Uncertainty and Transparency of Monetary Policy

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Abstract

What is the proper degree of central bank transparency? This paper investigates the issue in a framework characterized by: a) common uncertainty on potential output, and b) imperfect knowledge of the central bank target (and inference of the true policy reaction function) by the private sector. We show that full transparency is socially beneficial under a variety of parametrizations. Our results confirm, in a different set up, those of Faust and Svensson (2001, 2002), and Svensson (2006).

Keywords: Transparency; Kalman filter; Monetary Policy

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1 Introduction

Monetary policy transparency has considerably increased across countries in the last decade. This development is probably linked with the fact that many central banks have recently adopted (more or less explicitly) an inflation-targeting regime, where it is essential for the central bank to be able to anchor private sector's expectations. In a forward-looking environment, it would seem natural to be pro-transparency, as extensively argued in Woodford (2003).

However, Morris and Shin (2002) have seriously challenged this belief and opened a lively debate in the economic literature[1]. They argue that there can be a cost in providing more accurate public information, as agents may overreact to such information. In this framework, agents formulate expectations based on the underlying fundamentals, but a coordination motive arises from strategic complementarity in their actions. As a result, agents may be too sensitive to forecast errors in public information. Svensson (2006) underlines that Morris and Shin's result in favor of opaqueness can be misleading, because it was obtained for a very particular functional form of social welfare and for unreasonable parameter values. Morris and Shin modeled public information as a signal of exogenous disturbances; however, economic agents mainly receive endogenous signals, i.e. signals about the state of the economy which depend on economic policy objectives, actions and on public and private assessments of the overall economic conditions. Examples of such signals are the short-term policy rate set by central banks or its economic forecasts. The introduction of transparency issues along these lines leads Walsh (2007) to show that more *economic* transparency is not always welfare beneficial. The optimal degree of transparency depends on the relative quality of the signals available to the central bank and the

[1] Actually, Morris and Shin's paper was commented and discussed also outside the academia. The Economist, for example, in 2004 published an article which was inspired by the result found by Morris and Shin and whose title was "It's Not Always Good To Talk".

private sector and on the relative central bank's ability to forecast aggregate demand and supply shocks: if the central bank obtains more accurate signals on cost shocks, optimal transparency increases, whereas if it obtains more accurate signals on demand shocks, optimal transparency decreases. In modeling the information structure within the private sector, Walsh allows for firm-specific shocks and follows Cornand and Heinemann (2006), who introduce a rationale for partial transparency, in the sense of partial release of information. They find that extensive release of public information may induce excessive sensitivity of agents' expectations to noises in public information (as in Morris and Shin). However, if public information can be released only to a proportion of agents, there is only a limited effect on the higher-order expectations, thereby avoiding coordination failures and restoring positive values of (partial) transparency.

In this paper we investigate whether central bank's *political* transparency is desirable in presence of incomplete information about the state of the economy. We will assume that the central bank and the private sector share the same incomplete information on potential output. Moreover, the private sector does not observe the policy targets and cannot exactly infer the policy reaction function, linking the choice of the policy instrument to the final objectives. Orphanides (2001, 2003) widely documented the relevance a common noise in the measure of potential output for central bank's policy. Cuckierman and Lippi (2005) showed that, even if the policymakers efficiently estimate potential output, this does not avoid persistent *retrospective* policy errors. An interesting question is, therefore, if a more transparent central bank can limit the welfare cost of having incomplete information about potential output.

From a methodological point of view, this paper contributes to the literature which analyzes problems of incomplete information in DSGE models. In most papers it has been assumed an information structure featuring a common information set for the private sector larger than the central bank's one (Svensson and Woodford (2004), Boivin and Giannoni (2008)) [2]. We start by observing that policy objectives and intentions are not always revealed explicitly and truthfully to the public. Hence, we assume asymmetric information about policy targets in favor of the central bank and we analyze whether disclosing such policy targets may be beneficial in a framework of incomplete common information on potential output.

The paper is organized as follows: we describe the model in section 2 and we solve it in its state-space form in section 3. In section 4 we show the numerical properties of the model and check the robustness of our findings. Section 5 summarizes and concludes.

