Truthfulness of Central Bank Announcements

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Abstract

To evaluate the impact of central bank transparency, previous literature has assumed that the policymaker commits to truthful communication. However, by manipulating inflation expectations economic volatility might be reduced. This paper analyses the truthfulness with which a central bank communicates inflation targets or forecasts. It shows that, for a standard model, there is no rational expectations equilibrium with inflation announcements when the policymaker has incentives to misrepresent private information. This problem is solved by announcing late in the period, when inflation expectations are already formed but there is not yet information about future shocks. In this case, there are no incentives to mislead the public and inflation announcements are still informative about the central bank's intentions for future periods. Therefore, an equilibrium does exist and truth-telling is optimal for the central bank and welfare-improving for society. Based on the implications of the model, empirical data is examined and no evidence is found against the truthfulness of annual inflation targets.

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1 Introduction

The increasing amount of information released to the public by central banks brings attention to the influence of policy announcements on the formation of inflation expectations. To evaluate the economic impact of monetary policy transparency, it has been common practice to assume that the central bank commits to making truthful inflation announcements. The present paper, instead, analyses the scenario in which the policymaker strategically communicates information about inflation targets or forecasts so as to maximise society's welfare. By manipulating inflation expectations the central bank might potentially offset the effects of aggregate shocks on inflation, and therefore truth-telling may not be the best strategy. This paper shows that, for a standard setup, there is no rational expectations equilibrium with inflation announcements when the policymaker intends to misrepresent private information. This problem can be overcome by announcing late, when inflation expectations of the period of announcement are already formed but there is not yet information about future shocks. In this case, there are no incentives to mislead the public and inflation announcements reveal useful information about the central bank's intentions for future periods. As a result, an equilibrium exists and truth-telling improves social welfare and is also the optimal strategy for the central bank.

Over the last two decades, as central banks have become more independent, transparency and communication with the public have gained relevance in the conduct of monetary policy. Whereas secrecy was conventional 20 years ago, today it is the norm that the public be informed of the central bank's decisions. This trend in monetary policy has been recently documented in multiple papers (e.g. Dincer and Eichengreen, 2007; Geraats, 2009). Moreover, significant amount of theoretical and empirical research has been conducted to determine if transparency is beneficial from an economic point of view.[1]

As concluded by Geraats (2006), theoretical arguments bring about three main results of the effects of central bank transparency on the public perception of monetary policy. First, transparency improves the predictability of monetary policy because it reduces uncertainty about the state of the economy and the central bank's intentions. Second, transparency induces reputation building because it increases the sensitivity of inflation expectations to unanticipated policy actions. Third, by allowing the public to check the consistency of policy actions and outcomes with formal policy objectives, transparency enhances credibility and reduces long-run inflation expectations volatility. Based on these results, most of the recent economic literature highlights the economic desirability of transparency (e.g. Geraats, 2005; Svensson, 2006; Demertzis and Hughes Hallett, 2007).

[1] See Eijffinger and Van der Cruijsen (2007) for a survey of literature on central bank transparency.

Another part of earlier literature has also pointed out that transparency may be undesirable because its benefits come at the cost of flexibility, and hence the central bank's ability to stabilise the economy is reduced (e.g. Jensen 2002). Cukierman (2001), for instance, explores the impact of transparency in two different models, one with the conventional expectations-augmented Phillips curve and the other with a monetary transmission mechanism of a Neo-Keynesian type. The result obtained, for both models, is that transparency is detrimental to society's welfare because disclosing information about upcoming aggregate shocks increases variability of short-run inflation expectations and, consequently, inflation and output volatility.

In assessing the impact of monetary policy transparency it is common practice to assume that the monetary authority commits to truthful announcements. With the purpose of finding out whether transparency is beneficial or not, society's welfare is compared for opacity versus limited or full transparency. Under opacity the central bank does not disclose any private information. In contrast, under transparency, the central bank's private information is partially or fully revealed.[2] If transparency yields a higher level of welfare, we can conclude that society prefers it over secrecy. Nevertheless, it does not imply that the central bank's commitment to truthful communication is credible. The policymaker may still have incentives to misrepresent private information because in that way economic volatility can be reduced. When faced with inflationary shocks, for instance, the central bank might try to deceive agents into believing that the intended inflation target is lower than it actually is, such that the effect of shocks on inflation is offset by the effect of inflation expectations.

The question arises whether the central bank is able to improve society's welfare by manipulating inflation expectations. The present paper shows that, for a multiple-period model with a stochastic expectations augmented Phillips curve, there is no equilibrium under rational expectations when the central bank communicates inflation targets or forecasts with the purpose of reducing economic volatility by misleading inflation expectations. The intuition behind this result is as follows. Private agents use the announcement to extract information about the central bank's intentions. Since the policymaker knows that the inflation announcement influences inflation expectations, she finds it optimal to misrepresent private information so as to offset the effect of anticipated shocks on inflation. As rational agents foresee this situation, they incorporate the announcement into their information set but take into account the intention of the central bank to misrepresent. The policymaker anticipates this reaction and increases the degree of misrepresentation. But again, private agents also anticipate this and adjust their inflation expectations accordingly... and so on. As section 3 shows, this process does not converge to a rational expectations equilibrium with inflation announcements.

Canzoneri (1985) was the first to call attention to the lack of credibility of mone-

[2] Examples of partial transparency can be found in Jensen (2002) and Walsh (2007). The former sets up a model in which the control error of monetary policy may be partially revealed. The latter assumes that the central bank announces in a manner such that just a fraction of firms receives the information. Misrepresentation of private information is not considered in any of these papers.

tary policy announcements when the central bank has private information, specifically, the policymaker's forecast of the money demand shock. Therefore, private agents are unable to know with certainty whether an expansionary policy is a result of a perceived increase in money demand or an attempt to stimulate output above potential. As a result, monetary policy announcements cannot be trusted because the central bank has incentives to lie in order to achieve better outcomes.

A similar conclusion is reached by Stein (1989) in a cheap-talk game in which the central bank's exchange rate target is not known to the public and, in contrast to Canzoneri's (1985) paper, the monetary policy announcements are made before expectations are formed. Stein points out that the central bank is unable to credibly communicate its intentions by making precise announcements despite the fact that it would be better off by announcing its true target compared to making no announcements. Stein (1989) and Garfinkel and Oh (1995) show a way to overcome this problem. The central bank can partially reveal its private information when it announces the range in which such information lies, rather than announcing a specific value. The ranges from which the central bank picks the one to announce have to be large enough to discourage lying. If the central bank wants to lie it has to claim that its private information is in a different range and therefore the policymaker would have to significantly increase the degree of her misrepresentation. Imprecise announcements may make truth-telling preferable over such significant misrepresentations.

A common feature in the three above-mentioned papers is that the credibility problem of central bank announcements arises from the fact that one of the monetary authority's goals is inconsistent with the steady-state level and therefore, there is time inconsistency as described originally by Kydland and Prescott (1977) and Barro and Gordon (1983). In the present paper, in contrast, the central bank does not pursue any time-inconsistent policy and, despite this fact, it is still unable to credibly communicate its intentions. The source of the problem, as mentioned above, is the fact that the central bank intends to offset volatility that stems from economic shocks by manipulating inflation expectations. In this way, the paper points out the existence of difficulties with regard to credibility of inflation announcements even when there is no inflation bias in central bank preferences. Furthermore, imprecise inflation announcements would be an impractical solution to this problem since the optimal sizes of ranges would have to vary every period according to the central bank's forecasts of economic shocks which might not be known to the public.

In more recent literature, the possibility that the central bank strategically sets the level of the inflation announcement is proposed by Walsh (1998, p.363) and it is later incorporated into several papers.[3] A common feature of these papers is to assume that, as Walsh originally does, the policymaker is exogenously penalised for the deviation of actual inflation from the announcement and that the central bank's loss function includes an additional term which is increasing in the square of this deviation.

[3] See, for instance, Walsh (1999), Mahadeva and Sterne (2002) and the first paper of the present dissertation.

