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Informational Efficiency, Interest Rate Variability, And Central Bank Operations

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Abstract

It is shown how the frequency of central bank intervention in financial markets can affect the incentives for economic agents to acquire information, which will be reflected in market prices and thus become available to policy makers. The optimal frequency of intervention, and therefore the optimal interest rate variability, will balance the desirability of attaining given operational targets against the benefits of encouraging informational efficiency. The ability of the central bank to send clear signals of its own intentions will also depend on market informational efficiency.

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CONTENTS

SUMMARY

This paper demonstrates how a central bank's operating procedures may affect the incentives faced by market participants to acquire information, and thus the information available to the central bank in determining its short-term operational targets. In particular, information may be less valuable to market participants when intervention is carried out than when the market process is left undisturbed. Therefore, in market equilibrium, the more the central bank intervenes, the fewer informed traders can cover their costs. Consequently, market prices will contain relatively less information, and the central bank is left with a noisier signal on which to base decisions on its short-term strategy. The optimal intervention rule balances the need to intervene to keep money market prices in line with the operational target against the desire to promote the acquisition of information that allows the central bank to set a better target. In addition, the intervention rule will affect both the ability of market participants to make inferences about the central bank's policy stance and private information, and the incentives for 'Fed-watchers' to try to anticipate central bank policy. These considerations may also influence the choice of optimal frequency of intervention and how much variability around the central bank's operational targets should be allowed. A model is presented to illustrate and formalize this argument, and the optimal frequency of intervention is related to the underlying parameters.

I. Introduction

Market-based instruments for the implementation of monetary policy have been adopted and refined during the last two decades in industrialized, developing and transition countries. Broad monetary aggregates are generally controlled only indirectly through intervention in money markets, and correspondingly central banks and governments are more willing to allow interest rates to be determined by fluctuating supply and demand conditions (reviews of recent experience are contained in Batten *et al.* (1990) for major industrial countries and Downes and Vaez-Zadeh (1991) for several developing countries). This shift in strategy is often justified by appeal to the deterioration in the effectiveness and equitableness of direct methods of control as financial markets develop, and to the improvement in general allocative efficiency that should result when economic agents can base their saving and investment decisions on freely determined market prices. Here, it will be argued that a market-based approach to monetary policy with more interest rate flexibility can in addition improve policy formulation and thus in itself enhance policy effectiveness.

Typically a central bank will have a fairly clear overall longer-term objective of, say, keeping inflation under two percent per year, and may also establish medium-term targets for the inflation rate itself, a monetary aggregate, or the exchange rate. However, to implement policy on a day-to-day basis it needs to establish some sort of operational target or guideline. Usually this operational target is formulated in terms of money market interest rates. In industrial countries, and in an increasing number of developing and transition countries, these operational targets are attained by use of more or less frequent open-market operations, with the support of other instruments such as standing Lombard and deposit facilities and reserve requirements. A central bank thus equipped normally has the technical capacity to attain given operational targets almost exactly and on an all but continuous basis if it so chooses.[2] In fact fluctuations around the operational targets are permitted, with different central banks displaying different degrees of indifference when faced with such variability. An issue that has received relatively little attention is the weight that should be attached to deviations from the operational targets of monetary policy, or equivalently, how frequently and intensely the central bank should intervene to steer money market rates. The central bank needs to identify and evaluate the marginal benefits and costs of intervening a little more or a little less.

Here, one aspect of this choice will be examined, namely, the trade-off between the desire to keep money market rates close to a given operational target against the cost in terms of the selection of a less suitable operational target that arises when tight control of interest rates reduces incentives for market participants to collect policy-relevant information.[3] The starting point is the observation that a central bank does not have a precise, optimal operational target set in advance. Instead it must actively search for and analyze information,

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[2]Direct regulation can be an even more effective, albeit heavy-handed means to attain operational targets.

[3]Other arguments are presented in Hardy (1997), which can be read as a companion paper.

including that contained in market prices, before deciding on its short-term strategy and estimating an appropriate operational target (and in practice central banks do indeed monitor market developments closely). Yet in general one cannot take the generation and aggregation of information to be an exogenous phenomenon. Since the work of Grossman (1976) and Grossman and Stiglitz (1980), it has been recognized that if the production of information is costly, full informational efficiency is unlikely to be achieved. Market participants will typically be heterogeneous, with some more or less well informed traders, some traders relying on information contained in market prices, and perhaps some 'liquidity' or 'noise' traders who buy and sell assets in order to meet extraneous needs or based on ill-founded strategies; the equilibrium market structure that emerges and the amount of information aggregated in market prices will depend on these costs and various institutional features of the market.

A simple model is presented to show how the design of instruments and operating procedures can have an important effect on the informational efficiency of financial markets in which both the central bank and market participants have incomplete, and asymmetric information, and where information is costly. Market participants may collect both information on the economy in general not otherwise available to the central bank on a timely basis, and information that facilitates the anticipation of the central bank's own actions. The former is certainly valuable to the central bank, and the latter may be valuable if it leads the market to reinforce policy shifts. Limiting intervention may increase the incentive for market participants to acquire information, which will then be reflected in those market prices and thus be observed by the central bank.

It will further be shown how market participants will be able to make inferences about the policy stance and other information available to the central bank from the frequency and strength of intervention. The clarity of the signals transmitted from the central bank to the market participants will be affected by the strength of information acquisition efforts by market participants, and thus by the frequency of intervention.

II. Intervention and Incentives for Information Acquisition

A. Equilibrium Market Structure and the Central Bank Operational Targets

Both investors and central banks need to acquire and process information about the state of the economy in order to determine how best to achieve their various objectives. Here the relevant information is assumed to be summarized in two random state variables, denoted by x and y. For simplicity the two state variables are each assumed to be identically and independently distributed (i.i.d.) random shocks. This simplification allows time subscripts to be avoided without ambiguity. The state variable x represents the information potentially available on a timely basis to market participants but not to the central bank. Examples of what might be collected in x include data on the flow of payment orders in processing with the commercial bank, the volume of applications for loans by different sectors of the economy, investors' private assessments of the prospects for individual firms, investment plans, and aggregate spending and other macroeconomic statistics collected with a long lag and sampling errors. The state variable y represents the information directly available to the central bank when determining its operational target and its policy actions. A central bank normally knows its own preferences and, with more or less delay, its own balance sheet and a great variety of statistics on macroeconomic developments. It also has belief about the functioning of the transmission mechanism, based on which it can relate its longer-term objectives to operational targets, and its own preferences. The state variables will affect both the payoff from investments available to market participants, and the realization of the central bank's objective function. Therefore estimates of the state variables will influence demand for these investments, and enter into the central bank's operational targets, which must be set *ex ante*.