2 The model

We will focus on the informational side of a microfounded DSGE model featuring nominal rigidities and monopolistic competition. The supply-side of the economy is modeled according to a New Keynesian Phillips curve:[3].

$$\pi_t = \beta E_t \pi_{t+1} + \frac{(1-\omega\beta)(1-\omega)}{\omega}\kappa\left(y_t - \overline{y}_t\right) + \frac{(1-\omega\beta)(1-\omega)}{\omega}s_t \tag{1}$$

where β is the discount factor, $1-\omega$ is the constant fraction of firms adjusting their prices (Calvo's parameter), κ is the sum of the coefficient on relative risk aversion and the inverse of the wage elasticity of labor supply, and s_t is a cost-push shock. The cost-push shock is assumed to be an AR(1) process:

$$s_t = \rho_s s_{t-1} + \varepsilon_t \tag{2}$$

Since only cost-push shocks posit policy trade-offs, we follow Faust and Svensson (2002) and Walsh (2006, 2007)) and work with a simplified version

[2]Svensson and Woodford (2004) claim that the only case of asymmetric information in which it is coherent to assume a *common information set* for all members of private sector is the case in which the private sector has complete information about the state of the economy and the central bank does not. In fact, only in this case "the model's equations can be expressed in terms of aggregate equations that refer to only a single private sector information set, while at the same time, these model equations are treated as structural, and hence invariant under the alternative policies".

[3]See the Appendix for a quick derivation of the NKPC and Woodford (2003) for an extensive discussion of the complete microfoundation of DSGE models.

of the demand side. We assume that the central bank has imperfect control over the level of output (treated as a policy instrument, see below) and, in turn, over the output gap. More precisely, the following stochastic structure is adopted:

a) an autoregressive error term η_t makes the intended output gap $y_t^I - \overline{y}_t$ deviate from the actual output gap $y_t - \overline{y}_t$;

$$y_t - \overline{y}_t = y_t^I - \overline{y}_t + \eta_t \qquad \eta_t = \rho_\eta \eta_{t-1} + \mu_t \tag{3}$$

b) potential output is autoregressive: $\overline{y}_t = \rho_y \overline{y}_{t-1} + g_t$;

c) The central bank and the private sector share a distorted observation of the true potential output because of a measurement error:

$$\overline{y}_t^{\circ} = \overline{y}_t + \nu_t \qquad \nu_t \sim WN\left(0, \sigma_\nu^2\right) \tag{4}$$

Considering y_t as the policy instrument of the central bank is only a simplifying assumption. In the standard case of an IS equation derived from first principles, with consumption dynamics depending on real interest rates, we could treat either inflation or output as a control variable and subsequently derive the interest rate which is coherent with the prescribed relationship between output and inflation.[4]

The central bank is assumed to minimize the following loss function:

$$\mathfrak{L}_t = \frac{1}{2}\left[(\pi_t - \pi_t^*)^2 + \alpha\left(y_t - \overline{y}_t\right)^2\right] \tag{5}$$

where π_t^* is a *stochastic* inflation target, with the following AR(1) representation:

$$\pi_t^* = \rho_\pi \pi_{t-1}^* + \zeta_t \tag{6}$$

The assumption of a stochastic inflation target reflects the idea that the true central bank's target hardly remains constant over time. This seems to

[4]To that extent, a clear explanation is given in Clarida, Galí and Gertler (1999) and Svensson and Woodford (2003).

hold, for example, in the case of the Federal Reserve, which does not have any explicit inflation target. In a recent paper, Ireland (2007) estimates a New Keynesian model able to capture the behavior of the Federal Reserve's unobserved inflation target. His results show that that the target rose from 1.25% in 1959 to 8% in the last years of the 70s before falling back below 2.5% in 2004. In this exercise, the time-varying inflation target has a lagged component and it is function of both supply shocks[5] and a purely exogenous shock to the inflation target. The estimation provides evidence in favor of a relevant contribution of supply shocks, even if it is not possible to reject the null hypothesis according to which the movements in the inflation target are purely random[6].