Penalisation could, for instance, take the form of public embarrassment or, in a more formal way, a request for the resignation of the central bank governor. In these cases, the monetary policy game converges to an equilibrium because when the degree of misrepresentation is large, the central bank faces a severe punishment as well. In contrast, no exogenous penalisations are assumed in the present paper and all of the incentives that make transparency desirable or undesirable arise endogenously from the model.

This paper suggests that the central bank can find a way to communicate its intentions. The policymaker may announce inflation targets in a previous period to the one for which the target applies, when there is no yet information to predict future shocks and when it is late to incorporate new information into private sector inflation expectations that affect inflation of the period of announcement.[4] Without accurate information about upcoming shocks, there is not much opportunity to offset their effect on economic volatility and hence only the incentives to truthfully communicate the central bank's intentions remain. By disclosing information about its actual future target, the central bank improves future coordination between monetary policy and inflation expectations.

The analysis applies to different types of central bank announcements. The paper particularly focuses on short-run inflation targets and output and inflation forecasts. However, in the case of forecasts it would be very restrictive to assume that they are always released before the policymaker can be well informed about upcoming shocks since, in practice, new updated forecasts can be published as the time to observe the actual outcome approaches. In this case, an alternative solution is explored. The central bank may announce output and inflation forecasts at a late stage in the same period for which they apply. In this way forecasts can be accurate, because they incorporate information about anticipated shocks, but released when it is late to be incorporated into inflation expectations of the same period. Nevertheless, they are still useful because they are informative about the intentions of the policymaker for future periods.

Based on the implications of the model and in order to provide a first step for future empirical research, the paper examines the data on annual inflation target setting and finds no evidence against the hypothesis that central banks announce truthfully rather than strategically.

The remainder of the paper is organised as follows. Section 2 presents the model. Equilibrium is discussed in Section 3. Section 4 examines the empirical data. Section 5 concludes. Certain technical details are left to the appendix.

[4] In countries with low and stable inflation, the inflation target is constant and therefore known well in advance. In inflation-targeting countries that are currently disinflating and change their inflation targets every year (Colombia, Indonesia, Philippines, Romania and Turkey) the target for a reference year is known, on average, 5 quarters before the reference year starts. It does not imply, however, that under some special circumstances e.g. a global inflationary shock, the target cannot be revised later.

2 The Model

The model is a game between the central bank and the public. The former minimises inflation and output volatility and the latter intends to forecast inflation as accurately as possible. Every period, the central bank makes an announcement θ_t and, later in the same period, picks the monetary instrument m_t so as to minimise the expected value of the loss function

$$\Gamma_t = \lambda y_t^2 + (\pi_t - \pi_t^*)^2 \tag{1}$$

where y_t is the deviation of output with respect to its natural level, π_t is inflation, π_t^* is the implicit inflation target, $\lambda > 0$ is the relative weight on output stabilisation and the subscript t denotes the time period. Uncertainty about central bank preferences is modelled as uncertainty about the implicit target as in Tarkka and Mayes (1999) and Geraats (2005). Both papers analyse the impact on macroeconomic performance when the policymaker commits to truthfully revealing inflation and/or output forecasts, and hence there is economic transparency, as defined by Geraats (2002).

The implicit target changes over time as follows

$$\pi_t^* = \alpha\pi_{t-1}^* + (1-\alpha)\,\pi_0^* + \eta_t \tag{2}$$

where π_0^* is the long-run inflation target, which is exogenously given, $\alpha \in (0,1)$ and η_t is independently distributed with $E[\eta_t] = 0$ and $Var[\eta_t] = \sigma_\eta^2$. η_t is drawn at the beginning of the period and is only known to the central bank. For simplicity it is assumed that η_t is uncorrelated with other disturbances in the model. Equation (2) captures the empirical evidence that, as shown by paper 2 of this dissertation and Mahadeva and Sterne (2002), in countries with moderate to high inflation, there is persistence in short-run inflation targets.[5]

In order to simplify the assessment of social welfare it is assumed that the central bank's loss function is equal to society's loss. It should be noted that this assumption implies that changes in the implicit target will be a result of changes in the perceived optimal rate of inflation rather than a result of political pressure on the central bank by particular groups. As can be seen, (1) implies no inflation bias in the central bank's intentions.

Aggregate supply is described by an expectations-augmented Phillips equation:

$$\pi_t = \pi_t^e + y_t + s_t \tag{3}$$

where π_t^e represents inflation expectations and s_t is an aggregate supply shock. Aggregate demand is equal to the monetary instrument m_t plus an aggregate demand shock d_t:

$$y_t = m_t + d_t \tag{4}$$

[5] In the theoretical model of the first paper, the optimal short-run target was found to follow $\pi_t^* = \alpha_0 + \alpha_1\pi_{t-1} + (1-\alpha_1)\,\pi_0^*$ and realised inflation $\pi_t = \alpha_2 + \alpha_3\pi_{t-1} + (1-\alpha_3)\,\pi_0^* + \zeta_t$ where α_j, $j \in \{0,1,2,3\}$ are constant parameters and ζ is a control error. Using these two equations, their respective one-period-lagged versions and assuming there is no inflation bias ($\alpha_0 = \alpha_2 = 0$), it can be shown that π_t^* can be expressed as in (2) with $\alpha = \alpha_3$.

The variable m_t can be regarded as related to the negative of the interest rate or, alternatively, to the growth rate of the money supply. Aggregate shocks $\varepsilon_t \in \{s_t, d_t\}$ are separated into three different components, ε_t^p which is anticipated by both the central bank and the public, ε_t^b which is anticipated only by the central bank, and ε_t^u which is unanticipated by both the central bank and the public, where $\varepsilon_t = \varepsilon_t^p + \varepsilon_t^b + \varepsilon_t^u$. Each component is independently distributed with zero mean and $Var\left[\varepsilon_t^k\right] = \sigma_{\varepsilon^k}^2$, for $k \in \{p,\ b,\ u\}$. This separation allows for the analysis of different situations as particular cases of the model. For instance, when the central bank has perfect information $\varepsilon_t^u = 0$, $\forall t$ and $\sigma_{\varepsilon^u}^2 = 0$; and when both the central bank and the public are equally informed $\varepsilon_t^b = 0$, $\forall t$ and $\sigma_{\varepsilon^b}^2 = 0$. For ease of exposition, we collect the part of aggregated shocks that is anticipated by the central bank into a single term, such that $\varepsilon_t^{cb} = \varepsilon_t^p + \varepsilon_t^b$ and $\sigma_{\varepsilon^{cb}}^2 = \sigma_{\varepsilon^p}^2 + \sigma_{\varepsilon^b}^2$.

The timing for every period t is as follows:

(0) At the beginning of the period, η_t is drawn. It is only known to the central bank.

(1) The central bank makes an inflation announcement θ_t for period t.

(2) Private agents form inflation expectations π_t^e.

(3) The central bank sets the monetary instrument m_t.

(4) Shocks s_t, d_t and inflation π_t are realised.

3 Equilibrium

The model is solved by backward induction. In the third stage, the central bank sets the monetary instrument so as to minimise its expected loss function (1) subject to (3) and (4) and taking private sector inflation expectations as given. The solution to this problem implies

$$m_t = \frac{1}{1+\lambda}\left(\pi_t^* - \pi_t^e - s_t^{cb}\right) - d_t^{cb} \tag{5}$$

Substituting (4) and (5) into (3) yields

$$\pi_t = \frac{1}{1+\lambda}\left(\pi_t^* + \lambda\pi_t^e + \lambda s_t^{cb}\right) + s_t^u + d_t^u \tag{6}$$

Using (6) and rational expectations implies

$$\pi_t^e = E\left[\pi_t^* \mid I_t^p\right] + \lambda s_t^p \tag{7}$$

where I_t^p denotes the information set of private agents when they form inflation expectations, $I_t^p \equiv \left\{\lambda,\ \alpha,\ \pi_0^*,\ E\left[\eta_t\right],\ \sigma_\eta^2,\ \varepsilon_t^p,\ E\left[\varepsilon_t^k\right],\ \sigma_{\varepsilon^k}^2,\ \pi_{t-l},\ y_{t-l},\ m_{t-l}\right\}$ for $\varepsilon \in \{s, d\}$, $k \in \{p,\ b,\ u\}$ and $l \in \{1, 2, ..., t-1\}$.

