Central Bank Communication and Expectations Stabilization*

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February 28, 2007

Abstract

This paper analyzes the value of communication in the implementation of monetary policy. The central bank is uncertain about the current state of the economy. Households and firms do not have a complete economic model of the determination of aggregate variables, including nominal interest rates, and must learn about their dynamics using historical data. Given these uncertainties, when the central bank implements optimal policy, the Taylor principle is not sufficient for macroeconomic stability: for all reasonable parameterizations self-fulfilling expectations are possible. To mitigate this instability, three communication strategies are contemplated: i) communicating the precise details of the monetary policy — that is, the variables and coefficients; ii) communicating just the variables on which monetary policy decisions are conditioned; and iii) communicating the inflation target. The first two strategies restore the Taylor principle as a sufficient condition for stabilizing expectations. In contrast, in economies with persistent shocks, communicating the inflation target fails to protect against expectations driven fluctuations. These results underscore the importance of communicating the systematic component of current and future monetary policy decisions: announcing an inflation target is not enough to stabilize expectations — one must also announce how this target will be achieved.

*The views expressed in the paper are those of the authors and are not necessarily reflective of views at the Federal Reserve Bank of New York or the Federal Reserve System. The usual caveat applies.

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> A central bank that is inscrutable gives the markets little or no way to ground these perceptions [about monetary policy] in any underlying reality — thereby opening the door to expectational bubbles that can make the effects of its policies hard to predict. (Blinder, 1998)

1 Introduction

Since the 1990's, central banking practice has shifted from secrecy and opaqueness towards greater transparency about monetary policy strategy and objectives. At the same time, an increasing number of central banks have adopted an inflation targeting framework for monetary policy. One potential benefit from a successful implementation of inflation targeting is the anchoring of expectations, with its stabilizing effect on macroeconomic activity. Failing to anchor expectations might result in undesired fluctuations and economic instability.

Given the role of expectations, a central bank's communication strategy is a crucial ingredient of inflation targeting. Yet despite its importance, relatively little formal analysis in the context of dynamic stochastic general equilibrium models has been done on the mechanisms by which communication might prove beneficial. The analysis here addresses this hiatus. Using a simple model of output gap and inflation determination — of the kind used in many recent analyses of monetary policy — a number of communication strategies are considered which vary the kinds of information the central bank communicates about its monetary policy deliberations.

Motivated by Friedman (1968), communication is given content by introducing two informational frictions. First, the central bank has imperfect information about the current state of the economy and must therefore forecast the current inflation rate and output gap when contemplating its setting of the nominal interest rate in any period. Policy therefore responds to information and the state of the economy with a delay and is implementable in the sense of McCallum (1999) — see also Orphanides (2003). Second, households and firms have an incomplete model of the macroeconomy, knowing only their own objectives, constraints and beliefs. Consequently, they do not have a model of how aggregate state variables, including nominal interest rates, are determined. They therefore forecast the exogenous variables relevant to their decision problems by extrapolating from historical patterns in observed data. Such beliefs capture uncertainty about the future path of nominal interest rates that is not present in a rational expectations analysis of the model and creates a delay in the transmission of monetary policy: because beliefs take time to adjust to new information, policy changes affect the macroeconomy only gradually. These two frictions combined present a challenge for stabilization policy and formed the basis of Friedman's (1968) critique of nominal interest rate rules as a means to implement monetary policy.[1]

In this context, communication is modeled as providing agents with certain types of information about how the central bank determines its nominal interest rate setting. Worth underscoring is that uncertainty about the path of nominal interest rates is only one of several sources of uncertainty present in this economy. Indeed, households and firms are similarly unsure about how aggregate output and inflation are determined. The central question is whether uncertainty about the determination of interest rates is an especially important source of uncertainty and whether additional knowledge about the future path of nominal interest rates helps anchor expectations, assisting macroeconomic stabilization.[2]

Three communication strategies are considered. The benchmark strategy is one in which the central bank discloses, under full credibility, the policy rule employed to set nominal interest rates. Agents therefore know which variables appear in the policy rule and the precise restriction that holds among these endogenous variables at all points in time in the forecast horizon. An alternative interpretation of this communication strategy is that the bank discloses its forecasts of the entire future path of its policy instrument. A consequence of knowing the policy rule is that agents need not independently forecast the path of nominal interest rates — it is sufficient to forecast the set of variables upon which nominal interest rates depend. Because this relation is one of the many equilibrium restrictions agents are attempting to learn, by imposing this restriction on their regression model a more efficient forecast obtains.

[1] The analysis here evaluates the verity of this claim, building on the seminal analysis of Howitt (1992), and explores the value of communication in macroeconomic stabilization policy.

[2] On a technical level, the analysis is concerned with the question of whether communication assists convergence to the underlying rational expectations equilibrium of the model.

The second communication strategy makes available less information. Rather than conveying the precise policy rule, the central bank only announces the set of variables on which nominal interest rates are conditioned. This strategy might reflect partial central bank credibility or the inability to accurately communicate the complexities of the decision making process: market participants use available data and the information about the policy rule to verify the reaction function used to set the nominal interest rate.

Finally, motivated by the inflation targeting literature which emphasizes the potential benefits of announcing an inflation target for anchoring inflation expectations, we explore the advantages of only communicating the central bank's desired average outcomes for inflation, nominal interest rates and the output gap. Here the only information that is communicated is the central bank's commitment to conduct policy in such a way as to achieve the target for inflation on average. No information on how the central bank will achieve this objective is given.

The central results are as follows. First, in the case of no communication, policy rules that implement optimal policy under rational expectations frequently lead to self-fulfilling expectations. An aggressive response to inflation expectations — as adherence to the Taylor principle prescribes — does not guarantee stability. On the contrary, it is likely to further destabilize expectations. Importantly the Taylor principle is not sufficient for stability under learning dynamics in contrast to a rational expectations analysis of the model.

Second, communicating the entire policy decision process — that is, the relevant conditioning variables and policy coefficients — mitigates instability and allows successful implementation of optimal policy by stabilizing expectations. Hence, communicating accurate information about the systematic component of current and future monetary policy decisions anchors expectations and promotes macroeconomic stability. Since our approach to modeling household and firm beliefs represents a small departure from the rational expectations assumption — indeed this assumption is nested as a special limiting case — this result underscores the value of communication. These stabilization benefits can also be fully captured by a communication strategy that only conveys the set of endogenous variables on which monetary policy decisions are conditioned, as proposed by the second communication strategy. This information, combined with knowledge that nominal interest rates are a linear function of these objects, delivers convergence to rational expectations equilibrium and protects against expectations driven instability.

Furthermore we show the importance of incomplete information for the role of communication. We demonstrate that if the central bank has perfect information about the state of the economy, then communication is not required for expectations stabilization. Indeed, policy conditioned on the current inflation rate and output gap restores the Taylor principle. Because the central bank promptly responds to contemporaneous developments in the economy, large departures of expectations from equilibrium values are prevented. Thus it is the interaction of the two frictions that leads to instability. However, in practice the current state will never be accurately observed, making transparency and communication of monetary policy desirable.

Third, communication strategies that only announce an inflation target and the associated average long-run values of the nominal interest rate and output gap frequently lead to expectations driven instability. In an economy with persistent shocks, the conditions for convergence are identical to those for the benchmark no communication case where these quantities must be learned. Hence, in such economies, communicating the inflation target does little to help anchor expectations.

It is clear then that communication helps by providing information about the systematic component of policy and importantly by giving information on how the central bank intends to achieve its announced objectives. Credibility about the future conduct of policy matters not only because of the stabilization bias that emerges from a rational expectations equilibrium analysis, as is well known from Kydland and Prescott (1977), but also because it helps protect against departures from rational expectations equilibrium that arise from small expectational errors on the part of households and firms.

This finding has relevance for Orphanides and Williams (2005) which presents a model in which announcing the inflation target achieves a better inflation-output trade-off. Because it reduces the amplitude of macroeconomic fluctuations the announcement of the inflation target is welfare enhancing. However, in their model, regardless of whether or not the inflation target is announced, expectations are well anchored: self-fulfilling expectations cannot arise. The improvement in welfare results from agents having a more accurate forecast of future policy decisions. In contrast, this paper presents a model in which self-fulfilling expectations emerge even if the inflation target is announced and credible.

Related Literature: Geraats (2002) proposes five central aspects of central bank transparency: political, operational, procedural, economic, policy. The present analysis focuses on the benefits from communicating the goals of policy and the policy strategy adopted to achieve such goals. In the context of our model, this information is embodied in the policy rule adopted by the central bank. The analysis builds on an earlier literature commencing with Cukierman and Meltzer (1986) and more recently Faust and Svensson (2001). These papers consider two period models in which the central bank has an idiosyncratic employment target which is imperfectly observed by the public. Fluctuations in this target leads to central bank temptation to deviate from pre-announced inflation goals. However, increased transparency allows the private sector to observe the employment target with greater precision and therefore raises the costs to the central bank of deviating from its announced objectives. Transparency is therefore desirable as it provides a commitment mechanism. Svensson (1999) further argues on the ground of this result that for inflation targeting central banks it is generally desirable to publish detailed information on policy objectives, including forecasts. Such transparency enhances the public's understanding of the monetary policy process and raises the cost to a central bank from deviating from its stated objectives.

More recently, a literature has emerged focusing on the question of whether transparency of central bank forecasts of state variables is desirable. In these models, the public correctly understands central bank preferences but has imperfect information about the central bank's forecast of the aggregate state. Building on Morris and Shin (2002), Amato and Shin (2003), Hellwig (2005) and Walsh (2006), among others, show that full transparency about the central bank forecast is not always desirable because private agents may overreact to noisy public signals and under react to more accurate private information. More generally, Geraats (2002, 2006) argues that models based on diverse private information often have the property that pronouncements by the central bank may lead to frequent shifts in expectations leading to increased economic volatility.

