The Value of Central Bank Transparency When Agents Are Learning

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Abstract

We consider whether and how the central bank should be transparent about its interest rate policy when the private sector is modeled as adaptive learners. Transparent interest rate policies enable the private sector to adopt a correctly specified, reduced form model of inflation and output, while intransparent policies lead the private sector to adopt misspecified, reduced form models of inflation and output. With the correctly specified reduced form model, the private sector eventually learns the rational expectations equilibrium, but with the incorrectly specified model, it learns to believe in a restricted perceptions equilibrium. These possibilities arise regardless of whether the central bank operates under commitment or discretion. We provide conditions under which the policy loss under transparency is lower (higher) than under intransparency, thus enabling us to assess the value of transparency when agents are learning.

1 Introduction

The aim of central bank transparency is to lessen or eliminate informational asymmetries between central bank decision-makers and the private sector. Transparency of central bank decision-making has increased rapidly in recent years beginning with the adoption of inflation targeting by the central banks of New Zealand, Canada, the U.K. and Sweden in the early 1990s.[1] Over the same period, economists have made substantial progress in modeling the adaptive process by which agents form and update their expectations, with the aim of assessing whether rational expectations equilibria can be learned or not.[2] However, as Svensson (2003) points out, the connection between central bank transparency and the stability of equilibria under adaptive learning has been largely neglected. Presumably, the benefits of central bank transparency lie in more accurate expectation formation by the private sector, and in improved policy outcomes for central bankers.

Nevertheless, a recent literature on the stability of monetary policy rules when the private sector is learning largely ignores the role played by central bank transparency.[3] In this literature, the stability of rational expectations equilibria in the benchmark New Keynesian, sticky-price model is assessed under a variety of central bank rules for the interest rate target. The aim is to consider restrictions on the class of policy rules or on policy weighting parameters that ensure stability of rational expectations equilibrium under private sector adaptive learning. The private sector agents in these models, who are engaged in the process of forming expectations of future inflation and output, are (blissfully) unaware of the existence of a central bank. Consequently, there really is no possibility of assessing the role played by greater transparency on private sector learning behavior and the achievement of central bank objectives.

In this paper, we reconsider private sector learning in the context of the New Keynesian model with the aim of understanding the value of central bank transparency. Specifically, we first examine the consequences, for equilibrium stability under learning, of whether or not the central bank reveals its inflation and output targets or that it has committed itself to following a policy rule. Revelation of this information impacts on the specification of the perceived law of motion that agents use to form forecasts of future inflation and output.

In the intransparent case, where targets are not revealed and/or the private sector is uninformed of the central bank's commitment to a policy rule, the equilibrium is a 'restricted perceptions' equilibrium (RPE). In such an equilibrium, agents use a misspecified, *underparameterized* forecast model of inflation and output but, in equilibrium, they are unable to detect that their model is misspecified.[4] If agents instead used an *overparameterized* forecast model, they could always learn that the extraneous coefficients in their model should be set to zero and thereby learn to form forecasts consistent with the REE.[5] However, with an underparameterized model that possibility is ruled out; for this reason the underparameterized misspecification and the stability of the resulting RPE is the more interesting case to consider and they are the focus of our paper.

In the transparent regime, the central bank reveals its policy targets and/or its commitment to a policy rule and, as a consequence, the private sector adopts the correct forecast model. The resulting equilibrium is the standard rational expectations equilibrium.

We show that restricted perceptions and rational expectations equilibria are both stable under

[1]See, e.g. Geraats (2002) for a survey of the recent theoretical and empirical literature on central bank transparency.

[2]See, e.g., Evans and Honkapohja (2001).

[3]See, e.g. Bullard and Mitra (1999), Evans and Honkapohja (2003).

[4]See Evans and Honkapohja (2001) and Branch (2004) for definitions and a survey of the restricted perceptions equilibrium concept.

[5]Evans and Honkapohja (2001) use the term "strong E–stability" to refer to REE that are stable under learning when agents use overparameterized forecast models.

adaptive learning behavior on the part of the private sector, regardless of whether the central bank operates under a discretionary or commitment regime. Given this finding, we move on to a comparison of the central bank's policy losses under the two policy regimes. In the discretionary regime, we provide conditions on inflation and output targets under which the policy loss under transparency is lower or higher than under intransparency. Thus under discretion, the case for central bank transparency is mixed. This finding has implications for the literature on inflationary bias under discretionary monetary policy. In particular, we show that under discretion and intransparency, the central bank may *gain* from targeting output above the natural rate; the private sector does not incorporate the central bank's policy into its forecast model, and the restricted perceptions equilibrium in which the private sector resides does not lead the private sector to question its misspecified forecast model. Finally, in the case where the central bank chooses to commit once–and–for–all to an optimal policy rule, we show that transparency on the part of central bank always leads to a lower loss than does intransparency. Hence, the value of transparency is only unambiguously positive when the central bank operates under a commitment regime.

2 Related Literature

There are a couple of papers that examine whether central bank transparency promotes learning of a rational expectations equilibrium by the private sector. Orphanides and Williams (2003) show that if the central bank reveals its inflation target, the private sector finds it easier to learn the rational expectations equilibrium and so convergence to equilibrium occurs faster than if the inflation target is not revealed. Svensson and Faust (2001) show that central bank transparency acts as a kind of commitment device, allowing the private sector to detect deviations by the central bank from its announced targets.

Our approach to understanding the value of central bank transparency under learning builds upon and extends this prior work. In our view, central bank transparency involves more than simply revealing targets for inflation and output (e.g. better information). Transparency further requires the central bank to educate the public on the correct reduced form model to use in forming expectations of inflation and output.[6] The correct reduced form depends on both the central bank's targets and on the policy regime in which it operates (discretion or commitment). As the central bank is assumed to know this information, it is in a position to inform the private sector about the correct reduced form to use in forming expectations. In this sense, the central bank solves an important coordination problem for the private sector: which model to use for expectation formation.

By contrast, in Orphanides and William's work, it is assumed that the private sector always has the correct reduced form model but that it uses a truncated sample of data. Similarly, in Svensson and Faust (2001), the private sector's model of central bank policy is correctly specified. In our approach, the public may or may not have a misspecified reduced form model, depending on the transparency of central bank policy. Further, we assume that the private sector always uses the entire history of data in updating its expectations. Finally, by studying monetary policy under a commitment regime, we are able to disentangle the value of transparency from problems of time inconsistency.

