

The intraday price of money:  
evidence from the e-MID interbank market

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**Abstract.** We provide empirical evidence, based on tick-by-tick data for the e-MID euro area interbank market covering 2003 and 2004, that the overnight interest rate shows a clear downward pattern throughout the operating day. Thus a positive hourly interest rate (half basis point) implicitly emerges from the intraday term structure of the overnight rate. Such a pattern was not detected in the mid-nineties: we explain this evolution as an outcome of the recent trend towards real time settlement. The estimated intraday interest rate is lower than in the U.S.: this is due to the different cost of central bank daylight credit.

**Keywords:** intraday interest rate, overnight interbank market, real time settlement, central bank daylight overdrafts.

**JEL Codes:** G21, E43, E50.

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# 1 Introduction and summary

Is there a market price for "intraday money"? The answer to this question is interesting for banks, as it gives some insights into their liquidity management. It is also informative about the organization of payment systems, and relevant for central banking, in particular for understanding the implications of different policies in the provision of intraday credit. Transaction costs have so far prevented the emergence of an explicit market for loans with shorter maturities than overnight. However, an implicit intraday interest rate does exist whenever the overnight interest rates differ, depending on the exact time (within the same day) at which the delivery/repayment of funds takes place. So for example, the difference (if any) between the rate charged on an overnight loan delivered at 9 a.m. and a loan with the same maturity delivered at 10 a.m. implicitly defines the price of an hourly loan.

In this work we provide empirical evidence, based on tick-by-tick data for the e-MID interbank market, covering the years 2003 and 2004. E-MID is a screen-based market located in Milan, and it is currently the most liquid market in the euro area for the exchange of interbank deposits. This market has expanded considerably in recent years and it is now fully used by major European banks: indeed, non Italian banks account for about 40% of daily trades (as of March 2005). Our evidence shows that the overnight rate has a clear downward pattern throughout the operating day. Therefore, a positive hourly interest rate emerges from the intraday term structure of the overnight rate; we estimate the market price of an hourly interbank loan to be on average around a half basis point (annualized). Previous evidence on the Italian MID interbank market (1993-1996) did not show any clear intraday pattern of the overnight rate (see Angelini 2000).

We believe that this evolution is due to the trend towards real time settlement for payments, securities and foreign exchange transactions that took place in recent years. This

trend (originated by the need to avoid the risk arising from the settlement lag) has increased the value of intraday liquidity: thus it has created an incentive for banks to charge a price for it, and to engage in an active daylight liquidity management.

Broadly speaking, it appears that the time value of money at the intraday level is larger than what is generally thought. Although the shortest maturity for which an interest rate is quoted is overnight, our evidence suggests that intraday liquidity is a scarce resource with a positive price. The level of this price is affected by the intervention of central banks, providing intraday loans to banks<sup>1</sup>, and by other institutional features of the financial system.

In the next section we hypothesize that the intraday interest rate is positive, and provide a rationale for this prediction. In section 3 we present our empirical analysis. In section 4 our results are compared with previous evidence.

## 2 Identifying intraday interest rates

Our empirical analysis will be devoted to test whether a positive "intraday price of money" implicitly emerges from the intraday pattern of the overnight interest rate. Absent an explicit intraday market, an hourly interest rate is defined by the difference between interest rates charged on overnight loans delivered at different times within the same day<sup>2</sup>.

To be more precise, let us denote by  $t = 0, 1, \dots, 24$  the hours during the day, where  $t = 0$  denotes the opening time of the interbank market (say 9 a.m.). Assume that all overnight interbank loans have to be repaid at  $t = 24$ . We call  $r_0$  the interest rate on an overnight interbank loan delivered at  $t = 0$ ;  $r_1$  is the rate on a loan delivered at  $t = 1$ , and so forth until  $r_T$ , where  $T$  is the market closing time. So the list  $[r_0, r_1, \dots, r_T]$  describes the "intraday term structure" as the levels of the overnight rate for different lengths of the loan: 24 hours, 23 hours, ...,  $24 - T$  hours respectively.