On the other hand, Roca (2006) shows that some of these conclusions depend on the postulated objectives of the central bank. Similarly, Svensson (2006) and Woodford (2005) argue that the conclusions of Morris and Shin (2002) depend on implausible parameter assumptions.[3]

Our analysis departs from this literature by analyzing the value of communicating information about current and future nominal interest rate decisions of the central bank. Like Walsh (2006), the present analysis considers a theory of price setting that is consistent with recent New Keynesian analyses of monetary policy. Unlike Walsh, we propose a fully articulated dynamic stochastic general equilibrium model. Moreover, rather than assuming that the central bank and private agents have asymmetric information about the kinds of disturbances that affect the economy, we consider a framework in which these actors have symmetric information about shocks. The asymmetry instead lies in knowledge about how nominal interest rates are determined. This permits a tractable analysis of communication about endogenous decision variables of the central bank — that is the sequence of choices about the path of nominal interest rates — rather than announcements about exogenous state variables.[4]

The paper proceeds as follows. Section 2 delineates a simple model of the macroeconomy. Section 3 details private agents' expectations formation and the adopted criterion to assess macroeconomic stability. Section 4 provides results. Section 5 provides graphical analysis of the role of communication in stabilizing expectations. Section 6 concludes.

2 A Simple Model

The following section details a simple model of output gap and inflation determination that is similar in spirit to Svensson and Woodford (2005). The major differences are the incorporation of heterogeneous agents, non-rational beliefs, and the assumption of Rotemberg (1982) price setting rather than Calvo (1983) price setting as implemented by Yun (1996). The

[3]See also the latter for a review of the benefits of central bank communication and transparancy.

[4]Rudebusch and Williams (forthcoming) present an analysis that is similar in spirit, analyzing the consequences of asymmetric information about future policy actions. One of the constributions of our paper is to build on their analysis by developing microfoundations that are consistent with the assumption of asymmetric information about the economy.

analysis follows Marcet and Sargent (1989a) and Preston (2005), solving for optimal decisions conditional on current beliefs.

2.1 Microfoundations

Households. Households maximize their intertemporal utility derived from consumption and leisure

$$\hat{E}_{t-1}^{i} \sum_{T=t}^{\infty} \beta^{T-t} \left[\ln C_T^i - h_T^i \right]$$

subject to the flow budget constraint

$$B_t^i \leq R_{t-1} B_{t-1}^i + W_t h_t^i + P_t \Pi_t - P_t C_t^i$$

where B_t^i denotes holdings of the one period riskless bond, R_t denotes the gross interest paid on the bond, W_t the nominal wage and h_t^i labor supplied by household i. Financial markets are assumed to be incomplete and Π_t denotes profits from holding shares in an equal part of each firm. The nominal income in any period t is therefore $P_t Y_t^i = W_t h_t^i + P_t \Pi_t$. $\hat{E}_t^i$ denote the beliefs at time t held by each household i, which satisfy standard probability laws. Section 3 describes the precise form of these beliefs and the information set available to agents in forming expectations. However, two points are worth noting. First, in forming expectations, households and firms observe only their own objectives, constraints and realizations of aggregate variables. They have no knowledge of the beliefs, constraints and objectives of other agents in the economy: in consequence agents are heterogeneous in their information sets. Second, given the assumed conditioning information for expectations formation, consumption plans are made one period in advance and therefore predetermined.[5]

Each household consumes a composite good

$$C_t^i = \left[\int_0^1 c_t^i(j)^{\frac{\theta_t - 1}{\theta_t}} dj \right]^{\frac{\theta_t}{\theta_t - 1}}$$

[5] We consider a model with pricing and spending decisions determine one period in advance so as to put households, firms and policymakers on an indetical informational footing. This could be dispensed with by making the alternative assumption that the central bank has a policy reaction function that responds to one period ahead expectations of inflation. All results contunue to hold.

which is made of a continuum of differentiated goods, each produced by a monopolistically competitive firm j. The elasticity of substitution among differentiated goods, θ_t, is time-varying, with $E[\theta_t] = \theta > 1$. This is a simple way of modeling time-varying mark-ups, introducing a trade-off between inflation and output stabilization relevant to optimal policy design.

A log linear approximation to the first order conditions of the household problem provides the household Euler equation

$$\hat{C}_t^i = \hat{E}_{t-1}\left[\hat{C}_{t+1}^i - (i_t - \pi_{t+1})\right] \tag{1}$$

and the intertemporal budget constraint

$$\hat{E}_{t-1}\sum_{T=t}^{\infty}\beta^{T-t}\hat{C}_T^i = \omega_{t-1}^i + \hat{E}_{t-1}\sum_{T=t}^{\infty}\beta^{T-t}\hat{Y}_T^i \tag{2}$$

where

$$\hat{Y}_t \equiv \ln(Y_t/\bar{Y});\ \hat{C}_t \equiv \ln(C_t/\bar{C});\ \hat{\imath}_t \equiv \ln(R_t/\bar{R});\ \pi_t = \ln\left(P_t/P_{t-1}\right)\ \text{and}\ \omega_t^i = B_t^i/\bar{Y}$$

and $\bar{z}$ denotes the steady state value of any variable z.

Solving the Euler equation recursively backwards, taking expectations at time $t-1$ and substituting into the intertemporal budget constraint gives

$$\hat{C}_t^i = \omega_{t-1}^i + \hat{E}_{t-1}\sum_{T=t}^{\infty}\beta^{T-t}\left[(1-\beta)\hat{Y}_T^i - \beta\sigma(i_T - \pi_{T+1})\right]. \tag{3}$$

Optimal consumption decisions depend on current wealth and on the expected future path of income and the real interest rate.[6] The optimal allocation rule is analogous to permanent income theory, with differences emerging from allowing variations in the real rate of interest, which can occur due to either variations in the nominal interest rate or inflation.

[6] Using the fact that total household income is the sum of dividend and wage income, combined with the first order conditions for labor supply and consumption, would deliver a decision rule for consumption that depends only on forecasts of prices: that is, goods prices, nominal interest rates, wages and dividends. However, we make the simiplify assumption that households forecast total income, the sum of divdend payments and wages received.

Firms. There is a continuum of monopolistically competitive firms. Each differentiated consumption good is produced according to the linear production function

$$Y_{j,t} = A_t h_{j,t}$$

where A_t denotes a technology shock. Each firm chooses a price P_{jt} in order to maximize its expected discounted value of profits

$$\hat{E}^j_{t-1} \sum_{T=t}^{\infty} Q_{t,T} P_T \Pi_{j,T}$$

where

$$\Pi_{j,t} = \frac{P_{jt}}{P_t} Y_{j,t} - \frac{W_t}{P_t} h_{jt} - \frac{\psi}{2} \left(\frac{P_{jt}}{P_{jt-1}} - 1 \right)^2$$

denotes period profits and the quadratic term the cost of adjusting prices as in Rotemberg (1982).[7] Given the incomplete markets assumption it is assumed that firms value future profits according to the marginal rate of substitution evaluated at aggregate income

$$Q_{t,T} = \beta^{T-t} \frac{P_t Y_t}{P_T Y_T}$$

for $T \geq t$. The precise details of this assumption are not important to the ensuing analysis so long as in the log linear approximation future profits are discounted at the rate β^{T-t}.

The intratemporal consumer problem implies aggregate demand for each differentiated good is

$$Y_{jt} = \left(\frac{P_{j,t}}{P_t} \right)^{-\theta_t} Y_t$$

where Y_t denotes aggregate output and

$$P_t = \left[\int_0^1 (P_{j,t})^{1-\theta_t} \, dj \right]^{\frac{1}{1-\theta_t}}$$

is the associated price index. Summing up, the firm chooses a sequence for P_{jt} to maximize profits, given the constraint that demand should be satisfied at the posted price, taking as given P_t, Y_t, and W_t. Again, given the information upon which expectations are conditioned, prices are determined one period in advance.

[7] The results are similar to the case of a Calvo pricing model.

In a symmetric equilibrium, all firms set the same price, so that $p_t(j) = P_t$. Log-linearizing the first order condition for the optimal price we obtain

$$\hat{P}_t - \hat{P}_{t-1} = \pi_t = \hat{E}^i_{t-1}\beta\pi_{t+1} + \xi\hat{E}^i_{t-1}\left(\hat{s}_t + \hat{\mu}_t\right)$$

where, $\hat{P}_t = \log P_t$, $\xi = \theta Y/\psi$ is inversely related to the cost of adjusting the prices, $\mu_t = \theta_t\left(\theta_t - 1\right)^{-1}$ denotes the mark-up; $\hat{s}_t \equiv \ln\left(s_t/\bar{s}\right)$ marginal costs defined below; and $\hat{\mu}_t \equiv \ln\left(\mu_t/\bar{\mu}\right)$. Solving forward and making use of the transversality condition we obtain

$$\hat{P}_t = \hat{P}_{t-1} + \hat{E}^i_{t-1}\sum_{T=t}^{\infty}\left(\beta\right)^{T-t}\xi\left(\hat{s}_T + \hat{\mu}_T\right) \tag{4}$$

which states that each firm's current price depends on the expected future path of real marginal costs and cost-push shocks.