In the case where the private sector uses a misspecified model, the equilibrium concept is termed a "restricted perceptions" equilibrium to differentiate it from the more standard rational expectations equilibrium where the private sector uses the correctly specified model. Nevertheless, as Branch (2004) argues, a restricted perceptions equilibrium is just a different kind of rational expectations equilibrium in the Muth–like sense that agents use their (misspecified) model to form expectations,

[6] This broader interpretation of central bank indeterminacy is consistent with Winkler's (2000) definition as "genuine understanding of the monetary policy process and policy decisions by the public."

and the orthogonality condition, which ensures that forecast errors are uncorrelated with the variables in agents' information sets, always holds; that is, given the data generated by the system, agents cannot reject the hypothesis that their model is the correct one.

3 The Model

We adopt the standard, cashless, New Keynesian model that has been used extensively in the recent literature on learning and monetary policy.[7] The model of the private sector consists of the following equations:

$$\begin{aligned} y_t &= E_t y_{t+1} - \varphi(i_t - E_t \pi_{t+1}) + g_t && (1) \\ \pi_t &= \lambda y_t + \beta E_t \pi_{t+1} + u_t && (2) \\ v_t &= (g_t, u_t)' = F v_{t-1} + \epsilon_t && (3) \\ F &= \begin{bmatrix} \mu & 0 \\ 0 & \rho \end{bmatrix} \quad \epsilon_t = (\epsilon_t^g \epsilon_t^u)' \end{aligned}$$

The first equation for the output gap, y_t, is a forward looking IS equation, with i_t representing the one-period nominal interest rate set by the central bank. The second, aggregate supply equation relates the inflation rate, π_t, to the output gap and expectations of future inflation. It is assumed that $\lambda > 0$, $\varphi > 0$ and the discount factor, $0 < \beta < 1$. The variables g_t and u_t represent demand and supply shocks, respectively, and it is assumed that $|\mu|$, $|\rho| \in [0, 1)$, and that $\epsilon_t^i \sim$ i.i.d.$(0, \sigma_i^2)$, for $i = g, u$.

The model is closed by specifying how the central bank determines the nominal interest rate. We begin with the central bank's minimization problem,

$$\min E_0 \sum_{t=0}^{\infty} \beta^t L_t \tag{4}$$

where

$$L_t = (\pi_t - \overline{\pi})^2 + \alpha(y_t - \overline{y})^2. \tag{5}$$

Here, $\overline{\pi}$ and $\overline{y}$ are the central bank's targets for inflation and the output gap, $\beta \in (0, 1)$ is the period discount factor and $\alpha > 0$ is the relative weight given to deviations of the output gap from its target value.

3.1 Optimal policy under discretion

We first consider the case where the central bank cannot commit to future policies. Optimal monetary policy in this discretionary case amounts to minimization of (4) subject to a version of equation (2) modified to take account of the central bank's inability to influence private sector expectations:

$$\pi_t = \lambda y_t. \tag{6}$$

The first order conditions from this minimization problem can be rearranged to yield:

$$\lambda(\pi_t - \overline{\pi}) + \alpha(y_t - \overline{y}) = 0. \tag{7}$$

[7] See, Clarida, Gali and Gertler (1999) or Woodford (2003) for a complete exposition of this model and derivation from micro principles.

Using the optimality condition (7) in (2) we obtain a first order expectational difference equation for π_t,

$$\pi_t = \frac{\lambda(\alpha\overline{y} + \lambda\overline{\pi})}{\alpha + \lambda^2} + \frac{\alpha\beta}{\alpha + \lambda^2} E_t\pi_{t+1} + \frac{\alpha}{\alpha + \lambda^2}\mu_t. \tag{8}$$

Using equation (8) and the optimality condition (7) we can also obtain an expression for y_t:

$$y_t = \delta_1 - \delta_2 E_t\pi_{t+1} - \delta_3 u_t, \tag{9}$$

where

$$\delta_1 = \tfrac{\alpha\overline{y}+\lambda\overline{\pi}}{\alpha+\lambda^2}, \quad \delta_2 = \tfrac{\lambda\beta}{\alpha+\lambda^2}, \text{and} \quad \delta_3 = \tfrac{\lambda}{\alpha+\lambda^2}.$$

Finally, combining (9) and (1) we obtain the optimal interest rate target rule of the central bank:

$$i_t = \gamma_1 + \gamma_2 E_t\pi_{t+1} + \gamma_3 E_t y_{t+1} + \gamma_4 g_t + \gamma_5 u_t, \tag{10}$$

where

$$\gamma_1 = -\tfrac{\alpha\overline{y}+\lambda\overline{\pi}}{\sigma(\alpha+\lambda^2)}, \quad \gamma_2 = \left(\tfrac{\lambda\beta}{\sigma(\alpha+\lambda^2)} + 1\right), \quad \gamma_3 = \gamma_4 = \tfrac{1}{\sigma}, \quad \gamma_5 = \tfrac{\lambda}{\sigma(\alpha+\lambda^2)}.$$

Evans and Honkapohja (2003) refer to this version of the optimal interest rate policy rule as the *expectations-based rule*, as it is assumed that the central bank conditions on private sector forecasts of future inflation and output, and has ready access to such forecasts. Evans and Honkapohja consider another version of this optimal policy rule, derived under the assumption that the private sector has perfect rational expectations forecasts. This rule is of the form $i_t = \nu_1 + \nu_2 g_t + \nu_3 u_t$. However, as they show, the rational expectations equilibrium of the system under this version of the policy rule is never expectationally stable under adaptive learning dynamics. For this reason, we consider only the expectations-based version of the optimal policy rule (10) in our analysis.

Equations (1), (2) and (10) represent the economic system under discretionary policy, given private sector expectations. Letting $x = (\pi_t, y_t)'$, we can write this system in matrix form as:

$$x_t = A + BE_t x_{t+1} + Du_t \tag{11}$$

where

$$A = \begin{pmatrix} \lambda\delta_1 \\ \delta_1 \end{pmatrix}, \quad B = \begin{pmatrix} \beta - \lambda\delta_2 & 0 \\ -\delta_2 & 0 \end{pmatrix}, \quad D = \begin{pmatrix} \alpha\lambda^{-1}\delta_3 \\ \delta_3 \end{pmatrix}.$$

Here and throughout the paper we use the notation E_t to indicate expectations, that may or may not be rational in the traditional sense.