The implicit hourly interest rate, denoted by  $r$ , is easily defined by considering a synthetic long position in the interbank market, which may be created by lending overnight at  $t = 0$  and borrowing the same amount at  $t$  (with  $1 \leq t \leq T$ ): this is equivalent to lending money for  $t$  hours. By definition, the hourly return on such a loan is given by<sup>3</sup>:

$$r = \frac{r_0 - r_t}{t} \quad \text{for } t = 1, \dots, T \quad (1)$$

So a positive (implicit) hourly rate emerges if the intraday term structure is decreasing ( $r_0 > r_1 > \dots > r_T$ ): this is our prediction. To the contrary, a flat intraday term structure would point to a zero level of the hourly interest rate, implying that intraday liquidity would not have any significant economic value<sup>4</sup>. Equation (1) may be written as:

$$r_t = r_0 - r \cdot t \quad (2)$$

where the overnight rate linearly depends on the time of delivery. The estimated coefficient of this equation will provide an empirical measure of the hourly interest rate.

On theoretical grounds, the emergence of an intraday interest rate in the interbank market has been advocated by VanHoose (1991) and Angelini (1998): they both model bank liquidity management at an intraday level, distinguishing between a "morning session" and an "afternoon session". Despite some differences (the former focusses on trading in the interbank market, while the latter focusses on the timing of payment orders processing), they reach the same basic results: i) a positive value of the intraday interest rate emerges as the equilibrium level in the interbank market; ii) such a level crucially depends on the price of daylight overdrafts charged by the central bank<sup>5</sup>; iii) the intraday interest rate is equal to the difference between the overnight rate on interbank loans delivered in the morning and

the rate on loans delivered in the afternoon.

On empirical grounds, the reasons behind a positive intraday interest rate rely on the organization of payment systems, and more generally on the way in which the settlement of transactions is handled. The real time gross settlement has become widely used, particularly for large value payments<sup>6</sup>. This method of handling payments is highly demanding: banks have to maintain sufficient (idle) balances with the central bank, to be able to settle payments one by one in real time; alternatively, they may rely on central bank intraday credit, which also comes at some cost. The real time settlement has become the common standard also for securities transactions, with the so-called "delivery versus payment": this requires both parties in a transaction to simultaneously - often at a predetermined time - fulfill their obligations (cash payment for the buyer and securities delivery for the seller). A similar approach, labelled "payment versus payment", has been adopted by Continuous Linked Settlement (CLS<sup>7</sup>): in principle, the two legs of a foreign exchange transaction are settled simultaneously. All these arrangements - which have been introduced with the aim of reducing the settlement risk - have increased the time value of money at an intraday level.

### **3 Empirical analysis**

Trading in e-MID starts at 8 a.m. and ends up at 6 p.m. Trades are settled in real time, thanks to the "straight through processing" facility: once a deal is made, an automatic procedure makes the lending bank immediately deliver the amount due through a Target payment. Another important aspect of the market microstructure is the fixed maturity of the overnight contract. In particular, deals between Italian banks matures at 9 a.m. (next day): at this time previous day trades are settled in real time, as the borrowing bank has to repay the amount due through a Target payment. Deals involving (at least) a foreign bank

mature by noon (next day). These features enable us to apply the framework introduced in the previous section, where the starting time of an overnight contract unambiguously determines the length of the loan, which is known by both participants in the deal.

We consider trades (tick-by-tick data) that occurred in the e-MID market from 2003:01:02 to 2004:12:31, for a total of 293,667 observations<sup>8</sup>. We divided the day into 9 hourly time bands: from 9 a.m. to 6 p.m.<sup>9</sup>, denoted by  $t = 0, \dots, 8$ . For each working day the simple average overnight rate for each hourly time band and for the whole day were computed, and the differences between the two were calculated: these differences will be denoted by  $\bar{r}_t$  in the following. By making use of interest rate differentials from the daily average, instead of relying on their levels, we are able to insulate intraday patterns - which are our focus - from day-to-day changes in money market rates. The regression below was then run on 4,617 observations (9 time bands times 513 business days).

