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the case of August 2007

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the case of August 2007

Angelo Baglioni (*) - Andrea Monticini (**)

Abstract.   By analyzing high frequency data for the European interbank market, we show that the intraday interest rate (implicitly defined by the term structure of the ON rate) jumped by more than ten times at the outset of the financial turmoil in August 2007, resulting in an inefficiency of the money market. This took place despite the provision of unlimited free daylight overdrafts by the ECB, on a collateralized basis. We suggest that such result may be attributed to an increase of the liquidity premium and of the cost of collateral.

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1 Introduction

There is a broad consensus that the intraday interest rate should be set to zero on efficiency grounds. In this work we document that, while in normal times money market rates are roughly in line with this efficiency criterion, they may deviate by a large extent in a situation of liquidity tension, like the one taking place at the outset of the subprime financial turmoil. We provide an analysis of the European electronic interbank market (e-MID) with high frequency data, showing that the hourly interest rate − implicitly defined by the intraday pattern of the overnight rate − jumped by more than ten times (from 0.2 bp to 2.2 bp) in the reserve maintenance period starting on August 8th 2007. This finding has no straightfoward explanation, since the Eurosystem supplies intraday liquidity at no cost and without limit, except for the collateral requirement.

We attribute this result to the sudden increase of the liquidity and credit risks taking place at the outset of the financial turmoil, with two likely consequences. First, in times of liquidity crisis the intraday credit provided by the central bank is an imperfect substitute for an early delivery of overnight funds. Then the market price of intraday liquidity incorporates a liquidity premium, making it deviate from the cost of daylight central bank overdrafts. Second, the widening of the spread between unsecured and secured interbank interest rates implies an increase of the cost of collateral, making it more costly to get intraday credit from the central bank. A stronger demand of collateral, in order to guarantee a larger amount of available funds from the Eurosystem, has presumably contributed to making the collateral requirement more costly.

Several recent contributions in monetary theory, focussing on the role of money as a medium of exchange, point to the optimality of a zero intraday rate. For example, Zhou (2000) distinguishes between "consumption/investment debt" and "settlement debt": since

the latter does not affect the inter-temporal allocation of resources, the intraday rate is just a transaction cost which should be minimized. In Martin (2004) and Bhattacharya *et al.* (2007) a zero level of the intraday rate is optimal since it provides an insurance for consumers against liquidity shocks. Other works, more focussed on the mechanics of the payment systems, stress that a positive cost of intraday liquidity may induce individual banks to delay payments, putting a negative externality onto the banking system (see Angelini 1998, Bech and Garratt 2003, Mills and Nesmith 2008, Martin and McAndrews 2008). The issue of "delayed payments" have raised the concern of policymakers for its impact on the operational risk in the payment systems (see FED 2006, 2007).

Overall, this literature shows that the market equilibrium may be inefficient, since a positive cost of intraday credit may emerge as a market outcome. This creates a role for the active intervention of central banks, who are able to provide intraday liquidity at no cost. Our work contributes to this literature by showing that during a liquidity crisis the ability of the central bank to curb the (implicit) market price of intraday liquidity may be limited.

While the theory of the intraday interest rate is well developed, the empirical evidence is scarce, due to the absence of an explicit market for intraday credit. The implicit intraday rate has been estimated by Furfine (2001) for the federal funds market in the US and by Baglioni and Monticini (2008) for the e-MID market in Europe: both point to a very low level of the hourly rate (0.9 bp and 0.4 bp respectively) − although statistically significant. While the cost of intraday liquidity may be negligible under normal conditions, we show in this work that it may gain economic significance in times of liquidity tension, leading to an inefficiency of the money market.

In the next section we provide the empirical evidence: after defining the implicit intraday interest rate, we document the striking rise taking place at the outset of the financial crisis.

In section 3 we discuss this result and we suggest a rationale for it. Some concluding remarks are given in section 4. Finally, the Appendix extends the analysis to a longer time span, in order to check for the robustness of our results.