Information structure is the following: the central bank and the private sector are assumed to share the same incomplete information set on potential output. Such incompleteness stems from the noise present in observing potential output and the consequent difficulty in distinguishing cost-push shocks from potential output shocks. An asymmetric feature regards the central bank's inflation target, which is not perfectly known by the private sector. Transparency is therefore related to how the private sector perceives intended output, the central bank's policy instrument, which is related to the true inflation target. More specifically, the private sector is assumed to receive a signal ψ_t of y_t^I satisfying the following condition:

$$y_t^I = \psi_t + \chi_t \tag{7}$$

ψ_t is independent of χ_t, which is assumed to be a mean-zero normal shock. The private sector observes the central bank's signal ψ_t: the more transparent the central bank is about the signal, the better will be the private

[5] The supply shocks are connected to the New Keynesian model used as the reference model constituting the theoretical background of the estimation. In particular, the supply shocks are linked to the elasticity of demand for the intermediate goods and the aggregate technology shocks respectively.

[6] The policy implication is, hence, that a time-varying inflation target had relevant implications in terms of actual observed inflation: the American inflation in the 70s would have been lower if the Federal Reserve had maintained a constant inflation target.

sector's perception about the central bank's intended output and its true inflation target.

In the following section we characterize the problem in state-space form and we derive the solution of the model in terms of: a) the central bank's optimal policy and estimation of the state of the economy and b) the private sector's estimation of the state of the economy and the inflation target. The latter, in turn, will depend upon the degree of central bank transparency.

3 State-space form and model solution

The model described in the previous sections can be summarized in a canonical state-space representation with three blocks. The first block characterizes the economy according to a VAR representation; the second contains the loss criterion and the third block the measurement equation.

3.1 State-space form

The economy can be described by

$$\begin{bmatrix} X_{t+1} \\ E_t \pi_{t+1} \end{bmatrix} = A \begin{bmatrix} X_t \\ \pi_t \end{bmatrix} + B y_t^I + C_u u_{t+1} \tag{8}$$

where X_t is a vector containing the predetermined variables $\overline{y}_t$, s_t, η_t and π_t^*.

y_t^I is the intended policy which corresponds to output unless for a shock η_t and, finally, u_{t+1} is a composite vector of structural shocks with covariance matrix given by Σ_u. All the matrices are of appropriate dimensions.

The period loss function is a quadratic form of the goal variables Y_t in which W is a positive-semidefinite weight matrix:

$$Y_t = C \begin{bmatrix} X_t \\ \pi_t \end{bmatrix} + C_y y_t^I \quad C \equiv \begin{bmatrix} 0 & 0 & 0 & -1 & 1 \\ -1 & 0 & 1 & 0 & 0 \end{bmatrix} \quad C_y \equiv \begin{bmatrix} 0 \\ 1 \end{bmatrix} \tag{9}$$

where $W \equiv \frac{1}{2} \begin{bmatrix} 1 & 0 \\ 0 & \alpha \end{bmatrix}$ so that the policy maker aims at minimizing the loss function $L_t \equiv Y_t' W Y_t$.

The third block deals with the measurement equation:

$$Z_t = D \begin{bmatrix} X_t \\ \pi_t \end{bmatrix} + \Sigma_t^i \tag{10}$$

The matrix D selects the elements of the vectors X_t and π_t which can be observed; the central bank, in fact, can observe inflation target without noise, while potential output is observed with a noise ν_t. On the other hand, the private sector has a different information set than the central bank since its measurement error of potential output is still given by ν_t, but it does not observe the inflation target. In (10), the i over the matrix Σ_t indicates that the the measurement errors are different for the private sector and the central bank because of the different information sets available to each of them.

In two very different environments, Faust and Svensson (2001, 2002) and Svensson and Woodford (2004) have shown that when there exists asymmetric information between the private sector and the policy-maker, the estimation of the state of the economy depends on the policy followed by the central bank. The solution is therefore more complex than in the case with symmetric partial information. However, we know from Svensson and Woodford (2004) that the certainty equivalence principle holds. Hence, the policy set up by the central bank does not depend on the information structure available, and in particular it does not depend on the shocks represented in the state-space form.