The real marginal cost function is

$$S_t = \frac{w_t}{A_t} = \frac{C_t}{A_t}$$

where the second equality comes from the household's labor supply decision. After log-linearization we obtain

$$\hat{s}_t = \hat{C}_t - \hat{a}_t$$

so that current prices depend on expected future demand and technology. The responsiveness of current prices to changes in expected demand depends on the degree of nominal rigidity. A low degree of nominal rigidity implies a high value of ξ (corresponding to a low value of the cost ψ): in this case firms respond aggressively to changes in perceived demand because price changes are less costly. The opposite occurs in the case of higher costs of price adjustment. The degree of price rigidity plays a key role in the stability analysis.

2.2 Market clearing, efficient output and aggregate dynamics

The model is closed with assumptions on monetary and fiscal policy. The fiscal authority is assumed to follow a zero debt policy in every period t. Monetary policy is discussed in detail in the subsequent section. For now it suffices to note that a Taylor-type rule is implemented.

For a more general treatment of the interactions of fiscal and monetary policy under learning dynamics see Eusepi and Preston (2007) and Evans and Honkapohja (2006).

General equilibrium requires that the goods market clears, so that

$$A_t h_t - \frac{\psi}{2} (\Pi_t - 1)^2 = \int C_t dj = C_t. \tag{5}$$

This condition states that output net of adjustment cost is equal to aggregate consumption, determining the equilibrium demand for labor h_t at the wage $w_t = C_t$. This relation satisfies the log-linear approximation

$$\hat{h}_t + \hat{a}_t = \hat{C}_t = \hat{Y}_t.$$

For later purpose it is useful to characterize the *efficient* level of output — the level of output that would occur absent nominal rigidities under rational expectations. Under these assumptions, optimal price setting implies the long-linear approximation $E_{t-1}\hat{Y}_t^e = E_{t-1}\hat{a}_t$. Hence predictable movements in the efficient rate of output are entirely determined by the aggregate technology shock. We can use the definition of efficient output to characterize the aggregate dynamics of the economy in terms of deviations from the efficient equilibrium. Nominal bonds are also in zero net supply requiring

$$\int_0^1 B_t^i di = 0.$$

Aggregating firm and household decisions, using (3) and (4) provides

$$x_t = \hat{E}_{t-1} \sum_{T=t}^{\infty} \beta^{T-t} \left[(1-\beta) x_T + \beta \hat{r}_t^e - \beta\sigma(i_T - \pi_{T+1})\right] \tag{6}$$

and

$$\pi_t = \hat{E}_{t-1} \sum_{T=t}^{\infty} (\beta)^{T-t} \xi \left(x_T + \hat{\mu}_T\right) \tag{7}$$

where $\int_0^1 \hat{E}_t^i di = \hat{E}_t$ gives average expectations; $x_t = \hat{Y}_t - E_{t-1}\hat{Y}_t^e$ denotes the log-deviation of output from its expected efficient level; and $\hat{r}_t^e = \left(\hat{Y}_{t+1}^e - \hat{Y}_t^e\right)$ the corresponding efficient rate of interest. The average expectations operator does not satisfy the law of iterated expectations due to the assumption of completely imperfect common knowledge on the part of all households and firms. Because agents do not know the beliefs, objectives and constraints of others in the economy, they cannot infer aggregate probability laws. This is the property of the irreducibility of long horizon forecasts noted by Preston (2005).

2.3 The Monetary Authority

The monetary authority minimizes a standard quadratic loss function under the assumption that agents have rational expectations. This approach follows a now substantial literature on learning dynamics and monetary policy — see Howitt (1992) for the seminal contribution and Bullard and Mitra (2002), Evans and Honkapohja (2003) and Preston (2004, 2006), inter alia, for subsequent contributions — motivated by the question of robustness of standard policy advice to small deviations from the rational expectations assumption. For alternative treatments of policy design that take into account private agent learning see Gaspar, Smets, and Vestin (2005) and Molnar and Santoro (2005).

The optimal policy problem is

$$\min E_t \sum_{T=t}^{\infty} \left(\pi_T^2 + \lambda_x x_T^2\right)$$

subject to the constraints

$$x_t = E_{t-1} x_{t+1} - E_{t-1}\left(i_t - \pi_{t+1} - r_t^e\right) \tag{8}$$

$$\pi_t = \xi x_t + \beta E_{t-1}\pi_{t+1} + \hat{\mu}_t \tag{9}$$

which are the model implied aggregate demand and supply equations under rational expectations.[8] The weight $\lambda_x > 0$ determines the relative priority given to output gap stabilization. A second order accurate approximation to household welfare in this model can be shown to imply a specific value for λ_x. Because this is not central to our conclusions, and because this more general notation permits indexing a broader class of policy rules, we adopt this objective function unless otherwise noted.

[8] These expressions follow directly from (6) and (7) on noting that $\hat{E}_t$ satisfies the law of iterated expectations under the assumption of rational expectations — households and firms know the objectives, beliefs and constraints of other agents and can therefore determine aggregate probability laws in equilibrium.

The first order condition under optimal discretion is

$$E_{t-1}\pi_t = -\frac{\lambda_x}{\xi} E_{t-1} x_t. \tag{10}$$

Hence optimal policy dictates interest rates to be adjusted so that predictable movements in inflation are negatively related to those in the output gap.[9] This targeting rule combined with the structural relations (8) and (9) can be shown to determine the rational expectations equilibrium paths $\{i_t^*,\ \pi_t^*,\ x_t^*\}$ as linear functions of the exogenous state variables $\left\{r_{t-1}^e,\ \hat{\mu}_{t-1}\right\}$. Without loss of generality, and to make the analysis as simple and transparent as possible, we assume that the exogenous processes are determined by

$$\begin{aligned} r_t^e &= \rho_r r_{t-1}^e + \varepsilon_t^r \\ \hat{\mu}_t &= \rho_\mu \hat{\mu}_{t-1} + \varepsilon_t^\mu \end{aligned}$$

where $0 < \rho_r,\ \rho_\mu < 1$ and $(\varepsilon_t^r,\ \varepsilon_t^\mu)$ are independently and identically distributed random variables, with autoregressive coefficients known to households and firms.[10] Under these assumptions

$$i_t^* = \rho_r r_{t-1}^e + \frac{\rho_\mu \lambda_x + (1-\rho_\mu)\xi}{\xi^2 + \lambda_x(1-\beta\rho_\mu)} \rho_\mu \hat{\mu}_{t-1}$$

delineates the desired state contingent evolution of nominal interest rates required to implement the optimal equilibrium.

Following Svensson and Woodford (2005), rather than adopting the targeting rule (10) directly as the policy rule, we instead assume the central bank implements policy according to the nominal interest rate rule

$$i_t = i_t^* + \phi\left(\hat{E}_{t-1}\pi_t + \frac{\lambda_x}{\xi}\hat{E}_{t-1}x_t\right) \tag{11}$$

where $\phi > 0$. The central bank is assumed to observe private forecasts — through survey data — or to have an identical internal forecasting model. This rule has the property that if beliefs converge to the underlying rational expectations equilibrium then it is consistent

[9] Policies under optimal commitment could similarly be analyzed without substantial differences in the conclusions of this paper. However, because such policies introduce history dependence, analytical conditions are somewhat problematic and we therefore take the case of discretion for convenience.

[10] This assumption is innocuous and readily generalized.

with implementing optimal policy under a rational expectations equilibrium. This follows immediately from observing in this case that

$$\hat{E}_{t-1}\pi_t + \frac{\lambda_x}{\xi}\hat{E}_{t-1}x_t = 0$$

which in turn implies $i_t = i_t^*$ as required for optimality under rational expectations. Note also that it nests an expectations based Taylor rule as a special case, albeit with a stochastic constant.[11]

3 Learning and Central bank Communication

This section describes the agents' learning behavior and the criterion to assess convergence of beliefs. Agents do not know the true structure of the economic model determining aggregate variables. To forecast state variables relevant to their decision problems, though beyond their control, agents make use of atheoretical regression models. The regression model is assumed to contain the set of variables that appear in the minimum state variable rational expectations solution to the model. Each period, as additional data becomes available, agents re-estimate the coefficients of their parametric model.

An immediate implication is that model dynamics are self-referential: the evolution of firm and household beliefs influence the realizations of observed macroeconomic variables. Learning induces time variation in the data generating process describing inflation, output and nominal interest rates. The central technical question concerns the conditions under which beliefs converge to those that would obtain in the model under rational expectations, in which case the data generating process characterizing the evolution of macroeconomic variables is time invariant. Convergence is assessed using the notion of expectational stability outlined in Evans and Honkapohja (2001).

A more fundamental implication of this self-referential property is that it permits analyzing the role of communication in stabilizing expectations. In a rational expectations analysis, expectations are pinned down by construction of the equilibrium. By analyzing a model that

[11] The stochastic constant is largely irrelevant to the stability analysis under learning dynamics. Also, if the assumption of discretionary optimization is unappealing, then a rule of this form with appropriately defined stochastic constant can implement the optimal equilibrium under commitment. See Preston (2006) for details.

permits small deviations in beliefs — which imply uncertainty about the statistical processes characterizing the evolution of prices — from this traditional benchmark, the value of certain types of information regarding the monetary policy process in stabilizing expectations can be clearly and fruitfully evaluated.

