concluding remarks are presented in the final Section.

2. A look at the interbank market during the day

Figure 1 is based on deviations of overnight interest rates - available for one-hour intervals between 8.00 a.m. and 5.00 p.m. - from their daily mean. No significant trend within the day can be detected, but the pattern of volatility - measured by the standard deviation - is very roughly U-shaped, although with a much sharper increase at the end of the day. Figure 2 reports average trading volumes and bid-ask spreads. The spread declines somewhat during the first trading hour, remains fairly constant as transaction volumes grow until the hour between 12.00 and 1.00 p.m., then widens considerably towards the end of the day.

Figure 1

INTRADAY TREND AND VOLATILITY OF INTERBANK RATES (1)

(percentage points; deviations from the daily mean)

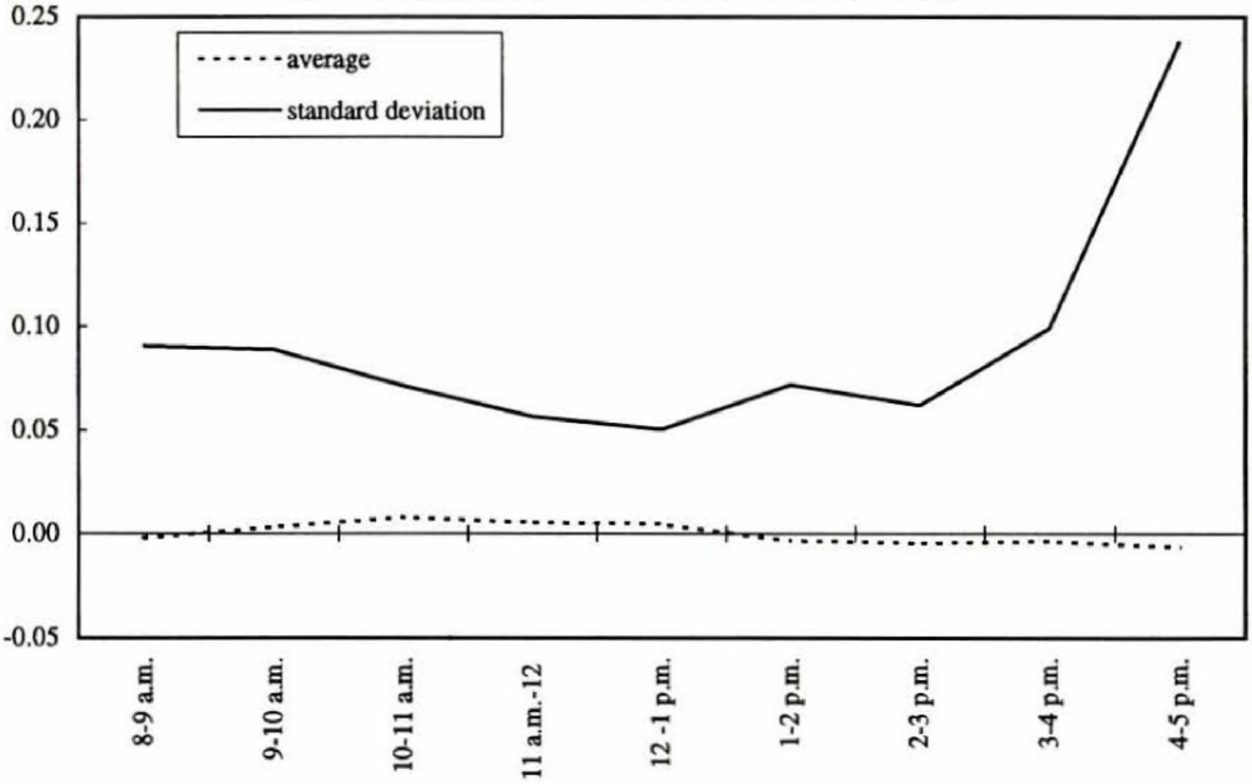
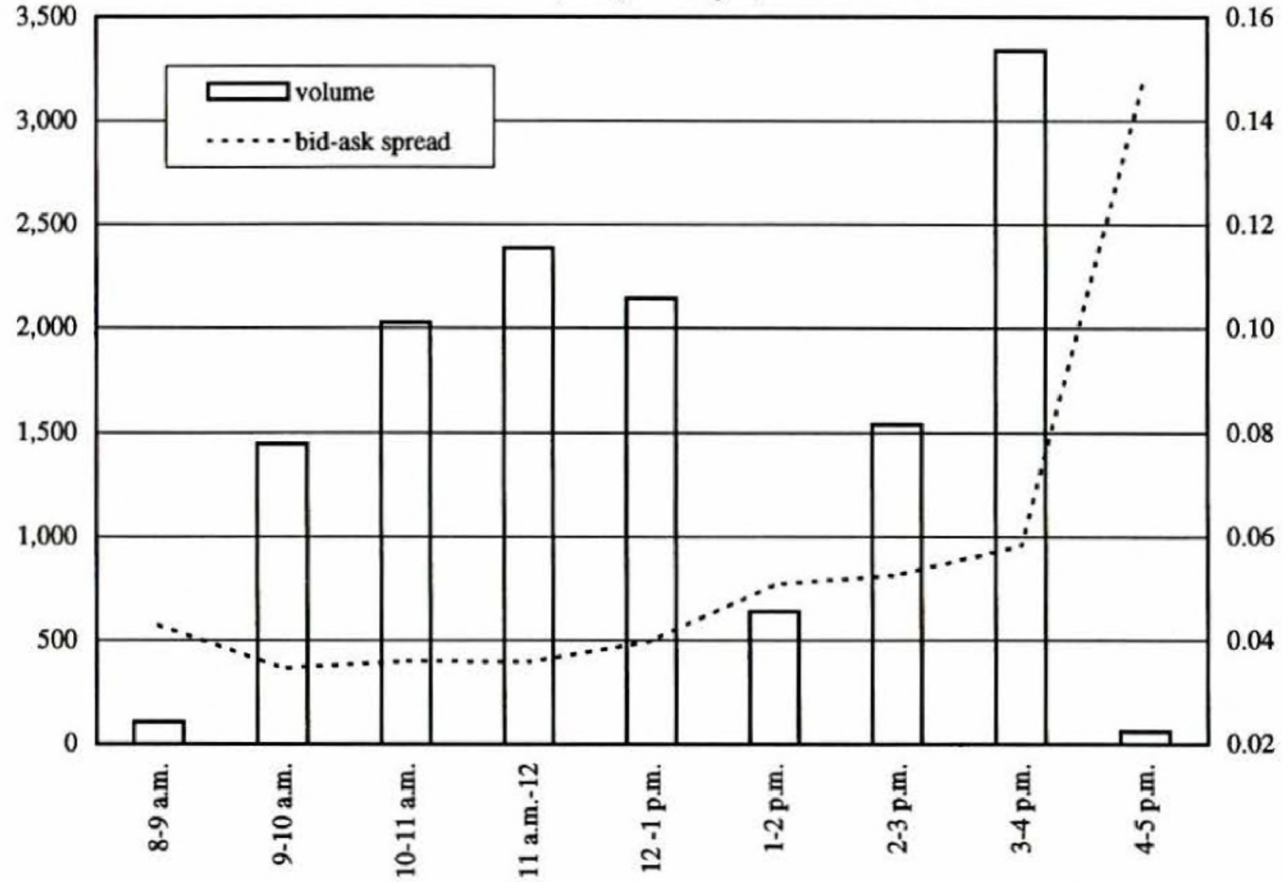