3.1 Symmetric information

As a benchmark, the model is first solved for the case in which private information held by the central bank is truthfully revealed to the public and hence I_t^p includes π_t^*, s_t^b and d_t^b. From equations (4)-(7) we can obtain the following expressions for inflation expectations, realised inflation and the output gap, respectively:

$$\pi_t^e = \pi_t^* + \lambda s_t^{cb} \tag{8}$$

$$\pi_t = \pi_t^* + \lambda s_t^{cb} + s_t^u + d_t^u \tag{9}$$

$$y_t = -s_t^{cb} + d_t^u \tag{10}$$

Substituting expressions (9) and (10) into (1) and taking the unconditional expected value we find that for any period t, the expected loss function for the symmetric information (SI) case is

$$E\left[\Gamma_t^{SI}\right] = (1+\lambda)\left(\sigma_{d^u}^2 + \lambda\sigma_{s^{cb}}^2\right) + \sigma_{s^u}^2 \tag{11}$$

Society's loss is increasing in the economic volatility associated with the variance of the unanticipated demand shock and the variance of all of the components of the aggregate supply shock.

3.2 Asymmetric information

This section analyses the model described by equations in section 2, allowing for the possibility that the central bank may be better informed than the private sector about the implicit inflation target and about demand and supply shocks. Three scenarios are considered. The first one corresponds to the model with no inflation announcements. By comparing this case to the one with symmetric information, we determine a sufficient condition under which transparency is preferred over secrecy. The second scenario incorporates inflation announcements into the model and shows that there is no rational expectations equilibrium with inflation announcements when the central bank has incentives to misrepresent private information. The third scenario provides a solution to this problem. It analyses the case in which the central bank communicates information about inflation targets and forecasts when inflation expectations of the period of announcement are already formed but there is not yet information about shocks of future periods. In this case an equilibrium exists and inflation announcements are still informative about the central bank's intentions for future periods.

3.2.1 No inflation announcements

Let us begin with the case in which there are no announcements (NA) in a two-period setup. In the second period, since private agents do not know π_2^*, they have to estimate its value from their information set I_2^p that includes the inflation outcome π_1, the monetary instrument m_1 and the output gap y_1. This implies, using equations (4)-(7),

$$\pi_2^e = \widehat{\pi}_{2|2}^* + \lambda s_2^p \tag{12}$$

$$\pi_2 = \pi_2^* + \lambda s_2^p + \frac{\lambda}{1+\lambda}\left(\widehat{\pi}_{2|2}^* - \pi_2^* + s_2^b\right) + s_2^u + d_2^u \tag{13}$$

$$y_2 = -s_2^p - \frac{1}{1+\lambda}\left(\widehat{\pi}_{2|2}^* - \pi_2^* + s_2^b\right) + d_2^u \tag{14}$$

where $\widehat{\pi}_{2|2}^* \equiv E\left(\pi_2^* \mid I_2^p\right)$. For simplicity of notation we will henceforth denote by $\widehat{r}_{T|t}$ the expected value of any variable r_T conditional on the information set available to the public in period t, (i.e. $\widehat{r}_{T|t} \equiv E\left(r_T \mid I_t^p\right)$). Notice that even if private agents could perfectly estimate the implicit target ($\widehat{\pi}_{2|2}^* = \pi_2^*$), equations (12)-(14) would not be equal to (8)-(10) because there would still be asymmetric information about s_t^b. Using equation (2) for periods one and two, it can be seen that

$$\pi_2^* = \pi_0^* + \alpha\eta_1 + \eta_2 \tag{15}$$

Taking the expected value conditional on I_2^p gives

$$\widehat{\pi}_{2|2}^* = \pi_0^* + \alpha\widehat{\eta}_{1|2} \tag{16}$$

To estimate η_1, the public constructs three signal variables using π_1, y_1, and m_1.[6] Substituting expressions (13)-(16) into (1) and taking the unconditional expected value produces

$$E\left[\Gamma_2^{NA}\right] = (1+\lambda)\left(\sigma_{d^u}^2 + \lambda\sigma_{s^p}^2\right) + \sigma_{s^u}^2 + \frac{\lambda}{1+\lambda}\left(\sigma_{s^b}^2 + \sigma_\eta^2 + \alpha^2\mu_1\right) \tag{17}$$

where μ_1 is the mean square error of $\widehat{\eta}_{1|2}$, (i.e. $\mu_1 \equiv E\left[\left(\widehat{\eta}_{1|2} - \eta_1\right)^2\right]$). Comparing (11) and (17), it can be seen that with asymmetric information uncertainty about the implicit target ($\sigma_\eta^2 + \alpha^2\mu_1$) increases the expected loss but the effect of the supply shock s_2^b on economic volatility is mitigated. The final result, on the expected loss, of these two contrary effects is formally analysed below in Proposition 1.

In period one the central bank takes into account that its policy instrument m_1 affects the estimator of the implicit target in period two. Therefore, the central bank picks m_1 with two purposes; first, to reduce the volatility that stems from shocks in the same period, and second, to reduce uncertainty about its intentions in period two. In the third stage of period one, the problem for the central bank is minimising

$$\begin{gathered} E\left[\Gamma_1 \mid I_{1(3)}^{cb}\right] + \beta\left[(1+\lambda)\left(\sigma_{d^u}^2 + \lambda\sigma_{s^p}^2\right) + \sigma_{s^u}^2\right] \\ + \beta\tfrac{\lambda}{1+\lambda}\left\{\left(\sigma_{s^b}^2 + \sigma_\eta^2\right) + \alpha^2 E\left[\left(\widehat{\eta}_{1|2} - \eta_1\right)^2 \mid I_{1(3)}^{cb}\right]\right\} \end{gathered} \tag{18}$$

with respect to m_1, where $\beta \in (0,1)$ is the discount factor and $I_{1(3)}^{cb}$ represents the information set of the central bank in period one at the moment of deciding upon the

[6] The public is not able to perfectly infer η_1 from I_2^p because the problem implies a system of three equations, one from each variable π_1, y_1 and m_1 in five unknowns s_1^b, s_1^u, d_1^b, d_1^u and η_1. Appendix A analyses the solution for period one and shows the three equations of the system, (49)-(51).

monetary instrument, i.e. in the third stage. Solving this problem implies cumbersome and non-illuminating algebra. For the purpose of this paper it is sufficient to know that, as shown in Appendix A, the solution implies

$$\pi_1 = \pi_0^* + \lambda s_1^p + c_1 d_1^b + c_2 s_1^b + c_3 \eta_1 + s_1^u + d_1^u \tag{19}$$

$$y_1 = -s_1^p + c_1 d_1^b - (1 - c_2) s_1^b + c_3 \eta_1 + d_1^u \tag{20}$$

where c_1, c_2 and c_3 are constant parameters. Comparing equations (13)-(14) to (19)-(20), it can be seen that unlike period two, inflation and the output gap in period one are affected by the anticipated demand shock d^b (Appendix A proves that $c_1 > 0$). As explained by Geraats (2000), a central bank that operates under opaqueness, restrains its stabilisation efforts to make the monetary instrument a better signal of its intentions. In the second and last period, there is no concern about improving the public's knowledge of the central bank's intentions for the future, and therefore there are no restrictions in setting monetary policy so as to fully respond to anticipated demand shocks. In period one, as mentioned above, there exist two different and not entirely compatible purposes for choosing m_1, and therefore flexibility of monetary policy is reduced. In period one, it is optimal to allow d_1^b to have some effect on the economy in order to pass on to the public some information about this shock and, in that way, to reduce μ_1 i.e. the mean square error of the estimator $\widehat{\eta}_{1|2}$.

