Informational deadlines, patterns of trade and the Hirshleifer effect

Anurag N. Banerjee
Durham Business School
Department of Economics and Finance
University of Durham
U.K.

Giulio Seccia*
School of Social Sciences
Economics Division
University of Southampton
U.K.

May 12, 2008

Abstract

Fully anticipated arrivals of payoff-relevant public information act as trading deadlines for financial investors. This entails a "deadline effect" by skewing large volumes of financial trades towards the date the information is due to reach the market. This occurs if and only if traders are risk-averse. Unanticipated information arrivals entail a loss of trade (the Hirshleifer effect) that is magnified by the deadline. With stochastic information arrivals deadline and Hirshleifer effects vanish. These issues are first analyzed in a non-stationary search model and then empirically validated by testing the effect of FRB's scheduled announcements on the CBOT Federal Funds Futures market.

Keywords: Search in financial market, Hirshleifer effect, deadline effect, monetary announcements, interest rate futures.
JEL classification number: D83, G12, G14, E58.

1. Introduction

In this paper we argue that the fully anticipated arrival of payoff-relevant public information acts as a treading deadline for financial investors and entails a "deadline effect" by skewing a large volume of financial transactions towards the date the information is due to reach the market. This occurs if and only if traders are risk averse. The eventuality of an unanticipated information arrival leads to a loss of trade also known as the Hirshleifer effect that is magnified by the presence of a deadline effect. Moreover if the timing of the information arrival is stochastic both deadline and Hirshleifer effects vanish. These issues are first analyzed in a theoretical model. We then empirically validate the model by testing the effect of Federal Reserve Bank's (FRB) scheduled monetary policy announcements on the Chicago Board of Trade (CBOT) 30-Day Federal Funds Futures market.
We study a dynamic matching and bargaining model with a continuum of active buyers and sellers

*Corresponding author. School of Social Sciences, Economics Division, University of Southampton, Southampton, SO17 1BJ, U.K. Tel. +44(0)23 8059 3529, giulio.seccia@soton.ac.uk

where the distributions of bid and ask prices of the traded asset are determined endogenously. We start by analyzing the pattern of trade when an infinite sequence of payoff-relevant public announcements reaches the market at known and perfectly anticipated dates, as in the case of companies' quarterly announcements of earnings, Central Banks' target rate decisions, and inflation and unemployment rates reports. At each point in time between information announcements each potential buyer meets a seller and both declare their reservation prices: if there is room for trade they agree to exchange at the symmetric Nash solution. Endowments and preferences are common knowledge and each agent can compute at each instant the endogenous distribution of reservation prices.

We show that the volume of trade increases as the "deadline" approaches by showing that the room for trade increases in expectation and the probability of exchange increases accordingly. This pattern of trade follows from bid and ask prices being pinned down at the date the information is due to reach the market. Buyers' optimal strategy is to start from a low bid and to increase their offer as they approach the deadline; sellers behave symmetrically by starting with a high ask price and decreasing it as the deadline approaches.

In our model agents do not discount time within announcements nor face transaction costs. The pattern of trade is uniquely due to the deadline effect. Moreover, we show that increasing volumes of trade can only occur when agents are risk averse as bid and ask prices of risk neutral agents are identical and constant, hence generating a null volume of transactions. An important corollary of this result follows when considering news reaching the market before expectations, i.e. unanticipated early announcements. The corollary says that a Hirshleifer effect can occur only if the deadline effect is present. If this was not the case, we would not be able to rule out that increasing trade is due to the activity of risk neutral agents only. Hence we could not claim that in this case unanticipated public information destroys insurance opportunities. In an economy populated uniquely by risk neutral agents an unanticipated early announcement would simply bring forward the next time interval. It follows that the deadline effect not only "amplifies" the Hirshleifer effect but it is also a necessary and sufficient condition for its occurrence. Finally, the model analyzes the economy under stochastic deadlines, i.e. when traders are uncertain about the exact date of the announcement. We show that in this case the volume of transactions is constant as traders behave at each instant as if it was the last opportunity to exchange before the public announcement. It follows that the deadline and Hirshleifer effects occur only under credible schedules. The key difference between the credible and the stochastic deadline is that in the former case the problem is non-stationary but it becomes stationary once the probability of an off-schedule announcement is greater than zero.

Although with important differences, our main results remind of the literature on dynamic monopoly (e.g., Spier 1992) and auction theory (e.g. Roth and Ockemfels (2003)) though both the dynamics of the exchange and the reasons for a "deadline effect" there are substantially different than the ones observed in our case. Modeling financial markets with a search mechanism is also not new (see Duffie, Gârleanu and Pedersen (2005) and (2006)) and search mechanisms are empirically relevant in the asset market we will refer to in the empirical analysis. Unlike Duffie, Gârleanu and Pedersen we analyze trading under a deadline without intra announcement discounting. Also in our economy we have a continuum of agents' types parameterized by their endowments. In the stochastic deadline case, however, our results are similar to their results when the agents are risk neutral.

Our empirical analysis validates the model by looking at the effects of the FRB monetary policy announcements on the volume of transactions of CBOT 30-Day Federal Funds Futures, the instrument typically traded for hedging against fluctuations in short term interest rates over the period 1998 to 2006. Monetary policy announcements are scheduled well in advance, the data are easily available and, with the exception of the rare events that we will refer to below, traders know the exact moment at which the public information will reach the market. In the empirical model traders form expectations about rate changes by applying Taylor's rule (see Taylor (1993) and (1999)) using publicly available information on GDP growth and inflation rates.

We first show that the deadline effect is indeed present with significantly more trading activity occurring before a change of Federal Funds rates. Consistently with the predictions of the theoretical model, this is true until 10th September 2001. The 11th September 2001 events changed traders expectations on the reliability of the monetary policy schedule, soon after which the FED was forced to cut Federal Funds rates outside its schedule. Consequently the traders started believing that there is a small but positive probability that the FRB might react to such rare events and change interest rates outside its schedule. As predicted by our theoretical model on stochastic announcements, the empirical analysis shows that no significant excess trade was taking place for CBOT® 30-Day Federal Funds Futures during the period 30th September 2001 until 1st September 2006.

We then provide evidence for the Hirshleifer effect. We believe this is the first study of this type that tries to quantify it by using financial markets data. Several authors have in fact extended and qualified Hirshleifer's result on the adverse effects of public information, identifying conditions for public information to have positive social value. But, despite the existing long theoretical literature[1], there is a lack of empirical work. The only pieces of evidence come from medical studies, in particular Lerman et al. (1996) and Quaid and Morris (1993) (see also Schlee (2001)). These studies report the case of patients rejecting the opportunity to take free tests assessing the chances of developing hereditary diseases. Such a behavior has been attributed to the fear of loosing insurance opportunities. We believe this explanation is not totally convincing as in these particular cases it is not obvious to discern economic motives from other psychological aspects. The lack of empirical studies is probably due to the difficulty in identifying instances where traders are "taken by surprise" by the *timing* of the arrival of information. Ideally, one would like to have financial traders knowing the exact calendar of the information release and being "surprised" by an earlier information arrival before having the opportunity to arrange their portfolios.

One of the few instances where this is possible are the releases of information regarding interest rates changes occurring outside scheduled meetings of monetary policy committees. Our analysis will concentrate on three of such events that occurred in the last decade: the announcement on 3rd January 2001, when the chairman of the U.S. Fed surprised the financial markets by announcing a half point interest rate cut outside the scheduled Federal Open Market Committee (FOCM) meeting; on a similarly unexpected half a point early announcement of 18th April 2001 and on the quarter point cut by the Fed on October 15, 1998 during the LTCM and Russian crises. In all cases the surprise was the timing rather than the content of the announcement.

[1]With different degrees of generality, Marshall (1974), Green (1981) and Hakansson et al. (1982) identify cases where a partial increase of information cannot be Pareto improving. Wilson (1975) shows that better information is Pareto impairing when agents have preferences represented by a log utility function. Recently, Schlee (2001) has given more general conditions guaranteeing that public information is Pareto impairing and finally, Eckwert and Zilcha (2003) have showed that information referring to tradable assets might be undesirable if agents are enough risk averse.

We argue that a “surprise” in the timing of monetary policy announcements prevented a significant volumes of securities - more than 50% of the average trade - to transact for hedging purposes. Section 2 describes the theoretical problem and analyzes the patterns of trade in the case of risk averse and risk neutral agents when the schedule is credible and the case of non-credible (or absent) schedule. Section 3 presents the empirical model and the analysis of U.S. interest rate futures data. Section 4 concludes. With the exception of Theorem 1, all proofs can be found in the appendix.

2. Description of the economy

We consider a one-good, one-asset economy extending over an infinite horizon under uncertainty and populated by a continuum of traders.

At time 0, traders receive a schedule of dates t_i, $i = 0, 1, \ldots, \infty$. At each instant t_i an announcement reaches the market revealing the joint state $\sigma_{i,1}$ and $\sigma_{i,2}$ for the asset's returns and agents' endowments, respectively.
The only available and indivisible asset offers a return $\rho_{i,\sigma_{i,1}} \in \mathbb{R}_+$ payable to the asset holder at each time t_i, $i = 0, 1, \ldots, \infty$. Agents do not discount time within announcements. Traders, denoted by a, are partitioned into buyers (agents not owning the asset) where $a = b$, and sellers (owners of one unit the asset) where $a = s$.
At t_i, $i = 0, 1, \ldots, \infty$ each agent a receives a stochastic and agent specific endowment $\omega^a_{i,\sigma_{i,2}} \in \mathbb{R}_+$ of the only available good according to a properly defined process. Hence at any time between announcements t_{i-1} and t_i for $i = 0, 1, \ldots, \infty$ each individual faces uncertainty represented by the joint realization $\sigma_i = (\sigma_{i,1}, \sigma_{i,2})$ of returns $\rho_{i,\sigma_{i,1}}$ and endowments $\omega^a_{i,\sigma_{i,2}}$[2]. This joint realization may or may not be correlated. At each date between information arrivals agents hold expectations on the future realization of σ.

The good is non storable and has to be consumed between announcements. Agents' preferences are time separable and state separable, and represented by the utility function:

$$U(x_0, \ldots, x_i, x_{i+1}, \ldots) = E_\sigma \sum_{i=0}^{\infty} \beta^i u(x_{i,\sigma}),$$

where x_i denotes consumption of the agent between t_i and t_{i+1} and β is the inter-announcement discount rate.