Our purpose is to see whether the overnight interest rate depends on the different hourly time bands within a day. Before coming to the econometric analysis, a quick look at the data is quite suggestive: see Figure 1, where the differentials between the overnight rates in each time interval and the daily average are plotted (together with 95% confidence bands). The intraday pattern of the overnight rate is clearly shown in the picture, with a steady decline over the whole day - taking a break during lunch time. The overall decrease amounts to 3.5 bp (basis points).

### **INSERT FIGURE 1 ABOUT HERE**

The impression given by the picture is fully confirmed by the econometric analysis conducted on the sample data: we estimate the parameters of equation (3). This assumes that the overnight interest rate is a linear function of the time when a trade takes place:

$$\bar{r}_t = c + \sum_{i=1}^8 \beta_i x_i + \varepsilon_t \quad (3)$$

where  $c$  is the constant and  $\varepsilon_t$  is the usual white noise. The  $x_i$  are dummy variables - where  $i$  stands for the hourly time bands following the first one - taking value 1 when  $t = i$  and zero otherwise. The regression results are given in Table 1.<sup>10</sup> The intercept provides an estimate for the deviation of the overnight rate in the first hourly band considered (9-10 a.m.) from the daily average. The value of each  $\beta_i$  provides an estimate of the change of the overnight rate between the beginning of the day and the hourly band  $t = i$ . As  $p$ -values show, all coefficients except  $\beta_1$  are significant at 1% level ( $\beta_2$  at 5%).

#### **INSERT TABLE 1 ABOUT HERE**

It can be seen from the table that the overnight rate in the first hourly band is 1.4 bp higher than the daily average. As the beta values show, the overnight rate gradually declines during the day; in the last operating hour, its level is about 3.5 bp below the initial level. The last column ( $\beta_i - \beta_{i-1}$ ) shows that the change of the overnight rate with respect to the previous hour is negative in all time bands, with only one exception (namely between the 1-2 p.m. and the 2-3 p.m. bands).

The above evidence seems to confirm our hypothesis that an implicit intraday money market exists: the price of an overnight interbank loan does depend on the length of the contract; in other words, the intraday term structure of the overnight interest rate defines a strictly positive hourly rate in the money market.

Equation (3), used for regression purposes, is an extension of equation (2): the latter relies on the simplifying assumption that the hourly interest rate is constant throughout the operating day. A synthetic measure of the hourly interest rate charged in the money market

is obtained by restating our results as follows:

$$\bar{r}_t = 1.4 - 0.44t \tag{4}$$

Equation (4) provides an empirical evaluation of equation (2) above<sup>11</sup>, and it shows that the hourly (annualized) price of money is estimated to be 0.44 bp on average, which amounts to an annualized daily rate of 10.56 bp (24 times 0.44).

## 4 Comparison with previous results

The empirical evidence regarding the price of intraday liquidity is still modest and not conclusive. Angelini (2000) analyzes the Italian screen-based interbank market (MID), with hourly data for the overnight interest rate from mid-1993 to end-1996: he finds that "no relevant intraday pattern in the level of interest rates can be detected" (page 66). Compared with his results, our estimates point to an evolution of the interbank market: an implicit intraday interest rate did not emerge during the mid-nineties, while it does some years later. In our view, this is due to the recent evolution of settlement procedures, calling for a more active intraday management of bank liquidity. When the bulk of payments were settled through netting systems, a sort of "free intraday liquidity" was provided by the netting mechanism itself: only the multilateral balance of payments had to be settled at the end of the day. The introduction of real time settlement in recent years (Target in 1999, Express<sup>12</sup> in 2000 and CLS in 2002) has made intraday liquidity more costly and it has created an incentive for banks to charge a price for it.

On the other hand, our estimate of the hourly interest rate (slightly less than a half basis point) is lower than that (0.9 bp) obtained by Furfine (2001) for the federal funds market.