From the same equations, (13)-(14) and (19)-(20), we can also state that with no announcements (NA), asymmetric information about the implicit target affects neither expected inflation nor the expected output gap, $E\left[\pi_t^{NA}\right] = E\left[\pi_t^{SI}\right] = \pi_0^*$ and $E\left[y_t^{NA}\right] = E\left[y_t^{SI}\right] = 0$ for $t \in \{1, 2\}$. However, as can be inferred from Proposition 1 below, uncertainty about the implicit target affects volatility in the economy and may either increase or reduce social welfare with respect to the symmetric information case.

Proposition 1 *When there is asymmetric information about the implicit target π_t^* and the supply shock s_t^b,*

(i) If volatility that stems from uncertainty about the implicit target shock (σ_η^2) is large enough relative to volatility caused by the effect on inflation expectations of revealing the supply shock s_b, society's welfare with symmetric information is higher than that with no announcements. Therefore, full transparency is socially beneficial. Formally, $E\left[\Gamma_t^{NA}\right] > E\left[\Gamma_t^{SI}\right]$ for $t \in \{1, 2\}$, if

$$\lambda (2 + \lambda) \sigma_{s^b}^2 < \sigma_\eta^2 \tag{21}$$

(ii) For the limiting case in which the implicit target shock η_t does not vary over time ($\sigma_\eta^2 = 0$), it is better for the policymaker to be opaque i.e. $E\left[\Gamma_t^{NA}\right]_{\sigma_\eta^2=0} \leq E\left[\Gamma_t^{SI}\right]$ for $t \in \{1, 2\}$.

Proof. First notice that since $E\left[\Gamma_t^{SI}\right]$ does not depend on decisions from previous periods then (11) applies to any period t. Also recall that $\sigma^2_{s^{cb}} = \sigma^2_{s^p} + \sigma^2_{s^b}$.

Part (i): Assume that (21) holds. By comparing (11) and (17), $E\left[\Gamma_2^{NA}\right] > E\left[\Gamma_2^{SI}\right]$. To compare the expected loss in period one, let m_{1*} be the solution to the minimisation of (18) when the central bank does not care about the future (i.e. $\beta = 0$). For this particular case,

$$E\left[\Gamma_1^{NA}\left(m_{1*}\right)\right] = (1+\lambda)\left(\sigma^2_{d^u} + \lambda\sigma^2_{s^p}\right) + \sigma^2_{s^u} + \frac{\lambda}{1+\lambda}\left(\sigma^2_{s^b} + \sigma^2_{\eta}\right) \tag{22}$$

By definition $E\left[\Gamma_1^{NA}\left(m_{1*}\right)\right] \leq E\left[\Gamma_1^{NA}\right]$. Comparing (22) to (11), we can see that $E\left[\Gamma_1^{NA}\left(m_{1*}\right)\right] > E\left[\Gamma_1^{SI}\right]$ (if and only if (21) holds). Therefore, $E\left[\Gamma_1^{NA}\right] > E\left[\Gamma_1^{SI}\right]$.

Part (ii): Note that since private agents know $E\left[\eta_t\right]$, by making $\sigma^2_{\eta} = 0$ we are eliminating uncertainty about π_t^*, and therefore information from the past is no longer useful to private agents. Solving the one-period model is enough to obtain the solution for any period. The expected loss is

$$E\left[\Gamma_t^{NA}\right]_{\sigma^2_{\eta}=0} = (1+\lambda)\left(\sigma^2_{d^u} + \lambda\sigma^2_{s^p}\right) + \sigma^2_{s^u} + \frac{\lambda}{1+\lambda}\sigma^2_{s^b} \tag{23}$$

The statement in the proposition follows from comparing (23) to (11). ■

Part (i) of Proposition 1 points out that if the informational advantage of the central bank about the supply shock is small relative to uncertainty about the central bank's intentions (and hence $\sigma^2_{s^b}$ is small relative to σ^2_{η}), it is better for the policymaker to be transparent because the cost of disclosing her private information about the supply shock would be smaller than the benefit from communicating the implicit inflation target. Since condition (21) is sufficient but not necessary, we cannot directly state that if it is not satisfied then secrecy outperforms transparency. However, as remarked by part (ii), when the variance of the implicit target shock η_t approaches zero, the central bank prefers secrecy over full transparency.

So far, to analyse the impact of inflation announcements on society's welfare we have assumed that the central bank either commits to truthfully reveal all of its private information or discloses nothing. However, using the results above we can show that partial transparency is preferred to both secrecy and full transparency. It is not difficult to see that if, rather than making $\sigma^2_{\eta} = 0$, we assume that η_t varies over time but is known to the public, the expected loss does not change and hence it is equal to the right-hand side of (23). Therefore, from part (ii) of Proposition 1 we can state that it is a better strategy for the policymaker to commit to reveal only the implicit target rather than all of its private information because the latter includes information about the supply shock which increases inflation expectations volatility. This is in the spirit of Geraats (2007) who concludes that the optimal communication strategy for the central bank is to be clear about the inflation target but ambiguous about supply shocks. In order to see that revealing only the implicit target is preferred over secrecy we can verify that $E\left[\Gamma_t^{NA}\right]_{\sigma^2_{\eta}=0} \leq E\left[\Gamma_t^{NA}\right]$ for $t \in \{1, 2\}$ by comparing (23) to (17) and (22).

The next section explores the strategic aspect of central bank inflation announcements. By manipulating inflation expectations, the central bank might reduce economic volatility, and therefore it has incentives to misrepresent private information.

3.2.2 Announcements

As mentioned in section 1, Stein (1989) remarks that the central bank is unable to communicate its private information by making precise announcements. He points out that if the central bank's announcement were believed by the public, the policymaker would misrepresent private information, and therefore the announcement would turn out to be noncredible.

Using the model described in section 2 this section analyses, as Stein does, the credibility problem of announcements when the central bank has incentives to misrepresent private information and, unlike Stein, extends the analysis to formally incorporate the possibility that the public tries to extract some information from the inflation announcement, even if the central banks acts strategically. If private agents know that the central bank has incentives to lie, they will not take the announcement at face value, but they can still try to use it to enhance their information set. The result obtained, as shown below, is that there is no rational expectations equilibrium for the model with inflation announcements. Since the central bank knows the private sector's reaction, the policymaker adjusts the announcement accordingly so as to be able to still deceive private agents; but they also foresee this new adjustment and the central bank again anticipates their new reaction and so on... ad infinitum and without convergence to an equilibrium with inflation announcements.

In order to distinguish between the case in which there are announcements from that in which there are not, the next definition indicates when a public statement provides useful information to forecast inflation, and hence can be regarded as an inflation announcement.

Definition 1. *A public statement made by the central bank in period t is an inflation announcement θ_t only if it is correlated with any piece of information that is not known to private agents but is relevant to forecast inflation in the same period or in future periods.*

If, for instance, the policymaker announced s_t^p, it would be equivalent to the case with no announcements as s_t^p is already known by private agents, and hence publishing its value does not provide any additional information in forecasting inflation.

Given Definition 1, we look for an answer to the question whether there is a rational expectations equilibrium in the model with announcements. The present section shows that there is no equilibrium in a one-period setup. Appendix B shows that if this equilibrium existed in a multi-period setup, it would be equal to that for the one-period model. The intuition is that in this equilibrium, the central bank's expected loss of any period t would depend on decisions made only in the same period.[7] As a result, every period the central bank can act as if it were the only one.