2 The empirical evidence

2.1 The implicit intraday interest rate: definition

Following Baglioni and Monticini (2008), we consider an overnight (ON) interbank market where all loans must be repaid at the same time next day. Thus the starting hour of a contract (denoted by t) unambiguously determines the length of a loan (assuming real time settlement). Then we may define the implicit hourly rate i_t simply by:

$$i_t = r_t - r_{t+1} \tag{1}$$

where r_t is the ON interest rate observed in the market at time t. By estimating the term structure of the ON rate ($r_0, r_1, ..., r_T$, where 0 and T are the market opening and closing times respectively) we are able to provide an estimate of the hourly interest rate.

2.2 The data set

With 15 billion euros traded daily (on average) and 250 members from all over Europe and the US, the Milan-based e-MID market is the major electronic marketplace for interbank loans in the euro area. Trades start at 8 a.m. and ends up at 6 p.m., and they are settled in real time through TARGET payments. All ON trades matures at the same time next day[1].

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[1]Trades involving only Italian banks are repaid at 9 a.m. next day, and trades involving international banks mature by noon next day.

The evidence presented here is based on all ON trades in the two reserve maintenance periods: 7.11.2007 - 8.7.2007 and 8.8.2007 - 9.11.2007.[2] As it is well known, the subprime crisis hit the financial markets on August 9th 2007, right at the beginning of the second maintenance period here considered. We drop the last day in each period: we consider this day as not informative, since the averaging facility[3] is not available by definition, and this makes this day different from all the others. The overall number of observations is 4,548 (of which 2,550 in the second period[4]).

Figure 1 shows the sudden rise of the intraday volatility of the ON rate starting on August 9th. Indeed, the average intraday standard deviation of the ON rate was 0.074 in the second maintenance period considered, compared with a 0.008 in the previous one. This goes together with a remarkable increase of day-to-day volatility: the standard deviation of daily average rates goes from 0.01 in the first period to 0.18 in the second one. Our interest is focussed on intraday volatility: in the following, we shall try to see how this translates into a rise of the intraday interest rate.

By the way, the average ON rate did not show any significant change in the reserve maintenance period starting on August 8th. In fact, the ON rate was on average 4.14 during that maintenance period, while it was 4.08 during the previous one; however this difference is not statistically significant[5].

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[2] Our results are robust to an extension of the time span considered, as we show in the Appendix.

[3] The reserve requirement is applied to the average end-of-day balance held in reserve accounts over the whole maintenance period, enabling banks to substitute the reserve of one day with that of some following day (within each period). Of course, this stabilizing mechanism is not available in the last day of a maintenance period.

[4] In this period August 15th has been dropped: this is a half-bank holiday, so very few trades are made.

[5] The null hypothesis $H_0 : \overline{r}_{P1} = \overline{r}_{P2}$ − where $\overline{r}_{P1}$ ($\overline{r}_{P2}$) is the ON average rate during the first (second) maintenance period considered − cannot be rejected both by the parametric Welch two sample t-test and by the non-parametric Wilcoxon rank sum test at the 10% level.
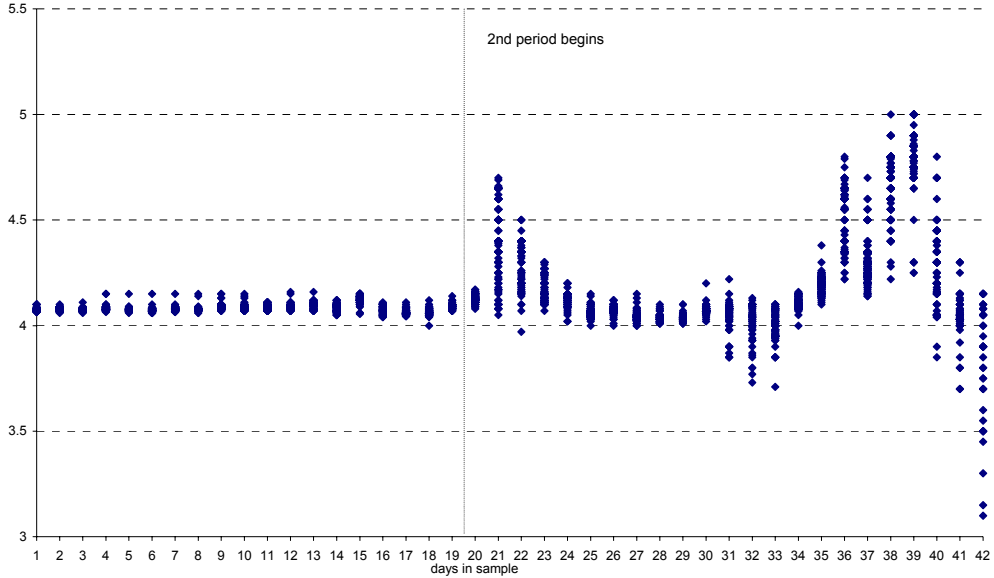
Figure 1: The ON rate: tick-by-tick data