Assumption 1 *$u(x)$ is strictly increasing and concave.*

2.1 Trade between announcements

At each trading session t buyers and sellers in the market meet randomly in pairs and contemporarily declare the reservation price b_t for the buyer and s_t for the seller, for the exchange of one unit of

[2]For notational simplicity we avoid the superscript a to $\omega_{i,\sigma_{i,2}}$ identifying the agent. However, when confusion may arise, we denote by $\omega^a_{i,\sigma_{i,2}}$ the endowment of a specific agent $a = b, s$. Similarly, we shall denote $\rho_{\sigma_{i,1}} = \rho_{\sigma_i}$ when no confusion may arise.

the asset. If $b_t \geq s_t$ they exchange the consumption good for the asset.
The price is determined by a pricing rule $M_t(b_t, s_t)$ with the following properties:

Assumption 2 *For each trading session t,*

a) $M_t(b_t, s_t)$ is continuous in b_t and s_t;

b) if $b_t = s_t = p_t$ then $M_t(p_t, p_t) = p_t$.

For example if the buyer (seller) makes a take-it-or-leave-it offer, then $M_t(b_t, s_t) = b_t$ ($M_t(b_t, s_t) = s_t$). If the proposer (buyer or seller) is chosen randomly with equal probability then one obtains $M_t(b_t, s_t) = \frac{1}{2}(b_t + s_t)$ as in Gale (1986). The bargaining can have a Nash solution at each t such that $M_t(b_t, s_t) = z_t b_t + (1 - z_t)s_t$ where the weight z_t is exogenously given as in Duffie, Gârleanu and Pedersen (2005) and (2006). Without loss of generality to our subsequent analysis we shall consider $M_t(b_t, s_t) = \frac{1}{2}(b_t + s_t)$.

Traders active in the market at t have history denoted by $h_t = in$. After trading, consumption takes place and the matched agents leave the market till the next announcement and till then their history h_t takes value *out*. If they cannot trade they proceed to the next trading session. The last opportunity to trade is the last trading session before the announcement reaches the market and not able to trade will have to consume their wealth at the end of the last session. There are no transaction costs or costs of holding the assets between the date the trade occurs and the realization of the state. We shall show that the following qualitative results do not depend on β though the bid and ask prices could depend on it.

Hence, at each trading session t agent $a = b, s$ is characterized by the endowment ω_{i,σ_i} and the history $h_t \in H_t = \{in, out\}$. The functions $b_t(\omega_{i,\sigma_i}) : H_t \to \Re_+$, and $s_t(\omega_{i,\sigma_i}) : H_t \to \Re_+$, represent bid and ask prices for the buyer b and seller s with endowment ω_{i,σ_i}, respectively. Being the preferences and the distribution of the endowments common knowledge, agents can compute the distribution of bid and ask prices. Buyers (sellers) maximize their expected utility of trading given the distribution of ask (bid) prices.

2.2 The $\mathcal{G}_{i,\epsilon}$ game

We discretize time between announcements t_i and t_{i+1}, $i = 0, 1, 2, \ldots$ by partitioning the interval into L subperiods, $l = 1, ..., L$, of length $\epsilon = \frac{t_{i+1} - t_i}{L}$. Each $t = t_i + l\epsilon$ denotes a trading session for the $i-$th interval. We will refer to this as the $\mathcal{G}_{\epsilon,i}$ game and we shall analyze it for frequent enough trading sessions, i.e. when $L \to \infty$ so that $\epsilon \to 0$.

At any trading session $t \in (t_i, t_{i+1})$ a buyer with bid b_t meeting a seller with ask price $x \in (0, b_t]$ obtains utility $u(\omega_{i,\sigma_i} - \frac{b_t + x}{2}) + \beta E_\sigma \overline{V}^s(\omega_{i+1,\sigma})$. Similarly a seller with ask price s_t meeting a buyer with bid $x \in [s_t, \infty)$ obtains utility $u(\omega_{i,\sigma_i} - \frac{s_t + x}{2}) + \beta E_\sigma \overline{V}^s(\omega_{i+1,\sigma})$. If they do not meet an eligible counterparty and if the deadline has not been reached they proceed to the next $t + \epsilon$-period. They consume their wealth otherwise.

The timeline between any two announcements for the $\mathcal{G}_{i,\epsilon}$ game can be described as follows:

	$t = t_i$			$t = t_{i+1}$
	σ_i realizes	$t_i < t_i + l\epsilon < t_{i+1}$	$t = t_{i+1} - \epsilon$	σ_{i+1} realizes
	•	•	•	•
	↓	↓	↓	↓
	asset pays-off	trade	last trade	asset pays-off
$\cdots$	endowments distributed	consumption	last consumption	endowments distributed

We can study agent $a = b, s$ problem by looking at the value function:

$$\overline{V}^h(\omega_0) = \max E_\sigma \sum_{i=1}^{\infty} \beta^i u(x_{i,\sigma}), \tag{1}$$

where x^h_{i,σ_i} denotes consumption at node (t_i, σ_i).

Therefore the ϵ-step optimization problem at $t = t_i + l\epsilon$ for agent $a = b, s$ active in the market (ie., with $h_t = in$) is given by:

$$\begin{aligned} V^b_\epsilon(t, in; \omega_{i,\sigma_i}) &= \max_{b_t} \int_0^{b_t} [u(\omega_{i,\sigma_i} - \frac{b_t + x}{2}) + \beta E_\sigma \overline{V}^s_\epsilon(\omega_{i+1,\sigma})] dF^s_{\epsilon,t}(x) \quad (2) \\ &+ (1 - F^s_{\epsilon,t}(b_t)) V^b_\epsilon(t + \epsilon,\, in; \omega_{i,\sigma_i}), \\ V^s_\epsilon(t, in; \omega_{i,\sigma_i}) &= \max_{s_t} \int_{s_t}^{\infty} [u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{s_t + x}{2}) + \beta E_\sigma \overline{V}^b_\epsilon(\omega_{i+1,\sigma})] dF^b_{\epsilon,t}(x) \quad (3) \\ &+ F^b_{\epsilon,t}(s_t-) V^s_\epsilon(t + \epsilon,\, in; \omega_{i,\sigma_i}),\ t \in (t_i + \epsilon, t_{i+1}], \end{aligned}$$

where $V^a_\epsilon(t + \epsilon, in; \omega_{i,\sigma_i})$ is agent a's value of the expected utility at $t + \epsilon$, $F^s_{\epsilon,t}(b_t)$ is the proportion of sellers willing to sell for a price less than b_t and $F^b_{\epsilon,t}(s_t-)$ is the proportion of buyers willing to buy for a price strictly less than s_t. Also, $\overline{V}^a_\epsilon(\omega_{i+1,\sigma})$ denotes agent $a = b, s$ value function at the first session of the next i-interval. Notice that the problems defined in equations (2) and (3) are non-stationary.

Once the last trading opportunity has elapsed and before assets returns are distributed the value function and continuation value for the agents that could not find a match is given by:

$$\underline{V}^b_\epsilon(\omega_{i+1,\sigma}) = u(\omega_{i,\sigma_i}) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma}), \tag{4}$$

$$\underline{V}^s_\epsilon(\omega_{i+1,\sigma}) = u(\omega_{i,\sigma_i} + \rho_{\sigma_i}) + \beta E_\sigma \overline{V}^s(\omega_{i+1,\sigma}). \tag{5}$$

The ϵ-bargaining game for the $i-$th interval is specified by the array:

$$\mathcal{G}_{i,\epsilon} = \left\langle \Omega_i,\ \left\{V^a_\epsilon(t, h_t; \omega^a_{i,\sigma_i})\right\}_{t=t_i+\epsilon}^{t_{i+1}}, \{a_{\epsilon,t}\}_{t=t_i+\epsilon}^{t_{i+1}}, \mathcal{H}_{i,\epsilon}, \mathcal{F}^a_{i,\epsilon}, a = b, s, \right\rangle.$$

where $\mathcal{H}_{i,\epsilon} = \cup_{t \in (t_i, t_{i+1})} H_t$ is the set of all feasible histories for the ϵ game and $\mathcal{F}^a_{i,\epsilon} = \{F^a_{\epsilon,t}\}_{t=t_i}^{t_{i+1}-\epsilon}$ is the set of bid and ask prices distributions.
By equilibrium of $\mathcal{G}_{i,\epsilon}$ we mean the *subgame perfect equilibrium*, i.e. for each buyer with history $h_t = in$ and endowment ω^b_{i,σ_i} the equilibrium strategy $B^*_{\epsilon,t}(\omega^b_{i,\sigma_i})$ is the solution to (4) if $F^{s*}_{\epsilon,t}$ is the distribution of the active sellers equilibrium strategies $S^*_{\epsilon,t}(\omega^b_{i,\sigma_i})$ for all ω^s_{i,σ_i}. Similarly, for each seller with history $h_t = in$ and endowment ω^s_{i,σ_i} the equilibrium strategy $S^*_{\epsilon,t}(\omega^b_{i,\sigma_i})$ is the solution to (5) if $F^{b*}_{\epsilon,t}$ is the distribution of active buyers equilibrium strategies $B^*_{\epsilon,t}(\omega^b_{i,\sigma_i})$ for all ω^b_{i,σ_i} . Unless necessary for clarity of exposition, in the analysis that follows we will drop the reference to the endowment in the optimal bid and ask price and the reference to the history in the value function in order to simplify notation.
Letting $S_{\epsilon,t}$ be the solution to the seller's problem (3) obtain:

$$\begin{aligned} V^s_\epsilon(t;\omega_{i,\sigma_i}) = &\int_{S_{\epsilon,t}}^{\infty} [u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S_{\epsilon,t}+x}{2}) + \beta E_\sigma \overline{V}^b_\epsilon(\omega_{i+1,\sigma})] dF^b_t(x) \\ &+ F^b_{\epsilon,t}(S_{\epsilon,t}-) V\epsilon^s(t+\epsilon;\omega_{i,\sigma_i}). \end{aligned} \tag{6}$$

This can be written as:

$$V^s_\epsilon(t;\omega_{i,\sigma_i}) - V^s_\epsilon(t+\epsilon;\omega_{i,\sigma_i}) = \int_{S_{\epsilon,t}}^{\infty} [u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S_{\epsilon,t}+x}{2}) + \beta E_\sigma \overline{V}^b_\epsilon(\omega_{i+1,\sigma}) - V^s_\epsilon(t+\epsilon;\omega_{i,\sigma_i})] dF^b_{\epsilon,t}(x). \tag{7}$$