In the third stage, the central bank minimises (1) with respect to the monetary instrument m_t. As has been already shown, it implies that m_t follows (5) and that, consequently, inflation can be expressed by (6). In the second stage, private agents form inflation expectations π_t^e. Using (6) and rational expectations implies that $\pi_t^e = E\left[\pi_t^* \mid I_t^p\right] + \lambda E\left[s_t^{cb} \mid I_t^p\right]$. The inflation announcement θ_t is incorporated into I_t^p so we need to distinguish the private agents' estimator before and after knowing θ_t. Let $\widehat{r}_{t(0)}$ be the estimator of any variable r_t conditional on the information set available to the public in period t, before knowing θ_t i.e. before the first stage. Taking into account the private sector's information set and for analytical convenience, we can express π_t^e in the following form:

$$\pi_t^e = \widehat{\pi}_{t(0)}^* + E\left[\pi_t^* - \widehat{\pi}_{t(0)}^* \mid \theta_t\right] + \lambda\left(s_t^p + E\left[s_t^b \mid \theta_t\right]\right) \tag{24}$$

In the first stage, the central bank minimises (1) with respect to θ_t, which affects the loss function through its effect on inflation expectations. Substituting (3)-(5) into (1) and taking the expected value conditional on the information set of the central bank yields

$$E\left[\Gamma_t \mid I_{t(1)}^{cb}\right] = (1+\lambda)\,\sigma_{d^u}^2 + \sigma_{s^u}^2 + \frac{\lambda}{1+\lambda}\left(\pi_t^e - \pi_t^* + s_t^{cb}\right)^2 \tag{25}$$

where $I_{t(1)}^{cb}$ represents the information set of the central bank in the first stage.

We do not yet know the explicit functional form of (24). Assuming that $\pi_t^* - \widehat{\pi}_{t(0)}^*$ and s_t^b are normally distributed, it is shown below that $E\left[\pi_t^* - \widehat{\pi}_{t(0)}^* \mid \theta_t\right]$ and $E\left[s_t^b \mid \theta_t\right]$ are linear functions in θ_t, $\widehat{\pi}_{t(0)}^*$ and s_t^p. Therefore, we can consistently assume that minimising (25) implies a solution for θ_t that is linear in π_t^*, s_t^b, s_t^p and $\widehat{\pi}_{t(0)}^*$ and that, accordingly, π_t^e takes the form

$$\pi_t^e = a_0 + a_\theta \theta_t + a_s s_t^p + a_{\pi^*}\widehat{\pi}_{t(0)}^* \tag{26}$$

where a_i for $i \in \{0, \theta, s, \pi^*\}$ are constants to be determined. Using (26), minimising (25) implies

$$\theta_t = \frac{\left(\pi_t^* - \widehat{\pi}_{t(0)}^*\right) - a_0 - (1+a_s)\,s_t^p - s_t^b + (1-a_{\pi^*})\,\widehat{\pi}_{t(0)}^*}{a_\theta} \tag{27}$$

for $a_\theta \neq 0$. Equation (27) shows that θ_t is correlated with both the forecast error $\pi_t^* - \widehat{\pi}_{t(0)}^*$ and s_t^b which are unobserved variables to the public, and hence following Definition 1 we can state that θ_t is an inflation announcement. Substituting (27) into (26) implies $\pi_t^e = \pi_t^* - s_t^{cb}$ and then substituting this result into (6) yields $\pi_t = \pi_t^* + s_t^u + d_t^u$. The announcement θ_t intends to influence inflation expectations in such a way that

[7] This is unlike the expected loss for the case with no announcements in which, as shown in section 3.2.1, the decision about the monetary instrument in period one (m_1) affects the expected loss of period two.

their effect on inflation offsets the effect of the anticipated supply shock s_t^{cb}. Therefore, realised inflation deviates from the implicit target only as a result of unanticipated shocks.

In order to determine parameters in equation (26) we proceed as follows. Since private agents know that the central bank announces θ_t following (27), they can construct a signal $x(\theta_t)$,

$$x(\theta_t) \equiv a_0 + a_\theta \theta_t + (1 + a_s) s_t^p - (1 - a_{\pi^*}) \widehat{\pi}_{t(0)}^* = \pi_t^* - \widehat{\pi}_{t(0)}^* - s_t^b \tag{28}$$

The right-hand side of the equality represents a noisy signal of $\pi_t^* - \widehat{\pi}_{t(0)}^*$ and s_t^b because private agents are not able to perfectly separate one variable from the other. The left-hand side provides the way in which this signal can be constructed by using variables that are known to the public. Finding $E\left[\pi_t^* - \widehat{\pi}_{t(0)}^* \mid \theta_t\right]$ and $E\left[s_t^b \mid \theta_t\right]$ represents a signal extraction problem as described by Harvey and De Rossi (2006, p. 970). Notice that since the forecast error $\pi_t^* - \widehat{\pi}_{t(0)}^*$ only depends on η_t and past information, it is uncorrelated with s_t^b. From a standard lemma on the multivariate normal distribution (Harvey, 1989, p. 165), the estimators are

$$E\left[\pi_t^* - \widehat{\pi}_{t(0)}^* \mid \theta_t\right] = \gamma x(\theta_t) \tag{29}$$

$$E\left[s_t^b \mid \theta_t\right] = -(1 - \gamma) x(\theta_t) \tag{30}$$

where $\gamma = \frac{1}{1+\sigma_{s^b}^2/MSE\left[\widehat{\pi}_{t(0)}^*\right]} \in (0,1)$ can be interpreted as a signal-to-noise ratio and $MSE\left[\widehat{\pi}_{t(0)}^*\right]$ is the mean square error of the estimator $\widehat{\pi}_{t(0)}^*$. The higher (lower) the variance $\sigma_{s^b}^2$ relative to the $MSE\left[\widehat{\pi}_{t(0)}^*\right]$, the noisier (better) the signal $x(\theta_t)$ for estimating $\pi_t^* - \widehat{\pi}_{t(0)}^*$ but the better (noisier) for estimating s_t^b. Substituting (28)-(30) into (24) and comparing the result to (26) we obtain the following system of equations:

$$a_0 = a_0 [\gamma - \lambda(1 - \gamma)]$$

$$a_\theta = a_\theta [\gamma - \lambda(1 - \gamma)]$$

$$a_s = \lambda + (1 + a_s)[\gamma - \lambda(1 - \gamma)]$$

$$a_{\pi^*} = 1 + (a_{\pi^*} - 1)[\gamma - \lambda(1 - \gamma)]$$

The only equilibrium to this system requires that $a_\theta = 0$, which implies that, from (27), θ_t is undefined.[8] Making $a_\theta = 0$, means that agents do not include θ_t as a relevant variable to forecast inflation. Taking into account Definition 1, this only occurs when there is no inflation announcement, and therefore it does not exist a rational expectations equilibrium with inflation announcements in this monetary policy game.

This problem does not arise under commitment to truthful communications. When the central bank commits to publish its actual inflation target or inflation forecast every period at stage one, private agents directly incorporate the announcement into their

[8]Note that since $\gamma \in (0,1)$ and $\lambda > 0$, $\gamma - \lambda(1 - \gamma) < 1$.

information set with no need to anticipate any strategic behaviour on the policymaker's part. In the case of the inflation target, private agents simply assume that the central bank is truthfully revealing the implicit target, and therefore they set $\widehat{\pi}^*_{t(2)} = \theta_t$. Similarly, in the case of an inflation forecast, private agents trust the inflation announcement and set $\pi^e_t = \theta_t$. How can the public verify that the central bank is indeed fulfilling this commitment? It is difficult to do so because the inflation outcome and changes in the monetary instrument depend on central bank preferences and forecasts of shocks that cannot be directly observed. To show its willingness to stick to the commitment, the central bank has to release, in addition to the inflation target or forecast, enough information to allow agents to determine that the inflation announcement is not affected by any intention to manipulate expectations. For instance, some central banks (e.g. Colombia, Hungary, UK) include in their inflation reports some inflation forecasts calculated by other (national or international) independent organisations.

3.2.3 Late inflation announcements

To solve the inability of the central bank to communicate its intentions, the policymaker can make inflation announcements 'late' in the period, when inflation expectations of the same period are already formed but there is not yet information about future shocks. With no information about upcoming shocks, it is not possible to know with certainty the direction that inflation expectations of future periods should take to reduce future economic volatility. In this case, misleading expectations would only increase expected volatility, and hence there are no incentives to misrepresent private information. Despite being announced at a late stage of the period, inflation announcements are still useful because they are informative about the central bank's future intentions, and therefore they enhance communication with the public and improves the predictability of monetary policy.