3.2 Non-inertial policy rule and signal-extraction problems

In order to solve the signal-extraction problem for both the agents involved in the model, we first need to solve the policy problem. We concentrate on a discretionary, non-inertial equilibrium as in Faust and Svensson (2001, 2002). In this case, the central bank follows a linear rule where its intended output is a function of the contemporary states of the economy:

$$y_t^I = \gamma_1 s_t + \gamma_2 \overline{y}_t + \gamma_3 \eta_t + \gamma_4 \pi_t^* \tag{11}$$

The private sector has to learn the time-varying policy target without observing y_t^I and $\widehat{\pi}_t$ directly. This learning process will be contingent on the signal ψ_t on the intended output received by the private sector. Since $\widehat{\pi}_t$ and y_t^I are unobserved by the private sector, we can go through (11) and (7) and solve the estimation-problem.

The variable

$$\gamma_1 s_t + \gamma_2 \overline{y}_t + \gamma_3 \eta_t - \psi_t \tag{12}$$

would allow to pin down the observation of inflation target if monetary policy is fully transparent. In this case, in fact, $\chi_t \to 0$, hence the signal ψ_t coincides with the intended output and, in turn, the difference between (12) and (11) amounts to $-\gamma_4 \pi_t^*$.

Since the inflation target is not observable, however, (12) minus (11) includes also an error term, given by χ_t. Therefore, for a given policy (11) chosen by the central bank, the private sector will infer the inflation target by using the following expression:

$$\iota_t = -\gamma_4 \pi_t^* + \chi_t \tag{13}$$

Notice that the private sector's inference about the inflation target depends on the central bank decision to reveal its intended output. In other words, it is not necessary for the central bank to explicitly reveal $\widehat{\pi}_t$ in order to be transparent about its inflation target

Solving this policy problem, we get a policy function, i.e. a matrix F constituted by the γ coefficients in (11) and a matrix G which links inflation to the states of the economy. We can plug these two matrices into (8) and then combine the resulting state-space form with the corresponding relevant measurement equation. The latter will be different if we analyze the signal-extraction problem of the central bank or of the private sector.

The measurement equation for the central bank is given by:

$$Z_t^{CB} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \overline{y}_t \\ s_t \\ \eta_t \\ \pi_t^* \\ \pi_t \end{bmatrix} + \begin{bmatrix} \nu_t \\ 0 \end{bmatrix} \tag{14}$$

whereas, for the private sector it will be the following:

$$Z_t^{PS} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\gamma_4 & 0 \end{bmatrix} \begin{bmatrix} \overline{y}_t \\ s_t \\ \eta_t \\ \pi_t^* \\ \pi_t \end{bmatrix} + \begin{bmatrix} \nu_t \\ \chi_t \end{bmatrix} \tag{15}$$

4 Parametrization and numerical results

Faust and Svensson (2001) show how to derive an analytical expression for the policy coefficients using the methods of undetermined coefficients. However, to study the properties of the model and evaluate the effect of varying the degree of transparency, they had to follow numerical methods. We will solve the model numerically. Our calibration relies on standard numerical values in the literature (see Woodford, 2003, and Giordani and Söderlind, 2004). The discount factor β is set equal to 0.99, the degree of price stickiness ω is set equal to 0.66. We set the coefficient of constant relative risk aversion equal to 2 and the inverse of labor-supply elasticity equal to 1.5: hence, the implied value for κ is 3.5.[7] The autoregressive

[7] The slope coefficient of the new Keynesian Phillips curve can be expressed according to the following representation:

$$\frac{(1-\omega)(1-\beta\omega)}{\omega}(\sigma+\phi)$$

where σ stands for the coefficient of relative risk aversion and ϕ is the inverse of labor supply elasticity.

coefficient of potential output is assumed to be 0.7, while for both the cost-push and the demand shock we pick a value of 0.4. The autoregressive coefficient for the inflation target is 0.05, a value consistent with the evidence of Ireland's estimates about the statistical properties of the time-varying inflation target for the Federal Reserve. Furthermore, we think that even in presence of a constant inflation target, as in the case of the European Central Bank, there can be phases in which it is not possible to strictly adhere to the target because of extraordinary external shocks.