3.2 Optimal policy under commitment

We next consider the case where the central bank can credibly commit to future policies. Thus, private sector expectations are not taken as given but are instead considered as variables that can be influenced to achieve policy objectives. Optimal monetary policy in this commitment case amounts to minimization of (4) subject to equation (2) holding in every period. The first order conditions from this minimization problem can be rearranged to yield:

$$\lambda(\pi_t - \overline{\pi}) + \alpha(y_t - y_{t-1}) = 0. \tag{12}$$

Notice that, by contrast with the optimality condition under discretion (7), the optimality condition under commitment (12) does not involve the target level for the output gap, so this target does not affect the policymaker's behavior, or for that matter, the economic system. A positive inflation target

$\bar{\pi} > 0$, however, implies that there will be a constant term in the actual process for inflation and output, which will play an important role in our analysis.

To find the expectations-based policy under commitment we consider the system (1), (2) and (12). From (2) and (12) we get

$$y_t = \frac{\lambda}{\alpha + \lambda^2}[\bar{\pi} + \frac{\alpha}{\lambda} y_{t-1} - \beta E_t \pi_{t+1} - u_t], \tag{13}$$

which combined with (1) gives the policy rule

$$i_t = \phi_0 + \phi_1 y_{t-1} + \phi_2 E_t \pi_{t+1} + \phi_3 E_t y_{t+1} + \phi_4 g_t + \phi_5 u_t, \tag{14}$$

where

$$\phi_0 = -\tfrac{\lambda\bar{\pi}}{\varphi(\alpha+\lambda^2)}, \quad \phi_1 = -\tfrac{\alpha}{\varphi(\alpha+\lambda^2)}, \quad \phi_2 = 1 + \tfrac{\lambda\beta}{\varphi(\alpha+\lambda^2)} \quad \phi_3 = \phi_4 = \tfrac{1}{\varphi}, \quad \phi_5 = \tfrac{\lambda}{\varphi(\alpha+\lambda^2)}$$

Equations (1), (2) and (14) represent the economic system under commitment, given private sector expectations. We can rewrite this system in matrix form

$$x_t = A + B E_t x_{t+1} + C x_{t-1} + D u_t \tag{15}$$

where $x_t = (\pi_t, y_t)'$ and

$$A = \begin{pmatrix} \frac{\lambda^2\bar{\pi}}{\alpha+\lambda^2} \\ \frac{\lambda\bar{\pi}}{\alpha+\lambda^2} \end{pmatrix}, \; B = \begin{pmatrix} \frac{\alpha\beta}{\lambda^2+\alpha} & 0 \\ \frac{-\lambda\beta}{\lambda^2+\alpha} & 0 \end{pmatrix}, \; C = \begin{pmatrix} 0 & \frac{\alpha\lambda}{\lambda^2+\alpha} \\ 0 & \frac{\alpha}{\lambda^2+\alpha} \end{pmatrix}, \; D = \begin{pmatrix} \frac{\alpha}{\lambda^2+\alpha} \\ -\frac{\lambda}{\lambda^2+\alpha} \end{pmatrix}.$$

4 Transparency regimes

We differentiate between two regimes. In the first, "transparent" regime, the private sector is aware that the central bank has nonzero targets for either inflation or output, though it may not know the precise values of these targets at any moment in time. Alternatively, agents might be precisely informed of these target values but remain unaware of other model parameter values, e.g. λ, β, α. In either case, the private sector will have to learn coefficients of the reduced form model which are combinations of both target values and other model parameters.[8] In addition, in the commitment policy regime, transparency also means that the private sector knows that it should condition its forecasts of inflation and output on the most recent observation of the output gap, y_{t-1}.

The second, "intransparent regime" differs from the transparent regime in that the private sector uses a *misspecified perceived law of motion.* The particular type of misspecification depends on whether the central bank is operating under discretion or commitment. In the case of intransparent and discretionary policy, we assume that the private sector is unaware that the central bank has nonzero targets for inflation or output; instead, the private sector acts as if these targets were zero. Alternatively, one can think of this regime as one where the central bank announces $\bar{\pi} = \bar{y} = 0$, but then chooses values for these targets that are strictly positive. For example, the central bank may announce $\bar{y} = 0$ but choose a target for $\bar{y} > 0$ so as to push output above potential. Alternatively, the central bank may want to have a nonzero inflation target if it is concerned about avoiding deflation. In the case of intransparent policy where the central bank has a commitment technology, intransparency may further imply that the private sector fails to condition its forecasts of inflation and output on the most recent observation of the output gap, y_{t-1}. As we shall see, the possibility that the central bank can commit to an interest rate policy for all time is less valuable if the private sector fails to appreciate that, in the commitment regime, it must condition its forecasts on the lagged output gap.

[8] Another possibility would be to allow the targets to be time–varying. In that case, agents would have to continually learn the new targets, perhaps by adopting a constant gain learning algorithm or using Kalman filtering. We leave such an analysis to future research.

5 Expectational Stability Under Discretionary Policy

We now consider the possibility that agents are learning how to form expectations of inflation and output. The two transparency regimes have implications for the perceived laws of motion that the private sector uses to form expectations. We focus first on the case of discretionary policy. In the transparent regime under discretionary policy, private sector agents are assumed to have laws of motion for inflation and output that are correctly specified:

$$\pi_t = a_1 + b_1 u_t, \tag{16}$$
$$y_t = a_2 + b_2 u_t. \tag{17}$$

These perceived laws of motion are correct in the sense that they are in the form of the minimal state variable (MSV) rational expectations solution to the system given by (8-9).

In the intransparent regime under discretionary policy, the private sector believes (or is told) –incorrectly– that $\overline{\pi} = \overline{y} = 0$. Consequently, their perceived law of motion is of the misspecified form:

$$\pi_t = b_1 u_t, \tag{18}$$
$$y_t = b_2 u_t. \tag{19}$$

We next consider whether the equilibria that arise under the two regimes are expectationally (E) – stable in the sense of Evans and Honkapohja (2001), as discussed in further detail below. We regard stability of the equilibria under adaptive learning (E-stability) as a necessary condition for further evaluation of the benefits of transparent versus intransparent central bank regimes; if the equilibria were not E–stable (unlearnable), there be no reason to consider the welfare consequences of the associated policy regimes.