In practice inflation targets are known, in general, before the reference period for which they apply.[9] We then assume that an inflation target θ_t, for period t, is announced at a late stage in period $t-1$. This assumption is important to obtain the condition derived in the empirical section for late inflation announcements (no correlation between $\pi_t - \theta_t$ and θ_t). However, the results presented in this section would not change if, instead, we assume that the inflation target is announced late in the same period for which it applies.

As commented in section 1, in the case of forecasts it would be restrictive to assume that they are always released before information about upcoming shocks is available since, in practice, updated forecasts can be published as the time to observe the actual outcome approaches. In order to allow for the possibility that inflation announcements may incorporate anticipated information about aggregate shocks, we assume that a forecast θ_t for period t, is announced at a late stage in the same period.

[9] As commented in footnote 4, in countries with low inflation the inflation target is constant and known well in advance. In countries with moderate to high inflation, which change their inflation targets every year, the annual target is known, on average, 5 quarters before the reference year starts.

The game is analysed in a two-period setup. In terms of the timing for every single period, we are switching places between the first and the second stage. The timing now is described as follows (cf. section 2)[10]

(0) At the beginning of the period, η_t is drawn. It is only known to the central bank.

(1) Private agents form inflation expectations π_t^e.

(2) The central bank announces $\theta_{t+1|t}$, an inflation target for period $t+1$ or θ_t, an inflation forecast for period t.

(3) The central bank sets the monetary instrument m_t.

(4) Shocks s_t, d_t and inflation π_t are realised.

Let us first focus on the case in which the central bank announces inflation targets. Notice that the timing above implies that the public's information set in period t does not include the inflation announcement made in the same period, $\theta_{t+1|t}$, but includes the one made in the previous period, $\theta_{t|t-1}$. To keep this fact in mind, we will write $I^p_{t,\theta_{t|t-1}}$ when referring to the public's information set in t.

In the second period, the monetary instrument is set following (5). Because it is the last period, there is no inflation target announcement at the second stage. Inflation expectations are based on $I^p_{2,\theta_{2|1}}$. Using (6) and rational expectations, we can express

$$\pi_2^e = E\left[\pi_2^* \mid I^p_{2,\theta_{2|1}}\right] + \lambda s_2^p \tag{31}$$

At the moment of announcing $\theta_{2|1}$, the central bank is not able to anticipate shocks of period two. Therefore, as confirmed below, private agents can consistently assume that there is truthful communication and that it is possible to obtain the best estimation of π_2^* from $\theta_{2|1}$. Then private agents follow

$$E\left[\pi_2^* \mid I^p_{2,\theta_{2|1}}\right] = \theta_{2|1} \tag{32}$$

Substituting (4)-(6), (31) and (32) into (1) and taking the expected value conditional on the information available to the central bank we obtain

$$E\left[\Gamma_2 \mid I^{cb}_{2(0)}\right] = (1+\lambda)\,\sigma^2_{d^u} + \sigma^2_{s^u} + \frac{\lambda}{1+\lambda}\left(\theta_{2|1} + \lambda s_2^p - \pi_2^* + s_2^{cb}\right)^2 \tag{33}$$

where $I^{cb}_{2(0)}$ represents the information set of the central bank at the beginning of period two. In the third stage of period one the central bank minimises

$$E\left[\Gamma_1 + \beta E\left[\Gamma_2 \mid I^{cb}_{2(0)}\right] \mid I^{cb}_{1(3)}\right]$$

[10] Alternatively, the stage for the inflation announcement could be the third one and the result would be the same.

with respect to m_1. Since, from (33), $E\left[\Gamma_2 \mid I_{2(0)}^{cb}\right]$ does not depend on m_1, the policy reaction takes the same form again (equation (5)). In the second stage, expectations are already formed, and therefore cannot be affected by the inflation announcement $\theta_{2|1}$. As a result, Γ_1 does not depend on $\theta_{2|1}$ either. Consequently, just Γ_2 is relevant for the decision in the second stage. In this stage, the central bank minimises

$$\begin{aligned} E\left[\Gamma_2 \mid I_{1(2)}^{cb}\right] &= (1+\lambda)\left(\sigma_{d^u}^2 + \lambda\sigma_{s^p}^2\right) + \sigma_{s^u}^2 + \\ &\quad \frac{\lambda}{1+\lambda}\left[\sigma_{s^b}^2 + \sigma_\eta^2 + \left(\theta_{2|1} - \alpha\pi_1^* - (1-\alpha)\pi_0^*\right)^2\right] \end{aligned}$$

with respect to $\theta_{2|1}$. The solution to this problem implies

$$\theta_{2|1} = \alpha\pi_1^* + (1-\alpha)\pi_0^* \tag{34}$$

The inflation target announced $\theta_{2|1}$, turns out to be the best possible estimation of the implicit target for period two, which is the right-hand side of (34) since the central bank cannot anticipate η_2 in period one. It should be noted that although (34) corresponds to truthful communication because the central bank is publishing its actual estimation of the implicit target for the next period, it is not equivalent to full transparency because no private information is disclosed at the beginning of the period despite the fact that it is available to the central bank and relevant to forecast inflation in the same period.

In periods one and two, inflation expectations, realised inflation and the output gap follow

$$\pi_t^e = \alpha\pi_{t-1}^* + (1-\alpha)\pi_0^* + \lambda s_t^p \tag{35}$$

$$\pi_t = \pi_t^* + \lambda s_t^p + \frac{\lambda}{1+\lambda}\left(s_t^b - \eta_t\right) + s_t^u + d_t^u \tag{36}$$

$$y_t = -s_t^p - \frac{1}{1+\lambda}\left(s_t^b - \eta_t\right) + d_t^u \tag{37}$$

Notice that equations (35)-(36) are similar to those for the case with no announcements (NA), (12)-(14). They would be equal if in the NA case there were perfect information about the implicit target of period $t-1$, so that the implicit target forecast error of period t would be $\pi_t^* - \widehat{\pi}_{t|t}^* = \eta_t$. As in the NA case, with late announcements (LA) neither expected inflation nor the expected output gap are affected by inflation announcements. For any period $t \in \{1,2\}$, $E\left[\pi_t^{LA}\right] = \pi_0^*$ and $E\left[y_t^{LA}\right] = 0$. However, more interesting results are obtained when comparing the LA case to the other cases (SI and NA) in terms of economic volatility, and hence in terms of social welfare. The expected loss function for $t \in \{1,2\}$ is

$$E\left[\Gamma_t^{LA}\right] = (1+\lambda)\left(\sigma_{d^u}^2 + \lambda\sigma_{s^p}^2\right) + \sigma_{s^u}^2 + \frac{\lambda}{1+\lambda}\left(\sigma_{s^b}^2 + \sigma_\eta^2\right) \tag{38}$$

Let us start by assuming again that the central bank can find a mechanism to credibly commit to full transparency. The question arises whether the policymaker prefers revealing all of its private information at the beginning of the period as compared to making late announcements. Proposition 2 gives us the condition under which the former is preferred over the latter.

Proposition 2 *When there is asymmetric information about the implicit target π_t^* and the supply shock s_t^b and the central bank announces, late in period $t-1$, an inflation target for period t,*

(i) If, and only if, volatility that stems from uncertainty about the implicit target shock (σ_η^2) is large enough relative to volatility caused by the effect on inflation expectations of revealing s_t^b, society's welfare with symmetric information is higher than that with late announcements, and therefore full transparency is socially preferred to late announcements. Formally, $E\left[\Gamma_t^{LA}\right] > E\left[\Gamma_t^{SI}\right]$ for $t \in \{1,2\}$, if and only if (21) holds.

(ii) Society is better off with late announcements than with no announcements, i.e. $E\left[\Gamma_t^{LA}\right] \leq E\left[\Gamma_t^{NA}\right]$ for $t \in \{1,2\}$.

Proof.

Part (i): By comparing (11) to (38).