Given this set of structural parameters, we simulate the stochastic properties of the shocks and the measurement errors. We solve the model for 100,000 draws of a uniform distribution for the variance of potential output, cost-push shock, demand shock and the inflation target. Specifically, we let $\left[\sigma_g^2, \sigma_\varepsilon^2, \sigma_\mu^2, \sigma_\zeta^2\right] \in [0, 5]$, while the measurement shocks are simulated in a different way depending if we are considering the central bank's or the private sector's perspective. Since the central bank is assumed to observe the inflation target, we capture its uncertainty about potential output by taking 100,000 points drawn uniformly from the parameter space $[0, 5]$.

With respect to the private sector, we take the same values drawn before for the central bank and derive the values for σ_χ^2 as a function of the central bank's degree of transparency. Namely, we define the degree of transparency $\tau \equiv \frac{\sigma_\psi^2}{\sigma_\psi^2 + \sigma_\chi^2}$ and compute inversely the value of $\sigma_\chi^2 = \frac{\sigma_\psi^2 (1-\tau)}{\tau}$. Of course, for high levels of transparency (i.e. $\tau \to 1$), σ_ψ^2 coincides with σ_η^2, while the less transparent the central bank is, the less informative is ψ_t about the intended policy y_t^I. We distinguish three regimes of transparency and for each of them we draw 100,000 points from a uniform distribution and, in turn, for the value of σ_χ^2. In particular, we consider a low level of transparency for $\tau \in [0, .3]$, a medium level of transparency if $\tau \in (.3, .6]$ and finally a high level of transparency when $\tau \in (.6, 1]$. For each of these parameter spaces, we draw 100,000 points uniformly and then compute residually the value of σ_χ^2 before computing the loss functions. Then the model is solved both for the central bank and the private sector. The average values of all the losses computed for these draws are shown in Table 1: the loss function for the central bank turns out to be independent of the degree of transparency, while that of the private sector is computed for each of the three different levels of central bank transparency.

As these loss functions can be considered a natural measure of welfare for the households[8], we compare the outcomes arising when the central bank decides to be more or less transparent. Table 1 shows that, given a loss function equal to 267.11 for the central bank, the private sector is better off when it is able to disentangle the error component in the instrument set by the central bank. In fact, the loss function for the private sector amounts to 317.44 for the first range of transparency that we consider; it is sufficient to increase the degree of transparency to the range $(.3, .6]$ to make the private sector better off, since in this case loss drops to 306.57, a value which is further reduced in the most transparent regime we examine: specifically, when $\tau \in (.6, 1]$ the loss amounts to 285.44. Increasing transparency, therefore, is beneficial in terms of the private sector's welfare, as it is also confirmed by solving the model for extreme values in the degree of transparency: with a regime which is not transparent at all, the loss function for the private sector reaches its maximum value, while a completely transparent regime allows the private sector to reach almost the same welfare level as the central bank, the difference being due only to the partial observation of the inflation target [9]. Similarly to what found by Faust and Svensson (2001), higher transparency may improve the outcome of discretionary policy. However, our result has been derived in a completely different setup, where agents are forward-looking and the central bank does not have any incentive to create unexpected inflation. On the other hand, Faust and Svensson's analysis is conducted entirely in a backward-looking model, where there exists

[8] In particular, Woodford (2003) derives a loss function like (5) as a second-order approximation of the representative household's utility.

[9] Namely, even without measurement error, private sector observes a fraction γ_4 of π_t^*.

a specific role for central bank's credibility. Faust and Svensson show that increasing transparency makes the discretionary policy closer to the social optimum by assuming that the central bank responds to both the actual time-varying policy target and the private sector's perception of the target. In our setup, we solve a standard DSGE model under discretion and show that a more transparent regime is beneficial for the private sector even in presence of incomplete information on potential output. The latter finding suggests a reflection about a common claim according to which if the central bank has limited knowledge of the state of the economy, it would help to be more opaque in order to make the private sector react less than it would do in case of explicit announcements about policy objectives, forecasts and policies. Here, we interpret the notion of transparency as related to how easily policy intentions can be grasped by the private sector. We show how the presence of incomplete information, in the form of unobserved potential output, cannot be considered a good reason for the policymaker to follow a less transparent regime.

4.1 Alternative scenarios and robustness

In this section, we undertake robustness analysis and check wether our results hold true when considering a) heterogeneity in the information set within the private sector, and b) heterogeneity in the information set between the central bank and the private sector with respect to observation of potential output.