The arena where the central bank intervenes and where market participants invest is a money market. In this market participants trade in an asset such as interbank funds. For convenience the asset will be assumed to take the form of a zero-coupon bond with price P (after normalization, possibly negative). The total payoff is equal to the zero-mean random state variable x adjusted by a parameter α that depends on the normalization. Hence the net return from buying one unit of the asset is $(\alpha x - P)$. This uncertainty may arise not from variability in the own-return on the asset but from other sources, such as variations in opportunity costs and liquidity constraints in other markets that are not modeled explicitly. For example, a commercial bank may wish to borrow funds in the money market to build up its working balances; the interest rate on the borrow will be known, but the bank may find it hard to predict its forthcoming liquidity inflows and outflows, and the future course of short-term rates and the prices of substitute financial assets.

The market mechanism may be thought of as a daily tender for a money market investment which starts by each participant submitting a bid schedule. For simplicity, it is assumed that the tender mechanism does not result in 'pooling' between different categories of bidders, perfectly inelastic demand schedules, or randomized strategies; that no one has an opportunity to revise a bid in the light of bids submitted by others; and that all participants are so unsophisticated that their bid schedules do not depend on the proportion of informed bidders present or whether or not the central bank participates (but see below).

Participants in the market are heterogeneous. A random number of 'noise' or 'liquidity' traders are present in the market in addition to the 'sophisticated' investors who decide whether or not to become informed. The total number of informed and uninformed market participants is normalized at unity. A proportion ψ of them choose in advance to invest in information acquisition and processing. They incur a fixed cost C but learn the realization of the state variable x before deciding on their demand schedule. The remaining proportion $1-\psi$ of sophisticated participants choose not to become informed and instead base their demand for the asset on its unconditional mean return, which is zero. Both the informed and the uninformed have elastic demand schedules relating to the quantity of the asset they wish to hold negatively to its price, and positively to their expectations of its payoff based on their respective information sets. The derivation of these demand schedules will not be addressed here. Rather, the schedules relating quantity to price will be assumed to take the specific linear forms

$$q^{d}_{I}(P) = \alpha x - P \tag{1a}$$

$$q^{d}_{U}(P) = - P \tag{1b}$$

for the informed and uninformed traders, respectively. Demand for the asset by the noise and liquidity traders is captured by an exogenous, i.i.d. random variable n. In the case of the money market, these disturbances might arise for instance because of variations in the public's demand for cash, balance of payments flows, and government receipts and outlays. Thus total net demand for the asset by market participants is

$$\psi q^{d}_{I}(P) + (1-\psi)q^{d}_{U}(P) + n = \psi(\alpha x - P) + (1-\psi)(-P) + n. \tag{2}$$

In the absence of intervention, the asset is in zero net supply. Therefore the price adjusts until the sum given in equation (2) equals zero. This competitive price P^{c} that clears the market is thus

$$P^{c} = \psi\alpha x + n\ . \tag{3}$$

The realized profits of the informed and uninformed traders (Π_{I1} and Π_{U1} respectively) equal the net return (αx - P^{c}) multiplied by the quantity received at the market clearing price:

$$\Pi_{I1} = (\alpha x - P^{c})q^{d}_{I}(P^{c}) = (\alpha x - P^{c})^{2} = [(1-\psi)\alpha x + n]^{2}$$

$$\Pi_{U1} = (\alpha x - P^{c})q^{d}_{U}(P^{c}) = (\alpha x-P^{c})(-P^{c}) = -(1-\psi)\psi x^{2} + (2\psi-1)\alpha x n + n^{2}\ .$$

Therefore the expected difference in profits is

$$E\Delta\Pi_{1} = E[\Pi_{I1} - \Pi_{U1}] = E[(\alpha x - P^{c})\alpha x] = (1-\psi)\alpha^{2}\sigma^{2}_{x}, \tag{4}$$

where use is made of (3) and the independence of x and n. The proportion of market participants who invest in becoming informed is such that on average the extra expected profits $E\Delta\Pi$ just match their fixed costs C. It is easy to derive that were there never any intervention, the equilibrium proportion would be

$$\psi = 1 - C/\alpha^{2}\sigma^{2}_{x}\ .$$

Consider now the objectives and operations of the central bank. It can be thought of as having a longer-term objective, say for inflation, which it seeks to achieve by controlling the money market price. [4] If the central bank had full information on the state of the economy and the monetary policy transmission mechanism, it could translate its longer-term objective into a precise operational target. In particular, this 'ideal' short-term operational target is assumed to depend on both state variables and take the form (after normalization) of $\gamma x + y$. The parameter γ is included for generality to capture aspects of the central bank's preferences and beliefs about the transmission mechanism. With full information there would be no reason ever to allow deviations from the operational target.

However, by assumption the central bank does observe x directly, and therefore it cannot prevent the money market price from deviating from the 'ideal' short-term operational target. Hence it is concerned to minimize on average the expected squared deviations from its estimate of the best operational target, conditional on the information available to it. Sometimes it will intervene in order to steer the money market price towards what it believes to be the best operational target based on the available information; other times it will refrain from intervention in order to improve the clarity of the information available in the market, allowing it to estimate a more suitable operational target. Specifically, the central bank aims to minimize the average across intervention and non-intervention periods of

$$V = E[(P - \gamma x - y)^2 \mid \Omega], \;\; \gamma \neq \alpha . \tag{5}$$

The variable Ω is the information set of the central bank, which, as will become apparent, will depend on whether or not it intervenes and on its overall operating procedures.

Using (3) and (5) it is easy to show that the expected squared deviation from the central bank's operational target in the absence of intervention is

$$\begin{aligned} V_1 = E[(P^c - \gamma x - y)^2] &= E[((\psi\alpha - \gamma)x + n - y)^2] \\ &= (\psi\alpha-\gamma)^2\sigma^2_x + \sigma^2_n + \sigma^2_y \end{aligned} \tag{6}$$

since all disturbances are assumed to be i.i.d.