Part (ii): By comparing (17) to (38), $E\left[\Gamma_2^{LA}\right] \leq E\left[\Gamma_2^{NA}\right]$. With regard to period one, as in the proof for Proposition 1, let m_{1*} be the solution to the minimisation of (18) when $\beta = 0$. By comparing (22) to (38), $E\left[\Gamma_1^{NA}(m_{1*})\right] = E\left[\Gamma_1^{LA}\right]$. By definition $E\left[\Gamma_1^{NA}(m_{1*})\right] \leq E\left[\Gamma_1^{NA}\right]$. Therefore $E\left[\Gamma_1^{LA}\right] \leq E\left[\Gamma_1^{NA}\right]$. ■

Although late inflation announcements communicate the implicit target of period $t-1$ and, in that way, the estimation of the target in period t is enhanced, the latter cannot yet be perfectly forecasted because there is still uncertainty about η_t. From part (i) of Proposition 2 we can state that if the policymaker is able to credibly commit to full transparency and if volatility that stems from uncertainty about η_t is significant relative to volatility caused by disclosing private information about the supply shock s_t^b, the central bank prefers full transparency over late inflation announcements. If, instead, volatility that stems from revealing s_t^b is large enough, the central bank prefers late inflation announcements. Nonetheless, partial transparency remains a better strategy. If the policymaker can credibly commit to reveal only the implicit target at the beginning of each period, society is better off than with late inflation announcements, as can be seen by comparing (23) to (38).[11]

On the other hand, if the central bank cannot find a mechanism to credibly commit to reveal private information at the beginning of the period, then we are more interested in comparing the case with late inflation announcements to the one with no inflation announcements. Part (ii) of Proposition 2 shows that society prefers the former to the latter. The intuition behind this result is as follows. Without inflation announcements there is only one policy instrument (m_1) for the two purposes mentioned in section 3.2.1, namely, (I) reducing volatility that stems from economic shocks in the first period and (II) reducing volatility that stems from uncertainty about the central bank's intentions

[11] Recall that (23) applies as well to the case in which we assume that η varies over time but is known to the public.

in the second period and, accordingly, giving a good signal of π_2^*. Since these two purposes are not entirely compatible, giving the public the best possible estimation of π_2^* would have to be done at the cost of not responding optimally to shocks in period one. In contrast, with late announcements the central bank has one additional instrument, the inflation announcement $\theta_{2|1}$, to reveal the best estimation of the implicit target π_2^* without compromising its ability to respond to shocks in the first period.

Appendix C shows that it is straightforward to extend the model to the infinite horizon. Results are the same, namely, the inflation announcement is the best possible estimation of the implicit target of the next period; inflation expectations, realised inflation and the output gap follow (35)-(36); and the expected loss function for any period t is equal to (38).

Now consider the case in which the central bank announces, at a late stage of period one, an inflation forecast for the same period. In this case some additional issues arise. If the actual inflation forecast is the only announcement, it is not possible for private agents to extract the implicit target π_1^*. The problem stems from the fact that the inflation forecast includes information about the supply shock s_t^b which is unanticipated by the public. Consequently, the best that the public can do with the available information set is to construct a noisy signal of the implicit target.[12] In this case, as in the one with no announcements, the central bank would set m_1 with the additional purpose of reducing uncertainty about the implicit target in period two, at the cost of not responding optimally to shocks in period one.

Alternatively, the central bank can announce an inflation forecast using only information about shocks that are anticipated by the public. Accordingly, the inflation forecast in period one is $\theta_1 = \pi_1^* + \lambda s_t^p$ and, in period two, agents can infer the value of π_1^*. To estimate π_2^* they follow $E\left[\pi_2^* \mid I_{2,\theta_1}^p\right] = \alpha\left(\theta_1 - \lambda s_t^p\right) + (1-\alpha)\,\pi_0^*$. In this case the rest of the solution is as described above for the inflation target announcement. However, since this inflation announcement does not incorporate any information about s_t^b, it is not the actual inflation forecast of the central bank.

If the central bank releases its actual inflation forecast, it also needs to disclose additional information: namely, the output forecast (as in Geraats 2005), to make it possible for the public to infer π_1^* perfectly. The remainder of this section assumes that the central bank commits to truthfully release the actual output and inflation forecasts at a late stage of each period, and then shows that this commitment is credible because there are no incentives for the policymaker to act strategically. To distinguish one forecast from the other, let us denote the inflation forecast by θ_t^π and the output forecast by θ_t^y. When referring to both, Θ_t will be used. If actual forecasts are revealed, the private sector can deduce π_1^* as follows. Taking into account that the central bank observes neither s_1^u nor d_1^u, the public can derive s_1^b from (3), $s_1^b = \theta_1^\pi - \pi_1^e - \theta_1^y - s_1^p$, and d_1^b from (4), $d_1^b = \theta_1^y - m_1 - d_1^p$. Finally, substituting these two equations into (5)

[12] Formally, private agents cannot perfectly deduce π_1^* because they have four pieces of information $(y_1,\, \pi_1,\, m_1,\, \theta_1)$ that represent a system of four equations in five unknowns $(s_1^b,\, s_1^u,\, d_1^b,\, d_1^u,\, \pi_1^*)$ with infinite possible solutions for π_1^*.

and solving for π_1^* yields

$$\pi_1^* = \theta_1^\pi + \lambda\theta_1^y \tag{39}$$

Alternatively, from equations (4)-(6) we can express the central bank's actual forecasts of inflation and output in the following way:

$$\theta_1^\pi = \frac{1}{1+\lambda}\left(\pi_1^* + \lambda\pi_1^e + \lambda s_1^{cb}\right)$$

$$\theta_1^y = \frac{1}{1+\lambda}\left(\pi_1^* - \pi_1^e - s_1^{cb}\right)$$

Using these expressions it can then be confirmed that (39) holds. The question arises whether the policymaker can credibly commit to release the actual output and inflation forecasts. We are interested in knowing whether there is a strategy better than truth-telling for the central bank when agents follow $E\left[\pi_1^* \mid I_{2,\Theta_1}^p\right] = \theta_1^\pi + \lambda\theta_1^y$, and therefore $E\left[\pi_2^* \mid I_{2,\Theta_1}^p\right] = \alpha\left(\theta_1^\pi + \lambda\theta_1^y\right) + (1-\alpha)\pi_0^*$. As in the case of the inflation target announcement, just Γ_2 is relevant for the decision in the second stage of period one. The central bank minimises

$$E\left[\Gamma_2 \mid I_{1(2)}^{cb}\right] = (1+\lambda)\left(\sigma_{d^u}^2 + \lambda\sigma_{s^p}^2\right) + \sigma_{s^u}^2 + \frac{\lambda}{1+\lambda}\left[\sigma_{s^b}^2 + \sigma_\eta^2 + \alpha^2\left(\theta_1^\pi + \lambda\theta_1^y - \pi_1^*\right)^2\right]$$

with respect to Θ_1. It is straightforward to see that the first order conditions of the problem can be expressed by only one equation which is, in fact, equal to (39). The optimal strategy for the central bank, in period one, is disclosing forecasts Θ_1 so that the private sector can perfectly deduce, in period two, the implicit target π_1^* and in that way the estimation of π_2^* is enhanced. Revealing actual forecasts is optimal and, thus, there is no other strategy that can be strictly preferred to truth-telling, although it has also to be noted that there exist other strategies that are equally preferred (e.g. announcing $\theta_1^\pi = \pi_1^*$ and $\theta_1^y = 0$, the inflation and output targets of period one). In any case, the public is able to deduce π_1^* from the announcements Θ_1 and the rest of the solutions and conclusions for this case are equal to those shown above for the case of the inflation target announcement: in periods one and two, inflation expectations, realised inflation and the output gap follow (35)-(36) and, as in Proposition 2, full transparency is socially preferred to late forecasts if and only if (21) holds. Also, the society is better off with late forecasts than with no announcements.

4 Do central banks announce strategically?

In order to provide a first step for future empirical research about the dependability of inflation announcements, this paper makes use of and updates the data set, collected for paper 2, of annual inflation targets and outcomes for inflation-targeting countries. This section explores whether there is empirical evidence to support the hypothesis that central banks announce annual inflation targets strategically and finds that there is no such evidence.