We believe it is worthy to consider the effects of different information sets within the private sector for two reasons. First, following Cornand and Heinemann (2006) and Walsh (2007), it is possible that partial release of information, *à la* Morris and Shin (2002), is beneficial. In case of wide release of information, the economic agents are induced to coordinate their expectations by taking into account the public information released by the policymaker: this can make the economy too sensitive to any noise in the public information itself. This information cost, however, can be limited if the central bank decides to provide information only to a fraction of agents because a low level of publicity reduces the incentive to overreact to the public signal, as the latter reaches only a fraction of agents. Second, partial release of information may be interpreted as a particular kind of rational inattention: even if the central bank disseminates its public signal to everyone without any discrimination within the private sector, only a fraction of agents incorporate the new information into their decisions. As a consequence, this strand of literature finds an optimal degree of transparency which does not generally coincide with full transparency. Taking that into account, we perform the following experiment: for each given degree of transparency τ, only a fraction P of agents in the private sector observes the inflation target as a function of the degree of transparency. Appendix B shows in detail how we introduce heterogeneity in the private sector, while here we report graphically the effects of differentiating the information set within the private sector. Again, we simulate the model for the same values of shocks and measurement errors in the interval $[0, 5]$, considering, as above, three regimes of transparency and $P \in [0, 1]$. Introducing heterogeneity within the private sector's information set should not be confused with varying the degree of central bank's transparency: in this exercise, we simulate the outcomes for both different levels of transparency and fraction of informed agents. Then we derive the private sector's loss function as a weighted average of the fraction of the loss of informed and uninformed households. We believe that this experiment allows to overcome a limit in the literature about policy transparency. Up to now, many contributions, (including Walsh (2007)), justified the presence of a fraction of uninformed agents by invoking rational inattention *à la* Sims, and considered the latter as a perfect substitute for low transparency. However, this equivalence is not obvious, as central bankers may be unable to inform only a fraction of agents. Figure 1 shows the percentage change in social loss relative to the case of full transparency.

We find that partial release of information is never optimal, unlike some previous results in the literature. In figure 1 the slope of the relative change in social loss monotonically increases with the degree of transparency. Under low transparency the cost of having only a fraction of informed agents is almost constant since even the informed agents observe π_t^* very noisily. Under high transparency, on the contrary, the relative loss decreases rapidly as a the information released by the central bank can improve significantly the learning process by the part of private sector. Therefore, providing information about the policy target reduces global uncertainty and, in turn, increases social welfare, in line with Faust and Svensson (2001, 2002), Svensson (2006) and Woodford (2005)[10].

We believe that there exists another reason why, in the present setup, being completely transparent enhances social welfare without any cost in terms of excessive sensitivity to the public signal. The private sector's information set has been modeled as a subset of the central bank's one; specifically, given that the central bank has incomplete information about potential output, the private sector shares this kind of incomplete information and, furthermore, does not perfectly observe the inflation target. Therefore, by releasing a precise signal about the inflation target, the private sector's loss decreases. However, information released by the central bank can be noisy, due to the imperfect knowledge about both the structure of and the shocks affecting the economy. For robustness purposes, we analyze whether these results hold under the assumption that the private sector is better informed on potential output. Such new informative asymmetry could reintroduce a problem of excessive reaction to public signals and reduce incentives for central bank transparency. We simulate the model for different degrees of uncertainty in the measurement of potential output. We take the same 100,000 values of

[10]In our setup, differently from Morris and Shin (2002) and other contributions, public information is not a focal point for private actions, because private agents are not forced to coordinate on the public signal, neglecting private information even if the latter is more accurate than the former. Nevertheless, Woodford (2005) and Svensson (2006) show the fragility of the Morris and Shin results to some relevant points like changing the welfare measure, or by calibrating their model with more realistic parameters.