2.3 The jump of the intraday rate

We begin our analysis by dividing the business day into 9 hourly time bands: from 9 a.m. to 6 p.m.[6], denoted by $t = 0, ...8$. For each business day, the average ON rate in each time band has been computed, from which the average rate of the whole day has been subtracted: we use interest rate differentials from the daily average (denoted by $\overline{r}_t$) in order to disentangle intraday patterns − which are our focus − from day-to-day patterns of the ON rate.

We estimate the following equation (2) in the two reserve maintenance periods here considered:

$$\overline{r}_t = c + \sum_{i=1}^{8} \beta_i \cdot x_i + \varepsilon_t \tag{2}$$

where x_i are dummy variables − i stands for the hourly time bands following the first one

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[6]The first operating hour (8 a.m. - 9 a.m.) has not been included in our analysis, since very few trades take place at this time.

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– taking value 1 when $t = i$ and zero otherwise; $\varepsilon_t \sim i.i.d.\,(0, \sigma_t^2)$ with possibly $\sigma_t^2 \neq \sigma_s^2$ for $t \neq s$. The intercept c provides an estimate of the interest rate differential from the daily average during the first hourly band considered (9-10 a.m.). The values of the dummy coefficients β_i provides an estimate of the difference between the ON rate in each time band and the ON rate in the first time band. Thus an estimate of the implicit hourly interest rate i_t (defined in eq.(1)) is provided by the consecutive changes $(\beta_i - \beta_{i+1})$ $(-\beta_1$ for the first time band). The number of observations used in the regressions equals the number of business days in each period times the number of hourly time bands: $19 \cdot 9 = 171$ and $23 \cdot 9 = 207$ for the first and second period respectively.

The regression analysis provides quite strong results – shown in Table 1. During the second period the estimated hourly interest rate is larger than in the previous period in *all* time bands; *the mean hourly rate jumps from 0.2 bp to 2.2 bp.* All coefficients are highly significant (with the exception of β_1 in the second period, due to high volatility in this hourly band). The standard errors have been obtained by heteroskedasticity and autocorrelation consistent (HAC) covariance matrix estimators (see Andrews and Monahan 1992).

In Figure 2 the fitted values of equation (2) are plotted – based on the estimated parameters shown in Table 1 – for the first period considered (dotted line) and for the second one (solid line): each line provides a view of the intraday term structure of the ON interest rate – expressed as a differential from the daily average – in each period. The difference between the two periods is striking. Before the crisis the term structure is quite flat: the ON rate remains within a range of ± 1 bp from the daily average. During the crisis the term structure is much steeper: the ON rate is almost 10 bp above the daily average in the first hour; then it steadily declines until reaching at the end of day a level 8 bp lower than the daily average. This implies – for example – that borrowing overnight at 9.30 a.m. costs

about 18 bp more than borrowing at 5.30 p.m.