3.1 Forecasting

This section outlines the beliefs of agents in our benchmark analysis in the case of no communication. As additional information is communicated to households and firms, the structure of beliefs will change accordingly. These modifications will be noted as they arise, with an illustrative example given below. The agents' estimated model at date $t-1$ can be expressed as

$$Z_t = \begin{bmatrix} x_t \\ \pi_t \\ i_t \\ \hat{\mu}_t \\ \hat{r}_t^e \end{bmatrix} = \omega_{0,t-1} + \omega_{1,t-1} Z_{t-1} + \bar{e}_t \tag{12}$$

where ω_0 denotes the constant, ω_1 is defined as

$$\omega_1 = \begin{bmatrix} \omega_{xx} & \omega_{x\pi} & \omega_{xi} & \omega_{xu} & \omega_{xr} \\ \omega_{\pi x} & \omega_{\pi\pi} & \omega_{\pi i} & \omega_{\pi u} & \omega_{\pi u} \\ \omega_{ix} & \omega_{i\pi} & \omega_{ii} & \omega_{iu} & \omega_{iu} \\ 0 & 0 & 0 & \rho_u & 0 \\ 0 & 0 & 0 & 0 & \rho_r \end{bmatrix}$$

and $\bar{e}_t$ represents an i.i.d. estimation error. Agents are assumed to know the autocorrelation coefficients of the shocks but estimate the other parameters (with time subscripts being dropped for convenience). Hence they are attempting to learn the average value of observed macroeconomic data and also a set of slope coefficients describing the reduced form relationship between these macroeconomic objects and fundamental disturbances to the economy.

This paper models communication as information about the dynamics of nominal interest rates. As an example of communication, suppose the central bank credibly announces that monetary policy will be conducted so that inflation, output and nominal interest rates will on average be zero in deviations from steady state. Then the model implication is that agents know this with certainty and impose this restriction on their regression model. Hence $\omega_{0,t-1} = 0$ and agents need only learn a subset of coefficients relevant to the reduced form dynamics of macroeconomic aggregates. This captures well the idea that communicating characteristics of the monetary policy strategy is an attempt to manage the evolution of expectations.

At the end of period $t-1$ agents form their forecast about the future evolution of the macroeconomic variables given their current beliefs about reduced form dynamics. Given the vector Z_{t-1}, expectations $T+1$ periods ahead are calculated as

$$\hat{E}_{t-1} Z_{T+1} = \left(I_5 - \omega_{1,t-1}\right)^{-1} \left(I_5 - \omega_{1,t-1}^{T-t+2}\right) \omega_{0,t-1} + \omega_{1,t-1}^{T-t+2} Z_{t-1}$$

for each $T > t-1$ and I_5 is a (5×5) identity matrix. To evaluate expectations in the optimal decision rules of households and firms, note that the discounted infinite-horizon forecasts are

$$\hat{E}_{t-1} \sum_{T=t}^{\infty} \beta^{T-t} Z_{T+1} = \hat{E}_{t-1} \sum_{T=t}^{\infty} \beta^{T-t} \left[\left(I_5 - \omega_{1,t-1}\right)^{-1} \left(I_5 - \omega_{1,t-1}^{T-t+2}\right) \omega_{0,t-1}\right]$$
$$+ \hat{E}_{t-1} \sum_{T=t}^{\infty} \beta^{T-t} \left[\omega_{1,t-1}^{T-t+2} Z_{t-1}\right].$$

This expression can be compactly written as

$$\hat{E}_{t-1} \sum_{T=t}^{\infty} \beta^{T-t} Z_{T+1} = F_0\left(\omega_{0,t-1}, \omega_{1,t-1}\right) + F_1\left(\omega_{1,t-1}\right) Z_{t-1},$$

where

$$\begin{aligned} F_0\left(\omega_{0,t-1}, \omega_1\right) &= \left(I_5 - \omega_{1,t-1}\right)^{-1} \left[(1-\beta)^{-1} I_5 - \omega_{1,t-1}^2 \left(I_5 - \beta\omega_{1,t-1}\right)^{-1}\right] \omega_{0,t-1} \\ F_1\left(\omega_1\right) &= \omega_{1,t-1}^2 \left(I_5 - \beta\omega_{1,t-1}\right)^{-1} \end{aligned}$$

are, respectively, a (5×1) vector and (5×5) matrix.

3.2 Expectational Stability

Substituting for the expectations in the equations for the output gap, inflation and the nominal interest rate, permits writing aggregate dynamics of the economy as

$$Z_t = \Gamma_0\left(\omega_{0,t-1}, \omega_{1,t-1}\right) + \Gamma_1\left(\omega_{1,t-1}\right) Z_{t-1} \tag{13}$$

with obvious notation. This expression captures the dependency of observed dynamics on agents' beliefs about the future evolution of the economy. Moreover, it implicitly defines the mapping between agents' beliefs and the actual coefficients describing observed dynamics as

$$T\left(\omega_{0,t-1},\ \omega_{1,t-1}\right)=\left(\Gamma_0\left(\omega_{0,t-1},\omega_{1,t-1}\right),\ \Gamma_1\left(\omega_{1,t-1}\right)\right).$$

A rational expectations equilibrium is a fixed point of this mapping. For such rational expectations equilibria we are interested in asking under what conditions does an economy with learning dynamics converge to each equilibrium. Using stochastic approximation methods, Marcet and Sargent (1989b) and Evans and Honkapohja (2001) show that conditions for convergence are characterized by the local stability properties of the associated ordinary differential equation

$$\frac{d\left(\omega_0,\omega_1\right)}{d\tau}=T\left(\omega_0,\omega_1\right)-\left(\omega_0,\omega_1\right), \tag{14}$$

where τ denotes notional time. The rational expectations equilibrium is said to be expectationally stable, or E-Stable, when agents use recursive least squares if and only if this differential equation is locally stable in the neighborhood of the rational expectations equilibrium.[12]

4 Main Findings

This section provides the core theoretical results of the paper. The model properties under both rational expectations and learning dynamics without communication are stated. The analysis of various communication strategies in the implementation of monetary policy is then explored.

4.1 Benchmark Properties

To ground the analysis, and provide a well known comparative benchmark, the stability properties of the model under rational expectations can be summarized as follows.

[12] Standard results for ordinary differential equations imply that a fixed point is locally asymptotically stable if all eigenvalues of the Jacobian matrix $D\left[T\left(\omega_0,\omega_1\right)-\left(\omega_0,\omega_1\right)\right]$ have negative real parts (where D denotes the differentiation operator and the Jacobian understood to be evaluated at the relevant rational expectations equilibrium).

Proposition 1 *Under rational expectations, the model given by equations (7), (6) and (11) has a unique bounded solution if* $\phi > 1$.

This is an example of the Taylor principle. If nominal interest rates are adjusted sufficiently to ensure appropriate variation in the real rate of interest, then expectations are well anchored. This feature along with other robustness properties noted by Levin, Wieland, and Williams (2003) and Batini and Haldane (1999) have lead to advocacy of forecast-based instrument rules for the implementation of monetary policy. See also Clarida, Gali and Gertler (1998, 2000) which adduce empirical evidence for such interest rate reaction functions. In contradistinction, under learning dynamics the model has strikingly different predictions for the evolution of household and firm expectations.

Proposition 2 *Consider the economy under learning dynamics where the central bank does not communicate the policy rule.*

(i) The REE is unstable under learning provided

$$(1+\phi)\xi > \phi(1-\beta)\frac{\lambda_x}{\xi} + \psi(\beta)$$

where $\psi(\beta) > 0$, $\lim_{\beta\to 1}\psi(\beta) = 0$ *and* $\lim_{\beta\to 0}\psi(\beta) = \infty$. *Hence:*

(ii) If $\beta \to 1$, *then the REE is unstable under learning for every* ξ *and* ϕ.

(iii) IF $\beta \to 0$, *then the REE is stable under learning for every* ξ *and* ϕ.

For many reasonable parameter values, the optimal policy under rational expectations cannot be implemented with learning and no communication, rendering the economy prone to self-fulfilling expectations. Indeed, standard parameterizations invariably take the household's discount rate to be near unity. In the limit $\beta \to 1$ instability occurs for all parameter values underscoring the importance of stabilizing long-term expectations. Conversely, as β becomes small, $\psi(\beta)$ becomes unboundedly large, guaranteeing stability of the equilibrium. Intuitively, as β increases the future becomes more important in agents' consumption plans and a correct prediction of the future path of the nominal interest rate, together with predictions about the output gap and inflation, becomes crucial for stability. This result underscores the importance of modelling the dependence of agents' decisions on expectations about macroeconomic conditions over the entire decision horizon.

It is the interaction of policy delays and learning dynamics that leads to instability. Consider a sudden increase in inflation expectations. This initially engenders higher output and inflation. The central bank's policy response occurs with a delay because it has imperfect information about the state of the economy. Because of learning dynamics, when an increase in the nominal interest rate does occur, it fails to curb the initial increase in expected and actual inflation. Private agents fail to correctly anticipate the future policy stance so that the initial increase in the policy instrument has limited effect on aggregate activity, in turn validating initial beliefs. Section 5 further explores the dynamics of belief formation under various assumptions about the degree of communication.

Two additional points are worth noting. First, under reasonable parameterizations an increase in ϕ renders the equilibrium less stable — for example if $\xi > (1 - \beta)$ and $\lambda_x < 1$. Moreover, a central bank that does not communicate has incentives to be less aggressive to inflation and more to output. As an example, a policy rule with $\phi < 1$ and λ_x sufficiently high will yield stability under learning. Why is λ_x important for expectations stabilization? Recall that prices depend on the expected sequence of output gaps into the indefinite future. As output gap expectations increase prices move accordingly affecting *future* inflation expectations. Thus the expected output gap becomes a better indicator of future inflation expectations. By responding to expected output gap the central bank can 'move ahead' of inflation expectations, preventing instability. The drawback of this policy choice is that values of λ_x that help preventing self-fulfilling expectation do not necessarily coincide with the central bank preferences for inflation and output-gap stabilization.