Central bank intervention takes the form of a periodic, uniform price auction. Rather than considering discrete periods, it will be convenient to treat the proportion of time that the central bank intervenes as a continuous variable (μ). Market participants submit multiple (price, quantity) bids corresponding to their net demand schedules. Again it is assumed that the tender mechanism is such that bidders do not try to mask or distort their demand schedules, and that demand for the asset is unaffected by the mere fact of central bank intervention. Therefore the central bank receives an aggregate schedule identical to the schedule given in equation (2). The central bank can decide on the cut-off price after seeing

[4]In this model prices and quantities convey the same information. So the operational target could be reformulated in terms of reserve money.

the bid schedule. However, the informed and uninformed bidders and the noise traders are not distinguishable, so the central bank cannot perfectly identify relevant information concerning the variable x. The best the central bank can do is to estimate the level of the state variable imperfectly from the signal

$$S = \psi\alpha x + n$$

(the intercept of the bid schedule) using its knowledge of the variances σ^2_x and σ^2_n, and the proportion ψ of informed traders. It is assumed for simplicity that the central bank uses $S/\alpha\psi$ as its unbiased estimator of x.[5] Therefore the central bank will set a cut-off price equal to[6]

$$P^* = \gamma S/\alpha\psi + y = \gamma x + \gamma n/\alpha\psi + y \tag{7}$$

and the minimized value of its expected loss function can be determined to be

$$V_0 = \gamma^2\sigma^2_n/\psi^2\alpha^2 . \tag{8}$$

One can now derive as before the profits of informed and uninformed traders at this price as

$$\Pi_{I0} = (\alpha x\text{-}P^*)q^d_I(P^*) = (\alpha x\text{-}P^*)^2 = [(\alpha\text{-}\gamma)x \ + \gamma n/\alpha\psi + y]^2$$

$$\Pi_{U0} = (\alpha x\text{-}P^*)q^d_U(P^*) = (\alpha x\text{-}P^*)(\text{-}P^*) = \text{-}\ (\alpha\text{-}\gamma)\gamma x^2 \ + \gamma n^2/\alpha^2\ \psi^2 + y^2 + \text{cross producs.}$$

Given the independence of the disturbance terms, the expected difference in profits is given by

$$E\Delta\Pi_0 = E[(\alpha x\text{-}P^*)\alpha x] = (\alpha\text{-}\gamma)\alpha\sigma^2_x . \tag{9}$$

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[5]The estimator that minimizes the expected sum of squared deviations is

$$\frac{\psi\alpha\sigma_x^2}{\psi^2\alpha^2\sigma_x^2 + \sigma_n^2}S .$$

It can be shown that, for a range of parameter values, the use of this more complex expression does not affect the qualitative results, and under some conditions certain discontinuities are avoided. See Hardy (1997) for a discussion of the use of such an estimator.
[6]Note that the central bank does not consider the effect on the incentives for information acquisition when determining the price in each individual period. This assumption is reasonable if the periods are short relative to the time taken to adjust the market structure of informed and uninformed traders.

The central bank needs to decide on the proportion μ of time when it intervenes. The average expectation of the loss function is a correspondingly weighted average of V_0 and V_1, as given in equation (8) and (6) respectively:

$$\mu V_0 + (1-\mu)V_1 = \mu\gamma^2\sigma^2_n/\psi^2\alpha^2 + (1-\mu)[(\psi\alpha-\gamma)^2\sigma^2_x + \sigma^2_n + \sigma^2_y]. \tag{10}$$

In market equilibrium the weighted average expected difference in the profits of informed and uninformed traders will just cover the informed traders' extra fixed costs, which from (9) and (4) is:

$$\begin{aligned} C &= \mu E\Delta\Pi_0 + (1-\mu)E\Delta\Pi_1 \\ &= \mu(\alpha-\gamma)\alpha\sigma^2_x + (1-\mu)(1-\psi)\alpha^2\sigma^2_x. \end{aligned} \tag{11}$$

The central bank chooses the intervention frequency so as to minimize the average expected loss given in equation (10), subject to the constraint that the proportion of informed traders is given implicitly by equation (11). [7] By way of illustration, the relationships between ψ, μ and variables of interest for a particular set of parameter values are given in Table 1 and shown graphically in Figures 1 and 2. Profits of the informed traders are lower relative to those of the uninformed when the central bank intervenes ($E\Delta\Pi_0$ is everywhere below $E\Delta\Pi_1$), so in market equilibrium the more frequent is intervention (the larger is μ) the smaller is the proportion of informed traders (ψ declines). As can be seen in Figure 2, when intervention is rare and so informed traders are prevalent, the value of the central bank's expected loss function when it does intervene is low. However intervening becomes more 'costly' than not intervening when traders are predominantly uninformed. The average expected loss function achieves a minimum when intervention is undertaken moderately often.

It is difficult to derive a general analytic solution to the constrained minimization problem. A number of simulations were run for different parameter values and an iterative search conducted to find the optimal intervention frequency (μ*) under various circumstances. Results for a variety of are presented in Table 2. The outcomes can be divided into three categories: when the central bank would wish to intervene continuously, when the central bank would wish never to intervene, and when the proportion of time intervention is conducted lies between 0 and 1 (an interior solution to the optimization problem).

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[7] A social planner would also be concerned about the costs incurred in information acquisition, which however would have to be scaled so as to be commensurate with the central bank's loss function.

Table 1. Scenario C1:
Proportion of informed traders and central bank loss function
$C = 0.5$ $\alpha = 1.0$ $\gamma = 0.9$ $\sigma^2_x = 2$ $\sigma^2_y = 2$ $\sigma^2_n = 2$ $\mu^* = 0.25$

μ	$E\Delta\Pi_0$	$E\Delta\Pi_1$	ψ	V_0	V_1	$\mu V_0 + (1-\mu)V_1$	$E(\hat{y}-y)^2$
0.00	0.20	0.500	0.750	2.301	4.001	4.001	2.000
0.01	0.20	0.503	0.748	2.892	4.046	4.034	1.986
0.02	0.20	0.506	0.747	2.904	4.047	4.024	1.972
0.06	0.20	0.519	0.740	2.955	4.051	3.985	1.916
0.10	0.20	0.533	0.733	3.012	4.056	3.951	1.860
0.14	0.20	0.549	0.726	3.077	4.061	3.923	1.805
0.18	0.20	0.566	0.717	3.150	4.067	3.902	1.750
0.20	0.20	0.575	0.713	3.191	4.070	3.894	1.718
0.22	0.20	0.585	0.708	3.235	4.074	3.889	1.696
0.24	0.20	0.595	0.703	3.281	4.078	3.887	1.669
0.25	0.20	0.600	0.700	3.306	4.080	3.887	1.655
0.26	0.20	0.605	0.697	3.332	4.082	3.887	1.642
0.28	0.20	0.617	0.692	3.386	4.087	3.891	1.616
0.30	0.20	0.629	0.686	3.445	4.092	3.898	1.590
0.32	0.20	0.641	0.679	3.509	4.097	3.909	1.564
0.36	0.20	0.669	0.666	3.656	4.110	3.947	1.513
0.40	0.20	0.700	0.650	3.834	4.125	4.009	1.463
0.44	0.20	0.736	0.632	4.054	4.143	4.104	1.415
0.48	0.20	0.777	0.612	4.332	4.166	4.246	1.368
0.52	0.20	0.825	0.588	4.693	4.195	4.454	1.325
0.56	0.20	0.882	0.559	5.182	4.232	4.764	1.284
0.60	0.20	0.950	0.525	5.877	4.281	5.239	1.248
0.64	0.20	1.033	0.483	6.934	4.347	6.003	1.217
0.66	0.20	1.082	0.459	7.695	4.389	6.571	1.193
0.70	0.20	1.200	0.400	10.124	4.500	8.437	1.179
0.74	0.20	1.354	0.323	15.519	4.666	12.697	1.176