Figure 2

VOLUMES EXCHANGED ON THE INTERBANK MARKET (1)

(daily averages)



(1) The data are from the overnight market. Sample period: July 28, 1993-October 31, 1995. In Figure 2, bid-ask spreads are measured on the right-hand scale in percentage points. Transaction volumes (left-hand scale) are in billions of lire.

The pattern of the bid-ask spread is also moderately U-shaped, especially considering that the exceptionally large increase for the period between 4.00 and 5.00 p.m. reflects practically no transactions, and is thus of only marginal relevance.

Thus, the behavior of price changes and bid-ask spreads is broadly consistent with what occurs in speculative markets. The main difference is in the volume of transactions, which follows a two-hump intraday pattern (Figure 2) as opposed to the normal U-shaped pattern.[7] Overall, an inverse relationship between spread and trading volume seems to hold between 8.00 a.m. and 2.00 p.m., consistently with theories predicting a negative correlation between transaction costs and volume. The opposite holds during most of the afternoon, when both spread and transaction volume gradually increase until the 3.00-4.00 p.m. interval. Thus, the behavior of the series during this part of the day is more similar to that of the stock and options markets and seems broadly consistent with the framework of Brock and Kleidon (1992).[8]

A closer look at the institutional arrangements of the interbank market and of the related payment system may help to account for the pattern of the volume of transactions. Normally, banks begin the day with a good idea of what their inflows and outflows are going to be. For instance, since

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7 In speculative markets the intraday variance of price changes typically follows a U-shaped pattern (see Wood, McInish and Ord, 1985); a similar pattern also characterizes bid-ask spreads (Brock and Kleidon, 1992; McInish and Wood, 1988). A positive relationship between price variability and trading volumes has been documented by a number of authors (see, among others, Epps and Epps, 1976; Karpov, 1987).

8 Brock and Kleidon (1992) explain the clustering of operations at the beginning and at the end of the day with the discontinuity which characterizes those moments: for instance, after the opening operators are free to adjust their portfolios in reaction to the flow of information that has accumulated overnight.

foreign exchange contracts are settled with a two-day lag, at the beginning of any given day banks know with certainty that the payments related to contracts signed two days before are coming due; therefore, they operate in the interbank market in the morning to offset the related inflows or outflows of funds.

However, not all operations can be foreseen. This is why recently banks have come to depend increasingly on screen-based information supplied by netting systems, which give them real time access to their balance vis-à-vis the other participants. At settlement, this balance yields a debt - or an excess of liquidity - which must be offset; failure to do so means either resort to the discount window or idle balances on the bank's settlement account with the central bank, with potentially high opportunity costs. Thus, banks monitor the intraday clearing balance and use it to (continuously) update the forecast of their end-of-day position, which improves gradually until the close of the day, when no uncertainty is left.

Figure 2 is broadly consistent with this story. The two-hump pattern reveals that trading activity takes place in two different phases during the day. Volumes increase gradually throughout the morning to peak between 11.00 and 12.00 a.m. As already mentioned, most of these operations reflect trades whose characteristics are known independently of the screen-based netting system. After the lunch break - between 1.00 and 2.00 p.m. - interbank operations grow fairly steadily up to the 3.00-4.00 p.m. interval, when a second peak in activity occurs, in connection with the settlement phase for the national clearing system. The pattern of transaction volumes and spreads in the afternoon clearly shows the importance for banks of tracking the end-of-day clearing balance: as the day passes and additional information flows in, banks revise their forecast of the balance, resorting increasingly to the interbank market to adjust their liquidity positions; thus, transaction volumes increase in spite of the widening bid-ask spread.

The role in the banks' intraday decision-making process played by the information on the interest rate and on the clearing balance is formalized in the following section.