Second, and related, the observation that policies giving greater weight to output gap stabilization are less likely to be prone to instability has relevance for recent debate on the merits of simple policy rules. For example, Schmitt-Grohe and Uribe (2005) demonstrate in a medium-scale model of the kind developed by Smets and Wouters (2002), that optimal monetary policy can be well approximated by a simple nominal interest rate rule that responds to contemporaneous observations of inflation. Moreover, policies that respond to the output gap are undesirable, since over-estimating the optimal elasticity by even small amounts can lead to a sharp deterioration in household welfare. What the above result demonstrates is that, in a world characterized by small departures from rational expectations, the policymaker may face a trade-off: strong responses to the output gap may reduce welfare, but they may protect against even more deleterious consequences from self-fulfilling expectations.

This finding contrasts with Ferrero (2004) and Orphanides and Williams (2005) which argue that under learning policy should be more aggressive in response to inflation. The difference in conclusion stems from the central bank's knowledge of the state of the economy. In the present analysis, the central bank has imperfect information about the current state and may therefore have reason to be cautious.

4.2 Eliminating Policy Delays

This striking instability result naturally raises the question of how can expectations be managed more effectively in the pursuit of macroeconomic stabilization. The model has two key information frictions. First, the central bank responds to information about the true state of the economy with a delay. This is an implication of the forecast-based monetary policy rule. Second, households and firms have an incomplete model of the macroeconomy and need to learn about the reduced-form dynamics of aggregate prices. It follows that agents are faced with statistical uncertainty about the true data generating process describing the evolution of nominal interest rates. Resolving these informational frictions may mitigate expectations driven instability.

In regards to the policymaker's uncertainty, suppose the central bank has perfect information about current inflation and the output gap. It can then implement the policy rule

$$i_t = i_t^* + \phi \left(\pi_t + \frac{\lambda_x}{\xi} x_t \right) \tag{15}$$

which is closer in spirit to the policy proposed by Taylor (1993). The following result obtains.

Proposition 3 *Consider the economy under learning dynamics. If the central bank implements monetary policy with the rule (15) without communication then $\phi > 1$ is sufficient for stability.*

Hence timely information about the state of the economy is invaluable to expectations stabilization. By responding to contemporaneous observations of the inflation rate and the output gap the Taylor principle is restored. Having perfect information about the aggregate state reduces the delay in the adjustment of monetary policy, allowing the central bank to anticipate shifts in expectations. Responding to changes in inflation in a timely fashion prevents large deviations from the rational expectations equilibrium. Comparing this result to proposition 2 underscores that instability stems from the interaction between the two sources of information frictions in the model. Given that central banks are unlikely in practice to have complete information about the current state of the economy, it is worth considering other approaches to effective management of expectations. The remainder of the paper therefore explores the role of communication.

4.3 The Value of Communication

Communication is modelled in a very direct and simple way. Under learning dynamics, households and firms are uncertain about the true data generating process characterizing the future path of nominal interest rates, the output gap and inflation. We can therefore ask what kinds of information about the monetary policy strategy assist in reducing the forecast uncertainty that emerges from having a misspecified model. Hence the developed framework permits a direct analysis of the benefits of communication in managing expectations.

Three communication strategies are considered. First, the central bank announces the precise details of its monetary policy, including both the variables upon which interest rate decisions are conditioned and all relevant policy coefficients. Second, the central bank communicates only the variables upon which policy decisions are conditioned. Third, the central bank communicates its inflation target. These strategies successively reduce the information made available to the public and therefore provide insight as to what kinds of information are conducive to macroeconomic stabilization.

4.3.1 Strategy 1

This communication strategy discloses all details of the monetary policy decision process. The central bank announces the precise reaction function used to determine the nominal interest rate path as a function of expectations. Agents therefore know which variables appear in the policy rule and its coefficients. Hence, agents need not forecast the nominal interest rate independently — they need only forecast the set of variables upon which nominal interest rates depend. An alternative, but equivalent strategy, is the central bank announces in every policy cycle t its conditional forecast path for the nominal interest rate, $\{E_{t-1}i_T\}_{T\geq t}$. Such a communication strategy might arguably characterize current practice by the Norges Bank and the Reserve Bank of New Zealand — see Norges Bank (2006). These forecasts can be used directly by the private sector in making spending and pricing decisions. Since they are by construction consistent with the adopted policy rule, if agents base decisions directly on these announced forecasts, it must be equivalent to households and firms knowing the policy rule and constructing the forecast path of nominal interest rates independently, subject to the caveats now noted.

To keep the analysis as simple as possible, we assume that the private sector and the central bank share the same expectations about the future evolution of the economy. This assumption is dispensable. Analyzing a model in which the central bank communicates its reaction function but in which there is disagreement about the forecasts is feasible though beyond the scope of this paper. See Honkapohja and Mitra (2005) for an analysis of a New Keynesian model in which only one period ahead forecasts matter and conditions under which heterogeneous forecasts deliver the same stability results.[13]

Regardless of how this communication strategy is implemented, we assume that the central bank is perfectly credible, in the sense that the public fully incorporates announced information in their forecasts without verification. Issues related to cheap talk, as analyzed by Stein (1989) and Moscarini (forthcoming) for example, are not considered. We assume the central bank is able to fully communicate its reaction function without noise so the market fully understands its policy goals and strategy, both in the current period and into the indefinite future.

Imposing knowledge of the policy rule on households' and firms' forecasting models — or knowledge of the central bank's conditional forecast path $\{E_{t-1}i_T\}_{T\geq t}$ — is equivalent to

[13] This paper, however, does not study a model which requires agents to forecast nominal interest rates.

substituting this equilibrium restriction into the aggregate demand equation to give

$$x_t = \hat{E}_{t-1} \sum_{T=t}^{\infty} \beta^{T-t} \left[(1-\beta) x_T + \beta \hat{r}_t^e - \beta\sigma(i_T^* + \phi\pi_T + \phi\frac{\lambda}{\xi}x_T - \pi_{T+1}) \right].$$

The remaining model equations are unchanged with the exception of beliefs. Since nominal interest rates need not be forecast, an agent's vector autoregression model is estimated on the modified state vector

$$Z_t = \begin{bmatrix} x_t \\ \pi_t \\ \hat{\mu}_t \\ \hat{r}_t^e \end{bmatrix}.$$

Under these assumptions, uncertainty about the model concerns only the laws of motion for inflation and output, which are affected by other factors of the model beyond monetary policy decisions. Hence perfect knowledge about the central bank's policy framework does not guarantee that market participants fully understand the true model of the economy, since agents continue to face uncertainty about the objectives and constraints of other households and firms in the economy. However, it does tighten the connection between the projected paths for inflation and nominal interest rates. This property proves fundamental.

Proposition 4 *Assume the bank communicates under perfect credibility the interest rate forecast* $\left\{E_{t-1}^{CB} i_T\right\}_{T=t}^{\infty}$ *or, equivalently, the policy rule (11). Then the REE is stable if* $\phi > 1$.

Communication of the policy rule completely mitigates instability under learning dynamics — even though the central bank and the private sector have incomplete information about the state of the economy. The result shows how communicating the reaction function helps shape beliefs about future policy, making it possible for agents to anticipate future policy. As an example, suppose inflation expectations increase. Under full communication, agents' conditional forecasts of inflation and nominal interest rates are coordinated according to (11). Agents therefore correctly anticipate that higher inflation leads to a higher path for nominal interest rates — one that is sufficient to raise the projected path of the real interest rate. As a result, output decreases, leading to a decrease in inflation, which in turn mitigates the initial increase in expectations, leading the economy back to equilibrium. In absence of communication, an agents' conditional forecasts for nominal interest rates and inflation give rise to projected falls in future real interest rates, generating instability. Section 5 discusses further intuition of how communication stabilizes expectations.

4.3.2 Strategy 2

Now suppose the central bank only announces the set of variables relevant to monetary policy deliberations so that agents do not know the precise restriction that holds between nominal interest rates, inflation and the output gap. Furthermore, suppose that while agents do not know the policy coefficients, they do know that nominal interest rates are set according to a linear function of these variables. By limiting knowledge of private agents about the monetary policy process relative to the benchmark full-information analysis several aspects of central bank communication can be captured. First, uncertainty about parameters and forecasts can be interpreted as a constraint on the communication ability of the central bank. This reflects the fact that the policy decision is the outcome of a complex process, the details of which are often too costly to communicate.[14] Second, the central bank might face credibility issues, leading the private sector to want to verify announced policies. Third, complete announcement might not be the optimal choice for the central bank, given the agent's learning process.[15]

This partial information about the policy process can be incorporated by households and firms in the following two-step forecasting model. First, using the history of available data, agents run a regression of nominal interest rates on expected inflation and the output gap

$$i_t = \psi_{0,t-1} + \psi_{\pi,t-1}\hat{E}_{t-1}\pi_t + \psi_{x,t-1}\hat{E}_{t-1}x_t + e_t.$$

This yields estimates of the coefficients of the policy rule.[16] Notice that, as shown in the appendix, we consider the more general case where the regression is estimate using a recursive instrumental variable method, allowing for the possibility that private sector and central bank forecasts are different or that the central bank can communicate its expectations with noise.

[14] See Mishkin (2004).

[15] A discussion of the optimal policy under learning is left for further research.

[16] There is an important subtlety in specifying this regression. We assume that private agents include a fixed constant and do not explicitly allow for a stochastic constant as in (11). This avoids multicollinearity problems in the case of convergent learning dynamics, given the presence of only two shocks.

As a second step, given these estimates, agents proceed in the same manner as strategy 1: they forecast the future paths of the output gap and inflation rate and then use the estimated policy rule to construct a set of nominal interest rate forecasts.