5.1 Transparent regime

Under the transparent regime, agents use the correctly specified, MSV perceived law of motion (16-17). The resulting rational expectations equilibrium is both determinate and E-stable as established by Evans and Honkapohja (2003, Proposition 3). A sketch of their finding will prove useful for comparison purposes. Using (16–17) to form expectations in (11) yields:

$$E\pi_{t+1} = a_1 + b_1 \rho u_t, \qquad Ey_{t+1} = a_2 + b_2 \rho u_t$$

Substituting these expectations into the system (11) yields an *actual* law of motion:

$$x_t = T(a) + T(b) u_t \tag{20}$$

where

$$T(a) = \begin{pmatrix} \lambda\delta_1 + (\beta - \lambda\delta_2)a_1 \\ \delta_1 - \delta_2 a_1 \end{pmatrix}, T(b) = \begin{pmatrix} (\beta - \lambda\delta_2)\rho b_1 + 1 - \lambda\delta_3 \\ -\delta_2 \rho b_1 - \delta_3 \end{pmatrix},$$

represent the matrices mapping from the perceived to the actual law of motion. Given this mapping, we can solve for the REE parameter values of (16–17):

$$\begin{aligned} \overline{a}_1 &= \tfrac{\lambda\delta_1}{1-\beta+\lambda\delta_2} & \overline{b}_1 &= \tfrac{1-\lambda\delta_3}{1-\rho(\beta-\lambda\delta_2)} \\ \overline{a}_2 &= \delta_1 - \delta_2 \overline{a}_1 & \overline{b}_2 &= -\delta_2 \rho \overline{b}_1 - \delta_3 \end{aligned}$$

Evans and Honkapohja show that this REE is stable under adaptive learning dynamics. To better understand what is meant by stability under adaptive learning dynamics, let $T(\theta)$ represent a general mapping from a perceived law of motion, represented by its parameter vector, θ, to the actual law of motion, the data generating process. In the case of the system, (20), the $T(\theta)$ map can be decoupled into the two matrices $T(a)$ and $T(b)$. A REE is said to be stable under adaptive learning dynamics or *expectationally (E)–stable* if the differential equation

$$\frac{d\theta}{d\tau} = T(\theta) - \theta,$$

representing a notional time (τ) adjustment process of the parameter vector θ toward the actual law of motion $T(\theta)$, is locally asymptotically stable when evaluated at the REE. Evans and Honkapohja (2001) show using standard stochastic approximation arguments, that under certain regularity conditions, this differential equation governs the stability of an adaptive, real time, stochastic recursive algorithm (SRA) such as recursive least squares learning.

E–stability of the MSV REE of the system (11) can be assessed by examining the eigenvalues of the matrices $DT(a) - I$ and $DT(b) - I$; E-stability obtains if the eigenvalues of these Jacobian matrices have all negative real part. As Evans and Honkapohja note, $DT(a) = B$, where B is the matrix defined in (11) and $DT(b) = \rho B$. Since $\rho \in [0, 1)$, E-stability obtains if the eigenvalues of the matrix B are less than unity. It is easily verified that the eigenvalues of B are $0 < \beta - \lambda\delta_2 < 1$ and 0. As these eigenvalues are both less than unity, it follows immediately that the rational expectations equilibrium is E–stable, as well as being determinate; in the case of system (11) determinacy imposes the same requirements on the matrix B.

5.2 Intransparent Regime

In the intransparent regime, we suppose that agents use the misspecified, underparameterized perceived law of motion, (16–17) to form expectations:

$$E\pi_{t+1} = b_1\rho u_t, \qquad Ey_{t+1} = b_2\rho u_t.$$

Using these expectations, the actual law of motion (ALM) for π_t, y_t is now given by:

$$\pi_t = \lambda\delta_1 + [(\beta - \lambda\delta_2)b_1\rho + 1 - \lambda\delta_3]\, u_t, \tag{21}$$
$$y_t = \delta_1 - (\delta_2 b_1\rho + \delta_3)u_t. \tag{22}$$

The fixed points of these actual laws of motion no longer correspond to the MSV REE values. For that to occur we would need to assume that agents condition their expectations on the information set $\{1, u_t\}$; here they condition on the restricted information set, $\{u_t\}$. Thus, we cannot assess expectational stability by examining the eigenvalues of $DT(\theta) - I$ as we did in the transparent (correctly specified) case.

To analyze convergence of the learning process in the intransparent, restricted perceptions case we need to project the actual law of motion onto the perceived law of motion. The stochastic recursive algorithm (SRA) for $b = (b_1, b_2)'$ can be written as:

$$b_t = b_{t-1} + t^{-1}R_t^{-1}u_{t-1}(x_{t-1} - b_{t-1}u_{t-1}) \tag{23}$$
$$R_t = R_{t-1} + t^{-1}(u_{t-1}u_{t-1} - R_{t-1}) \tag{24}$$

In order to write this SRA in the standard recursive form, we need to perform the transformation $R_t = S_{t-1}$, as the right hand side of (23) must have only terms dated $t - 1$. Following Evans and Honkapohja (2001), the ODE associated with the SRA can be obtained as

$$\frac{d\Phi}{d\tau} = h(\Phi) = \lim_{t\to\infty} EQ(t, \Phi, z_t) \tag{25}$$

where $\Phi_t = (b_t,\, R_t)'$, $z_t = u_{t-1}$ and

$$Q(t,\Phi,z_t) = \begin{pmatrix} S_{t-1}^{-1}u_{t-1}(x_{t-1} - b_{t-1}u_{t-1}) \\ (\frac{t}{t+1})(u_{t-1}u_{t-1} - S_{t-1}) \end{pmatrix} \tag{26}$$

The second line implies that as $t \to \infty$, S_t converges to $S = Eu_tu_t = \sigma_u^2$, the asymptotic variance for the variable used in the learning process. It is easier to consider separately the ODE for b_1 and b_2. Using (21) we have for b_1

$$Q_{b1}(t,\Phi,z_t) = S_{t-1}^{-1}u_{t-1}\left\{\lambda\delta_1 + \left[(\beta - \lambda\delta_2)\rho b_1 + 1 - \lambda\delta_3 - b_1\right]u_{t-1}\right\}$$

and thus

$$h_{b_1}(\Phi) = (\beta - \lambda\delta_2)\rho b_1 + 1 - \lambda\delta_3 - b_1$$

Similarly for b_2, using (21) we have:

$$Q_{b2}(t,\Phi,z_t) = S_{t-1}^{-1}u_{t-1}\left[\delta_1 - (\delta_2 b_1\rho + \delta_3 + b_2)u_{t-1}\right]$$

and thus

$$h_{b_2}(\Phi) = -\delta_2\rho b_1 - \delta_3 - b_2$$

Expectational stability requires that the eigenvalues of the Jacobian matrix

$$Dh_b(\Phi) = \begin{pmatrix} (\beta - \lambda\delta_2)\rho - 1 & 0 \\ -\delta_2\rho & -1 \end{pmatrix}$$

have negative real parts. The eigenvalues of this matrix are $(\beta - \lambda\delta_2)\rho - 1$ and -1, both of which are real and negative. Indeed, the Jacobian $Dh_b(\Phi)$ is equivalent to the Jacobian $DT(b) - I$ for the correctly specified system (transparent regime).