Since the individuals are willing to trade then:

$$u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S_{\epsilon,t}+x}{2}) + \beta E_\sigma \overline{V}^s_\epsilon(\omega_{i+1,\sigma}) \geq V^s_\epsilon(t+\epsilon;\omega_{i,\sigma_i}) \text{ for all } x \in [S_t,\infty) \text{ and } \epsilon > 0. \tag{8}$$

This implies that $V^s_\epsilon(t;\omega_{i,\sigma_i})$ is a monotone decreasing function in t and therefore continuous except for countable many points. Letting $\lim_{\epsilon\to 0} V_\epsilon(t+\epsilon,\omega_{i,\sigma_i}) \equiv V(t,\omega_{i,\sigma_i})$, we can summarize the result as follows:

Lemma 1 *The value function of $V(t,\omega_{i,\sigma_i})$ exists and is measurable.*

2.3 The deadline effect

From (7) it follows that:

$$\begin{aligned} V^s_\epsilon(t;\omega_{i,\sigma_i}) - V^s_\epsilon(t+\epsilon;\omega_{i,\sigma_i}) &= \int_{S_{\epsilon,t}}^{\infty} [u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S_{\epsilon,t}+x}{2}] + \beta E_\sigma \overline{V}^b_\epsilon(\omega_{i+1,\sigma}) - V^s_\epsilon(t+\epsilon;\omega_{i,\sigma_i})) dF^b_{\epsilon,t}(x) \\ &\geq \int_{S_{\epsilon,t}}^{\infty} [u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S_{\epsilon,t}] + \beta E_\sigma \overline{V}^b_\epsilon(\omega_{i+1,\sigma}) - V^s_\epsilon(t+\epsilon;\omega_{i,\sigma_i})) dF^b_{\epsilon,t}(x) \qquad (9) \\ &= [u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S_{\epsilon,t}] + \beta E_\sigma \overline{V}^b_\epsilon(\omega_{i+1,\sigma}) - V^s_\epsilon(t+\epsilon;\omega_{i,\sigma_i})] \left(1 - F^b_{\epsilon,t}(S_{\epsilon,t})\right). \end{aligned}$$

From (9) it follows that for a given continuity point $t \in (t_i, t_{i+1})$:

$$\lim_{\epsilon \to 0}[V^s_\epsilon(t;\omega_{i,\sigma_i}) - V^s_\epsilon(t+\epsilon,\omega_{i,\sigma_i})]$$
$$\geq \lim_{\epsilon \to 0}[u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S_{\epsilon,t}) + \beta E_\sigma \overline{V}^b_\epsilon(\omega_{i+1,\sigma}) - V^s_{t+\epsilon}(\omega_{i,\sigma_i})]\left(1 - F^b_{\epsilon,t}(S_t)\right).$$

Since $\left(1 - F^b_{\epsilon,t}(S_{\epsilon,t})\right) > 0$ it follows that:

$$0 \geq \lim_{\epsilon \to 0} u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S_{\epsilon,t}) + \beta E_\sigma \overline{V}^b_\epsilon(\omega_{i+1,\sigma}) - \lim_{\epsilon \to 0} V^s_{t+\epsilon}(\omega_{i,\sigma_i})$$
$$\lim_{\epsilon \to 0} V^s(t+\epsilon;\omega_{i,\sigma_i}) \geq \lim_{\epsilon \to 0}[u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S_{\epsilon,t}+x}{2}) + \beta E_\sigma \overline{V}^b_\epsilon(\omega_{i+1,\sigma})]. \tag{10}$$

Since the seller is willing to trade at $S_{\epsilon,t}$ then:

$$\lim_{\epsilon \to 0} u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S_{\epsilon,t}) + \beta E_\sigma \overline{V}^s_\epsilon(\omega_{i+1,\sigma}) \geq \lim_{\epsilon \to 0} V^s_{t+\epsilon}(\omega_{i,\sigma_i}). \tag{11}$$

Therefore given (11) and (10) we have:

$$\lim_{\epsilon \to 0} V^s(t+\epsilon;\omega_{i,\sigma_i}) = \lim_{\epsilon \to 0}[u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S_{\epsilon,t}) + \beta E_\sigma \overline{V}^b_\epsilon(\omega_{i+1,\sigma})]. \tag{12}$$

Let us now define $\lim_{\epsilon \to 0} S_{\epsilon,t} \equiv S_t$, $\lim_{\epsilon \to 0} B_{\epsilon,t} \equiv B_t, \lim_{\epsilon \to 0} \overline{V}^b_\epsilon(\omega_{i+1,\sigma}) \equiv \overline{V}^b_\epsilon(\omega_{i+1,\sigma})$. Equation (12) becomes:

$$V^s(t;\omega_{i,\sigma_i}) = u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S_t) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma}). \tag{13}$$

Consider now any two continuity points $t, t' \in (t_i, t_{i+1}]$ such that $t > t'$, then:

$$V^s(t;\omega_{i,\sigma_i}) \leq V^s(t';\omega_{i,\sigma_i}).$$

Hence one obtains:

$$u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S_t) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma})] \leq u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S_{t'}) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma})].$$

Since $u(\cdot)$ is monotonically increasing obtain:

$$S_t(\omega_{i,\sigma_i}) \leq S_{t'}(\omega_{i,\sigma_i}), \tag{14}$$

for all continuity points $t, t' \in (t_i, t_{i+1}]$ such that $t > t'$. A similar proof shows that:

$$B_t(\omega_{i,\sigma_i}) \geq B_{t'}(\omega_{i,\sigma_i}). \tag{15}$$

The following theorem summarizes the result.

Theorem 1 *Suppose trading sessions are frequent enough, i.e., L sufficiently large. Then, for all continuity points $t > t' \in (t_i, t_{i+1}]$ a buyer with an endowment ω_{i,σ_i} has an optimizing bid such that:*

$$B_t(\omega_{i,\sigma_i}) \geq B_{t'}(\omega_{i,\sigma_i}),$$

and a seller with endowment ω_{i,σ_i} has an optimizing ask price such that:

$$S_t(\omega_{i,\sigma_i}) \leq S_{t'}(\omega_{i,\sigma_i}).$$

REMARK: Note that the monotone decreasing function $V^s(t; \omega_{i,\sigma_i})$ is L^p integrable with respect to t and is finite. Then by Lusin's Theorem (p. 230, Billingsley (1986)), $V^s(t; \omega_{i,\sigma_i})$ can be approximated arbitrarily close by a continuous function. This implies that the set of ϵ-step sellers' problems defined by (3) for which $V^s(t; \omega_{i,\sigma_i})$ are continuous in t are dense in the set of all ϵ-step sellers' problems. Hence the set of problems for which the continuation value is discontinuous is negligible. Similarly, the set of ϵ-step buyers' problems defined in (3) is also dense.

Let $v_{\epsilon,t} = v_t$ denote the expected volume of trade been defined as the proportion of exchanges taking place at a given instant t. Then, for the ϵ-game:

$$v_{\epsilon,t} = \int \int 1\{(\omega^b_{i,\sigma_i}, \omega^s_{i,\sigma_i}) : B_{\epsilon,t}(\omega^b_{i,\sigma_i}) \geq S_{\epsilon,t}(\omega^s_{i,\sigma_i})\} dF^b_{\epsilon,t}(S_{\epsilon,t}(\omega^s_{i,\sigma_i})) dF^s_{\epsilon,t}(B_{\epsilon,t}(\omega^b_{i,\sigma_i})),$$

where $1\{\cdot\}$ is an indicator event.
Therefore the expected volume of trade is simply the probability of trade:

$$v_{\epsilon,t} = \Pr\{(\omega^b_{i,\sigma_i}, \omega^s_{i,\sigma_i}) : B_{\epsilon,t}(\omega^b_{i,\sigma_i}) \geq S_{\epsilon,t}(\omega^s_{i,\sigma_i})\}.$$

Let now $v_t \equiv \lim_{\epsilon \to 0} v_{\epsilon,t}$. The following theorem shows that the probability of trade is higher the closer to the date of the announcement. This implies that the volume of trade is non-decreasing. We shall further show in Section 2.2 and 2.3 that the probability of trade is either zero (when constant) or strictly increasing. Hence, $v_t = v_{t'}$ for $t > t'$ implies $v_t = 0$ for "almost all t".

Theorem 2 *For any two continuity points $t, t' \in (t_i, t_{i+1}]$ such that $t > t'$, $v_t \geq v_{t'}$.*

Proof of Theorem 2: See Appendix.

Theorem 1 and 2 are quite intuitive: buyers start by making a low bid and increase their offer as the deadline approaches. Sellers behave symmetrically. Though intuitive this might not be necessarily the case: if a buyer knows that the sellers are now going to reduce their ask price, she might end up bidding less (and not more) as the probability of having a lower offer accepted is now higher than at a previous trading period. However, the continuous time model prevents (up to a countable number of points) discontinuous shifts in the distributions of either sides and the prove of the result follows.

2.4 Risk neutral agents

In this section we study the pattern of trade in an economy populated by risk neutral agents and we shall show that in this economy the volume of trade is nil. This implies that if increasing trade is observed then agents must be risk averse and the loss of trade due to early arrival of information is due to the Hirshleifer effect.

Let agents' utility function be given by $u(x) = a + kx$ with the same distribution of endowments described before.

Lemma 2 *For all $t \in (t_i, t_{i+1})$ the continuation values are constant and they are given by:*

$$V^s(t; \omega_{i,\sigma_i}) = \underline{V}^s(\omega_{i,\sigma_i}),$$

and

$$V^b(t; \omega_{i,\sigma_i}) = \underline{V}^b(\omega_{i,\sigma_i}).$$

Proof of Lemma 2: See Appendix.

Theorem 3 *If agents are risk neutral then the bid and ask prices are endowment and ϵ-independent and constant for all $t \in (t_i, t_{i+1}]$ and are given by:*

$$B_i^* = S_i^* = \sum_{j=1}^{\infty} \beta^j E_\sigma(\rho_{\sigma_{i+j}}).$$

Proof of Theorem 3: See Appendix.