The reason may be found in the different policies followed by the Fed and by the ECB in the provision of intraday liquidity. It is quite intuitive that the cost of daylight borrowing from the central bank sets an upper bound to the market price of intraday liquidity - as for any commodity for which there is an unlimited supply at a fixed price.

The Fed charges a fee on the daylight overdrafts: an annualized daily rate of 36 bp, which is equivalent to an annualized hourly fee of 1.5 bp  $(36/24)^{13}$ . On one hand, no bank is willing to pay more than 1.5 bp to raise funds one hour earlier in the interbank market, as she can always get a one hour loan from the Fed at that price. On the other hand, the market price for intraday liquidity may be lower than 1.5 bp, reflecting a situation of liquidity abundance.

The Eurosystem does not apply any price on intraday lending, but its rules require all lending to be collateralized: banks have to pledge eligible securities in order to borrow from the central bank<sup>14</sup>. Thus in the euro area the only cost of intraday borrowing from the central bank is that of pledging collateral. We may think of it as an opportunity cost: a bank is constrained to hold specific kinds of securities, losing its freedom to trade them and to exploit other investment opportunities<sup>15</sup>. It is difficult to provide a reliable estimate of such cost, since it is not always clear whether a bank is actually constrained to hold those securities or she holds them as part of her optimal portfolio management. Our estimate of the intraday interest rate provides an indirect evidence that the cost of collateralizing intraday loans from the Eurosystem is lower than the fee charged by the Fed.

## Notes

<sup>1</sup>The purpose of this type of intervention is the smooth operation of the payments system, so it may be traced back to the lender of last resort function of the central bank; it plays no role in the management of monetary policy. The price charged by the central bank on intraday credit does not affect the overnight interest rate, since it is not possible to replicate an overnight loan with intraday overdrafts.

<sup>2</sup>The theoretical case of an explicit market for intraday liquidity is analyzed in the working paper, available at <http://www.ssrn.com>.

<sup>3</sup>For simplicity,  $r$  is here assumed to be constant throughout a single day. This assumption will be relaxed in the next section.

<sup>4</sup>A negative (implicit) hourly rate may be excluded by a simple no arbitrage argument. In presence of an increasing intraday term structure, a bank would be able, by borrowing earlier and lending later in the day, to get an intraday loan and make a profit at the same time. These profit opportunities (beyond transaction costs) should vanish in equilibrium.

<sup>5</sup>Bech and Garratt (2003) - in their analysis of the strategic choice of banks relative to the timing of payment sending - assume that the interest rate in the (implicit) intraday money market equals the cost of intraday liquidity supplied by the central bank: this cost either takes the form of an explicit fee or it is the opportunity cost of pledging collateral (see our discussion in section 4).

<sup>6</sup>This is the method employed by Fedwire and Target, which handle the bulk of large value payment orders in the U.S. and in the euro area respectively; the first is managed by the Federal Reserve System and the second by the Eurosystem. For an analysis of the evolution of payment systems and of the implications for central banking, see Baglioni (2006).

<sup>7</sup>CLS Bank, based in New York, provides settlement services for foreign exchange transactions in all the main currencies. Its members (shareholders and users) are banks located in

the U.S., Europe and several other countries. They are required to meet a strict timetable (in the morning, European time) for the settlement of their payments. See [www.cls-group.com](http://www.cls-group.com) and European Central Bank (2003) for information.

<sup>8</sup>We thank e-MID s.p.a. for providing this data set to us.

<sup>9</sup>The period between 8.00 a.m. and 9.00 a.m. was not considered, because the trading activity is not sufficient at this time: in fact, in most of the days there are less than 10 observations in this time band, while the average number of observations in each time band is over 60.

<sup>10</sup>The estimates used in this work come from Time Series Modelling Version 4; see Davidson (2006).

<sup>11</sup>Actually the estimated equation is  $\bar{r}_t = \bar{r}_0 - r \cdot t$ , as we make use of deviations from the daily average rate (measured in basis points).