Proposition 1 *If agents use the perceived law of motion (18)–(19) to form expectations, the restricted perceptions equilibrium, where*

$$\overline{b}_1 = \frac{1 - \lambda\delta_3}{1 - \beta\delta + \lambda\delta_2\rho}, \overline{b}_2 = -\delta_2\rho\overline{b}_1 - \delta_3,$$

is expectationally stable.

6 The Value of Transparency Under Discretionary Policy

Regardless of whether policy is transparent or not, the resulting equilibria – rational expectations (RE) or restricted perceptions (RP) – is expectationally stable. Further, the equilibrium values of $\overline{b}_1$, $\overline{b}_2$ are the same in both equilibria. The only difference is that in the REE, we have $a_1 > 0$, $a_2 > 0$ whereas in the RPE, these values are 0. Given this distinction, we have that $E_t^{REE}\pi_{t+1} > E_t^{RPE}\pi_{t+1}$, and using (8) and (9) we can write:

$$\pi_t^{REE} = \pi_t^{RPE} + \frac{\alpha\beta}{\alpha + \lambda^2}\overline{a}_1 \tag{27}$$

$$y_t^{REE} = y_t^{RPE} - \frac{\lambda\beta}{\alpha + \lambda^2}\overline{a}_1 \tag{28}$$

Given that $\overline{a}_1 > 0$, we find that $\pi_t^{REE} > \pi_t^{RPE}$ while $y_t^{REE} < y_t^{RPE}$. Since the period loss function (5) is increasing in both π_t and y_t, whether or not the transparent regime (REE) leads to a lower (higher) loss for the central bank requires further restrictions on the analysis.

Consider first, the simplest case where $u_t = 0$ for all t. In this case, we have that in the REE,

$$\begin{aligned} \pi_t^{REE} &= \overline{a}_1 = \frac{\lambda(\alpha\overline{y} + \lambda\overline{\pi})}{\lambda^2 + \alpha(1-\beta)} \\ y_t^{REE} &= \overline{a}_2 = \frac{(1-\beta)(\alpha\overline{y} + \lambda\overline{\pi})}{\lambda^2 + \alpha(1-\beta)} \end{aligned}$$

Using these expressions in (27-28) we have:

$$\begin{aligned} \pi_t^{RPE} &= \frac{\lambda(\alpha\overline{y} + \lambda\overline{\pi})}{\alpha + \lambda^2} \\ y_t^{RPE} &= \frac{\alpha\overline{y} + \lambda\overline{\pi}}{\alpha + \lambda^2} \end{aligned}$$

Now suppose further that $\overline{\pi} = 0$, while $\overline{y} > 0$. This is the case that is often used to characterize the inflationary bias of discretionary policy, i.e. the central bank targets an output level above the natural rate, resulting in a suboptimal equilibrium in which inflation is persistently greater than the target value of zero, and there is no gain in output.[9] The well-known inflationary bias result is, of course, derived under the assumption that agents are fully rational and have the correct model specification. By contrast, in our set-up, agents are adaptive learners; furthermore, in the intransparent regime, they use a misspecified forecast model and learn to believe in a restricted perceptions equilibrium.

For the case $\overline{\pi} = 0$, $\overline{y} > 0$, we have that:

$$\begin{aligned} \pi_t^{REE} &= \frac{\lambda\alpha}{\lambda^2 + \alpha(1-\beta)}\overline{y} > \pi_t^{RPE} = \frac{\alpha\lambda}{\alpha + \lambda^2}\overline{y} > \overline{\pi} = 0, \\ y_t^{REE} &= \frac{\alpha(1-\beta)}{\lambda^2 + \alpha(1-\beta)}\overline{y} < y_t^{RPE} = \frac{\alpha}{\alpha + \lambda^2}\overline{y} < \overline{y}, \end{aligned}$$

and it follows from (5) that $L_t^{REE} > L_t^{RPE}$ for any value of α. Thus we find that, if the private sector is using the misspecified model, the central bank could benefit (in the form of a lower period loss) by setting a target for output above the natural rate, i.e. by being intransparent about its policy, relative to the transparent (REE) case.[10]

Consider next the case where $\overline{y} = 0$ but $\overline{\pi} > 0$. Non-zero inflation targets have been adopted explicitly (e.g. the Bank of England) or implicitly (e.g. the Federal Reserve) by most central banks for a variety of practical reasons relating to flexibility of monetary policy.[11] In this case we have:

$$\begin{aligned} \overline{\pi} > \pi_t^{REE} &= \frac{\lambda^2}{\lambda^2 + \alpha(1-\beta)}\overline{\pi} > \pi_t^{RPE} = \frac{\lambda^2}{\alpha + \lambda^2}\overline{\pi}, \\ 0 = \overline{y} < y_t^{REE} &= \frac{\lambda(1-\beta)}{\lambda^2 + \alpha(1-\beta)}\overline{\pi} < y_t^{RPE} = \frac{\lambda}{\alpha + \lambda^2}\overline{\pi}. \end{aligned}$$

and it follows from (5) that $L_t^{REE} < L_t^{RPE}$ for any value of α.

[9] The inflationary bias result was first identifed by Kydland and Prescott (1977) and formalized by Barro and Gordon (1983) as the outcome of a strategic policy game. Clarida et al. (1999) and Woodford (2003) demonstrate how the inflationary bias outcome also arises in the context of New Keynesian model considered here.

[10] We could further imagine that the central bank actively exploits the fact that agents are learning by appearing to be transparent, i.e. publically announcing that $\overline{\pi} = \overline{y} = 0$, thereby inducing the private sector to exclude the constant term from its PLM. Despite its announcement, however, the central bank sets $\overline{y} > 0$ and enjoys a lower period loss.