Proposition 5 *If households and firms understand the variables upon which nominal interest rate decisions are conditioned, then the REE is stable under learning if* $\phi > 1$*.*

Thus the central bank need not disclose all details of the monetary policy strategy. It is sufficient that information be given regarding the endogenous variables relevant to the determination of policy and the functional form of the rule — but not its parameterization. Credible public pronouncements of this kind, combined with a sufficient history of data, provide agents with adequate information to verify the implemented rule. And despite the estimation uncertainty attached to the policy coefficients, local to the rational expectations equilibrium of interest, expectations are nonetheless well anchored relative to the no communication case. Indeed, this communication strategy is equally useful in protecting against instability from expectations formation as strategy 1 in which agents know the true policy coefficients. Of course, the out-of-equilibrium dynamics would differ across these two strategies — the estimation uncertainty being relevant to the true data generating process of macroeconomic variables — which in turn has welfare implications. Analyzing such implications is beyond the scope of this paper.

4.3.3 Strategy 3

Over the past two decades numerous countries have adopted inflation targeting as a framework for implementing monetary policy. A central part of this monetary policy strategy has been the clear articulation of a numerical target for inflation. As a final exercise, we consider a communication strategy that conveys not only the desired average outcome for inflation — that is the inflation target — but also the associated values for nominal interest rates and the output gap. Given that our analysis is in deviations from steady state, these three values are clearly zero. As discussed in section 3, given this knowledge agents no longer need to estimate a constant in their regression model, leading to more accurate forecasts of the future path of nominal interest rates.

Proposition 6 *Assume the central bank communicates only the inflation target $\pi^* = 0$ and the associated values for the output gap and nominal interest rates, $x^* = i^* = 0$.*

1. *Define $\rho = \max(\rho_u, \rho_r)$ and let $\rho \to 1$. Then the REE is unstable under learning if (17) holds;*
2. *Let $\beta \to 1$. Then the REE is unstable under learning if*

$$\xi(\phi + 2\rho) > 2\frac{\phi\lambda}{\xi}(1-\rho) + \tilde{\psi}(\rho), \tag{16}$$

   where $\tilde{\psi}(\rho) > 0$, $\tilde{\psi}(1) = 0$.

Economies subject to persistent shocks may be prone to expectations driven instability. Indeed, the stability conditions for the no communication case obtain for cost-push or efficient rate disturbance processes having roots near unity. This result nicely demonstrates a fundamental insight of rational expectations analysis: it is not enough to announce an inflation target — one must also announce how one will achieve this target. Only by providing information regarding the systematic component of monetary policy can expectations be effectively managed.

To further interpret this condition a graphical analysis is useful. The model is calibrated with $\beta = 0.99$, $\theta = 10$ and $\phi = 2$. Figure 1 plots three contours demarcating stability and instability regions, below and above respectively, as functions of the parameters $(\xi,\ \lambda_x)$. Each contour is indexed by the maximum autoregressive coefficient in the two disturbance processes. Finally, the dashed line indicates the weight on output gap stabilization that is optimal from a welfare theoretic perspective. It is immediate that as the maximum eigenvalue increases the set of parameter values for which expectations are stabilized considerably narrows. For a given degree of price stickiness, as the persistence in exogenous disturbance rises a much stronger response to the output gap is required. An implication is that the optimal policy may not be implementable if the policy maker is concerned with prohibiting self-fulfilling expectations. Similarly, for a given weight on output gap stabilization, only in economies with less flexible prices does learnability of rational expectations equilibrium obtain. Hence, the degree of nominal rigidity in price setting has important implications for stabilization policy under learning dynamics. Economies with greater rigidity tend to be conducive to expectations

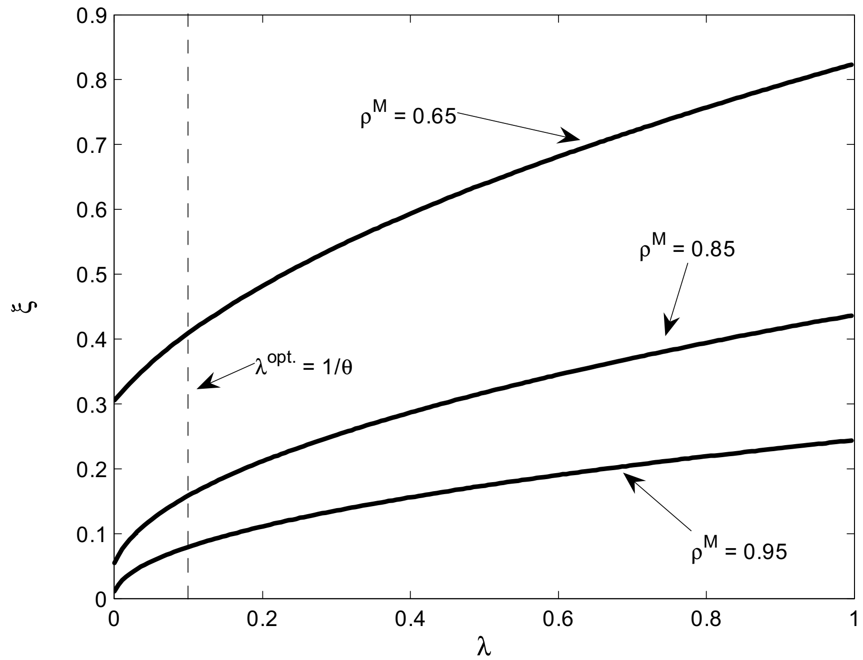

Figure 1: Announcing the target is not enough

stabilization. Because prices move little, agents are better able to forecast future economic conditions, in turn promoting macroeconomic stability. This is not a property of the model under rational expectations: expectations are well anchored so long as the Taylor principle is satisfied, regardless of the degree of nominal friction. See Eusepi and Preston (2007) for a more thorough treatment of this matter. They show that this dependency is a property of a broader class of models with Ricardian fiscal policy, with the converse dependency being true of some models with non-Ricardian fiscal policy.

5 The Dynamics of Expectations

To close our discussion of the role of communication in expectations stabilization we pursue an analysis of the dynamics of expectations formation under communication strategies 1 and 3. Consider first the strategy in which the central bank announces the inflation target $\pi^* = 0$. Furthermore, suppose that exogenous disturbances have sufficiently weak serial correlation so that monetary policy induces local stability under learning — the case of nonconvergence in learning dynamics being clearly undesirable for macroeconomic stabilization. The following demonstrates that in this case, the transitional dynamics of agents' beliefs, despite convergence to rational expectations equilibrium, exhibit substantially greater fluctuations than under the full communication strategy.

To characterized beliefs, we study the associated ordinary differential equation of the E-Stability mapping. Figure 2 plots the local dynamics of the agents' estimates of $\omega_{\pi,r}$ and $\omega_{i,r}$ — the estimated slope coefficients on the efficient rate disturbance. Given a sufficiently large sample of data, the evolution of these belief coefficients are arbitrarily well described by the linear ordinary differential equation

$$\dot{\omega}_1 = (J^* - I_3)\,\omega_1$$

where

$$\omega_1 = \begin{pmatrix} \omega_{xr} & \omega_{\pi r} & \omega_{ir} \end{pmatrix}'.$$

This represents the first order dynamics of the ODE (14) whose eigenvalues determine E-Stability properties. The economy is initially in the deterministic steady state (with no shocks occurring in the simulation). We then perturb the beliefs of private agents, making the initial estimate of the inflation coefficient, $\omega_{\pi r}$, higher than its rational expectations value. This can be interpreted as an increase in inflation expectations or equivalently an expectational error on the part of agents.

Figure 2 shows that after the increase in inflation expectations, the expected interest rate increases, albeit gradually. This reflects the fact that market participants cannot correctly anticipate the response of the central bank to the increase in inflation expectations. The gradual increase in the expected interest rate follows from observing the increase in the actual interest rate. Of particular interest is the oscillatory adjustment in beliefs. As agents update their beliefs in response to the initial expectational error, expectations about nominal interest rates exhibit a cyclical pattern.

Figure 3 shows the response of the nominal interest rate to the increase in inflation expectations. The interest rate increases gradually after the rise in inflation expectations, but it fails to have a strong initial impact on inflation expectations because of the absence of

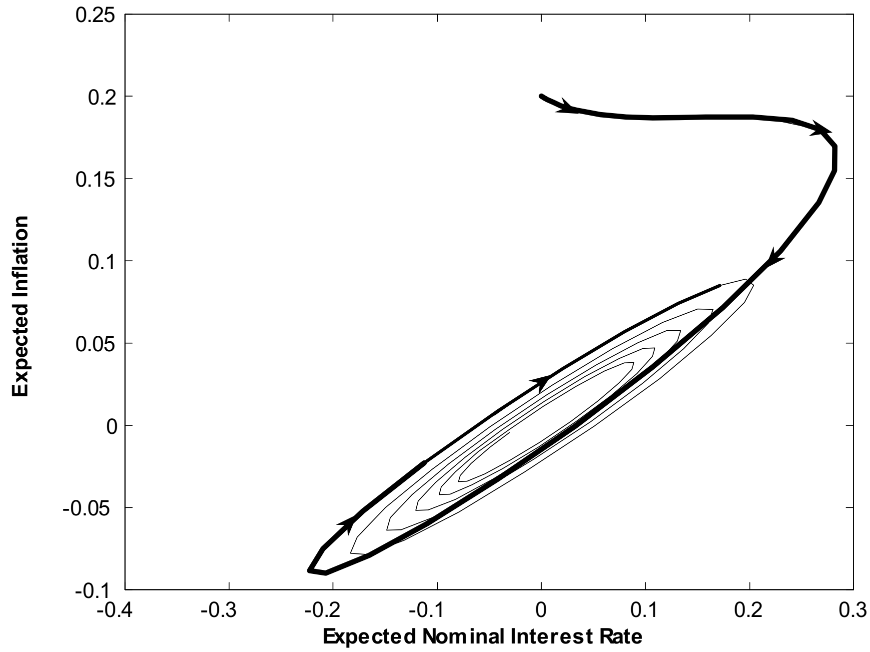

Figure 2: Expectation Dynamics

communication: market participants fail to anticipate correctly the future path of the policy instrument.