Table 1 - The estimated intraday rate before and during the crisis

Time band	Coefficient	July 11th - August 6th		August 8th - September 10th	
		Value in bp	$\beta_i - \beta_{i+1}$	Value in bp	$\beta_i - \beta_{i+1}$
9-10 a.m.	c	0.71*** (0.11)	0.34	9.50*** (2.7)	3.20
10-11 a.m.	β_1	−0.34** (0.17)	0.07	−3.20 (2.97)	3.77
11-12 a.m.	β_2	−0.41*** (0.15)	−0.21	−6.97** (2.96)	0.39
12-1 p.m.	β_3	−0.20** (0.09)	0.31	−7.36*** (2.87)	0.99
1-2 p.m.	β_4	−0.51*** (0.16)	0.17	−8.35*** (2.83)	1.54
2-3 p.m.	β_5	−0.68*** (0.15)	0.41	−9.89*** (2.94)	0.44
3-4 p.m.	β_6	−1.09*** (0.11)	0.43	−10.33*** (3.02)	3.94
4-5 p.m.	β_7	−1.52*** (0.22)	0.17	−14.27*** (3.41)	3.29
5-6 p.m.	β_8	−1.69*** (0.34)		−17.56*** (4.41)	
	$Adj.R^2 = 0.34$		**Mean = 0.21**	$Adj.R^2 = 0.21$	**Mean = 2.19**
	$D.W. = 1.87$			$D.W. = 1.66$	

Note: (*), (**), and (***) denote 10%, 5%, 1% significance level respectively, based on HAC standard errors (shown in parenthesis).

3   Interpreting our results

As it is well known, the intraday interest rate is crucially affected by the cost of daylight credit provided by the central bank. Intuitively, a bank short of liquidity say at 9 a.m. has
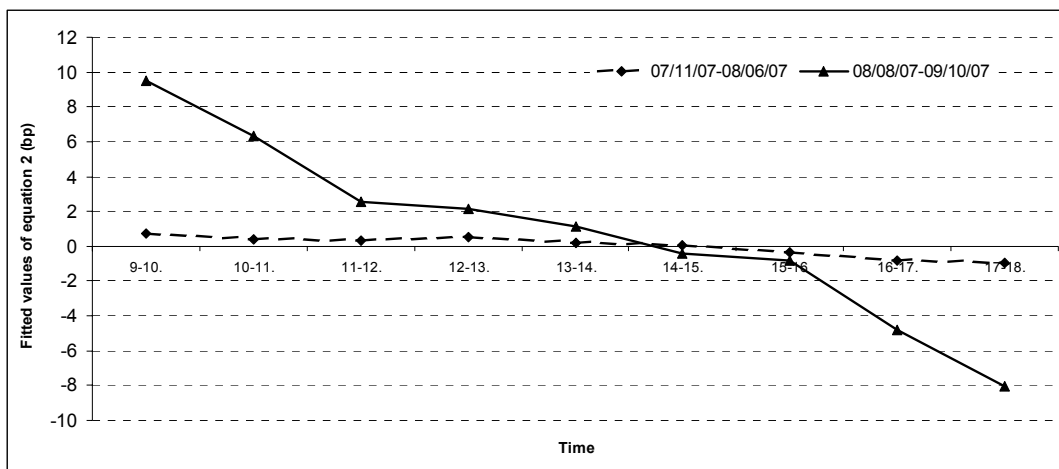
Figure 2: The switch of the ON intraday term structure

two alternatives: (i) borrow immediately in the interbank ON market, (ii) obtain intraday credit from the central bank and borrow later (say at 4 p.m.) in the ON market. If these two alternatives were perfect substitutes, such bank would not be willing to pay an implicit intraday interest charge (resulting from the difference between the ON rates at 9 a.m. and at 4 p.m.) larger than the cost of a seven hour loan from the central bank. This is the reason why the cost of daylight liquidity provided by the central bank may be seen as an upper bound for the implicit intraday interest rate, at least under normal conditions.

Consequently we have two candidate (not alternative) explanations for the jump of the intraday interest rate that we have documented in this work. First, the two above alternatives are not perfect substitutes, particularly in times of liquidity tension. Second, the cost of intraday credit from the central bank has increased during the financial crisis. Let us examine them in turn.

There is a widely accepted evidence that the financial turmoil beginning in August 2007 produced a remarkable increase of the liquidity risk perceived by the participants in the money market; in particular, the uncertainty on the availability of funds in the interbank

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market grew substantially[7]. In such circumstances a risk averse bank might have a strict preference for borrowing early in the ON market rather than wait and borrow later (relying in the meantime on the intraday liquidity from the central bank), in order to make sure that she has enough funds to achieve her end-of-day targeted liquidity position. If this is the case, the intraday liquidity provided by the central bank is not a perfect substitute for an anticipated delivery of ON funds. That's why a borrowing bank might be ready to pay an implicit intraday interest rate higher than the cost of central bank daylight credit. In other words, she is willing to pay a liquidity premium on an ON loan delivered early in the day.