[11] The Bank of England's website gives two reasons for its non–zero inflation target: 1) "having a positive inflation target allows real interest rates to be negative which might be a useful policy option when demand is weak," and 2) the "measured rate of inflation tends to overstate the true inflation rate."

More generally, we next consider the case where the shock process u_t is not constrained to be zero for all t, but is AR(1) with $\rho \in [0, 1)$. In this case, analytic results are not possible, so we turn to numerical simulations. In conducting these numerical simulations, we adopt Clarida, Gali and Gertler's (CGG) (2000) calibration of the two structural parameters of the model. CGG assume that each period of model time corresponds to a year and they set $\varphi = 1$ and $\lambda = 0.3$. In addition, we assume that $\beta = .99$ and that $\rho = \mu = .35$ in (3).

The main findings from our simulations can be summarized as follows.[12] If $\overline{\pi}$ is chosen to be sufficiently large and $\overline{y}$ is chosen to be sufficiently small, specifically, if

$$\begin{array}{lllll} \overline{\pi} & > & \pi_t^{REE} & > & \pi_t^{RPE} \text{ and} \\ y_t^{RPE} & > & y_t^{REE} & > & \overline{y}, \end{array}$$

for all t, then we have $L_t^{REE} < L_t^{RPE}$ and any value of α, and there is value to central bank transparency as we have defined it. If the above inequalities are reversed, then we have the opposite finding, namely that $L_t^{REE} > L_t^{RPE}$ for any value of α, and the central bank can benefit (in the sense of a lower period loss) under the intransparent regime. The logic of these simulation findings follows directly from the definition of the loss function (5) and from the analysis of the REE and RPE values of π_t and y_t given above for the case where $u_t = 0$ for all t.

We summarize our findings for the discretionary case with following proposition.

Proposition 2 *Under discretion, a transparent monetary policy that enables the private sector to adopt the correct forecasting model, may result in a larger or smaller loss to the central bank than an intransparent monetary policy, where the private sector adopts a misspecified forecasting model.*

7 Expectational Stability Under Commitment

In the transparent regime under commitment, private sector agents are assumed to have laws of motion for inflation and output that are correctly specified:

$$\pi_t = a_1 + b_1 u_t + c_1 y_{t-1}, \tag{29}$$

$$y_t = a_2 + b_2 u_t + c_2 y_{t-1}. \tag{30}$$

This case has previously been analyzed by Evans and Honkapohja (2002) and the interested reader is referred to that paper for further details. Evans and Honkapohja (2002) show that the MSV REE is determinate and E-stable. See, in particular, their propositions 4 and 5. Our focus will therefore be on showing that various RPE under commitment are also E–stable.

In the intransparent regime under commitment, there are three possibilities for how agents might underparameterize their perceived laws of motion. Each different misspecification (PLM) gives rise to a different RPE, and so we consider each case in turn.

In the first case, we suppose that the central bank's inflation target is zero, and the private sector also believes that it is zero. The target for output could be different from zero; however, as we have seen, in the commitment regime, the value of $\overline{y}$ does not affect the law of motion for the endogenous variables, so we focus only on the central bank's inflation target. In this first case, the terms in vector A of (15) would be zero and a correctly specified PLM for the endogenous variables would include only the lagged output gap, y_{t-1} and the cost-push shock u_t. But in our first misspecified case we suppose that private agents are unaware of the commitment policy that is being implemented by the

[12] These findings depend on the value chosen for ρ. To get the results reported, the supply shock must not be too persistent. The specific treshold value depends on the value chosen for $\overline{\pi}$ and $\overline{y}$.

CB, or do not believe in the ability of the CB to commit. Accordingly, they neglect the lagged output gap in their PLMs; that is their only misspecification. The perceived laws of motion for inflation and output are thus:

$$\pi_t = b_1 u_t, \tag{31}$$
$$y_t = b_2 u_t, \tag{32}$$

and the ensuing expectations are

$$E_t \pi_{t+1} = b_1 \rho u_t, \tag{33}$$
$$E_t y_{t+1} = b_2 \rho u_t. \tag{34}$$

To analyze whether the resulting RPE is stable under learning, we must again project the ALM on to the PLM. The SRA for $b = (b_1, b_2)'$ is given by (23–24), and we again make use of the transformation $R_t = S_{t-1}$. For convenience we rewrite the system (15) as:

$$\pi_t = k_1 E_t \pi_{t+1} + k_2 y_{t-1} + k_3 u_t, \tag{35}$$
$$y_t = k_4 E_t \pi_{t+1} + k_5 y_{t-1} + k_6 u_t, \tag{36}$$

where the k_i are the non-zero entries in the matrices B, C and D of (15). The ODE associated with the SRA is again given by (25)–(26), where we now have $z_t = (u_{t-1}, y_{t-2})$. We consider separately the ODE for b_1 and b_2. For b_1 we have:

$$Q_{b_1}(t, \Phi, z_t) = S_{t-1}^{-1} u_{t-1}[(k_1 b_1 \rho + k_3 - b_1) u_{t-1} + k_2 y_{t-2}] \tag{37}$$

and thus

$$\begin{aligned} h_{b_1}(\Phi) &= R^{-1}\left[\sigma_u^2 (k_1 b_1 \rho + k_3 - b_1) + k_2 \sigma_{uy}^2\right] \\ &= k_1 b_1 \rho + k_3 - b_1 + k_2 \sigma_{uy}^2 (\sigma_u^2)^{-1} \end{aligned} \tag{38}$$

where $\sigma_{uy}^2 = E u_{t-1} y_{t-2}$. While σ_u^2 is exogenous, σ_{uy}^2 is endogenous, and can be computed as

$$\begin{aligned} E u_{t-1} y_{t-2} &= E(\rho u_{t-2} + \epsilon_{t-1}^u)(k_4 b_1 \rho u_{t-2} + k_5 y_{t-3} + k_6 u_{t-2}) \\ &= k_4 b_1 \rho^2 E u_{t-2}^2 + k_5 \rho E u_{t-2} y_{t-3} + k_6 E u_{t-2}^2, \end{aligned} \tag{39}$$

where we have used the fact that ϵ_t^u is i.i.d. with zero mean and is uncorrelated with any other variable. Since in equilibrium the processes for u_t and y_t are (asymptotically) stationary, we have that $E u_{t-1} y_{t-2} = E u_{t-2} y_{t-3}$ and thus

$$\sigma_{uy}^2 = \frac{k_4 b_1 \rho^2 + k_6 \rho}{1 - k_5 \rho} \sigma_u^2. \tag{40}$$