Given the weak initial effect on inflation, and therefore on inflation expectations, the central bank keeps increasing the nominal interest rate until inflation expectations start declining. As the response of inflation expectations is inertial, the central bank tends to overtighten. Hence inflation expectations, and as a consequence inflation, keep decreasing until they become negative, overshooting their rational expectations equilibrium values. With low interest rates and low inflation expectations a new cycle starts. The central bank eases its policy stance but expectations react with a delay, leading to excessively low nominal interest rates and high inflation expectations. Agents' beliefs eventually converge though the speed of convergence depends on the chosen parameters.

Now consider an identical analysis under full communication where market participants understand the policy rule and can correctly forecast the future path of the policy instrument. Figure 4 shows that expected inflation and the expected interest rate rise and fall together

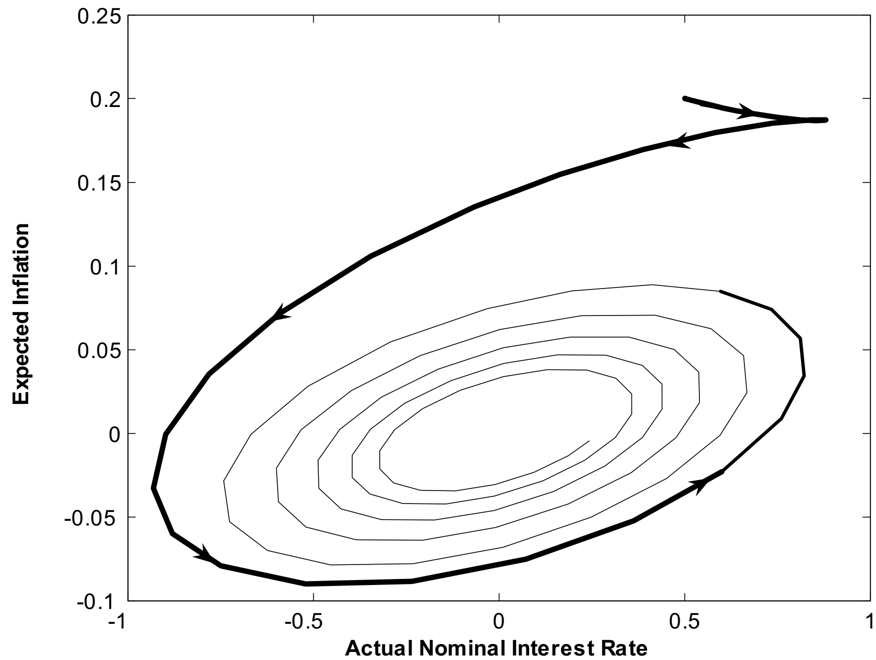

Figure 3: Responding to Expected Inflation

until they converge back to the equilibrium. There is no overshooting. This is explained by market participants correctly anticipating that the interest rate will be higher in the future in response to higher inflation expectations. The anticipated positive response of the nominal interest rate increases the expected real interest rate with a reduction in output that further reduces inflation expectations. Notice also that the increase in the actual interest rate is lower than the case of no communication. Moreover, convergence in beliefs is monotonic — there are no oscillatory dynamics in expectations. This underscores that managing expectations, even in the case of stability under learning dynamics, has stabilization benefits. This is one of the central contributions of Orphanides and Williams (2005), though in the context of a reduced form model of the macroeconomy.

The central bank can bring about inflation stabilization without excessive volatility of the policy instrument by fully articulating its monetary policy strategy. In the case of no communication, the central bank is more likely to over-react to changing economic conditions with the result of excessively volatile interest rates and potentially destabilizing effects on

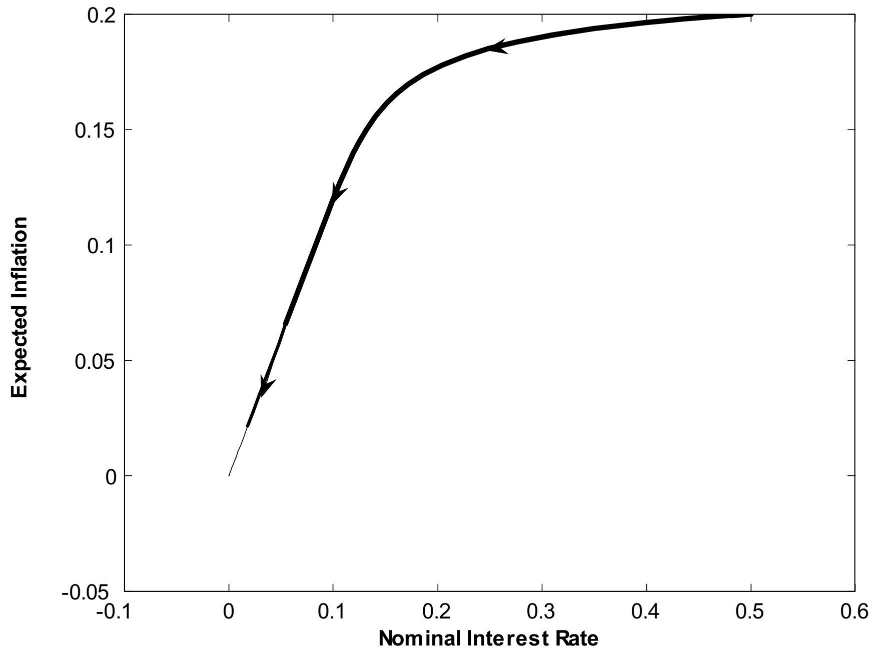

Figure 4: The Benefits of Communication

expectations.

6 Conclusion

This paper develops a dynamic stochastic general equilibrium model for the analysis of the role of communication in a central bank's monetary policy strategy. Three communication strategies are considered when the central bank attempts to implement optimal policy. First, the central bank announces the exact details of its monetary policy decision process. This includes both the variables appearing in its policy rule and the relevant policy coefficients. Second, the central bank discloses only the variables appearing in the policy rule. This limits the information households and firms have relative to the full information case, possibly reflecting imperfect credibility of central bank announcements. Third, the central bank announces only its desired inflation target and associated long-run values of the output gap and nominal interest rates.

The central results are as follows. Under no communication the policy rule fails to stabilize macroeconomic dynamics, promoting expectations driven fluctuations — self-fulfilling expectations are possible. However, by announcing the details of the policy process stability is restored. Communication permits households and firms to construct more accurate forecasts of future macroeconomic conditions, engendering greater stability in observed output, inflation and nominal interest rates.

If instead the central bank only discloses the variables upon which interest rate decisions are condition, stability still obtains for all parameter values. Even though this communication strategy imparts less information about the policy process relative to the full communication case, the resulting estimation uncertainty is small. Hence, agents once again can make more accurate forecasts which is conducive to macroeconomic stabilization.

Finally, if the central bank only announces the desired inflation target, economies with persistent shocks will frequently be prone to expectations driven fluctuations. This makes clear that it is not sufficient to announce desired objectives — one must also announce the systematic component of policy which describes how these objective will be achieved.

A Appendix

A.1 Propositions and Proofs

Proposition 2: Under no communication, the REE is unstable under learning if

$$(1+\phi)\xi > \phi(1-\beta)\frac{\lambda}{\xi} + \psi(\beta) \tag{17}$$

where $\psi(\beta) > 0, \psi(1) = 0$.

Proof: The ODE (14) evaluated at the rational expectations equilibrium, can be decomposed in four independent sub-systems. The first includes the three constant terms,

$$\dot{\omega}_0 = \left(J_{\omega_0^*} - I_3\right)\omega_0 \tag{18}$$

where $J_{\omega_0^*}$ contains a sub-matrix of the Jacobian, evaluated at the REE equilibrium. The second and the third include the coefficients to the exogenous shocks,

$$\dot{\omega}_u = \left(J_{\omega_u^*} - I_3\right)\omega_u \tag{19}$$

where $\omega_u = \begin{pmatrix} \omega_{xu} & \omega_{\pi u} & \omega_{iu} \end{pmatrix}'$ and

$$\dot{\omega}_r = \left(J_{\omega_r^*} - I_3\right)\omega_r \tag{20}$$

where $\omega_r = \begin{pmatrix} \omega_{xr} & \omega_{\pi r} & \omega_{ir} \end{pmatrix}'$. Finally, the fourth includes the coefficients on the endogenous variables

$$vec\left(\dot{\omega}_e\right) = \left(J_{\omega_e^*} - I_9\right) vec\left(\omega_e\right), \tag{21}$$

where

$$\omega_e = \begin{pmatrix} \omega_{xx} & \omega_{x\pi} & \omega_{xi} \\ \omega_{\pi x} & \omega_{\pi\pi} & \omega_{\pi i} \\ \omega_{\pi x} & \omega_{\pi\pi} & \omega_{\pi i} \end{pmatrix}.$$

In order to show the instability result, it is sufficient to evaluate the real parts of the eigenvalues of the matrix $\left(J_{\omega_0^*} - I_3\right)$. Necessary conditions for stability under learning are

$$\text{Trace}\left(J_{\omega_0^*} - I_3\right) < 0 \tag{22}$$

$$\text{Determinant}\left(J_{\omega_0^*} - I_3\right) > 0 \tag{23}$$

and

$$-\text{Sm}\left(J_{\omega_0^*}-I_3\right)*\text{Trace}\left(J_{\omega_0^*}-I_3\right)+\text{Determinant}\left(J_{\omega_0^*}-I_3\right)>0, \tag{24}$$

where Sm denotes the sum of all principle minors of $\left(J_{\omega_0^*}-I_3\right)$. The trace can be calculated as

$$-\xi-\frac{\beta\phi\lambda}{1-\beta}<0$$

while the determinants is

$$(\beta-1)^{-2}\left[\xi\left(\phi-1\right)+\left(1-\beta\right)\frac{\phi\lambda}{\xi}\right]$$

which is positive under the assumption $\phi>1$.