3. A simple model of banks' behavior

Let t_0 and t_1 denote the beginning and the end of the business day and X denote the net outflow resulting from total outgoing minus incoming payment operations made on behalf of clients during the day; assume that both types of operations payments are exogenous from the bank's viewpoint. Let $r_{b,t}$ be a short-term (e.g. overnight) interbank rate and assume that the bid-ask spread is zero.[9] In this framework, banks face two sources of uncertainty: *i*) the interbank rate, $r_{b,t}$, fluctuates during the day, and is therefore a random variable from the individual bank's viewpoint; *ii*) the end-of-day position, X, is also random. Let the density function of X and $r_{b,t}$ conditional on information available at time t be $f(X,r_{b,t}|I_t)$, and let X be defined over the support $(-\infty,+\infty)$. Finally, let R_t be the amount borrowed ($R_t>0$) or lent ($R_t<0$) in the interbank market.

Assumption A1: Banks preferences are characterized by a utility function U, $U'>0$, $U''<0$.

As will become clear later on in this section, the assumption is necessary since risk-neutral banks would be indifferent to shifts in the relative volatility of interest rates, which are the driving element of the model. For

9 This assumption is not meant to understate the importance that intraday bid-ask spreads may have in determining the pattern of intraday transactions. An attempt to control for this effect is made in Section 5.

simplicity I focus on a two-period problem, and assume that banks can operate only at the beginning or at the end of the business day.

Assumption A2: Banks can operate in the interbank market only once, either at t_0 or at t_1.

In other words, banks have only "one shot" at adjusting their position. This assumption is realistic if the costs of accessing the market are high, and tends to become improbable as adjustment costs are reduced; in the present context, it allows me to focus on the issue at hand without resorting to a full-fledged dynamic model, and it should not affect the qualitative results of the analysis, which should hold as long as adjustment costs are positive.

Assumption A3: Reserve requirements are zero.

Since the amount of required reserves is known with certainty at the moment when optimization problems such as (1) below must be solved, the reserve requirement can be set to any constant value without loss of generality. Yet this Assumption A3 allows me to avoid modeling the effect of the holding period on the demand for reserves, which would substantially complicate the model. Concerning the latter aspect, the assumption is not innocuous, since the mechanism regulating reserve requirements may generate an incentive for banks to reduce transaction volumes as the end of the holding period approaches. A discussion of this effect is provided in the Appendix; an attempt to control for it is made in the empirical section.

Banks maximize the expected utility of the negative of costs; concerning the latter, two situations may occur. If the end-of-day balance net of the amount borrowed (or lent) in the interbank market is less than zero, i.e. if $X\text{-}R_t<0$, the bank will only incur the cost of borrowing funds in the interbank market, $r_{b,t}R_t$. Conversely, if the inequality is reversed the bank will find itself short of base money, and will incur the additional cost of borrowing from the central bank at the discount rate r_d; in this case, total costs will be given by the cost of illiquidity, $r_d(X-R_t)$, plus the cost of borrowing funds, $r_{b,t}R_t$.[10]

Two decisions must be made by the bank at the beginning of the day: one on the size of the single interbank operation allowed, R_t; the other on *when* to perform it. In other words, for either $t=t_0$ or $t=t_1$ the bank will solve:

$$(1) \qquad \underset{R_t}{Max} \int_{r_{b,t}}\int_{-\infty}^{R_t} U(-R_t r_{b,t}) f(X, r_{b,t}|I_t)\, dX dr_{b,t}$$
$$+ \quad \int_{r_{b,t}}\int_{R_t}^{+\infty} U(-r_d X - R_t(r_{b,t} - r_d)) f(X, r_{b,t}|I_t)\, dX dr_{b,t}.$$

The model in (1) is closely related to the basic static model used in the literature on demand for reserves under uncertainty mentioned in the introduction (see Poole, 1968). The first term represents expected utility if the bank ends the day with an excess of funds $(X\text{-}R_t)$, thereby incurring an opportunity cost; the second term incorporates the additional cost borne by the bank in case it is forced to resort to the discount window. In both terms, integration is performed over the whole support of the interbank rate, whereas the limits in the inner integral define an appropriate partition of the support of X.[11]

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10 Clearly, if the bank expects to end the day with a surplus, it can lend funds in the interbank market (i.e. set $R_t<0$), and earn the corresponding rate.

11 First-order conditions for problem (1) are not reported since they are not essential to the discussion; second-order conditions, although somewhat cumbersome to derive, can be easily checked and shown to hold.

Suppose first that the bank decides to operate at t_0. At this time, the bank observes the interest rate r_{b,t_0}, whereas X is unknown. Hence I_t={r_{b,t_0}}, and the bank solves:

$$\Psi_{t_0} \equiv \underset{R_{t_0}}{Max} \int_{-\infty}^{R_{t_0}} U(-R_{t_0} r_{b,t_0}) f(X, r_{b,t_0} | r_{b,t_0}) dX + \int_{R_{t_0}}^{+\infty} U(-r_d X - R_{t_0}(r_{b,t_0} - r_d)) f(X, r_{b,t_0} | r_{b,t_0}) dX. \tag{2}$$

Conversely, suppose that the bank chooses to wait until t_1. Since the inequality $r_d > r_{b,t}$ will always hold in equilibrium, for the bank operating at t_1 it will always pay to observe the realization of X and borrow exactly

$$R_{t_1} = X. \tag{3}$$

In other words, by choosing to operate at t_1 the bank commits itself to setting R_{t_1} equal to the realization of the clearing balance, thereby eliminating all uncertainty related to the latter random variable. Thus, in this case I_t={X} and the bank solves:

$$\Psi_{t_1} \equiv \underset{R_{t_1}}{Max} \int_{r_{b,t_1}} \int_{0}^{R_{t_1}} U(-R_{t_1} r_{b,t_1}) f(X, r_{b,t_1} | X) dX dr_{b,t_1} + \int_{r_{b,t_1}} \int_{R_{t_1}}^{+\infty} U(-r_d X - R_{t_1}(r_{b,t_1} - r_d)) f(X, r_{b,t_1} | X) dX dr_{b,t_1}. \tag{4}$$

Substituting (3) into (4), the above problem reduces to:

$$\Psi_{t_1} = \int_{r_{b,t_1}} U(-r_{b,t_1} X) f(X, r_{b,t_1} | X) dr_{b,t_1}. \tag{5}$$

Summing up, the solution of problem (1) yields optimal decision rules. The optimal amount to borrow or lend, R_t, will be determined from the first-order condition of (2) in case the bank decides to operate in the morning; in the alternative case, it will be optimal to set $R_{t_1}=X$, as we have just seen.