Substituting (40) in (38) we obtain the ODE for b_1:

$$h_{b_1}(\Phi) = k_1 b_1 \rho + k_3 - b_1 + k_2 \frac{k_4 b_1 \rho^2 + k_6 \rho}{1 - k_5 \rho} \tag{41}$$

Going through the same steps for b_2 we get

$$h_{b_2}(\Phi) = k_4 b_1 \rho + k_6 - b_2 + k_5 \frac{k_4 b_1 \rho^2 + k_6 \rho}{1 - k_5 \rho}. \tag{42}$$

Convergence of the two learning algorithms requires all the eigenvalues of the Jacobian matrix of this system to have negative real parts:

$$Dh_b(\Phi) = \begin{pmatrix} k_1\rho + \frac{k_2k_4\rho^2}{1-k_5\rho} - 1 & 0 \\ k_4\rho + \frac{k_5k_4\rho^2}{1-k_5\rho} & -1 \end{pmatrix} \tag{43}$$

Numerical calculations under the CGG parameterization show that the restricted perceptions equilibrium is always E-stable.

Proposition 3 *If $\bar{\pi} = 0$ and agents use the perceived law of motion (31)–(32) to form expectations, the restricted perceptions equilibrium, where*

$$\bar{b}_1 = \frac{k_3(1-k_5\rho) + k_2k_6\rho}{1 + k_1\rho(k_5\rho - 1) - \rho(k_5 + k_2k_4\rho)}, \bar{b}_2 = k_4\bar{b}_1\rho + k_6 + k_5\frac{k_4\bar{b}_1\rho^2 + k_6\rho}{1-k_5\rho},$$

is expectationally stable.

We next turn to the more general case where the central bank sets $\bar{\pi} > 0$. The new system to be analyzed is given by:

$$\pi_t = k_{0_\pi} + k_1E_t\pi_{t+1} + k_2y_{t-1} + k_3u_t, \tag{44}$$
$$y_t = k_{0_y} + k_4E_t\pi_{t+1} + k_5y_{t-1} + k_6u_t, \tag{45}$$

where k_{0_π} and k_{0_y} are two nonzero constant terms; the REE values for these terms correspond to the elements in vector A of (15). We will study three different forms of PLM misspecification for this system, labeling them PLM1, PLM2 and PLM3.

In the first, most severe case, PLM1, agents neglect both the constant terms and the lagged value of output. The PLMs for inflation and output in this case are:

$$\pi_t = b_1u_t, \tag{46}$$
$$y_t = b_2u_t, \tag{47}$$

(the same PLM (31)-(32) was considered in the case where $\bar{\pi} = 0$). In this case the ODEs (41) and (42) do not change. It follows that Proposition 3 applies to this case as well; the RPE is $E-stable$ and the equilibrium values for b_1 and b_2 are the same as in the case with $\bar{\pi} = 0$.

In the second case, PLM2, agents correctly recognize that lagged output is relevant for the dynamics of the system, but continue to neglect the constant term. The PLMs for inflation and output in this case are:

$$\pi_t = b_1u_t + c_1y_{t-1}, \tag{48}$$
$$y_t = b_2u_t + c_2y_{t-1}. \tag{49}$$

The constant terms that are being neglected are uncorrelated with the other two variables, u_t and y_{t-1}, that are relevant for the dynamics of the system and that are included in the private sector's PLM. Agents thus learn the parameters $b = (b_1, b_2)'$ and $c = (c_1, c_2)'$ just as when they used the correctly specified PLM; indeed, the RPE values for b and c are the same as the REE values of these coefficients, and it follows from Evans and Honkapohja's Proposition 5 that E-stability of the RPE obtains. The RPE expectations for inflation and output are simply transformed by a constant relative to the REE expectations.

In the third and final case, PLM3, agents correctly include a constant in their forecast model but neglect to include the lagged output variable. One interpretation of this specification is that the private sector believes the central bank to be operating under discretion, while the central bank is in fact operating under commitment. The PLMs in this case are:

$$\pi_t = a_1 + b_1 u_t, \tag{50}$$
$$y_t = a_2 + b_2 u_t. \tag{51}$$

In this case, E-stability obtains iff all eigenvalues of B in (15) are less than one, which is readily verified to be true.[13] While the equilibrium values for $b = (b_1, b_2)'$ are the same as those in the first case (PLM1), agents must now, in addition learn the constant terms $a = (a_1, a_2)'$. The equilibrium values for the constants, a are different from the values that agent would learn using the correctly specified PLM, as neglecting the lagged output alters the ODE for the constant terms. Specifically, these values are now

$$a_1 = \frac{k_{0_\pi}}{1-k_1} \tag{52}$$
$$a_2 = k_{0_y} + \frac{k_4 k_{0_\pi}}{1-k_1}. \tag{53}$$

The ensuing expectations are those of case PLM1 translated by the new constants a_1 and a_2.

We summarize our results under PLM1–PLM3 with the following proposition.

Proposition 4 *If $\overline{\pi} > 0$ and agents use PLM1, PLM2 or PLM3 as their perceived laws of motion for inflation and output, the resulting restricted perceptions equilibrium is always expectationally stable.*

8 The Value of Transparency Under Commitment

We now consider whether the central bank's loss is greater or lower under a policy of transparency, where forecasts correspond to REE forecasts, or under a policy of intransparency, where forecasts correspond to RPE forecasts. In the previous section we considered four different RPE. We now consider the loss to the central bank under each of these RPE relative to the central bank's loss under REE (and transparency) in the commitment case. To our knowledge, the value of central bank transparency under full commitment has not been previously addressed. That is because the value of central bank transparency has been inextricably linked with reducing the temptation of central bankers to create surprise inflation, a temptation that arises only under discretionary regimes. By studying the commitment case, we rule out this possibility and ask whether transparency has any further value when agents are learning.

We proceed straight to the stochastic version of our model and again resort to simulations in evaluating the value of the transparent versus the intransparent regimes using the same CGG calibration of the structural parameters of the model and assumptions for the shock process u_t that we used in the discretion case. In particular, we first calculate the value of the central bank's loss (5) for 100 time periods, over a grid of different values of α from .01 to 1.01 with a stepsize of .01. For each value of α, we report the average of 1,000 simulations.