$\sigma_\nu^2 \in [0,5]$ for the central bank, while for the private sector we take 100,000 values in the uniform distribution $\in [0, 2.5]$. We assume that the private sector's forecast about potential output is a linear combination of the signal received by central bank and its own observation. Under an assumption of asymmetric information set about potential output by the part of the private sector, we reexpress the observation equation (4) must be distinguished for the central bank and the private sector:

$$\overline{y}_t^{CB} = \overline{y}_t + \nu_t^{CB} \qquad E\left(\nu_t^{CB}\right) = 0 \qquad Var\left(\nu_t\right) = \sigma_{\nu,CB}^2 = \frac{1}{\vartheta} \tag{16}$$

$$\overline{y}_t^{PS} = \overline{y}_t + \nu_t^{PS} \qquad E\left(\nu_t^{PS}\right) = 0 \qquad Var\left(\nu_t^{PS}\right) = \sigma_{\nu,PS}^2 = \frac{1}{\varpi} \tag{17}$$

where ϑ and ϖ indicate the precision of the signals received by central bank and private sector respectively. Under the assumption of uncertainty about the quality of the two signals (16) and (17), the private sector's learning process uses a linear combination of these:

$$\mathcal{S}_t = \varphi \overline{y}_t^{CB} + (1-\varphi)\,\overline{y}_t^{PS} \qquad \varphi \equiv \frac{\vartheta}{\vartheta + \varpi} \tag{18}$$

Table 2 shows the numerical properties of this modification to our baseline model, for different levels of transparency as defined above. We still obtain that the private sector's loss is decreasing in the degree of central bank transparency, even when the private sector's signal on potential output is more precise.

Finally, in Figure 2 we show the percentage change in social loss relative to the case of full transparency as a function of the number of informed agents. The message remains coherent with that of Figure 1 above. Social welfare improves when all the agents are informed. Hence, it is not sufficient to assume that the private sector about potential output to modify the conclusion in favor of full transparency and full release of information.

5 Concluding remarks

In the last two decades we have observed a sharp increase in the degree of central bank transparency. In this paper, we justify this choice by numerically simulating a DSGE model featuring uncertainty on potential output and imperfect knowledge of the central bank's inflation target by the private sector. Our welfare criterion includes a stochastic inflation target, following the analysis of Ireland (2007). We assume that private sector does not observe the inflation target and it observes a noisy measure of potential output, identical to what observed by the central bank. If the central bank follows a non-inertial optimal policy, the private sector's estimation of the state of the economy also depends on the degree of central bank transparency.

Under higher transparency, private sector's forecasts become more accurate and its welfare increases. This finding is robust to assuming heterogeneity of the information set within the private sector, unlike some previous examples in the literature (Cornand and Heinemann (2006), Walsh (2007)). Moreover, it also holds when the private sector is assumed to have better information on potential output with respect to the central bank.

From a methodological point of view, the major contribution of the paper is to extend the analysis of informational asymmetries in a DSGE model to the case of an unobservable policy goal.

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A Derivation of the NKPC

Firms set prices à la Calvo (1983). Each period a random fraction $(1-\omega)$ sets new prices so that the aggregate price level evolves as a convex combination of the lagged price level p_{t-1} and optimal reset prices $\widehat{p}_t^*$:

$$p_t = (1-\omega)\widehat{p}_t^* + \omega p_{H,t-1} \tag{19}$$

For the price-adjusting firms, the optimal reset price will be equal to the expected discounted value of current and future nominal marginal cost mc_t, markup μ and a cost-push shock s_t affecting the firm's desired price:

$$\widehat{p}_t^* = (1-\omega\beta)\sum_{i=0}^{\infty}(\omega\beta)^i E_t\left(mc_{t+i} + s_{t+i}\right) + \mu \tag{20}$$

The previous expression can be written in a more compact form:

$$\widehat{p}_t^* - p_{t-1} = \omega\beta \mathrm{E}_t\left(\widehat{p}_{t+1}^* - p_t\right) + \pi_t + (1-\omega\beta)\left(\widehat{mc}_t + s_t\right) \qquad \widehat{mc}_t \equiv mc_t + \mu \tag{21}$$

Under the price structure for p_t, a log-linear version of the domestic price inflation around a zero inflation steady state is

$$\pi_t = (1-\omega)\left(\widehat{p}_t^* - p_{t-1}\right) \tag{22}$$

which, combined with equation (21) gives

$$\pi_t = \beta E_t \pi_{t+1} + \frac{(1-\omega\beta)(1-\omega)}{\omega}\left(\widehat{mc}_t + s_t\right) \tag{23}$$

Assuming that real marginal costs $\widehat{mc}_t$ are linearly correlated to output gap, $\widehat{mc}_t = \kappa\left(y_t - \overline{y}_t\right)$ we arrive at equation (1) in the main text.