Concerning the timing of the operation, the decision rule will be of the form:

* operate at t_1 if the following inequality holds:

$$\Psi_{t_0} < \Psi_{t_1} . \tag{6}$$

* operate at t_0 if the opposite inequality holds.

4. Results

Suppose that during the month there are special days, which I shall call "reserve" days, when the volatility of the interbank rate increases relative to "normal" days.[12] Let n and r superscripts denote "normal" and "reserve" days, so that e.g. the density functions f characterizing the different days will be indexed as f^n and f^r, and so on. Further, let E denote the expectation operator with respect to the appropriate conditional density function.

Assumption A4: *i*) $E^n(r_{b,t_1})=E^r(r_{b,t_1})$;

ii) Banks perceive $f^n(X,r_{b,t_1}|X)$ to be larger than $f^r(X,r_{b,t_1}|X)$ in the sense of second-order stochastic dominance.

Assumption A4 is a convenient way of formalizing the fact that on reserve days the distribution of the interbank rate is affected by a mean-preserving spread. In other words, bank treasurers know that during reserve days the volatility of the rate is greater than during normal days, whereas its mean remains unaffected.

12 Reserve days mark the end of the reserve requirement holding period, which goes from the 15th of month i to the 14th of the following month (the "reserve" day for that month). Over this period, banks must hold average reserve requirements computed on the basis of the stock of deposits of month i-1, which becomes known with certainty around the beginning of the holding period of month i; see also the Appendix.

Assumption A5: $f^n(X, r_{b,t_0} \mid r_{b,t_0}) = f^r(X, r_{b,t_0} \mid r_{b,t_0})$.

The assumption requires that the volatility of the end-of-day balance, X, be the same during reserve and normal days. Finally, assume that during normal days (6) holds, so that the bank chooses to transact in the interbank market at the end of the day.

Proposition 1: *i*) $\Psi^r_{t_1} < \Psi^n_{t_1}$;
ii) $\Psi^r_{t_0} = \Psi^n_{t_0}$;
iii) If the increase in the volatility of $r_{b,t}$ from normal to reserve days is large enough to reverse the sign of inequality (6), the bank will switch to operating in the morning.

Point *i*) of the proposition follows directly from theorem 2 in Hadar and Russell (1971); strict inequality obtains in this case due to the fact that strict concavity of the utility function is assumed, whereas Hadar and Russell assume quasiconcavity. Point *ii*) follows from the fact that the volatility increase does not affect problem (2), since in that case the interbank rate is observed. The last point is the key one, and it is straightforward.

The reasoning underlying the proposition is the following. Assuming that banks are risk averse, the timing of the operations in the interbank market will depend on the variances of the interest rate ($r_{b,t}$) and of the clearing balance (X) conditional on information available at the beginning of the day. Whenever the former is, say, very large relative to the latter, the end-of-day interest rate may differ widely from the value observed in the morning, so the value of incoming information on X is relatively low; thus, banks choose to operate relatively early during the day. The opposite behavior will tend to prevail whenever the clearing balance is the relevant source of uncertainty.[13]

Proposition 2: banks' expected utility is lower during reserve days.

This can be seen by putting together the expressions in proposition 1.*i*) and 1.*ii*), and (6), which was assumed to hold during normal days. The result is intuitive, given the assumption of risk aversion.

5. Empirical evidence

The model set out in Section 3 predicts that the volatility of $r_{b,t}$ relative to that of X is a key element in determining the timing of banks' operations in the interbank market. A test of this prediction can be performed thanks to the fact that on reserve days the intraday volatility of the interbank rate is much higher than average (Figure 3).[14]

On the other hand, while I have no comparable information on the behavior of the end-of-day clearing balance, X, there are strong reasons to believe that this variable is homoskedastic across reserve and non-reserve days, as required by assumption A5. As mentioned, X results mainly from operations made on behalf of clients, for whom the 14th day of the month should not be in any way special; hence its variability should be constant across reserve and normal days.