<sup>12</sup>Express (Express II since 2003) has introduced in Italy the real time gross settlement for securities transactions, implementing the "delivery versus payment" approach. See [www.montetitoli.it](http://www.montetitoli.it) for information.

<sup>13</sup>The effective daily rate is 27 bp: 36 bp times 18/24, as Fedwire operating hours are 18. The daily charge (neglecting the deductible) results from the product between such a rate (divided by 360) and the average per-minute overdraft incurred by a bank in a day. See McAndrews and Rajan (2000) and Richards (1995) for more information.

<sup>14</sup>Eligible securities are debt instruments satisfying the eligibility criteria set out by the ECB: see European Central Bank (2006), chapter 6.

<sup>15</sup>An alternative to holding eligible securities is to borrow them: in this case the cost of collateral may be approximated by the price of securities lending. For more details, see Baglioni and Hamoui (2003).

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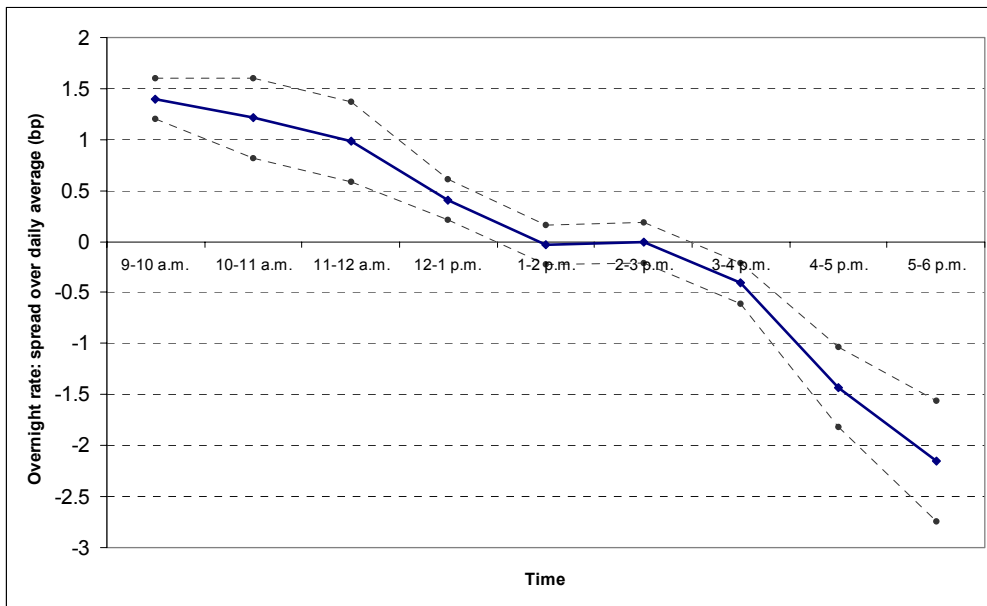


Figure 1 - The intraday pattern of interest rates (averaged over 2003-2004)

**Table 1 - An estimate of the intraday term structure**

Time band	Coefficient	Value (bp)	<i>p</i> -value	$\beta_i - \beta_{i-1}$
9-10 a.m.	<i>c</i>	1.40	0	
10-11 a.m.	$\beta_1$	-0.19	0.35	-0.19
11-12 a.m.	$\beta_2$	-0.42*	0.03	-0.23
12-1 p.m.	$\beta_3$	-0.99**	0	-0.57
1-2 p.m.	$\beta_4$	-1.43**	0	-0.44
2-3 p.m.	$\beta_5$	-1.41**	0	0.02
3-4 p.m.	$\beta_6$	-1.81**	0	-0.40
4-5 p.m.	$\beta_7$	-2.83**	0	-1.02
5-6 p.m.	$\beta_8$	-3.55**	0	-0.72
	$R^2 = 0.09$			<i>Mean</i> = -0.44

Note: Asterisks (\*) and (\*\*) indicate significance at the 5% and 1%, respectively.