The general finding from these simulation exercises can be summarized as follows. The period loss function under the transparent, commitment regime (REE) is always unambiguously smaller than under the intransparent commitment regime (RPEs). Specifically, for the first RPE, where $\overline{\pi} = 0$

[13] The eigenvalues of B are $0 < \frac{\alpha\beta}{\lambda^2+\alpha} < 1$ and 0.

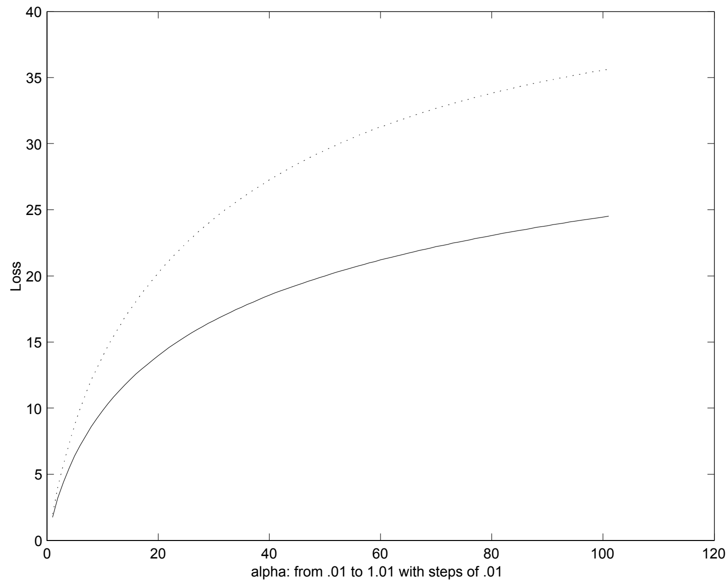

Figure 1: Plot of the loss against α in RPE (dotted line) and REE (solid line).

and the private sector neglects to include lagged output (the PLM given by (31)–(32)), the simulation results are shown in Figure 1. The RPE results are obtained by using (31)–(32) to form expectations in (44) and (45).

For the remaining three RPEs, obtained by using PLM1-PLM3, we imagine that the CB chooses $\overline{\pi} = .02$ (an inflation target of 2 percent per year) and compare the central bank's loss under transparency (REE) and intransparency (RPE) using the same parameterization. The resulting plots for PLM1 and PLM3 are similar to the one in Figure 1, and are thus omitted. When using PLM2 the loss under transparency is still smaller than in the intransparent regime, but the difference would be imperceptible using the same scale as in Figure 1, so we suppress this figure as well. Using PLM2, the only difference between the two regimes is represented by the constants a_1 and a_2, which are neglected in the intransparent regime but which are correctly recognized under transparency. Since these values are very small, the resulting dynamics for the endogenous variables are similar in the two regimes.

We summarize our findings under the four PLMS with the following proposition.

Proposition 5 *For our calibration of the model under commitment, the gains from transparency in terms of a smaller loss to the central are unambiguously positive.*

9 Conclusions

Despite talk by central bankers about transparency of monetary policy goals and targets, vagueness remains en vogue. For instance, in the U.S., the Fed's policy with regard to inflation targeting was recently characterized as follows:

> "Though Mr. Greenspan adamantly opposes setting any official inflation target, Fed officials have implicitly aimed to keep core inflation near 2 percent."[14]

[14] *New York Times*, "Up, Yes. But How Much, How Fast?," June 27, 2004

Given this vagueness about monetary policy goals, it would not be so surprising if the private sector assumed that policy targets were zero, leading them to adopt a misspecified perceived law of motion, as we have assumed. Further, as we have shown, the announcement of target levels for output and inflation may not suffice; in the case where the central bank operates under commitment, the public would have to be further instructed that their perceived laws of motion should include lagged values of the output gap. In other words, commitment is not enough if agents are learning; you also have to instruct the private sector on how to form their expectations.

In this paper, we have made a first effort to link transparency of monetary policy to the specification of the forecast rule adopted by the private sector. We have equated transparency of policy with the private sector's adoption of the correct reduced form forecast model and intransparency with the private sector's adoption of an underparameterized, misspecified model. This view of central bank transparency is one of public understanding of the policymaker's model as opposed to the more traditional view of transparency which equates transparency with more or better information.

We have shown that for certain classes of underparameterized models, the resulting restricted perceptions equilibrium is expectationally stable, meaning that the private sectors' misspecified forecast rules would lead to outcomes for inflation and output that would not invalidate the private sectors' beliefs that their forecast rules were correct.

The results we present suggest that in the case of discretionary policy, the value of transparency relative to intransparency of policy is ambiguous, and depends on policy target values. A particularly interesting finding arises when the inflation target is zero, and the private sector neglects to include a constant term in its forecast models due to intransparency of central bank policy. In this case the central bank benefits from its intransparent policy in that its loss under the resulting RPE is less than its loss in the REE, corresponding to transparent central bank policy. This finding runs counter to the standard inflation-bias outcome when agents have rational expectations and cannot be fooled.

By contrast, in the case where the central bank operates under commitment, we find that, for the same calibration studied in the discretionary case, our results unambiguously favor transparent over intransparent policy; the central bank does not gain as much from a commitment regime if the public does not adopt the appropriate forecasting rules. This result on the importance of transparency under commitment is novel; all of the prior literature studying the benefits/costs of central bank transparency is in the context of discretionary policy regimes, where greater transparency reduces the central bank's temptation to create surprise inflation. By studying a commitment regime, we have begun the process of disentangling the transparency from problems of time-inconsistency.

There are several directions for further research. For example, one could examine the case where the central bank is also learning simultaneously with the private sector. The simplest case would be to imagine that the central bank has the correct perceived law of motion for the interest rate and is learning the appropriate coefficients of this PLM. Alternatively, one might imagine that the central bank has a misspecified law of motion for i_t, i.e. one that is inconsistent with the optimality condition, and explore the resulting RPE in that case. An example of such an interest rate rule might be a simple Taylor-type instrument rule.

Given the tremendous effort that has been expended on increased transparency of central bank policy in recent years, it is surprising that so little effort has been expended on modeling precisely how transparency might aid the private sector in forming expectations. We hope that the findings presented in this paper will lead others to think more deeply about this important policy question.

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