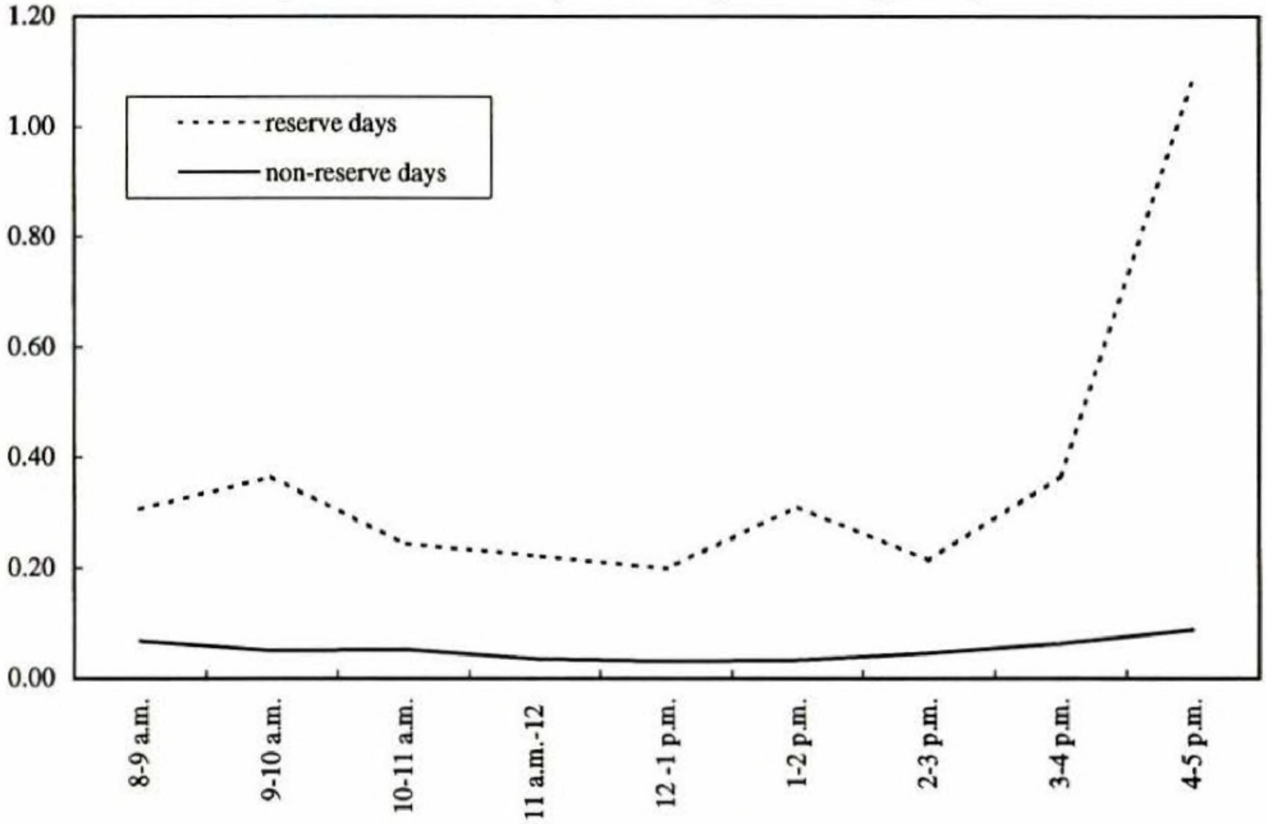
13 Note that this result applies to both the supply and the demand side of the interbank market, as R_t is not restricted from taking on negative values; in other words, both sellers and buyers of funds in the interbank market will prefer operating earlier or later, depending on the sign of inequality (6).

14 An analogous excess volatility has been documented for the United States by Stigum (1990), who reports that on settlement Wednesdays, twice a month, the variability of the Fed funds rate increases substantially.

INTRADAY VOLATILITY OF INTERBANK RATES: RESERVE VS. NON RESERVE DAYS (1)

Figure 3

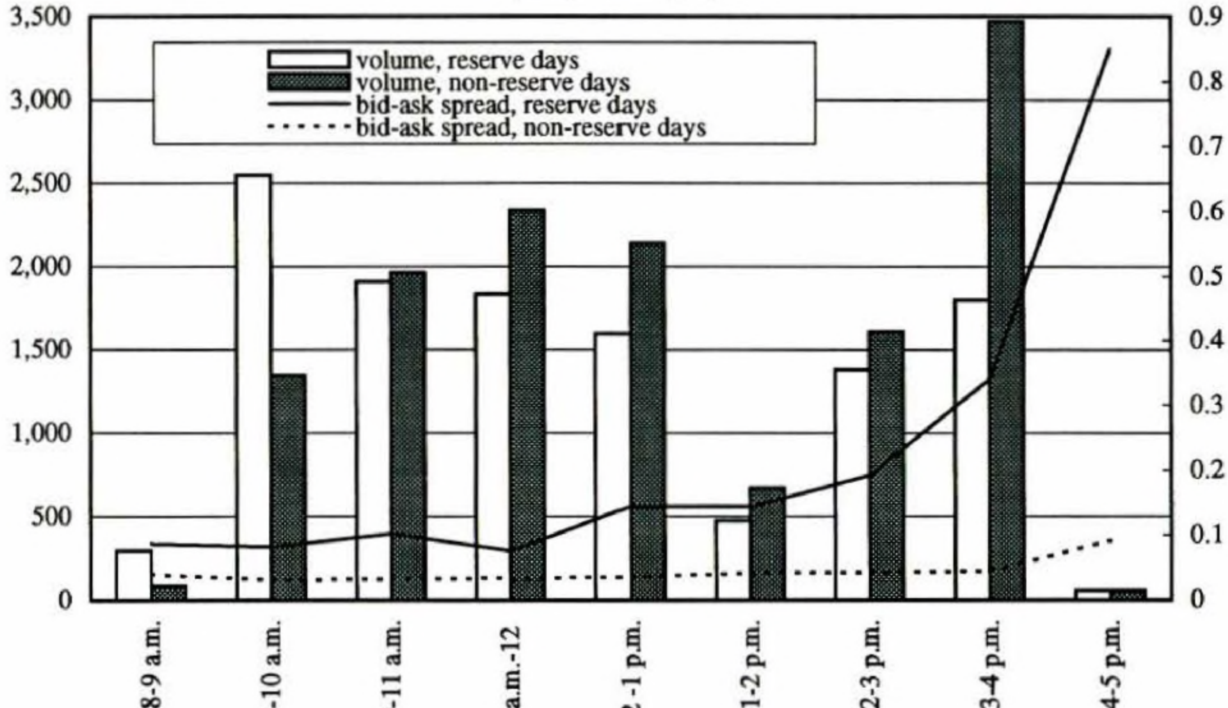
(standard deviation of deviations from the daily mean)



VOLUMES AND SPREADS ON THE INTERBANK MARKET: RESERVE VS. NON-RESERVE DAYS (1)

Figure 4

(daily averages)



(1) The data are from the overnight market. Sample period: July 28, 1993-October 31, 1995. In Figure 4, bid-ask spreads are measured on the right-hand scale in percentage points. Transaction volumes (left-hand scale) are in billions of lire.