B Different information sets within the private sector

In this section we show formally how we introduce heterogeneity in the information sets of the private sector. Specifically, we assume that a fraction

P does not observe the inflation target, while the rest of agents observes $\widehat{\pi}_t$, at least partially, as a function of the degree of transparency. As stressed in section 4, the observed inflation target is deeply dependent on how much transparent central bank is, according to

$$\sigma_\chi^2 = \frac{\sigma_\psi^2 (1-\tau)}{\tau}$$

so that for extreme degrees of transparency, the signal delivered by central bank will reflect perfectly the true inflation target Accordingly, the measurement equation for the informed part and the uninformed part will be respectively:

$$Z_t^I = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\gamma_4 & 0 \end{bmatrix} \begin{bmatrix} X_t \\ \pi_t \end{bmatrix} + \begin{bmatrix} \nu_t \\ \frac{\sigma_\psi^2 (1-\tau)}{\tau} \end{bmatrix} \tag{24}$$

$$Z_t^U = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\gamma_4 & 0 \end{bmatrix} \begin{bmatrix} X_t \\ \pi_t \end{bmatrix} + \begin{bmatrix} \nu_t \\ \chi_{t|\tau \longrightarrow 0} \end{bmatrix} \tag{25}$$

The loss function for the private sector will be function of the fraction of informed and uninformed agents, hence it will be a weighted average of the loss for the informed part and the uninformed part, with weights equal to P and $(1-P)$.

Table 1: Numerical simulation

Regime	**Central Bank's Loss**	**Private Sector's Loss**
$0 \leq \tau < 0.3$	267.1082	317.4385
$0.3 < \tau \leq 0.6$	267.1082	306.5697
$0.6 < \tau \leq 1$	267.1082	285.4359
$\tau = 0$	267.1082	320.8341
$\tau = 1$	267.1082	267.1125

Table 2: Numerical simulation with private sector having a more precise signal about potential output

Regime	**Private Sector's Loss**
$0 \leq \tau < 0.3$	294.8310
$0.3 < \tau \leq 0.6$	284.6931
$0.6 < \tau \leq 1$	262.9250
$\tau = 0$	298.2852
$\tau = 1$	244.2209

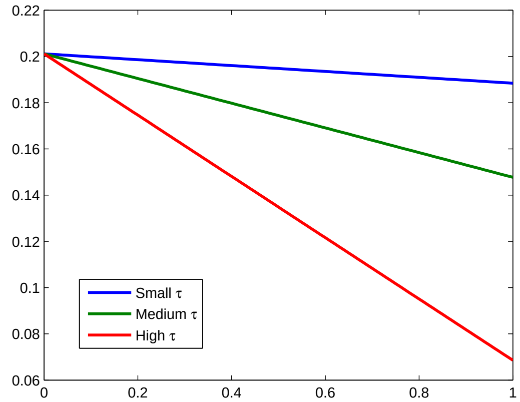

Figure 1: The effect of having different levels of informed agents on social loss (percent change relative to having full transparency for the entire private sector)

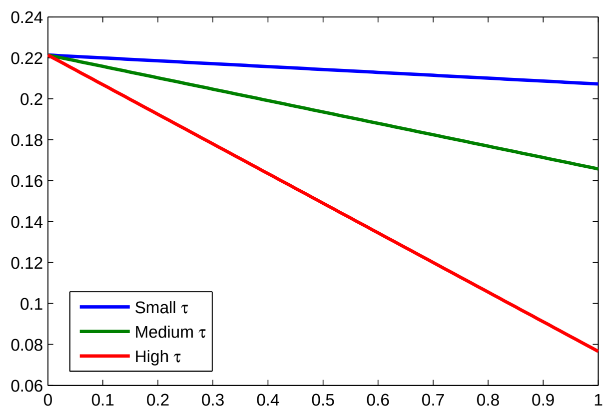

Figure 2: The effect of having different levels of informed agents on social loss with different perception of the potential output between the central bank and the private sector (percent change relative to having full transparency for the entire private sector)