Evaluating (24) provides

$$\frac{2-4\beta+2\beta^2+\beta\left(-\xi+\left(1-\beta\right)\phi\frac{\lambda}{\xi}-\xi\phi\right)}{(1-\beta)^2}$$

which is *negative* provided

$$(1+\phi)\xi>\phi(1-\beta)\frac{\lambda}{\xi}+\psi\left(\beta\right)$$

where $\psi\left(\beta\right)=\beta^{-1}\left(2-4\beta+2\beta^2\right)$.

Proposition 3: Assume that the central bank has perfect information about inflation and output gap. Then the REE is stable under learning for all parameter values, independently of central bank communication.

Proof: The proof follows the logic of Proposition 2. The only condition affected by the change in policy rule is (24). For the evolution of the constant terms we get

$$\frac{(\phi\lambda\beta+\xi(1-\beta))(-2\phi\lambda\beta(1-\beta)-2\xi\beta^2-\xi^2\beta(\phi-1)+4\xi\beta-2\xi)}{-\left(1-\beta\right)^3\xi^2}$$

which is positive for every parameter value. For the shock coefficients we get

$$\frac{\left(-2\beta\lambda\phi\left(1-\rho^M\beta\right)-\beta\xi^2\left(\phi-\rho\right)-2\xi\left(2\beta\rho-\beta-1\right)\left(\beta\rho-1\right)\right)\left(-2\beta\xi\rho+\beta\xi+\beta\lambda\phi+\xi\right)}{-\left(1-\beta\right)^3\xi^2}>0.$$

It is straightforward to show that the coefficients on the endogenous variables converge to their values under rational expectations. These results are available on request.

Proposition 4: Assume the bank communicates under perfect credibility the interest rate forecast $\left\{E_{t-1}^{CB} i_T\right\}_{T=t}^{\infty}$ or, equivalently, the policy rule (11). Then the REE is stable if $\phi > 1$.

Proof: The system has lower dimensionality, since agents do not have to forecast the nominal interest rate equation. Given that they know the steady state of the system, stability under learning is governed by the dynamics of agent's estimates of the shocks' coefficients and the lagged endogenous variables coefficients (also in this case they evolve as three separate subsystems). Consider first the stability of the coefficients. We have $\left(\tilde{J}_{\omega_u^*} - I_2\right) = \tilde{F}\left(\rho_u\right)$ and $\left(\tilde{J}_{\omega_r^*} - I_2\right) = \tilde{F}\left(\rho_r\right)$ so that instability can be determined by analyzing $\tilde{F}\left(\rho\right)$. The trace of $\tilde{F}\left(\rho\right)$ is negative

$$\frac{\left(\beta + \frac{\beta\phi\lambda}{\xi} - 2\beta\rho + 1\right)}{\left(-1 + \beta\rho\right)} < 0$$

and the determinant can be expressed as

$$\beta \frac{\frac{\phi\lambda}{\xi}(1 - \beta\rho) + \xi(\phi - \rho) + (1 - \beta\rho)(1 - \rho)}{(-1 + \beta\rho)^2}$$

so that it is positive provided $\phi > 1$. Finally $\tilde{J}_{\omega_e^*} - I_6$ can be shown to have stable eigenvalue for every parameter values.

Proposition 5: If households and firms understand the variables on which nominal interest rate decisions are conditioned on, then the REE is stable under learning if $\phi > 1$.

Proof: The Actual law of Motion can be re-written as:

$$Z_t = T_0\left(\omega_0, \hat{\phi}\right) + T_1\left(\omega_1, \hat{\phi}\right) Z_{t-1}$$

The evolution of $\hat{\phi}$ is described by:

$$\hat{\phi}_t = \hat{\phi}_{t-1} + \gamma_t \tilde{R}_{t-1}^{-1} \begin{bmatrix} 1 \\ r_{t-1}^n \\ \mu_{t-1} \end{bmatrix} \left(\hat{\imath}_t - \hat{\phi}_{t-1}' \begin{bmatrix} 1 \\ \hat{E}_{t-1} x_t \\ \hat{E}_{t-1} \pi_t \end{bmatrix} \right)$$

where we assume agents use a Recursive Instrumental Variable estimator, to encompass the case of noise in the announced forecast:

$$\tilde{R}_t = \tilde{R}_{t-1} + \gamma_t \left(\begin{bmatrix} 1 \\ r_{t-1}^n \\ \mu_{t-1} \end{bmatrix} \begin{bmatrix} 1 \\ \hat{E}_{t-1} x_t \\ \hat{E}_{t-1} \pi_t \end{bmatrix}' - \tilde{R}_{t-1} \right)$$

so we can substitute for the correct coefficients

$$\hat{\phi}_t = \hat{\phi}_{t-1} + \gamma_t \tilde{R}_{t-1}^{-1} \begin{bmatrix} 1 \\ r_{t-1}^n \\ \mu_{t-1} \end{bmatrix} \left(\phi' - \hat{\phi}'_{t-1}\right) \begin{bmatrix} 1 \\ r_{t-1}^n \\ \hat{E}_{t-1}x_t \\ \hat{E}_{t-1}\pi_t \end{bmatrix}$$

$$\hat{\phi}_t = \hat{\phi}_{t-1} + \gamma_t \tilde{R}_{t-1}^{-1} \begin{bmatrix} 1 \\ r_{t-1}^n \\ \mu_{t-1} \end{bmatrix} \begin{bmatrix} 1 \\ \hat{E}_{t-1}x_t \\ \hat{E}_{t-1}\pi_t \end{bmatrix}' \left(\phi - \hat{\phi}_{t-1}\right)$$

and

$$\tilde{R}_t = \tilde{R}_{t-1} + \gamma_t \left(\begin{bmatrix} 1 \\ r_{t-1}^n \\ \mu_{t-1} \end{bmatrix} \begin{bmatrix} 1 \\ \hat{E}_{t-1}x_t \\ \hat{E}_{t-1}\pi_t \end{bmatrix}' - \tilde{R}_{t-1} \right)$$

Taking limits we have

$$\dot{\hat{\phi}} = \tilde{R}^{-1} M\left(\Omega, \hat{\phi}\right)\left(\phi - \hat{\phi}\right)$$

and

$$\dot{\tilde{R}} = M\left(\Omega, \hat{\phi}\right) - \tilde{R}.$$

Assuming that

$$M\left(\Omega, \hat{\phi}\right) = E_{t\to\infty} \left(\begin{bmatrix} 1 \\ r_{t-1}^n \\ \mu_{t-1} \end{bmatrix} \begin{bmatrix} 1 \\ \hat{E}_{t-1}x_t \\ \hat{E}_{t-1}\pi_t \end{bmatrix}' \right)$$

is finite we get

$$\tilde{R} \to M\left(\Omega, \hat{\phi}\right)$$

and therefore

$$\hat{\phi} \to \phi.$$

The stability conditions are then the same as for the case of full communication.

Proposition 6: Assume the central bank communicates only the inflation target $\pi^* = 0$ and the associated values for the output gap and nominal interest rates $x^* = i^* = 0$.

1. Define $\rho^M = \max(\rho_u, \rho_r)$ and let $\rho^M \to 1$. Then the REE is unstable under learning if (17) holds;

2. Let $\beta \to 1$. Then the REE is unstable under learning if

$$\xi (\phi + 2\rho) > 2\frac{\phi\lambda}{\xi} (1 - \rho) + \tilde{\psi}(\rho), \tag{25}$$

where $\tilde{\psi}(\rho) > 0$, $\tilde{\psi}(1) = 0$.

Proof: In case the agents know the constant of the system ($\omega_0 = 0$), stability is determined by (19), (20) and (21). It can be shown that $\left(J_{\omega_u^*} - I_3\right) = F(\rho_u)$ and $\left(J_{\omega_r^*} - I_3\right) = F(\rho_r)$ so that instability can be determined by analyzing $F\left(\rho^M\right)$.

1. It can be shown that $F(1) = \left(J_{\omega_0^*} - I_3\right)$ and that F is continuous in ρ. The rest follows from Proposition 1.

2. Let $\beta \to 1$. We proceed as in Proposition 1. The trace of $F\left(\rho^M\right)$ is equal to -3, while the determinant is

$$(\rho - 1)^{-2} \left(g\left(\rho^M\right) + \xi\left(\phi - \rho^M\right) + \frac{\phi\lambda}{\xi}\left(1 - \rho^M\right) \right) > 0$$

given $\phi > 1$ and

$$g\left(\rho^M\right) = 1 - 2\rho^M + \left(\rho^M\right)^2 > 0.$$

Finally, the last element is

$$\frac{\tilde{\psi}(\rho) + 2\frac{\phi\lambda}{\xi}(1 - \rho) - \xi(\phi + 2\rho)}{(\rho - 1)^2}$$

which gives (25).

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