A symmetric argument applies to a bank long of liquidity, taking into account that the random flow of payments makes her end-of-day liquidity position a stochastic variable; this source of uncertainty is stronger early in the day and it vanishes towards the closing time of business. A bank might prefer to delay lending in the ON market, since by lending early she bears the risk that, in case of need, she will not be able to get an interbank loan later in the day. Then she may want to charge a liquidity premium for lending early in the ON market.

Coming to the second explanation, we have to remember that the ECB does not charge any fee on intraday credit; the only cost comes from the collateral requirement. There is some evidence that the cost of collateral increased sharply since the beginning of the financial crisis. At the same time, the demand of collateral became stronger, making eligible securities become a scarce resource: this may have contributed to increasing the cost of satisfying the collateral requirement.

A reliable measure of the cost of collateral is hard to find out. If a bank has to borrow eligible securities, she incurs in an explicit cost. However if a bank holds eligible securities in

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[7]The jump of the spread between the three-month Euribor and the T-Bill rate (or the Eonia swap rate) is usually taken as an indicator of liquidity hoarding and of weak money market activity. See ECB (2007, 2008) for detailed information.

her portfolio, she bears only an opportunity cost, provided such securities have an alternative use in the financial market (this is true for government bonds, for example). If a bank is able to use as collateral securities which are not accepted in the market (like ABS), even the opportunity cost is absent.

Nonetheless, a tentative way to measure the cost of collateral is provided by the Euribor-Eurepo spread[8]. On one hand, a bank may "borrow" eligible securities through a buy and sell back transaction, earning the interbank secured interest rate (Eurepo); it has to fund the deal by borrowing at the unsecured interbank rate (Euribor): in such a case the spread is a measure of the explicit cost of collateral. On the other hand, a bank holding government bonds and using them as collateral with the ECB gives up a profit opportunity, namely using such bonds to borrow money at the repo rate and lend at the higher unsecured rate: in such a case the spread is a measure of the opportunity cost of collateral.

The evidence points to a remarkable increase of the Euribor-Eurepo spread across the two reserve maintenance periods here considered. The average three-month spread goes from 7.6 bp before the liquidity crisis to 51.6 bp during the crisis[9]; the difference is statistically significant[10]. The main reason behind this jump has presumably to be found in the higher credit risk perceived by market participants. Whatever its origin, the widening of the spread implies a higher cost of collateral.

As far as the demand of collateral is concerned, a measure is provided by the amount of eligible securities deposited at the Eurosystem. This is usually quite stable: it remained

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[8]Euribor and Eurepo are indexes of the interbank interest rates in the euro area, unsecured and secured respectively. They are provided by the European Banking Federation and are based on the information provided by a panel of prime banks. See http://www.eurepo.org/ for detailed information and for daily data.

[9]Standard deviations are 1.2 and 15.6 respectively. The two means are statistically significant (based on two tails t-test).

[10]The null hypothesis of equal means is rejected both by the parametric Welch two sample t-test and by the non-parametric Wilcoxon rank sum test at the 1% level.

around 1,000 billions euros during the first seven months of 2007, with only minor changes. In August 2007 the amount deposited increased by roughly 20%, and by another 20% during the last four months of the year (reaching a level above 1,400 billions by year-end)[11]. This increase has been due to the need of relying on the liquidity provided by the central bank, given the difficulties and the uncertainty in raising liquidity in the market. The ECB has been very active in providing liquidity, in order to restore normal conditions in the money market: the frequency and the amounts of interventions increased dramatically (see ECB 2008 for a full description); this in turn induced banks to deposit more collateral.

Summing up, the sudden increase of the liquidity and credit risks taking place at the outset of the financial crisis has apparently had a significant impact on the implicit intraday interest rate. A direct effect may be identified in the liquidity premium for the early delivery of funds in the ON interbank market, making the market price of intraday liquidity get higher than the cost of a daylight overdraft from the central bank. An indirect effect may be seen in the increased cost of collateral, making it more costly to get intraday credit from the central bank.