Figure 1. Relative profits

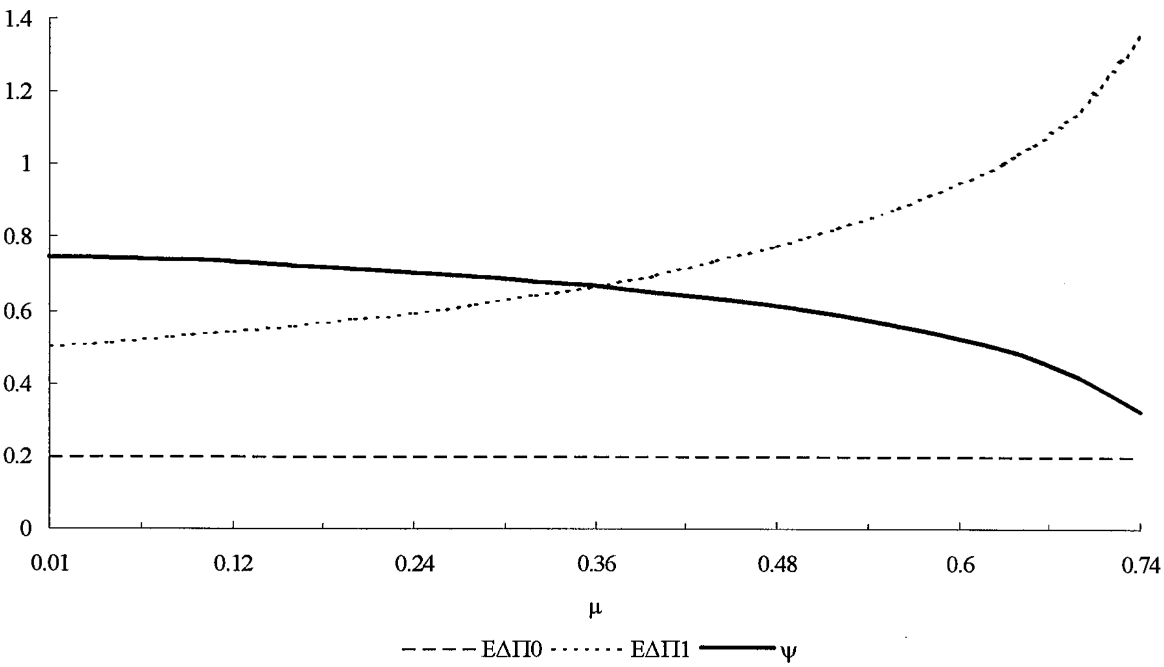

Figure 2. Central bank loss function

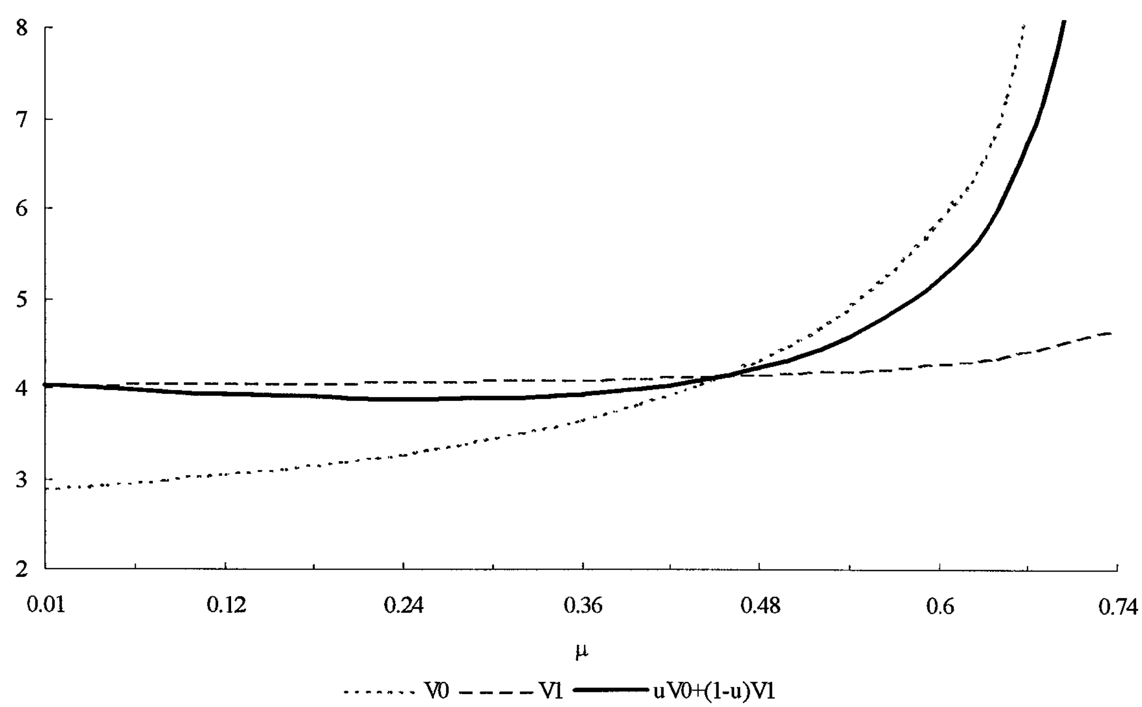

Table 2. Optimal Frequency of Intervention and Proportion of Informed Traders

Scenario	C	α	γ	σ^2_x	σ^2_y	σ^2_n	μ^*	$\mu^* V_0^* + (1-\mu^*) V_1^*$	ψ^*
A1	6.0	1.0	0.90	2	2	2	1.00	1.620	0.000
A2	0.1	1.0	0.90	2	2	2	1.00	1.620	1.000
A3	0.5	1.0	0.90	6	2	2	1.00	1.620	1.000
A4	0.5	1.0	0.70	2	2	2	1.00	0.980	1.000
B1	1.0	1.0	0.90	2	2	2	0.00	4.320	0.500
B2	0.5	1.0	0.90	1	2	2	0.00	4.160	0.500
B3	0.5	1.0	1.50	2	2	2	0.00	4.245	0.750
C1	0.5	1.0	0.90	2	2	2	0.25	3.887	0.700
C2	0.6	1.0	0.90	2	2	2	0.12	4.040	0.673
C3	0.4	1.0	0.90	2	2	2	0.40	3.638	0.733
C4	0.5	1.02	0.90	2	2	2	0.32	3.777	0.702
C5	0.5	0.98	0.90	2	2	2	0.18	3.973	0.700
C6	0.5	1.0	0.95	2	2	2	0.14	4.024	0.717
C7	0.5	1.0	0.85	2	2	2	0.38	3.670	0.689
C8	0.5	1.0	0.90	3	2	2	0.52	3.402	0.761
C9	0.5	1.0	0.90	1.5	2	2	0.06	4.076	0.652
C10	0.5	1.0	0.90	2	3	2	0.34	4.585	0.673
C11	0.5	1.0	0.90	2	1.5	2	0.17	3.492	0.719
C12	0.5	1.0	0.90	2	2	3	0.13	4.998	0.728
C13	0.5	1.0	0.90	2	2	1.5	0.32	3.288	0.679

According to this model, the central bank should intervene continuously if the proportion of informed traders is either always zero or always unity, say because informational costs are either very high or very low (consider scenarios A1 and A2). Then intervention does not affect the amount of information available. Continuous intervention could also be optimal under other circumstances, for example, if there is so relatively little 'noise' in the system so that information about the state variable x can always easily be extracted (as in scenario A3). If, in contrast, fixed costs are moderately high (scenario B1) or variance caused by noise traders is large relative to uncertainty over the state variable (scenarios B2 and B3) then the information revealed by market prices is very valuable and the proportion of informed traders declines very rapidly with the frequency of intervention, and it could be best never to intervene.

Perhaps the most interesting set of cases involve interior solutions with μ between zero and one, which illustrated in scenarios C1-C13 in Table 2 and summarized in Table 3. A higher fixed cost C tends to reduce the proportion of informed traders, and to compensate the central bank needs to intervene less frequently (compare C1 with C2 and C3). A reduction in the parameter α of the payoff function or an increase in the parameter γ of the central bank's loss function or will lead to a reduction in the optimal frequency of intervention because then the unintervened market price is closer to the central bank's operational target; as a consequence the proportion of informed traders rises (compare scenario C1 with scenarios C4-C7). The optimal frequency of intervention rises with an increase in σ^2_x , the variance of x (compare C1 with C8 and C9). When σ^2_y increases, implying that variation in the state variable y known to the central bank is more important, more frequent intervention is desirable (compare C1 with C10 and C11). Lastly, the difficulty faced by the central bank in making inferences about the state variable x depends on the intensity of 'noise' trading. Hence, an increase in the variance σ^2_n of the 'noise' induces a reduction in the optimal frequency of intervention (compare C1 with C12 and C13).