Theorem 3 simply states that if the economy consists only of risk neutral agents, buyers and sellers will have the same endowment independent reservation price given by the value of the stream of future returns. Since we assumed agents trade for $b_t \geq s_t$, this implies that when agents are risk neutral the volume of trade is zero for almost all t, i.e. they trade at the first instance only. Moreover, an unanticipated early release of information when agents are risk neutral has the only effect of bringing forward the next time interval with no effect either on the pattern of trade or on agents' welfare. This result is similar to Duffie, Gârleanu and Pedersen (2005).

The following corollary shows that if the distribution of returns is stationary then the bid and ask prices are equal and constant across announcement periods.

Corollary 1 *If ρ_σ is a stationary process then for all $i = 1, \ldots, \infty$:*

$$B_i^* = S_i^* = \frac{\beta}{(1-\beta)} E_\sigma(\rho_\sigma).$$

2.5 Strict risk aversion is necessary for the deadline effect

In the previous section we proved that when agents are risk neutral then bid and ask prices are stationary and degenerate. We did not prove, however, that this cannot be the case in the presence of risk averse agents. In this section we show that this is indeed the case. We start by showing that a constant volume of trade is possible if and only if the bid and ask prices are stationary between any two consecutive announcements. We then show that the latter occurs only under risk neutrality.

We consider now the case where trade is flat or there is no trade. The following lemma shows that the distribution of bid and ask prices is stationary.

Lemma 3 *The probability of trade is constant if and only if the bid and ask prices are stationary for almost all sellers and buyers, i.e.* $v_t = v$ *if and only if*

$$\Pr\{\omega_{i,\sigma_i} : S_t(\omega_{i,\sigma_i}) = S(\omega_{i,\sigma_i}) \text{ for all } t\} = 1, \tag{16}$$

and

$$\Pr\{\omega_{i,\sigma_i} : B_t(\omega_{i,\sigma_i}) = B(\omega_{i,\sigma_i}) \text{ for all } t\} = 1. \tag{17}$$

Proof of Lemma 3: See Appendix.

Note that (16) and (17) imply that $F^b_t(x) = F^b(x)$ and $F^s_t(x) = F^s(x)$ are stationary distributions. We are now in a position to prove the following result.

Theorem 4 *If the probability of trade is constant, then buyers and sellers are risk neutral.*

Proof of Theorem 4: See Appendix.

We know from the previous section that if buyers and sellers are risk neutral then there will be no trade. Theorem 4 shows that the only possible constant volume is zero, in other words if trade is possible it must be strictly increasing. Therefore in this asset market if trade happens it is not possible that only risk neutral agents are present.

Hirshleifer Effect: The result that drives the dynamics of trade is the decreasing reservation value. This implies that an early release of information is equivalent to assigning to each active trader the autarkic utility level thus entailing a loss of welfare. Notice that if agents are risk neutral they do not trade and their reservation value remains constant (Lemma 3). Hence if traders are risk averse they suffer a net welfare loss in case of an early release of information at any time t and the extent of the loss is given by $V^h(t,\omega) - \bar{V}^h(\omega)$, $h = b, s$ for all agents active in the market at t with endowment ω.

2.6. Stochastic deadlines

This section analyzes traders' behavior in absence of a schedule of announcements, i.e. the case of stochastic deadlines. This is equivalent to the case where traders assign a positive probability that the information provider might act outside its schedule or to the case in which traders recognize that a payoff relevant announcement might occurs following events beyond the provider's control, independently of previous commitments. In this section we show that if the probability of an announcement at any instant is strictly positive, then the volume of trade is uniform over time.

Suppose that the announcements are stochastic. Let there be an announcement at t_i, then define q_t for every point $t \in (t_i, \infty)$ as:

$$1 - q_t = \Pr(\text{Announcement at } t). \tag{18}$$

Assumption 3 *Assume that the probability of an announcement is strictly positive for all t, i.e:*

$$\sup_{t \in (t_i, \infty)} q_t < 1. \tag{19}$$

As before we consider each agents ϵ-step problem, where if the agents do not meet a counterparty they proceed to the next period with the possibility that an announcement would come with probability $1 - q_{t+\epsilon}$ leaving them with the autarkic utility $\overline{V}^h(\omega_{i,\sigma_i}), h = b, s$. The optimization problem can be written as:

$$\begin{aligned} V^s(t; \omega_{i,\sigma_i}) = \max_{s_t} & \int_{s_t}^{\infty} [u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{s_t + x}{2}) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma})] dF_t^b(x) \\ & + F_t^b(s_t) \left[q_{t+\varepsilon} V^s(t+\epsilon; \omega_{i,\sigma_i}) + (1 - q_{t+\epsilon}) \overline{V}^s(\omega_{i,\sigma_i}) \right], \end{aligned} \tag{20}$$

$$\begin{aligned} V^b(t; \omega_{i,\sigma_i}) = \max_{b_t} & \int_{0}^{b_t} [u(\omega_{i,\sigma_i} - \frac{b_t + x}{2}) + \beta E_\sigma \overline{V}^s(\omega_{i+1,\sigma})] dF_t^s(x) \\ & + (1 - F^s(b_t))[q_{t+\epsilon} V^b(t+\epsilon; \omega_{i,\sigma_i}) + (1 - q_{t+\epsilon}) \underline{V}^b(\omega_{i,\sigma_i})]. \end{aligned} \tag{21}$$

The result follows from the fact that the problem becomes stationary when the deadlines are stochastic.

Theorem 5 *Given assumption (19) for a given ω_{i,σ_i} :*

a) $V^a(t, \omega_{i,\sigma_i}) = \underline{V}^a(\omega_{i,\sigma_i}),\ a = b, s,$
b) $S_t(\omega_{i,\sigma_i}) = S^*(\omega_{i,\sigma_i})$ and $B_t(\omega_{i,\sigma_i}) = B^*(\omega_{i,\sigma_i}),$
c) The trading volume $v_t = v^*$ is constant,

where $B_t(\omega_{i,\sigma_i})$ and $S_t(\omega_{i,\sigma_i})$ to (20) and (21).

Proof of Theorem 5: See Appendix.

The following theorem shows that when the announcements are not credible or no schedule is fixed, traders behave at each instant as they would behave at the last trading opportunity in a credible schedule regime.
Denote by $\underline{\mathrm{S}}_{t_{i+1}}(\omega_{i,\sigma_i})$ and $\underline{\mathrm{B}}_{t_{i+1}}(\omega_{i,\sigma_i})$ the optimal bid and ask prices of the last trading opportunity.

Theorem 6 *The bid and ask prices for any* $t \in (t_i, t_{i+1})$ *are given by* $S^*(\omega_{i,\sigma_i}) = \underline{S}_{t_{i+1}}(\omega_{i,\sigma_i})$ *and* $B^*(\omega_{i,\sigma_i}) = \underline{B}_{t_{i+1}}(\omega_{i,\sigma_i})$.

Proof of Theorem 6: See Appendix.

Hirshleifer effect: Notice that since the reservation value for a given agent ω is constant, there are no adverse effects of an early release of information and hence there is no Hirshleifer effect. However, in the scheduled case the expected utility of a trader at $t < t_{i+1}$ is higher than in the case of unscheduled announcements.

3. The Empirical Model

Most independent central banks deliver information on their monetary policy decisions to the public by announcing interest rate levels at scheduled and publicly available dates. Other central banks prefer to exercise discretion by informing the markets about interest rate changes whenever considered appropriate. Under the hypothesis of rational expectations, no transaction costs and complete markets, the procedures and the timing of the announcements would hardly matter as prices would perfectly reflect information and traders would continuously adjust their portfolios. However, as our empirical observation will show some financial markets respond differently to different procedures. Although a schedule is often adopted "to increase transparency, accountability and the dialogue with the public"[3], the important difference between the two procedures is that with scheduled announcements traders know precisely at which moment in time the information will reach the markets. The Federal Reserve of United States since 1994, the Bank of England since 1997 and the ECB since 1998 are among the central banks adopting the first procedure. Discretionary announcement dates were however largely employed by monetary authorities like the U.K. Treasury before the Bank of England independence in 1998 and the European central banks before the ECB was established.

Even when interest rate changes are supposed to occur at scheduled dates only, central banks retain the option of acting between announcements. They will do so when they believe that more information is beneficial to the economy at large. Once uncertainty resolves, however, there is no scope for traders to exchange income across states of nature as all agents would arbitrage by transferring income into the realized state and out of the states that did not realize. Here timing plays a relevant role. This gives us an ideal opportunity to test our theoretical model on the effects of US monetary policy on the market for interest rate futures after the adoption of a schedule of monetary announcements.

We analyze the market of CBOT® 30-Day Federal Funds futures. These are futures on the daily federal funds overnight rate reported by the Federal Reserve Bank of New York[4]. The observations included in the dataset are from 3rd January 1998 to 10th September 2001 and from 30th September 2001 to 1st September 2006. There are 73 scheduled FOMC meetings during this time and all the three unscheduled meetings fall in this period. This gives an opportunity to test for the Hirshleifer effect due to these early announcements. We did not include data from 11th September 2001 until

[3]See Bank of Canada press release (2000).

[4]For more details about these contracts see http://www.cbot.com/cbot/pub/cont_detail/0,3206,1525+14446,00.html.

29th September 2001 due to the extraordinary circumstances during that period. Hence the fourth unscheduled meeting on 17th September 2001 has not been considered.
In the following analysis the underlying assumption is that there are no significant changes in the structure of the economy. We thus restrict ourselves to relatively recent developments. However, for longer time series data this assumption would be difficult to sustain.

3.1 Graphical analysis

We look at the distribution of trading volume around scheduled meetings. Figure 1 refers to the period 3rd January 1998 to 10th September 2001 and shows that on average there is more trade around scheduled meetings followed by an interest rate change than during any other day.

[Figure 1]

After September 2001, during the period 30th September 2001 to 1st September 2006 this pattern seems to have changed. Figure 2 shows that on average there is hardly any difference in trading volume around scheduled meetings followed by an interest rate change than during any other day.

[Figure 2]

The following section shows that the increase in trade in the days before a scheduled meeting is significant during the period 3rd January 1998 to 10th September 2001 but looses significance after September 2001.