Thus, if banks behave according to the optimal decision rule derived from the previous model, the share of interbank operations performed in the early morning hours will be larger on reserve days - when the volatility of the interbank rate is higher - than on normal days. This is indeed the case, as shown in Figure 4, which reports transaction volumes on the Italian interbank market for reserve and normal days. The difference is particularly evident for payments processed during the 9.00-10.00 a.m. and 3.00-4.00 p.m. intervals. To support the graphical evidence, I tested the null hypothesis that transaction volumes are on average the same on reserve and normal days in each time interval, against the alternative of different means (Table 1). Using F tests, the null was rejected at the 1 per cent significance level for the 8.00-9.00 a.m., 9.00-10.00 a.m., and 3.00-4.00 p.m. intervals. Similar results were obtained with nonparametric tests.

Table 1

TESTS FOR DIFFERENT MEANS IN TRANSACTION VOLUMES: RESERVE VS. NON RESERVE DAYS (1)

Hours	8-9 a.m.	9-10 a.m.	10-11 a.m.	11-12 a.m.	12-1p.m.	1-2 p.m.	2-3 p.m.	3-4 p.m.	4-5 p.m.
F	25.73**	32.4**	1.34	4.56*	2.77	0.63	0.96	40.65**	0.94
K-S	2.07**	2.34**	1.06	1.14	1.54*	0.89	1.44*	3.26**	0.81

(1) One and two asterisks denote significance at the 5 and 1 per cent level, respectively. K-S denotes the asymptotic two-sided Kolmogorov-Smirnoff statistic. Degrees of freedom for the numerator of the F statistics: 1; for the denominator: 326. Sample period: July 28, 1993, through November 8, 1994. The tests reported are performed on deviations from daily means; analogous tests performed on levels yield similar results.

Note that ex-post measures of interest rate volatility - like the ones adopted here - could not possibly affect banks' behavior in the sense indicated by the model if there were no way of predicting the increase in volatility. Indeed, a bank treasurer who can avail himself of time series on intraday data will be able to predict the excess interest rate volatility characterizing reserve days, as he would for any other event occurring systematically during the month.[15] This is why comparing banks' behavior on reserve and normal days is a convenient way to test this theory, although any other episode of predictable volatility increase could be used for the same purpose.

Next, I considered the impact of the bid-ask spread on the behavior of transaction volumes. Figure 4 shows that the spread during the 3.00-4.00 p.m. interval is proportionately much higher on reserve days than normal days. This might explain why the volume of transactions for this interval is significantly lower on reserve days, quite independently from the volatility of interest rates.

To control for this effect, I regressed the volume of transactions on a set of hour dummies, the bid-ask spread and a series of interaction terms. Table 2 reports three alternative specifications. When only the dummies controlling for the 8.00-9.00, 9.00-10.00 a.m. and 3.00-4.00 p.m. intervals are included, the bid-ask spread is significant and displays differential effects for reserve and non-reserve days, as well as for morning as against late afternoon. however, the Hausman test signals misspecification. If all the hour dummies are included in the regression, the bid-ask spread displays a negative sign until the early afternoon, consistent with the graphical evidence of Section 2; this effect disappears on reserve days.

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15 The need to model prices and quantities jointly has been emphasized recently (see, among others, Jones, Kaul and Lipson, 1994). Here, I do not analyze their joint determination because all that is required for my purposes is that the volatility increase of the interest rate on reserve days *be perceived* as exogenous by individual market participants, as required by assumption *A4-ii*). At the aggregate level, the causality need not go from the increased volatility to the timing of transactions; a feedback or a reverse causality could also be operating.

Table 2

DEPENDENT VARIABLE: TRANSACTION VOLUME (1)
(hourly data; billions of Italian Lire)

*dures*8-9	445.3* (252.3)	434.5*** (152.1)	396.6* (213.5)
*dures*9-10	1458.0*** (203.2)	1405.6*** (152.8)	1407.0*** (175.2)
*dures*10-11	-	143.2 (153.7)	180.6 (178.2)
*dures*11-12	-	-296.9 (154.4)	-482.5** (182.7)
*dures*12-1	-	-278.5 (155.3)	-268.4 (191.0)
*dures*1-2	-	142.3 (156.3)	113.0 (187.8)
*dures*2-3	-	1162.2 (159.9)	206.4 (177.3)
*dures*3-4	-1163.9*** (218.4)	-1263.8*** (161.0)	-1270.4*** (185.1)
bidask	-8120.9*** (489.0)	-	-141.7 (536.0)
*bidask*dumorn*	6199.6*** (680.9)	-	-2086.8** (832.0)
*bidask*dures*	7231.8*** (547.4)	-	486.1 (543.9)
*bidask*dumorn*dures*	-5174.1*** (839.4)	-	2077.7** (936.9)
trend^2	-.141*** (.029)	-.076*** (.021)	-.104*** (.025)
trend^3	1.88e-3*** (3.48e-4)	10.87e-4*** (2.5e-4)	1.45e-3*** (3.12e-4)
trend^4	-6.30e-6*** (1.09e-6)	-3.80e-6*** (8.06e-7)	-5.03e-6*** (1.00e-6)
R squared	0.38	0.66	0.59
Breusch-Pagan test	35.40***	6.09**	4.12**
Hausman test	1008.3***	9.04	19.1
no. of observations	4293	5175	4293

(1) ***duresi-j*** are dummy variables equal to one during the i-jth time interval of reserve days, and zero otherwise; ***dures*** equals one during reserve days and zero otherwise; ***bidask*** is the bid-ask spread; ***dumorn*** equals one during the six time intervals between 8 a.m. through 2 p.m. and zero otherwise; ***trend*** is a linear trend over the holding period. Corresponding hour dummies for non reserve days and a constant term were also included in the regressions, and all proved highly significant. One, two and three asterisks denote significance at the 10, 5 and 1 per cent level, respectively. Estimation period: July 28, 1993, through October 31, 1995. Estimation method: GLS, random effects. The data were treated like a panel, where the days were considered as the individual units, and the hours during the day played the role of time. Analogous OLS regressions yielded qualitatively similar results. Standard errors are reported within brackets. The Hausman test checks the model specification against the fixed- effect version, while the Breusch-Pagan test checks for the presence of random effects. For the regressions including bid-ask spread variables, observations with missing bid-ask spread values were eliminated.