These results seem intuitively plausible. They suggest that the argument presented here will be especially important where the money market is still developing and other financial markets are thin. Then market participants will still be deciding on whether or not to incur large sunk costs in information acquisition and interpretation, and the economies of scope in information processing between financial markets will be limited. The argument will also be of special relevance to countries were the central bank's own sources of information are poor, as in many developing and transition economies. In these circumstances the money market may at first be illiquid, volatile and perhaps monopolistic, but not intervening may nonetheless be especially valuable in promoting market efficiency and ultimately in improving monetary policy implementation.

Table 3. Effect of an Increase in Parameter Values on the Optimal Frequency of Intervention and Proportion of Informed Traders

	increase in parameter	optimal intervention frequency (μ^*)	equilibrium proportion of informed traders (ψ^*)
C	fixed cost of information acquisition	decrease	decrease
α	weight of x in payoff	increase	increase
γ	weight of market information (x) in operational target	decrease	increase
σ^2_x	variance of market information (x)	increase	increase
σ^2_y	variance of central bank's information (y)	increase	decrease
σ^2_n	variance of noise trading (n)	decrease	increase

It should be pointed out that the model presented here can yield a wide variety of outcomes. There are discontinuities in the derived loss function and the constraint such that multiple local minima are possible. Under certain parameter combinations, it can occur that becoming informed is relatively more profitable when the central bank intervenes than when the market is left undisturbed (for example scenario A4 in Table 2). Then intervention both ensures that the operational target is met and that the availability of information to the central bank is maximized.

The model can be extended in several directions. The bidding in the central bank's tender could be affected by an additional disturbance term, which might arise for several reasons. For example, the central bank might intervene by conducting *ad hoc* open market operations based on quotes from a relatively small number of major financial institutions; these institutions may not be have available the full information available to the market as a whole, or they may engage in a sophisticated bidding strategy against the central bank. The central bank could be assumed to receive its own (noisy) signal concerning the state variable x, or the signal received by informed traders could be imperfect. Either all informed could receive the same signal, or each could receive a signal containing idiosyncratic noise. Both the informed and the uninformed traders may have additional stochastic liquidity demand for the asset. In this case a solution can exist where $\gamma = \alpha$.

A more ambitious extension would be to allow the proportion of informed market participants (ψ) to enter the demand schedules q^d_I and q^d_U. Since the correlation between the price P and the payoff x depends positively on ψ, the uninformed could do better by bidding more aggressively (display a more price elastic demand schedule) the higher is the proportion ψ. The expected profits of the informed would then decline more steeply as ψ rises, and they may be induced to bid less aggressively. The introduction of such feedback, which is not directly relevant to the questions addressed in this paper, should not qualitatively affect the results because the presence of noise traders prevents the uninformed from designing a bid schedule that is perfectly correlated with the state variable x. The model would however become a great deal more complex, not just algebraically but also because one would have to specify the utility functions, budget constraints and alternative investment opportunities of all market participants.