3.2 Modeling trading volume

In order to model the trading behavior of risk averse agents we look at the traded volume of short term futures as a function of changes of the federal funds rate following the announcements of scheduled and unscheduled meetings. We analyze the following model:

$$\begin{aligned} \ln v_t &= f(r_{t_i} - E_t(r_{t_{i+1}})) + \sum_{j=-2}^{2} (\alpha_j^0 D_{t-j}^0 + \alpha_j^u D_{t-j}^u + \alpha_j D_{t-j}^+) + \epsilon_t, \\ \epsilon_t &\sim ARFIMA(p,d,q), \end{aligned} \tag{22}$$

where v_t is the daily volume traded of CBOT® 30-Day Federal Funds Futures at time t in the Chicago Board of Trade. r_t is the federal funds rate at t determined by the FOMC after the scheduled and unscheduled meetings. Δr_t is the change in r_t at t and $E_t(r_{t_{i+1}})$ is the market expectation of change of rate at the i^{th} meeting given public information at time t. We differentiate between the announcements which change the federal fund rate and which do not by introducing two dummy variables,

$$D_t^0 = I\left[|\Delta r_t| = 0 \text{ and there is a scheduled meeting at } t\right],$$

and

$$D_t^{+} = I\left[|\Delta r_t| \neq 0 \text{ and there is a scheduled meeting at } t\right],$$

where I is an indicator function.

D_{t-j}^{0} and D_{t-j}^{+}, $j = 1, 2$ capture the effects of possible excess trading the day before scheduled announcements whereas to capture the increase in trade the day after the announcements we include the dummies D_{t+j}^{0} and D_{t+j}^{+}, $j = 1, 2$. We also introduce a separate but similar set of variables in order to capture the effects of the surprise or unscheduled rate changes by introducing the following dummy variable:

$$D_t^{u} = I\left[|\Delta r_t| \neq 0 \text{ and there is a unscheduled meeting at } t\right].$$

In order to capture the effects of possible excess trading the day before the unscheduled announcement we use $D_{t-j}^{u}, j = 1, 2$. For the day after announcement effects we include the lead dummies D_{t+j}^{u}, $j = 1, 2$.

We model the error term as an *ARFIMA* process, since there is some evidence that trading volumes of financial instruments follow a long memory process[5].

We shall show that the trade in the days before the unscheduled meetings on 15th October 1998, 3rd January 2001 and 18th April 2001 was significantly lower with respect to the trade before scheduled meetings and hence prevented agents from insuring against the cuts in the interest rate.

3.3 The model for expected interest rate changes

In his simple interest rate determination, Taylor (1993) and (1999) proposed as a descriptive rule capturing some important factors influencing monetary policy and the general stance of policy from the mid 1980s onward. This simple rule is given by:

$$r_{t_i} = \pi_{t_i} + 0.5 y_{t_i} + 0.5(\pi_{t_i} - 2) + 2, \tag{23}$$

where r_t is the federal funds rate at t determined by the FOMC after the scheduled and unscheduled meetings, π_t is the annual inflation rate for a 12 month period as released by the Bureau of Labor Statistics (BLS) at time t and y_t is the advanced, preliminary and final estimates of the quarterly change in GDP as released by the Bureau of Economic Analysis. We also use the seasonally adjusted inflation figures released by the BLS, but this did not make any difference to the analysis.
The variables entering Taylor's rule, GDP and inflation rate are common knowledge. These variables are officially estimated and announced by the relevant agencies between meetings. Traders know the rule and change their interest rate expectations accordingly. Conditional on the realization of the macroeconomic variables, the economy is static and agents' portfolio composition is stationary.
At each period before the announcement, risk averse agents form expectations on the basis of the Taylor's rule and trade in interest rate futures in order to hedge against interest rate uncertainty.

[5] See: Bollerslev and Jubinski (1999), Lobato and Velasco (2000) and Kumar (2004).

They re-trade in the period after the announcement on the basis of the differences of expected and realized change of interest rate.
We assume that the market believes that the FOMC will be using a form of Taylor's rule to produce their monetary policy targets. If the market reacts on the basis of any official announcement of inflation rates and GDP then:

$$E_t(r_{t_{i+1}}) = \gamma_0 + \gamma_1 \pi_t + \gamma_2 y_t, \text{ for } t \in (t_i, t_{i+1}]. \tag{24}$$

Moreover, if the market believes that FOMC is strictly following the Taylor's rule, then $\gamma_1 = 1.5$ and $\gamma_2 = 0.5$.

Let $\Delta\pi_t$ the change in inflation rate and Δy_t the change in GDP growth estimates at t. We compute the expected change of interest rate $(r_{t_i} - E_t(r_{t_{i+1}}))$ as:

$$\Delta r_t^e = r_{t_i} - E_t(r_{t_{i+1}}) = \gamma_1 \Delta\pi_t + \gamma_2 \Delta y_t. \tag{25}$$

We can directly compute the change according to Taylor's rule as:

$$\Delta r_t^{taylor} = r_t - E_t(r_i) = 1.5\Delta\pi_t + 0.5\Delta y_t.$$

3.4 Estimation of the model and results

We assume the function f is linear in model (22). Using (25) we replace $r_t - E_t(r_i)$ as $\gamma_1\Delta\pi_t + \gamma_2\Delta y_t$. We therefore estimate the following model (referred as Model 1) as:

$$\ln v_t = c + \gamma_1 |\Delta\pi_t| + \gamma_2 |\Delta y_t| + \sum_{j=-2}^{2} (\alpha_j^0 D_{t+j}^0 + \alpha_j^s D_{t+j}^+ + \alpha_j^u D_{t+j}^u) + \epsilon_t,$$

where $\epsilon_t \simeq ARFIMA(p, d, q)$.

We use the absolute value as the volume changes only with the magnitude of change in growth and inflation.

In the next model we use the change in the original Taylor's rule for the expected change of FED rate by the market and estimate the following model (referred as Model 2) as:

$$\ln v_t = c + \gamma \Delta r_t^{taylor} + \sum_{j=-2}^{2} (\alpha_j^0 D_{t+j}^0 + \alpha_j^s D_{t+j}^+ + \alpha_j^u D_{t+j}^u) + \epsilon_t, \tag{26}$$

where $\epsilon_t \simeq ARFIMA(p, d, q)$[6].

The results for the period 3rd January 1998 to 10th September 2001 are reported in Table 1 and for the period 30th September 2001 to 1st September 2006 are reported in Table 2.

[6]The period considered changes to the Taylor's rule is always non-negative.

Table 1

Table 2

From the results in Table 1 we see that the effect of $\Delta\pi_t$ on the volume of trade is not significant whereas Δy_t is significant. The change in growth becomes less significant during the second period regression as shown Table 2. From the results in Table 1 and 2 we find that the effect of Taylor's rule is significant for the entire period. So the market indeed believes that the FED is following the Taylor's rule. We also find evidence of long memory in both periods. We have fitted a *ARFIMA(0,d,0)* model in the first period and a *ARFIMA(0,d,1)* model in the second period. The fractional difference parameter d is statistically significant and is less that 0.5 showing long memory characteristics.

3.5 Comparing trading of unscheduled announcements with trading of scheduled announcements

Our hypothesis is that the day before a FOMC meeting the market will be more active due to insurance taking activities. This activity will be more so if the market anticipates a change in Federal Funds rates. Table 1 shows that the market does not react the day(s) before scheduled announcements if there is 0 point change but there is a statistically significant amount of trading activity the day(s) before if a change occurs. The Portmanteau statistic shows that there is no residual correlations in the error term. Looking at the median values in Figure 1, we observe that this might be as large as 50% increasing the days before the announcement. We already discussed in our theoretical section that increasing trade is consistent with risk averse agents only.
If we look at the trading activity the day before the unscheduled announcement, then we see that there is no significant excess trade. In fact there is a negative (though not significantly so) trading activity before 15th October 1998, 3rd January 2001 and 18th April 2001 rate changes even though two of these were a half a point change. The results are robust irrespective of how the market formulates his expectations about rate changes (Model 1 and 2). As previously observed agents' risk aversion gives rise to a Hirshleifer effect when information on short term interest rates are given to the market before the scheduled date.

3.6 Comparing with non-credible scheduling

After the September 11th events the Federal Reserve was forced to act outside its schedule by reducing the interest rate to boost market's sentiments on 15th September 2001. Traders learned that such a rare circumstance can force the Federal Reserve to act outside its schedule and hence makes the schedule less credible.
When the schedule is less credible our theoretical model shows that the traders will behave at any instant t as if they were in the day before the announcement and therefore will not change their bid and ask significantly with time. This would imply that the volume of trade remains constant. This is consistent with the results in Table 2 and Figure 2.

4. Conclusion

In this paper we argued that scheduling the communication of payoff relevant public information changes financial markets' behavior non-trivially by entailing a deadline effect. We tested the theoretical model on monetary policy announcements and we showed that a large volume of trade is indeed shifted toward the period before new information is schedule to come. Moreover, off the schedule information arrivals lead to a loss of trade if and only if the deadline effect is also present. The occurrence of outside the schedule monetary policy announcements has given us the opportunity to quantify the Hirshleifer effect. We believe our analysis is relevant independently of the specific application to monetary policy.
We did not suggest that while considering whether to anticipate any payoff relevant information (e.g., interest rates in the case of the monetary authority) the information provider should have as main objective the traders' edging opportunities only, as other important factors related to the economy at large, or the shareholders interests in the case of firms' announcements, might be determinant.

How markets and economies perform under different regimes remains an open question.

References

Bank of Canada (2000), "Bank of Canada to adopt fixed dates for announcing Bank rate changes," http://www.bankofcanada.ca/en/press/pr00-13.htm.
Billingsley, P. (1995), *Probability and Measure,* Chicago: Wiley and Sons.
Bollerslev, T. and D. Jubinski (1999), "Equity Trading Volume and Volatility: Latent Information Arrivals and Common Long-Run Dependencies," *Journal of Business & Economic Statistics,* American Statistical Association, **17**(1), 9-21.
Duffie, D., N. Gârleanu , and L.H. Pedersen (2005), "Over-the-Counter Markets," *Econometrica*, **73**(6), 1815-1847.
Duffie, D., N. Gârleanu , and L.H. Pedersen (2006), "Valuation in Over-the-Counter Markets," mimeo.
Eckwert, B. and I. Zilcha (2003), "Incomplete risk sharing and the value of information," *Economic Theory,* **21**(1), 43-58.
Gale, D. (1986), "Bargaining and Competition, Part I: Characterization," *Econometrica*, Vol. 54, pp. 785-806.
Hakansson, N.H., J.G. Kunkel and J.A. Ohlson (1982), "Sufficient and necessary conditions for information to have social value in pure exchange," *Journal of Finance,* **37**(5), 1169-1181.
Hirshleifer, J. (1971), "The private and social value of information and the reward of inventive activity," *American Economic Review,* **61**, 561-574.
Kumar, A. (2004), "Time Series Behaviour of Stock Trading Volume:An Evidence from Indian Stock Market," Econometric Society 2004 Far Eastern Meetings 783, Econometric Society.
Lerman, Carin et al. (1996), "BRCAI testing of families with hereditary breast-ovarian cancer," *Journal of the American Medical Association,* **275**, 1885-92.
Lobato, I.N. and C. Velasco (2000), "Long Memory in Stock-Market Trading Volume," *Journal of Business & Economic Statistics,* **18**(4), 410–427.