Finally, I tried to control for possible lower frequency effects. The analysis of Section 3 is suitable for describing the timing of interbank transactions between days, as well as at the intraday level; therefore, one can conjecture that banks might want to shift part of their interbank activity from reserve days to adjacent days, characterized by narrower spreads and lower interest rate volatility.

An additional reason to expect a declining trend of transaction volumes over the holding period - especially during the last days - is that the probability that banks will be able to postpone adjusting their reserve positions goes to zero as the end of the period approaches; this will gradually reduce expected utility, and should therefore induce banks, other things being equal, to anticipate transactions (see the Appendix).

An effort to capture seasonal effects within the holding period is made in the regressions of Table 2 by including several powers of a linear trend. The resulting pattern is given in Figure 5, which confirms that transaction volumes begin to decline several days prior to the reserve day. The Figure also shows that a strong declining trend exists in the course of the reserve day itself: this is most likely attributable to the above-mentioned end-of-the-holding-period effect. Altogether, I interpret this as evidence that the marginal increase in expected utility from shifting a share of transactions to earlier periods can compensate for the expected loss from larger errors concerning the end-of-day reserve target.[16]

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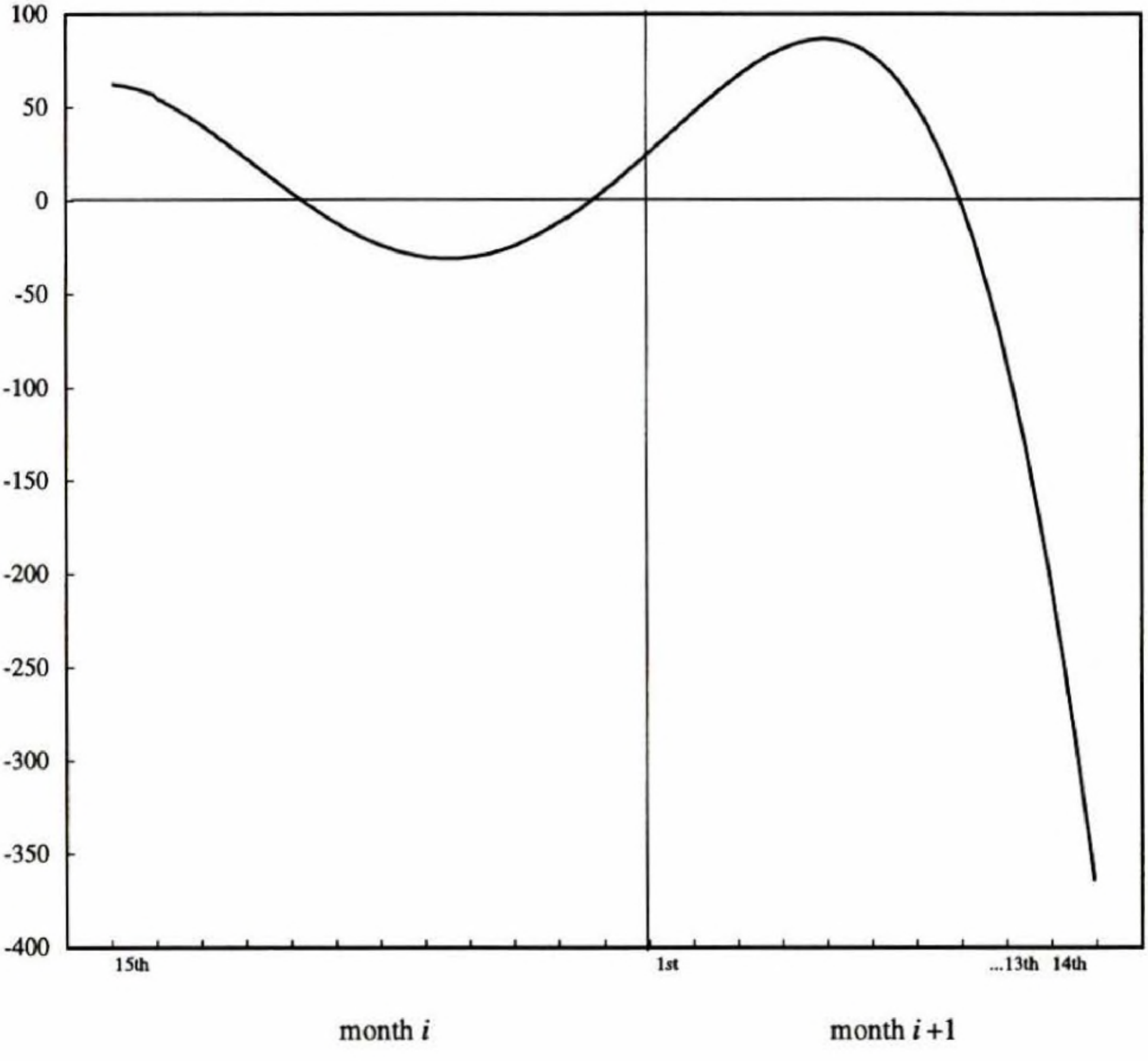
[16] I repeated the regressions in Table 2 on a shorter sample period (July 28, 1993, through December 31, 1994) as a check for robustness; I also instrumented the bid-ask spread to control for possible simultaneity problems. No substantial change in the results was detected in either case.