B. Central Bank Signaling

It is interesting to consider how the transmission of information from the central bank to market participants in this model is affected by the frequency of intervention. The central bank may wish to broadcast some of its own information on the state variable y, especially if the information concerns the future direction of policy. Market participants can extract a signal from prices when intervention takes place. As can be seen from equation (7), the 'intervened' price depends on x, y and the noise term. The informed traders know the realization of x already, so when they observe P^* they can identify a signal (P^*-γx) that depends just on the state variable y and the noise term n on which to base their estimate of y. Assuming a linear estimator and a quadratic loss function, the informed's problem is to choose a parameter ξ_I to minimize

$$E[(\xi_I (P^*-\gamma x) - y)^2] = E[(\xi_I (y + \gamma n/\psi\alpha) - y)^2] = (\xi_I -1)^2\sigma^2_y + \xi^2_I\gamma^2\sigma^2_n /\psi^2\alpha^2 .$$

It is easy to derive from the first order conditions for a minimum that the optimal setting of ξ_I is

$$\xi_I = \frac{\sigma_y^2}{(\gamma/\alpha\psi)^2\sigma_n^2 + \sigma_y^2} .$$

During the fraction (1-μ) of time without intervention, no information on y is received by any market participant, so its value is estimated at zero (its unconditional mean) and the expected squared deviation of the estimate is σ^2_y. The expected squared deviation averaged over intervention and non-intervention periods can be shown to equal

$$E[(\hat{y} - y)^2 | x, P^*] = \mu \frac{(\gamma/\alpha\psi)^2\sigma_n^2\sigma_y^2}{(\gamma/\alpha\psi)^2\sigma_n^2 + \sigma_y^2} + (1-\mu)\sigma_y^2 . \tag{12}$$

Taking the first derivative with respect to μ and simplifying yields

$$\partial \mathrm{E}\left[(\hat{y}-y)^2 \mid x, P^*\right]/\partial\mu \;=\; -\frac{\alpha^2\psi^2\sigma_y^4}{\gamma^2\sigma_n^2+\alpha^2\psi^2\sigma_y^2} \;-\; \frac{2\mu\gamma^2\sigma_n^2\sigma_y^4\alpha^2\psi\psi'}{\left(\gamma^2\sigma_n^2+\alpha^2\psi^2\sigma_y^2\right)^2}\;. \tag{13}$$

The first term on the right-hand-side of (13) represents the direct effect of giving market participants more occasion to observe a signal of y by intervening more frequently; it is certainly negative. The second term is positive since ψ' (the change in the proportion of participants who are informed as μ increases, which can be derived from (11)) is negative; intervention discourages expenditure on information acquisition, so more frequent intervention increases the 'noise to signal ratio' on the intervention days. In the simulations the first effect dominated; by way of illustration, the expected squared deviation of the informed participants' estimate of y in Scenario C1 is reported in Table 1, where the monotonic decline with increasing μ is apparent.

The uninformed can also make inferences about the state variable y. Because they do not know the realization of x, their best estimate of y on intervention days is

$$\frac{\sigma_y^2}{\gamma^2\sigma_x^2+(\gamma/\alpha\psi)^2\sigma_n^2+\sigma_y^2}\,.P^*\;. \tag{14}$$

The overall average expected squared deviation of the estimates made by the uninformed can easily be derived. As is the case for informed market participants, more frequent intervention provides the uninformed with more observations of prices affected by y, improving the average accuracy of the estimates, but also decreases the proportion of participants who are informed, reducing accuracy when intervention does occur.

III. Profitability of Policy Anticipation

Anecdotal evidence suggests that market participants devote as much effort to anticipating policy moves as to analyzing underlying economic conditions. Financial institutions employ 'Fed-watchers' (or 'Buba-watchers', etc.) to divine the central bank's intentions based primarily on informal or estimated policy reaction functions, and the more or less cryptic pronouncements of central bankers and others. It is, therefore, of interest to extend the model to consider the effect of policy anticipation on the central bank's objective function, and on its optimal operating procedures.

The approach taken here is to assume that besides the proportion ψ of market participants who pay a fee C to learn the realization of the state variable x, an additional proportion ϕ pay a total fee (C + D) to acquire both knowledge of x and a signal u that conveys imperfect information on the realization of the state variable y. In particular, the signal and the state variable are related by

$$u = y + m$$

where m is another zero-mean i.i.d. random variable with variance σ^2_m. Variables associated with these 'Fed-watchers' will be denoted by an 'F'.

It is interesting to consider the case where the return on the asset depends on both state variables independent of whether or not the central bank intervenes. The dependence on the state variable y might arise because y represents fundamental developments in the economy at large, and/or because of continuous anticipation of central bank policy actions. In particular, it is assumed that the net profit of spending an amount P on the asset is a random amount $(\alpha x + \beta y - P)$, where β is another parameter that depends on the normalization.

Each Fed watcher has a demand schedule

$$q^d_F(P) = \alpha x + \beta(y + m) - P \tag{15}$$

analogous to that of other market participants given their superior information set (compare with equations (1a) and (1b)).

Then aggregate demand is

$$\psi q^d_I(P) + \phi q^d_F(P) + (1-\psi-\phi)q^d_U(P) + n =$$
$$\psi(\alpha x - P) + \phi(\alpha x + \beta(y + m) - P) + (1-\psi-\phi)(-P) + n. \tag{16}$$

With zero net supply, the market clearing, competitive price is

$$P^{c\prime} = (\psi+\phi)\alpha x + \phi\beta y + \phi\beta m + n. \tag{17}$$

Expected profitability of the informed relative to that of the uninformed when no intervention takes place is

$$E\Delta\Pi_{I1} = E[\Pi_{I1} - \Pi_{U1}] = E[(\alpha x + \beta y - P^{c\prime})(\alpha x - P^{c\prime}) - (\alpha x + \beta y - P^{c\prime})(-P^{c\prime})]$$
$$= E[(\alpha x + \beta y - P^{c\prime})\alpha x] = (1 - \psi - \phi)\alpha^2\sigma^2_x \tag{18}$$

The expected relative profitability of the Fed-watchers is

$$\mathrm{E}\Delta\Pi_{\mathrm{F1}} = \mathrm{E}[\Pi_{\mathrm{F1}} - \Pi_{\mathrm{U1}}]$$

$$= \mathrm{E}[(\alpha x + \beta y - P^{c\prime})(\alpha x + \beta(y+m) - P^{c\prime}) - (\alpha x + \beta y - P^{c\prime})(-P^{c\prime})]$$

$$= \mathrm{E}[(\alpha x + \beta y - P^{c\prime})(\alpha x + \beta(y+m))\,]$$

$$= (1 - \psi - \phi)\alpha^2\sigma^2_{\mathrm{x}} + (1 - \phi)\beta^2\sigma^2_{\mathrm{y}} - \phi\beta^2\sigma^2_{\mathrm{m}} \tag{19}$$