Marshall, J.M. (1974), "Private incentives and public information," *American Economic Review,* **64**, 373-90.
Quaid, Kimberly A. and Michael Morris (1993), "Reluctance to undergo predictive testing for Huntington's disease," *American Journal of Medical Genetics,* **45**, 41-45.
Roth, A.E. and A. Ockenfels (2003), "Last minute bidding and the rules for ending second-price auctions: evidence from eBay and Amazon auctions on the internet," *American Economic Review,* **92**, 1093-1103.
Rudin, W. (1976), *Principles of mathematical analysis,* London: McGraw-Hill.
Schlee, E.E. (2001), "The value of information in efficient risk-sharing arrangements," *American Economic Review,* **91**, 509-524.
Spier, K.E. (1992), "The dynamics of pretrial negotiations," *Review of Economic Studies,* **59**, 103-108.
Taylor, J.B. (1993), "Discretion versus policy rules in practice," Carnegie-Rochester Conference Series on Public Policy **39**, 195-214.
Taylor, J.B. (1999), "An Historical analysis of monetary policy rules," in: J.B. Taylor (ed.) *Monetary Policy Rules,* Chicago: Chicago University Press, 319-341.

Appendix

We first prove following two results (Lemma A 1 and Lemma A 2) that will be useful in proving Lemma 1 in the text.

Lemma A 1 *The risk neutral agent's value function is such that:*

$$\frac{\partial V^h(t;\omega_{i,\sigma_i})}{\partial \omega_{i,\sigma_i}} = k \textit{ for all } t \in (t_i, t_{i+1}]. \tag{27}$$

Proof of Lemma A 1: Consider seller s ϵ-step problem. For any $t \in (t_{i+1}, t_{i+1}+\epsilon]$ the derivative of the last period value function (5) is given by:

$$\frac{\partial V^s(t;\omega_{i,\sigma_i})}{\partial \omega_{i,\sigma_i}} = \frac{\partial u(\omega_{i,\sigma_i} + \rho_{\sigma_i}) + \beta E_\sigma \overline{V}^s(\omega_{i+1,\sigma})}{\partial \omega_{i,\sigma_i}} = k.$$

If (27) holds for $t+\epsilon$ then it holds for any $t \in (t_i, t_{i+1}]$. In fact since S_t is the argmax of the problem in (3) it follows that:

$$\begin{aligned}\frac{\partial V^s(t;\omega_{i,\sigma_i})}{\partial \omega_{i,\sigma_i}} = &\int_{S_t}^{\infty} \frac{\partial}{\partial \omega_{i,\sigma_i}}[u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S_t + x}{2}) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma})] dF_t^b(x) \\ &+ F_t^b(S_t)\frac{\partial}{\partial \omega_{i,\sigma_i}} V^s(t+\epsilon;\omega_{i,\sigma_i}).\end{aligned}$$

Therefore:

$$\frac{\partial V^s(t;\omega_{i,\sigma_i})}{\partial \omega_{i,\sigma_i}} = \int_{S_t}^{\infty} k dF_t^b(x) + F_t^b(S_t)k = k.$$

It now suffices to notice that this is true for all ϵ-step problems to obtain the result. The proof is similar for buyers.

□

Lemma A 2 *The risk neutral agents' reservation price is endowment independent, i.e.:*

$$\frac{\partial B_t}{\partial \omega_{i,\sigma_i}} = \frac{\partial S_t}{\partial \omega_{i,\sigma_i}} = 0, \quad \textit{for all } t \in (t_i, t_{i+1}].$$

Proof of Lemma A 2: For a given $t \in (t_i, t_{i+1}]$ define:

$$G_t(s_t,\omega_{i,\sigma_i}) = \int_{s_t}^{\infty} [u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{s_t + x}{2}) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma})] dF_t^b(x) + F_t^b(s_t) V^s(t+\epsilon;\omega_{i,\sigma_i}), \quad (28)$$

and notice that:

$$G_t(S_t,\omega_{i,\sigma_i}) = V^s(t;\omega_{i,\sigma_i}).$$

Being S_t the argmax and the second derivative of G_t negative, we obtain :

$$\frac{\partial S_t}{\partial \omega_{i,\sigma_i}} = - \left. \frac{\frac{\partial G_t(s_t,\omega_{i,\sigma_i})}{\partial s_t \partial \omega_{i,\sigma_i}}}{\frac{\partial G_t(s_t,\omega_{i,\sigma_i})}{\partial s_t \partial s_t}} \right|_{s_t = S_t}.$$

Taking derivative with respect to ω_{i,σ_i} and using Lemma 1 obtain:

$$\begin{aligned} \frac{\partial G_t(s_t,\omega_{i,\sigma_i})}{\partial \omega_{i,\sigma_i}} &= \int_{s_t}^{\infty} \frac{\partial}{\partial \omega_{i,\sigma_i}} [u(\omega_{i,\sigma_i} + \frac{s_t + x}{2}) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma})] dF_t^b(x) \\ &+ F_t^b(s_t) \frac{\partial}{\partial \omega_{i,\sigma_i}} V_{t+\epsilon}^s(\omega_{i,\sigma_i}) \\ &= \int_{s_t}^{\infty} k dF_t^b(x) + F_t^b(s_t) k = k, \end{aligned}$$

then:

$$\frac{\partial G_t(s_t,\omega_{i,\sigma_i})}{\partial s_t \partial \omega_{i,\sigma_i}} = 0.$$

It follows that:

$$\frac{\partial S_t}{\partial \omega_{i,\sigma_i}} = 0, \text{ for all } t \in (t_i, t_{i+1}].$$

The proof is similar for the buyers.

□

Proof of Theorem 2: Consider two continuity points $t, t' \in (t_i, t_{i+1})$ such that $t > t'$. Consider also a seller s with endowment ω^s_{i,σ_i} and a buyer b with endowment ω^b_{i,σ_i} at the node (t_i, σ_i), such that $B_{t'}(\omega^b_{i,\sigma_i}) > S_{t'}(\omega^s_{i,\sigma_i})$. Then from Proposition (14) and (15) we have $B_t(\omega^b_{i,\sigma_i}) \geq B_{t'}(\omega^s_{i,\sigma_i})$ and $S_t(\omega^s_{i,\sigma_i}) \leq S'_t(\omega^s_{i,\sigma_i})$, we obtain $B_t(\omega^b_{i,\sigma_i}) > S_t(\omega^s_{i,\sigma_i})$. Therefore,

$$\{(\omega^b_{i,\sigma_i}, \omega^s_{i,\sigma_i}) : B_t(\omega^b_{i,\sigma_i}) > S_t(\omega^s_{i,\sigma_i})\} \supseteq \{(\omega^b_{i,\sigma_i}, \omega^s_{i,\sigma_i}) : B_{t'}(\omega^b_{i,\sigma_i}) > S_{t'}(\omega^s_{i,\sigma_i})\}.$$

It follows that:

$$\begin{aligned} v_t &= \Pr\{(\omega^b_{i,\sigma_i}, \omega^s_{i,\sigma_i}) : B_t(\omega^b_{i,\sigma_i}) \geq S_t(\omega^s_{i,\sigma_i})\} \\ &\geq \Pr\{(\omega^b_{i,\sigma_i}, \omega^s_{i,\sigma_i}) : B_{t'}(\omega^b_{i,\sigma_i}) \geq S_{t'}(\omega^s_{i,\sigma_i})\} = v_{t'}. \end{aligned}$$

□

Proof of Lemma 2: Consider the ϵ-step problem. By Lemma A 2 since the ask prices S_t and the bid prices B_t are independent of the endowment ω_{i,σ_i} at each $t \in (t_i, t_{i+1}]$ then the distribution $F^b_t(x)$ is degenerate. Let B^*_t be the degenerate bid of the buyers, then:

$$\begin{aligned} dF^b_t(x) &= 1 \text{ if } x = B^*_t \\ &= 0 \text{ otherwise.} \end{aligned}$$

Notice that since the distribution of bids is degenerate at B^*_t, no seller will ask strictly less than B^*_t and hence it will be optimal to proceed to the next period. Therefore $F^b_t(S_t) = 1$. Hence it follows from (6) that:

$$V^s(t; \omega_{i,\sigma_i}) = V^s(t + \epsilon; \omega_{i,\sigma_i}) \text{ for all } t \in (t_i, t_{i+1}).$$

Since $V^s(t; \omega_{i,\sigma_i}) = u(\omega_{i,\sigma_i} + \rho_{\sigma_i}) + \beta E_\sigma \overline{V}^s(\omega_{i+1,\sigma})$ for all $t \in (t_{i+1}, t_{i+1} + \epsilon)$ the result follows. The proof is similar for the buyers' reservation price.