4 Concluding remarks

We have shown that at the outset of the "sub-prime financial turmoil" (August 2007) the implicit hourly interest rate in the euro area money market jumped by more than ten times, reaching a remarkable level: borrowing overnight early in the morning would cost 18 bp more than borrowing late in the afternoon. We suggest that this evidence may be attributed to an increase of the liquidity premium and of the cost of collateral. These two rationales have only been discussed here; a deeper analysis is beyond the scope of this paper and it is left

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[11]See data at http://www.ecb.int/stats/payments/securities/html/coll1.en.html.

to future research.

The theory and practice of central banking point to the need of a supply of daylight credit by the central banks, aiming at keeping the price of intraday liquidity as close to zero as possible. However, this kind of intervention creates a credit exposure of central banks, who react by implementing some protective measures like: caps, fees, or collateral. Several studies[12] compare the relative costs and benefits of such measures; there is a growing consensus that the collateral requirement is the most efficient solution[13]. Our evidence shows that, in a situation of liquidity stress, even the provision of free daylight overdrafts − on a collateralized basis − may be unable to prevent the market price of intraday liquidity from reaching quite a high level.

Appendix

In this appendix we check whether the evidence provided in this work is robust to an extension of the time period considered. We estimate equation (2) over the time span including the four reserve maintenance periods ending on August 7th 2007, and we estimate equation (2) again over the four maintenance periods starting on August 8th 2007. The number of observations is 75·9=675 and 84·9=756 respectively. As it can be seen from Table 2, the above results are confirmed, although the jump of the intraday interest rate is smaller: the estimated mean hourly rate during the liquidity crisis is 5.7 times larger than in the previous period.

A further check has been done, by regressing equation (2) over the time span including the three reserve maintenance periods ending on July 10th 2007, and by regressing equation

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[12]Some have been mentioned in the Introduction. See also Mills (2006), Furfine and Stehm (1998), Lacker (1997).

[13]This has been implemented in Europe, but not in the U.S.: instead of applying a collateral requirement, the Fed charges an explicit fee on daylight credit. See http://www.ecb.int/paym/coll/html/ and McAndrews - Rajan (2000) for detailed information on the euro area and the U.S. respectively.

(2) again over the three maintenance periods starting on September 12th 2007. This exercise enables us to check whether the impact of the liquidity crisis on the intraday interest rate does not vanish after the first maintenance period during the crisis. To save space, we do not show the results in detail in a separate table, but we limit to say that the estimated mean hourly rate after the liquidity shock is 4.1 times larger than before[14].

Table 2 - The estimated intraday rate over an expanded time span

Time band	Coefficient	April 18th - August 6th		August 8th - December 10th	
		Value in bp	$\beta_i - \beta_{i+1}$	Value in bp	$\beta_i - \beta_{i+1}$
9-10 a.m.	c	1.19*** (0.23)	0.71	6.33*** (1.34)	2.65
10-11 a.m.	β_1	−0.71*** (0.27)	0.09	−2.65* (1.64)	1.62
11-12 a.m.	β_2	−0.80*** (0.28)	0.21	−4.27*** (1.49)	0.65
12-1 p.m.	β_3	−1.01*** (0.28)	0.41	−4.92*** (1.44)	1.15
1-2 p.m.	β_4	−1.42*** (0.26)	0.06	−6.07*** (1.42)	0.80
2-3 p.m.	β_5	−1.48*** (0.26)	0.22	−6.87*** (1.41)	1.23
3-4 p.m.	β_6	−1.70*** (0.26)	0.15	−8.10*** (1.44)	2.45
4-5 p.m.	β_7	−1.85*** (0.31)	0.25	−10.55*** (1.70)	0.92
5-6 p.m.	β_8	−2.10*** (0.31)		−11.47*** (1.90)	
	$Adj.R^2 = 0.16$		**Mean = 0.26**	$Adj.R^2 = 0.19$	**Mean = 1.43**
	$D.W. = 1.75$			$D.W. = 1.61$	

Note: (*), (**), and (***) denote 10%, 5%, 1% significance level respectively, based on HAC standard errors (shown in parenthesis).

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[14]Of course, regression results are available upon request.

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