The central bank's expected loss function when it does not intervene is easily shown to be

$$V_1{}' = \mathrm{E}[(P^{c\prime} - \gamma x - y)^2] = ((\psi+\phi)\alpha-\gamma)^2\sigma^2_{\mathrm{x}} + \phi^2\beta^2\sigma^2_{\mathrm{y}} + \phi^2\beta^2\sigma^2_{\mathrm{m}} + \sigma^2_{\mathrm{n}}\,. \tag{20}$$

Consider now the situation when the central bank does intervene. As before it will be assumed that the individual market participants just bid their demand schedules, which are unaffected by whether or not the central bank is intervening. The central bank therefore observes an aggregate bid schedule given by (16). Since it knows the value of y and all the parameters, it can identify a noisy signal $S' = (\psi+\phi)\alpha x + \phi\beta m + n$ and therefore estimate the value of x, albeit imperfectly. The central bank is assumed to use the simple unbiased estimate

$$\hat{x} = x + \frac{\phi\beta m + n}{(\psi + \phi)\alpha}\,.$$

On this basis the central bank sets a price

$$P^{*\prime} = \gamma\hat{x} + y = \gamma S'/(\psi+\phi)\alpha + y = \gamma x + \gamma[\phi\beta m + n]/(\psi+\phi)\alpha + y. \tag{21}$$

The minimized expected loss function can easily be shown to be

$$V_0^{\prime} = \frac{\gamma^2}{(\psi + \phi)^2\alpha^2}\left[\phi^2\beta^2\sigma_m^2 + \sigma_n^2\right]. \tag{22}$$

The expected difference in profitability between the informed and the uninformed is

$$\mathrm{E}\Delta\Pi_{\mathrm{I0}} = \mathrm{E}[(\alpha x + \beta y - P^{*\prime})\alpha x]$$

$$= (\alpha - \gamma)\alpha\sigma^2_{\mathrm{x}}\,. \tag{23}$$

The expected difference in profitability between the Fed-watchers and the uninformed is

$$\mathrm{E}\Delta \Pi_{F0} = \mathrm{E}[(\alpha x + \beta y - P^{*\prime})(\alpha x + \beta(y+m))]$$

$$= (\alpha-\gamma)\alpha\sigma_x^2 + \beta(\beta-1)\sigma_y^2 - \frac{\gamma\phi\beta^2\sigma_m^2}{(\psi+\phi)\alpha} \,. \tag{24}$$

Clearly the Fed-watchers gain from their knowledge of the state variable y, which allows them to anticipate the central bank's actions better, but since they receive a 'noisy' signal they may to some extent be led astray.

The central bank's problem still consists of choosing the frequency of intervention μ so as to minimize the average value of its expected loss function

$$\mu V_0' + (1-\mu)V_1' = \mu\frac{\gamma^2\left[\phi^2\beta^2\sigma_m^2 + \sigma_n^2\right]}{(\psi+\phi)^2\alpha^2} + (1-\mu)\left[(\psi+\phi-\gamma)\alpha^2\sigma_x^2 + \phi^2\beta^2(\sigma_m^2+\sigma_y^2) + \sigma_n^2\right]. \tag{25}$$

However, it now faces two constraints, one relating to the equilibrium number of ordinary informed traders and one to the equilibrium number of Fed-watchers. In market equilibrium the ordinary informed traders must on average earn just enough extra profits compared to the uninformed that they just cover their fixed costs C, so the condition is that

$$\mathrm{C} = \mu \mathrm{E}\Delta \Pi_{I0}' + (1-\mu)\mathrm{E}\Delta \Pi_{I1}'$$

$$= \mu(\alpha-\gamma)\alpha\sigma_x^2 + (1-\mu)(1-\psi-\phi)\alpha^2\sigma_x^2 \,. \tag{26}$$

The number of Fed-watchers will likewise be determined by the condition that their extra profits on average just cover their extra fixed costs C+D:

$$\mathrm{C} + \mathrm{D} = \mu \mathrm{E}\Delta \Pi_{F0}' + (1-\mu)\mathrm{E}\Delta \Pi_{F1}'$$

$$= \mu\left[(\alpha-\gamma)\alpha\sigma_x^2 + \beta(\beta-1)\sigma_y^2 - \frac{\gamma\phi\beta^2\sigma_m^2}{(\psi+\phi)\alpha} + \alpha\sigma_y^2\right] +$$

$$(1-\mu)\left[(1-\psi-\phi)\alpha^2\sigma_x^2 + (1-\phi)\beta^2\sigma_y^2 - \phi\beta^2\sigma_m^2\right] \tag{27}$$

The sum of these terms just equals the extra profits available to a market participants from bearing the extra cost D and acquiring the signal u, that is, from becoming a Fed-watcher, whether or not the market participant is also informed about the state variable x. This separation between the value of learning x and the value of leaning u depends on the mutual independence of all disturbance terms and the additive nature of the costs of information acquisition.

Simulations were run to establish how the value of the objective function (25) varies with μ under the two constraints (26) and (27), and thus to obtain the optimal frequency of intervention, and some results are presented in Table 4. Comparing Tables 2 and 4 one can see that the presence of Fed-watchers tends to decrease the optimal frequency of intervention because on the one hand the addition of the demand schedules of the Fed-watchers reduces the benefit of intervening, and on the other the Fed-watchers help ensure that the unintervened market price in part varies with the state variable y. Generally the relative population of other informed market participants (ψ) is lower when they face competition from the Fed-watchers, but the total population of informed participants ($\psi+\phi$) is somewhat higher. Indeed, most of the variation in the optimal frequency of intervention is due to shifts into and out of Fed watching by the informed as parameters change, rather than adjustment in the total proportion of informed traders.

The presence of Fed-watchers can thus be seen to have several, in part conflicting effects. The opportunity to earn profits as a Fed watcher may increase the total number of informed traders, increasing informational efficiency and allowing the central bank to make better inferences about the state variable x. The Fed-watchers also anticipate Fed policy even when no intervention occurs, and in this way they partly 'do the work' of the central bank when it is absent from the market. However, Fed-watchers can also misinterpret the central bank's intentions (as represented by the noise term m). The result is greater, and useless variability around the central bank's operational targets whether or not intervention is undertaken, and information available to market participants is masked from the central bank.