□

Proof of Theorem 3: Consider two points $t, t' \in (t_i, t_{i+1}]$ such that $t > t'$. By Lemma 2:

$$V^s(t + \epsilon; \omega_{i,\sigma_i}) = V^s(t' + \epsilon; \omega_{i,\sigma_i}).$$

Taking limits on both sides obtain:

$$u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S_t) + \beta E_\sigma \overline{V}^s(\omega_{i+1,\sigma}) = u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S_{t'}) + \beta E_\sigma \overline{V}^s(\omega_{i+1,\sigma}).$$

It follows that:

$$S_t = S_{t'} = S^*_i.$$

The same is true for the bid prices $B_t = B^*_i$. In the last trading period of the interval $(t_{i+1}, t_{i+1} + \epsilon]$, the ask price S^*_i can be solved as:

$$u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S_i^*) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma}) = u(\omega_{i,\sigma_i} + \rho_{\sigma_i}) + \beta E_\sigma \overline{V}^s(\omega_{i+1,\sigma}),$$

or

$$S_i^* = \beta \frac{E_\sigma \overline{V}^s(\omega_{i+1,\sigma}) - E_\sigma \overline{V}^b(\omega_{i+1,\sigma})}{k} \text{ for all } \omega_{i,\sigma_i}.$$

Similarly, in the last period the bid B_i^* can be solved as:

$$u(\omega_{i,\sigma_i} - B_i^*) + \beta E_\sigma \overline{V}^s(\omega_{i+1,\sigma}) = u(\omega_{i,\sigma_i}) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma}).$$

It follows that:

$$B_i^* = \beta \frac{E_\sigma \overline{V}^s(\omega_{i+1,\sigma}) - E_\sigma \overline{V}^b(\omega_{i+1,\sigma})}{k} \quad \text{for all } \omega_{i,\sigma_i}.$$

Let

$$P_i^* = B_i^* = S_i^* = \beta \frac{E_\sigma \overline{V}^s(\omega_{i+1,\sigma}) - E_\sigma \overline{V}^b(\omega_{i+1,\sigma})}{k} \tag{29}$$

then from (**??**) we have:

$$\begin{aligned} \overline{V}^s(\omega_{i+1,\sigma}) - \overline{V}^b(\omega_{i+1,\sigma}) &= u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + P_i^*) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma}) - u(\omega_{i,\sigma_i} - P_i^*) - \beta E_\sigma \overline{V}^s(\omega_{i+1,\sigma}) \\ &= k\rho_{\sigma_i} + 2kP_i^* + \beta \left(E_\sigma \overline{V}^b(\omega_{i+1,\sigma}) - E_\sigma \overline{V}^s(\omega_{i+1,\sigma}) \right) \end{aligned}$$

from (29) we have,

$$\begin{aligned} \overline{V}^s(\omega_{i+1,\sigma}) - \overline{V}^b(\omega_{i+1,\sigma}) &= k\rho_{\sigma_i} + 2k\beta \frac{E_\sigma \overline{V}^s(\omega_{i+1,\sigma}) - E_\sigma \overline{V}^b(\omega_{i+1,\sigma})}{k} \\ &\quad + \beta \left(E_\sigma \overline{V}^b(\omega_{i+1,\sigma}) - E_\sigma \overline{V}^s(\omega_{i+1,\sigma}) \right) \\ &= k\rho_{\sigma_i} + \beta \left(E_\sigma \overline{V}^s(\omega_{i+1,\sigma}) - E_\sigma \overline{V}^b(\omega_{i+1,\sigma}) \right). \end{aligned}$$

Taking expectations on both sides obtain:

$$E_\sigma(\overline{V}^s(\omega_{i,\sigma}) - \overline{V}^b(\omega_{i,\sigma})) = kE_\sigma(\rho_{\sigma_i}) + \beta E_\sigma(\overline{V}^s(\omega_{i+1,\sigma}) - \overline{V}^b(\omega_{i+1,\sigma})).$$

Solving recursively obtain:

$$E_\sigma(\overline{V}^s(\omega_{i,\sigma}) - \overline{V}^b(\omega_{i,\sigma})) = k \sum_{j=1}^{\infty} \beta^j E_\sigma(\rho_{\sigma_{i+j}}).$$

Therefore from (29) we have:

$$B_i^* = S_i^* = P_i^* = \sum_{j=1}^{\infty} \beta^j E_\sigma(\rho_{\sigma_{i+j}}).$$

$\square$

Proof of Lemma 3: Suppose (16) and (17) hold then for any pair $t \neq t'$

$$v_t = \Pr\left\{(\omega^b_{i,\sigma_i}, \omega^s_{i,\sigma_i}) : B(\omega^b_{i,\sigma_i}) \geq S(\omega^s_{i,\sigma_i})\right\} = v_{t'}.$$

If (16) does not hold then by (14) there exists a τ such that for all $t > \tau$ there exists subset of sellers such that:

$$\Omega_\tau = \{\omega^s_{i,\sigma_i} : S_\tau(\omega^s_{i,\sigma_i}) \geq S_t(\omega^s_{i,\sigma_i})\} \text{ and } \Pr(\Omega_\tau) > 0.$$

This implies:

$$\begin{aligned}
v_\tau &= \Pr\left\{(\omega^b_{i,\sigma_i}, \omega^s_{i,\sigma_i}) : B(\omega^b_{i,\sigma_i}) \geq S_\tau(\omega^s_{i,\sigma_i})\right\} \\
&= \Pr\left\{(\omega^b_{i,\sigma_i}, \omega^s_{i,\sigma_i}) : B(\omega^b_{i,\sigma_i}) \geq S_\tau(\omega^s_{i,\sigma_i}) \text{ s.t. } \omega^s_{i,\sigma_i} \in \Omega_\tau)\right\} \\
&+ \Pr\left\{(\omega^b_{i,\sigma_i}, \omega^s_{i,\sigma_i}) : B(\omega^b_{i,\sigma_i}) \geq S(\omega^s_{i,\sigma_i}) \text{ s.t. } \omega^s_{i,\sigma_i} \in \Omega^c_\tau\right\} \\
&< \Pr\left\{(\omega^b_{i,\sigma_i}, \omega^s_{i,\sigma_i}) : B(\omega^b_{i,\sigma_i}) \geq S_t(\omega^s_{i,\sigma_i}) \text{ s.t. } \omega^s_{i,\sigma_i} \in \Omega_\tau)\right\} \\
&+ \Pr\left\{(\omega^b_{i,\sigma_i}, \omega^s_{i,\sigma_i}) : B(\omega^b_{i,\sigma_i}) \geq S(\omega^s_{i,\sigma_i}) \text{ s.t. } \omega^s_{i,\sigma_i} \in \Omega^c_\tau\right\} \\
&= \Pr\left\{(\omega^b_{i,\sigma_i}, \omega^s_{i,\sigma_i}) : B(\omega^b_{i,\sigma_i}) \geq S_t(\omega^s_{i,\sigma_i})\right\} = v_t.
\end{aligned}$$

a contradiction. Similarly if (17) does not hold there is a contradiction.

$\square$

Proof of Theorem 4: Consider a seller s with endowment ω_{i,σ_i} at the node (t_i, σ_i). Since:

$$u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma}) = u(\omega_{i,\sigma_i} + \rho_{\sigma_i}) + \beta E_\sigma \overline{V}^s(\omega_{i+1,\sigma}),$$

and $E_\sigma \overline{V}^b(\omega_{i+1,\sigma}) < E_\sigma \overline{V}^s(\omega_{i+1,\sigma})$ then $S > 0$. By Lemma 3 and the envelope theorem:

$$\begin{aligned}
\frac{\partial V^s(t; \omega_{i,\sigma_i})}{\partial \omega_{i,\sigma_i}} &= \int_S^\infty \frac{\partial}{\partial \omega_{i,\sigma_i}} \left[u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S+x}{2}) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma})\right] dF^b(x), \\
&+ F^b(S) \frac{\partial}{\partial \omega_{i,\sigma_i}} V^s(t + \epsilon; \omega_{i,\sigma_i}), \\
u'(\omega_{i,\sigma_i} + \rho_{\sigma_i}) &= \int_S^\infty u'(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S+x}{2}) dF^b(x) + F^b(S) u'(\omega_{i,\sigma_i} + \rho_{\sigma_i}) \\
0 &= \int_S^\infty \left[u'(\omega_{i,\sigma_i} + \rho_{\sigma_i}) - u'(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S+x}{2})\right] dF^b(x) \text{ for all } \omega_{i,\sigma_i} \text{ and } x \geq S.
\end{aligned}$$

Since $u'' \leq 0$ we have $u'(\omega_{i,\sigma_i} + \rho_{\sigma_i}) - u'(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S+x}{2}) \geq 0$ for almost all $x \geq S$. So the last equation is true if:

$$u'(\omega_{i,\sigma_i} + \rho_{\sigma_i}) = u'(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S+x}{2}) \text{ for a.e. } x \geq S, \text{ or} \tag{30}$$

$$dF^b(x) = 0 \text{ for all } x \geq S(\omega_{i,\sigma_i}). \tag{31}$$

If (30) is true then the utility is linear. If (31) is true then the distribution of bid prices are degenerate at some B^* for all ω_{i,σ_i} at the node (t_i, σ_i):

$$u(\omega_{i,\sigma_i} - B^*) + \beta E_\sigma \overline{V}^s(\omega_{i+1,\sigma}) = u(\omega_{i,\sigma_i}) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma}), \text{ for all } \omega_{i,\sigma_i}.$$

Taking derivatives obtain:

$$u'(\omega_{i,\sigma_i} - B^*) = u'(\omega_{i,\sigma_i}), \text{ for all } \omega_{i,\sigma_i},$$

implying that the utility function is linear.

□

Proof of Theorem 5: Fix a seller with endowment $\omega_{i,\sigma}$ and define a functional $\Phi : \mathcal{V} \to \mathcal{V}$, where $\mathcal{V}$ is the space of bounded continuous functions such that:

$$\begin{aligned}\Phi\left(V^s(t;\omega_{i+1,\sigma})\right) = & \int_{S_t}^{\infty} [u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S_t + x}{2}) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma})] dF_t^b(x) \\ & + F_t^b(S_t -)\left[q_{t+\epsilon} V^s(t+\epsilon; \omega_{i,\sigma_i}) + (1 - q_{t+\epsilon})\, \overline{V}^s(\omega_{i,\sigma_i})\right],\end{aligned}$$

where S_t is the argmax of (20). We show that Φ is a contraction mapping. Let $V^s(t;\omega_{i+1,\sigma})$ and $V'^s(t;\omega_{i+1,\sigma})$ be two functions then:

$$\Phi(V^s(t;\omega_{i+1,\sigma})) - \Phi(V'^s(t;\omega_{i+1,\sigma})) = q_{t+\varepsilon} F_t^b(S_t -)(V^s(t+\epsilon;\omega_{i+1,\sigma}) - V'^s(t+\epsilon;\omega_{i+1,\sigma})).$$

Since $\sup_{t \in (t_i,\infty)} q_t < 1$ and $F_t^b(S_t) \leq 1$, we can choose a $\delta < 1$ such that $\sup_{t\in(t_i,\infty)} q_t F_t^b(S_t -) \leq \delta < 1$ therefore,

$$\left\|\Phi(V^s(t;\omega_{i+1,\sigma})) - \Phi(V'^s(t;\omega_{i+1,\sigma}))\right\| \leq \delta \left\|V^s(t+\epsilon;\omega_{i+1,\sigma}) - V'^s(t+\epsilon;\omega_{i+1,\sigma})\right\|. \tag{32}$$

Therefore by the contraction mapping theorem: a) $V^s(t, \omega_{i+1,\sigma}) = \overline{V}^s(\omega_{i+1,\sigma})$. b) The ask prices $S_t(\omega_{i,\sigma_i}) = S^*(\omega_{i,\sigma_i})$ for all ω_{i,σ_i}. The proof for the bid prices is similar. c) As before the expected volume at t, is given by:

$$\begin{aligned} v_t &= \Pr\{(\omega^b_{i,\sigma_i}, \omega^s_{i,\sigma_i}) : B^*(\omega^b_{i,\sigma_i}) \geq S^*(\omega^s_{i,\sigma_i})\} \\ &= v^*. \end{aligned}$$

since the bid and ask prices are stationary.