TREND OVER THE HOLDING PERIOD (1)
(transaction volumes; billions of Italian lire; deviation from the mean of the holding period)



(1) The solid vertical line marks the end of the calendar month. The curve was generated using the estimated coefficients of the variables *trend*^{2}, *trend*^{3} and *trend*^{4} from the regression reported in the second column of Table 2. In turn these variables are the corresponding powers of a linear trend over the holding period. The curves generated with the estimated coefficients from the other regressions in the table have a similar shape.

To summarize, the key point is that even controlling for bid-ask spreads and low-frequency effects, the volume of transactions on reserve days is consistently and significantly higher during the early morning hours, coherently with the prediction of the theory in Section 3.

6. Conclusions

In order to achieve their desired end-of-day liquidity positions, banks must offset the flow of funds generated by commercial and financial transactions of various kinds on behalf of clients. To this end, they customarily operate in the short-term segment of the interbank market, borrowing or lending the desired amount of liquidity. This paper has presented and tested a simple model of banks' intraday behavior, which postulates that the optimal timing of operations will depend on the information available on two key stochastic variables: the end-of-day clearing balance, mainly influenced by transactions made on behalf of clients, and a short-term interest rate, such as the overnight. The gathering of information on these two sources of uncertainty is characterized by a trade off: if banks choose to operate early in the business day, they face no interest rate uncertainty, as they observe the interbank rate prevailing at the moment, but face uncertainty concerning the clearing balance, which is observed only at the end of the business day. On the other hand, postponing operations entails greater interest-rate-related uncertainty, since the rate in the afternoon may differ substantially from its morning level.

The theory predicts that a change in the intraday volatility of either of these variables relative to the other may induce risk-averse banks to shift operations from the morning to the afternoon, or vice-versa. This prediction is tested exploiting the fact that on reserve days, i.e. at the end of the reserve holding period, the observed volatility of short-term interbank rates is substantially larger than during the rest of the month. The empirical evidence presented supports the theory, showing that on reserve days banks shift a statistically significant share of interbank transactions from the afternoon to the early morning hours. Since one essential ingredient of the model is the assumption of risk aversion, the tests performed in the empirical Section can also be viewed as evidence of risk-averse behavior by banks. This result is particularly relevant, considering that very little empirical evidence on this issue is available, and that the assumption of risk neutrality is relatively common in the literature dealing with banks.

The paper also shows that due to the increased interest rate volatility, banks' expected utility on reserve days is lower than in the rest of the month. Although no attempt is made at gauging the order of magnitude of this effect, the obvious policy implication is that such increased volatility should be removed; this prescription is corroborated by the adverse impact on the value of the overnight rate as an indicator of the stance of monetary policy. There is little doubt that the mechanism regulating reserve requirements over the holding period underlies the excess volatility. Among the possibilities for reducing the latter one should consider implementing some type of carry-over mechanism; alternatively, towards the end of the holding period the central bank could announce suitable upper and lower interest rate thresholds, and stand ready to intervene - through channels to be defined - as market rates approach them. A comparative analysis of the various possible mechanisms should be the next topic of a research agenda on these issues.

APPENDIX

The data

The dataset comprises 27 months of data from the Italian screen-based interbank market, from July 28, 1993, through October 31, 1995. The data, pertaining to the overnight segment of the market, are available at one-hour intervals, from the 8.00-9.00 a.m. through the 5.00-6.00 p.m. interval. The time series are: transaction volumes (aggregate monetary value of the individual operations performed in each interval); interest rates (average of rates on the individual operations, weighted by transaction volumes); bid-ask spreads (average bid minus average ask rates).

The interbank market closes at 6.00 p.m. but most of its activity is completed by 4.00 p.m., when liquidity positions on reserve accounts at the central bank must be adjusted to meet the clearing system deadline. As transactions were recorded after 5.00 p.m. only on a tiny number of days, I discarded the 5.00-6.00 p.m. interval. Italy's screen-based interbank market started operations in 1990, and over the sample period analyzed transaction volumes and number of operators show no significantly trends; this eliminates potential problems of the sort pointed out by Tauchen and Pitts (1983).

Reserve requirements over the holding period

In Italy the so-called mobilization system for reserve requirements is adopted. Under this regime banks may mobilize a percentage of their compulsory reserves, provided that the average level for the "holding period" does not fall below the reserve requirement. The holding period goes from the 15th of one month to the 14th of the next, which is the "reserve" day for that month. In addition, a bank's reserves may never fall below an amount equal to the reserve requirement less the percentage (currently 10 per cent) that can be mobilized. The reserve requirement is computed on the basis of the stock of deposits held on average during month i-1, which becomes known with certainty around the beginning of the holding period of month i. The mobilization system went into effect on October 15, 1989, shortly before the launch of the screen-based interbank market. For further details on both issues, see Banca d'Italia (1990, pp. 45-6).

In practice, on "normal" days, provided the bank is not fully utilizing the amount that can be mobilized, an unexpected long or short position may be offset the following day with a short or long one of the same amount. This implies that the expected cost of operating in the interbank market will tend to be lower on normal days than on reserve days. In particular, one can assume that these costs differ by some amount, say α, that is positively related to the probability that the bank will be able to postpone compensating the excess (deficiency) of reserves before the end of the holding period. Clearly, as reserve day approaches this probability gradually tends to zero, and so should α. This may in principle affect the distribution of the volume of transactions between days, as well as in the course of the reserve day itself. This effect is controlled for in Section 5: the nonlinear trends are introduced in the regressions of Table 2 to capture the effect of a smooth decline of α over the holding period on the volume of transactions. The holding period is explicitly taken into account in the model in Griffiths and Winters (1995).

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