The results in Table 4 illustrates the sensitivity of the optimal $\mu^{*\prime}$ and other endogenous variables to variation in the parameters. The signs of the changes in $\mu^{*\prime}$are the same as those presented in Table 2 for the model without Fed-watchers, and the signs of the changes in $\psi^{*\prime}$ are mostly similar. Generally the proportion of market participants who are Fed-watchers is inversely related to the optimal frequency of intervention and the proportion of other informed traders. The proportion $\phi^{*\prime}$ increases with σ^2_y and β, which raise the profitability of Fed watching, and decreases when D and σ^2_m increase, since these variables capture their costs. The equilibrium proportion of Fed-watchers is lower, the higher are α or σ^2_x, because then the central bank intervenes more frequently, and rises with γ and σ^2_n, which are associated with a decrease in central bank intervention. A decrease in the fixed cost C increases the total number of informed and especially that of non-Fed-watchers, so the Fed-watchers are crowded out and the optimal frequency of intervention rises.

Table 4. Optimal Frequency of Intervention with Informed Traders and Fed-watchers

Scenario	C	D	α	β	γ	σ^2_x	σ^2_y	σ^2_n	σ^2_m	$\mu^{*\prime}$	$\mu^{*\prime}V_0^{*\prime}+(1-\mu^{*\prime})V_1^{*\prime}$	$\psi^{*\prime}$	$\phi^{*\prime}$
A1′	6.0	1.0	1.0	1.0	0.9	2	2	2	8	1.00	1.620	0.000	0.000
B1′	1.0	1.0	1.0	1.0	0.9	2	2	2	8	0.00	4.020	0.400	0.100
C1′	0.5	1.0	1.0	1.0	0.9	2	2	2	8	0.115	3.728	0.653	0.076
C2′	0.6	1.0	1.0	1.0	0.9	2	2	2	8	0.00	3.750	0.600	0.100
C3′	0.4	1.0	1.0	1.0	0.9	2	2	2	8	0.32	3.578	0.716	0.037
C4′	0.5	1.0	1.02	1.0	0.9	2	2	2	8	0.22	3.669	0.669	0.056
C5′	0.5	1.0	0.98	1.0	0.9	2	2	2	8	0.09	3.666	0.701	0.083
C6′	0.5	1.0	1.0	1.0	0.95	2	2	2	8	0.00	3.780	0.650	0.100
C7′	0.5	1.0	1.0	1.0	0.85	2	2	2	8	0.30	3.599	0.667	0.040
C8′	0.5	1.0	1.0	1.0	0.9	3	2	2	8	0.46	3.403	0.768	0.008
C9′	0.5	1.0	1.0	1.0	0.9	1.5	2	2	8	0.00	3.782	0.567	0.100
C10′	0.5	1.0	1.0	1.0	0.9	2	3	2	8	0.19	4.263	0.583	0.132
C11′	0.5	1.0	1.0	1.0	0.9	2	1.5	2	8	0.04	3.411	0.697	0.046
C12′	0.5	1.0	1.0	1.0	0.9	2	2	3	8	0.00	4.745	0.650	0.100
C13′	0.5	1.0	1.0	1.0	0.9	2	2	1.5	8	0.21	3.180	0.652	0.056
D1	0.5	1.0	1.0	1.1	0.9	2	2	2	8	0.11	3.679	0.634	0.098
D2	0.5	1.0	1.0	0.9	0.9	2	2	2	8	0.12	3.799	0.680	0.050
D3	0.5	1.7	1.0	1.0	0.9	2	2	2	8	0.15	3.917	0.724	0.000
D4	0.5	0.3	1.0	1.0	0.9	2	2	2	8	0.10	3.641	0.583	0.150
D5	0.5	1.0	1.0	1.0	0.9	2	2	2	9	0.14	3.747	0.660	0.066
D6	0.5	1.0	1.0	1.0	0.9	2	2	2	7	0.09	3.703	0.644	0.092

IV. Conclusions

Central banks recognize more clearly than ever the general advantages of implementing monetary policy by the use of market based instruments. Here it is argued that the allocative and efficiency gains that can result should not and need to come at the expense of effective monetary policy. Rather, the use of market-based instruments and limited intervention can improve the implementation of monetary policy by increasing the relevant information available to the central bank.

A central bank's operating procedures may affect the incentives faced by market participants to acquire information, and thus the information available to the central bank in determining its short-term operational targets. In particular, information may be less valuable to market participants when intervention is carried out than when the market process is left undisturbed. Under normal circumstances the informed traders are able to recover their extra costs by making profits at the expense of the uninformed and noise traders. A central bank is itself an informed trader, but one that is not interested in profit maximization or keeping its information confidential, and is large enough to influence prices decisively. There may be little scope for using an informational advantage if all market participants can trade with the central bank at a price determined on the basis of monetary policy considerations. Therefore, in market equilibrium the more the central bank intervenes, the higher profits for informed traders will have to be during nonintervention periods for them to recover their fixed costs. The number of informed traders must fall for each remaining one to earn higher profits during non-intervention periods. Consequently, market prices will contain relatively less information, and the central bank is left with a noisier signal on which to base decisions on its short-term policy actions. The optimal intervention rule balances the need to intervene to keep money market prices in line with the operational target, and the desire to promote the acquisition of information that allows the central bank to set a better target. The central bank's operating procedures will also significantly affect the ability of market participants to infer the central bank's policy stance and private information from its actions. The incentives for 'Fed watching' and the anticipation of central bank actions by market participants will also depend on the frequency of intervention, and the prevalence of such activities will feed back into the choice of the optimal operating procedure.

The discussion has been framed in terms of the operational procedures currently employed by central banks in most industrialized countries in their domestic operations, but the arguments can be generalized to apply to countries following an exchange rate based strategy. Where the authorities choose to target the exchange rate, they now mostly implement policy by trading in the foreign exchange market or using their domestic monetary instruments, rather than by imposing exchange restrictions such as capital controls or other regulations. It has also become commoner for exchange rate targets to be defined by relatively wide 'bands', as exemplified by the Exchange Rate Mechanism of the European Monetary System, rather than by a narrow 'peg', as under the Bretton Woods system. Hence, the central bank must still evaluate the marginal costs and benefits of allowing more or less variance in the financial market 'price' which it targets in its operations. Furthermore the same considerations apply to economies in many stages of development and may indeed be especially forceful in economies where financial markets are still being established. Indeed, the arguments presented here can be considered as special instances of the general arguments for the informational superiority of liberal market systems. If unconstrained markets promote the more efficient allocation of resources by private economic agents, they may also help the central bank make the choices faced in the implementation of monetary policy in a complex and changing economic environment.

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