□

Proof of Theorem 6: From part a) of Theorem 5 notice that $F^h_t(x) = F^h(x), h = b, s$ are stationary distributions and $V^h(t; \omega_{i,\sigma_i}) = \overline{V}^h(\omega_{i,\sigma_i}), h = b, s$. Then:

$$\begin{aligned}
\overline{V}^s(\omega_{i,\sigma_i}) &= \int_S^\infty [u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S+x}{2}) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma})] dF^b(x) \\
&+ F^b(S) \left[q_{t+\epsilon} \overline{V}^s(\omega_{i,\sigma_i}) + (1 - q_{t+\epsilon}) \overline{V}^s(\omega_{i,\sigma_i}) \right] \\
&= \int_S^\infty [u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S+x}{2}) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma})] dF^b(x) \\
&+ F^b(S) \overline{V}^s(\omega_{i,\sigma_i}).
\end{aligned}$$

Therefore:

$$\int_S^\infty [u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S+x}{2}) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma}) - \overline{V}^s(\omega_{i,\sigma_i})] dF^b(x) = 0,$$

implying that:

$$u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + \frac{S+x}{2}) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma}) = \overline{V}^s(\omega_{i,\sigma_i}) \text{ for almost all } x \in (S, \infty).$$

In particular, for $x \to S$:

$$u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma}) = \overline{V}^s(\omega_{i,\sigma_i}) \text{ for almost all } x \in (S, \infty).$$

Hence:

$$u(\omega_{i,\sigma_i} + \rho_{\sigma_i} + S) + \beta E_\sigma \overline{V}^b(\omega_{i+1,\sigma}) = u(\omega_{i,\sigma_i} + \rho_{\sigma_i}) + \beta E_\sigma \overline{V}^s(\omega_{i+1,\sigma}),$$

that implies that S is the price of the last trading opportunity when scheduled announcements are credible. The same argument applies to the buyers.

□

Figures and Tables

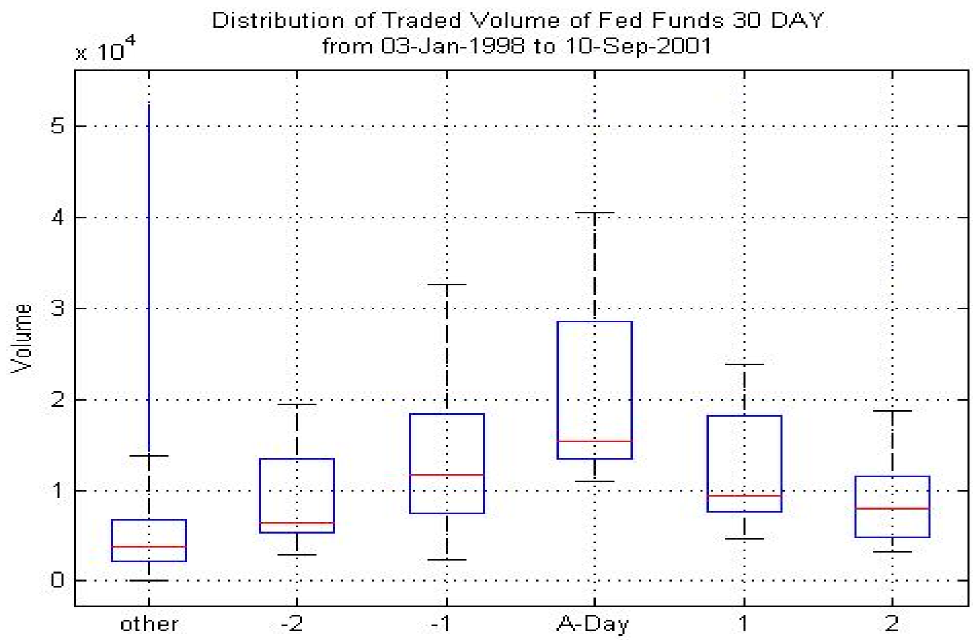

Figure 1: Average trade before scheduled announcements: 03-Jan-1998 to 10-Sept-2001

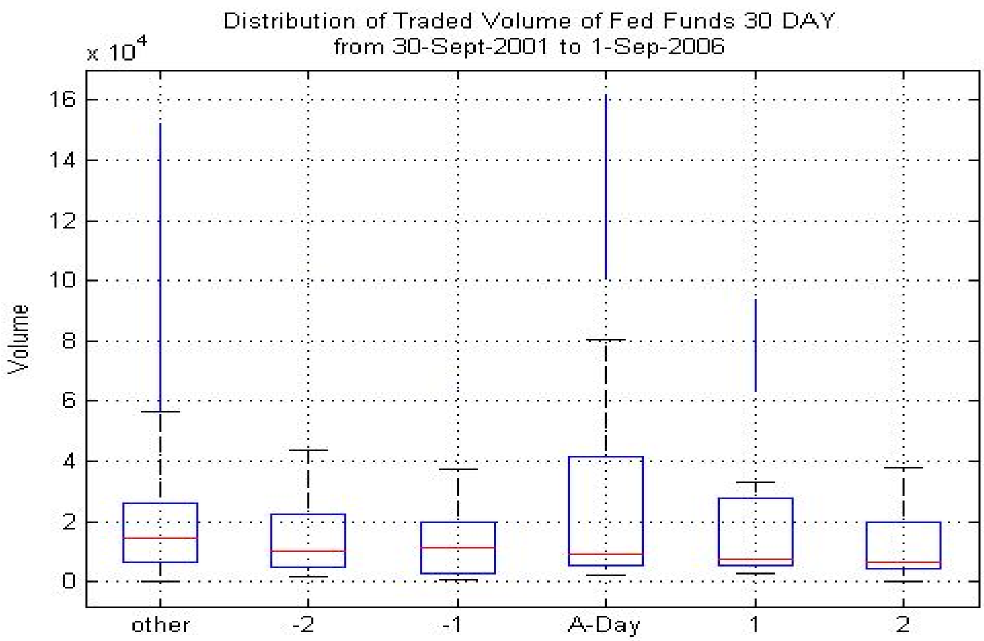

Figure 2: Average trade before scheduled announcements: 30-Sept-2001 to 10-Sept-2006

Maximum likelihood estimation of ARFIMA(0,d,0) model				
The dependent variable is: Log(CBOT30DAY)				
Period 03-Jan-1998 to 10-Sept-2001				
no. of observations 837				
	Coefficient	Pvalue	Coefficient	Pvalue
d	0.427894	0.000	0.426891	0.000
Constant	8.37389	0.000	8.37335	0.000
ADgrowth	0.174863	0.014		
ADInfA	0.110562	0.61		
DTaylor			0.213838	0.026
D^{+}_{t-2}	**0.422211**	**0.015**	**0.416856**	**0.016**
D^{+}_{t-1}	**0.532**	**0.011**	**0.525994**	**0.011**
D^{+}_{t}	1.06449	0.000	1.05844	0.000
D^{+}_{t+1}	0.636989	0.000	0.62778	0.000
D^{+}_{t+2}	0.270115	0.095	0.27336	0.092
D^{0}_{t-2}	0.158405	0.306	0.144168	0.351
D^{0}_{t-1}	0.014239	0.932	0.01118	0.947
D^{0}_{t}	0.620035	0.000	0.616916	0.000
D^{0}_{t+1}	0.296439	0.057	0.295324	0.058
D^{0}_{t+2}	0.023155	0.874	0.022341	0.879
D^{u}_{t-2}	**-0.08446**	**0.833**	**-0.09496**	**0.812**
D^{u}_{t-1}	**-0.25557**	**0.539**	**-0.32117**	**0.438**
D^{u}_{t}	0.811639	0.024	0.808777	0.024
D^{u}_{t+1}	0.702514	0.049	0.693214	0.053
D^{u}_{t+2}	0.07015	0.835	0.068385	0.839
AIC.T	1547.47033		1547.14237	
Portmanteau(6):	8.2652	0.1422	8.0513	0.1534

Table 1: Estimation Results: 03-Jan-1998 to 10-Sept-2001

Maximum likelihood estimation of ARFIMA(0,d,1) model				
The dependent variable is: Log(CBOT30DAY)				
Period 30-Sept-2001 to 01-Sept-2006				
no. of observations 1203				
	Coefficient	Pvalue	Coefficient	Pvalue
d	0.469941	0.000	0.469948	0.000
MA(1)	-0.22664	0.000	-0.22672	0.000
Constant	9.24217	0.000	9.24208	0.000
ADgrowth	0.100691	0.092		
ADinfA	0.284078	0.204		
DTaylor			0.196705	0.035
D^+_{t-2}	**0.145935**	**0.501**	**0.145878**	**0.501**
D^+_{t-1}	**-0.03143**	**0.845**	**-0.03137**	**0.845**
D^+_t	0.605718	0.000	0.605795	0.000
D^+_{t+1}	0.50414	0.001	0.504271	0.001
D^+_{t+2}	0.110923	0.487	0.110609	0.488
D^0_{t-2}	-0.17232	0.612	-0.1724	0.612
D^0_{t-1}	-0.15395	0.362	-0.15388	0.362
D^0_t	0.531587	0.001	0.531808	0.001
D^0_{t+1}	0.20119	0.216	0.201658	0.214
D^0_{t+2}	0.005355	0.974	0.006474	0.968
AIC.T	2631.429		2629.433	
Portmanteau(6):	2.6242	0.6225	2.6131	0.6245

Table 2: Estimation Results: 30-Sept-2001 to 10-Sept-2006