Previous sections point out that there is a strategic aspect in the decision about the level of the inflation announcement, as have been previously remarked by Canzoneri (1985), Stein (1989) and more recently by Walsh (1999). The fact that the policymaker has private information gives her incentives to manipulate inflation expectations so as to offset the effect of anticipated shocks. For instance, in an economy facing inflationary shocks, the central bank would like to make private agents believe inflation will be low. In this way, the effect on inflation expectations compensates for the potential effect of the shock on inflation. In contrast, when the central bank makes truthful inflation announcements, the effect of supply shocks is either not incorporated into the announcement, if the announcement is made well in advance, or is truthfully revealed if the announcement is made when information about upcoming shocks is available.

To derive a condition that can be empirically tested, let us analyse more formally the difference between strategic and truthful announcements in the particular case of inflation targets. The last part of section 3.2.3 shows that the inflation target announcement conforms to truth when it is made at a late stage in the previous period. In this case, the announcement follows (34), or (61) in Appendix C, and realised inflation is described by (36). In the same section, it was important to distinguish the period in which the inflation announcement is made, so we denoted the inflation target that applies to period t but is announced late in period $t-1$ by $\theta_{t|t-1}$. Since in this section the relevant period is the one for which the target applies, for simplicity of notation $\theta_{t|t-1}$ will be denoted simply by θ_t. Taking this into consideration and using (34) and (36) the following condition can be obtained,

$$Cov\left[\pi_t - \theta_t, \theta_t\right] = 0 \tag{40}$$

where $Cov\left[.\right]$ is the covariance between the variables inside the brackets. This condition is not particular to the case of late announcements presented in this paper. If we assume that, as in earlier literature, the central bank commits to truthful communication the result is the same. In this case, at the beginning of every period the central bank reveals the implicit target and hence $\theta_t = \pi_t^*$. Then, solving the model implies that realised inflation is $\pi_t = \pi_t^* + \frac{\lambda}{1+\lambda} s_t^b + \lambda s_t^p + s_t^u + d_t^u$. Using both expressions we can verify that (40) holds.

A more general condition is obtained when we take into account the possibility that there might be some correlation between the implicit inflation target and the demand shock or the supply shock. In the present paper, for the sake of simplicity, it has been assumed that there was no such correlation. Instead, we could assume that inflationary shocks might increase the optimal rate of inflation for a specific period. For instance, the error term in equation (2) could follow $\eta_t = z_1 d_t + z_2 s_t + \varphi_t$ where z_1 and z_2 are nonnegative constants and φ is white noise. Assume for simplicity that d_t and s_t are completely anticipated by both the central bank and the public. It can then be shown that if the central bank truthfully reveals the implicit target the following condition holds[13]

$$Cov\left[\pi_t - \theta_t, \theta_t\right] \geq 0 \tag{41}$$

[13] $Cov\left[\pi_t - \theta_t, \theta_t\right] = z_2 \lambda \sigma_s^2$.

The same condition applies to the model of paper 2. In countries with high inflation, the purchasing power of wages is substantially reduced over a year and past inflation plays a significant role in wage setting, and therefore in determining current inflation. In this case, as empirically confirmed by Mahadeva and Sterne (2002), in countries with moderate-to-high inflation central banks tend to overshoot the target, and (41) holds.[14] Recall that in the first paper of the present dissertation, incentives to make truthful announcements arise from the fact that the central bank is exogenously penalised for deviations from its own announcements.

Having established (41), we are interested in knowing if the same condition applies to an economy in which the central bank misrepresents private information and is able to deceive private agents. Assume that agents trust the central bank and so they set $E\left[\pi_t^* \mid I_t^p\right] = \theta_t$. Therefore, inflation expectations are $\pi_t^e = \theta_t + \lambda s_t^p$. The central bank announces strategically and minimises (25), which implies that $\theta_t = \pi_t^* - (1+\lambda)\, s_t^p - s_t^b$. In this case, the central bank is able to offset the effect of anticipated shocks by manipulating expectations and then realised inflation deviates from the implicit target only as a result of unanticipated shocks, $\pi_t = \pi_t^* + s_t^u + d_t^u$. It can be verified that[15]

$$Cov\left[\pi_t - \theta_t, \theta_t\right] < 0 \tag{42}$$

This result is not particular to the case in which full credibility is given to the inflation target announcement. It is also satisfied when private agents make use of the available information in many alternative ways. For instance, (42) holds when private sector inflation expectations follow a more general form to allow for any value of the coefficient on the supply shock s_t^p and also include a weighted average between the inflation target announced and the private agents' estimator of the implicit target, $\pi_t^e = a_0 + a_\theta \theta_t + (1 - a_\theta)\, \widehat{\pi}_{t(0)}^* + a_s s_t^p$ with $a_\theta \leq 1$. Notice that this form even admits negative values for a_θ, which allows for the possibility that private agents consider the fact that the central bank is pretending to have a very low (high) inflation target just to offset the effect of an inflationary (deflationary) shock.

Appendix D.2 analyses the general case, in which inflation expectations are described by (26), for given parameters a_i $i \in \{0, \theta, s, \pi^*\}$. Notice that the two cases mentioned above are special cases of the general one for which $a_0 = a_{\pi^*} = 0$, $a_\theta = 1$ and $a_s = \lambda$, in the first case (i.e. full credibility) or $a_{\pi^*} = 1 - a_\theta$, in the second case. It is shown in the appendix that a sufficient (but not necessary) condition to satisfy (42) is that $a_\theta \leq 1$ and $(1 - a_\theta - a_{\pi^*})(1 - a_{\pi^*}) \geq 0$. This condition allows for a great variety of cases and plausible values of coefficients.

Condition (42) is also satisfied when we allow for correlation between the implicit target and the demand shock or the supply shock (i.e. $\eta_t = z_1 d_t + z_2 s_t + \varphi_t$ as above).

[14] As mentioned in footnote 5, in the model of the first paper the announcement follows $\theta_t = \alpha_0 + \alpha_1 \pi_{t-1} + (1-\alpha_1)\, \pi_0^*$ and realised inflation, $\pi_t = \alpha_2 + \alpha_3 \pi_{t-1} + (1-\alpha_3)\, \pi_0^* + \zeta_t$. Using both equations it can be seen that $Cov\left[\pi_t - \theta_t, \theta_t\right] = \frac{\alpha_3 - \alpha_1}{\alpha_1} Var\left[\theta_t\right]$. Numerical solutions in the first paper show that $0 < \alpha_1 < \alpha_3 < 1$ and hence $\frac{\alpha_3 - \alpha_1}{\alpha_1} > 0$.

[15] $Cov\left[\pi_t - \theta_t, \theta_t\right] = -(1+\lambda)^2 \sigma_{s^p}^2 - \sigma_{s^b}^2$

If private agents trust the inflation announcement and the central bank announces strategically, (42) holds as long as $z_2 < 1 + \lambda$.[16] It is reasonable to expect that an increase in the supply shock will not affect the optimal rate of inflation more than proportionally (and hence $z_2 \leq 1$). Therefore, we should expect (42) holds for strategic inflation target announcements.

The analysis above suggests a simple way in which we can empirically analyse dependability of inflation target announcements. When the central bank makes truthful announcements, such announcements are either uncorrelated or positively correlated with the difference between inflation and the inflation target announced for the same period. If, in contrast, inflation target announcements are strategic, the correlation is negative. Since information about both variables realised inflation and inflation target announcements is available, empirical evidence for (41) versus (42) can be examined.

The data set is the one used in the second paper of this dissertation updated to take into account new inflation targeters (Indonesia, Romania, Slovakia and Turkey) and information for years 2007 and 2008. It includes 134 observations of annual inflation targets and outcomes for the *disinflation periods* of 19 inflation targeting countries.[17] Periods in which the annual target is constant and equal to the long-run target are not included in the sample. A constant target is likely to happen when the economy has attained low inflation. However, it must be remarked that constant inflation targets are completely consistent with truthful announcements. By covariance properties (40) is equivalent to state that $Cov[\pi_t, \theta_t] = Var[\theta_t]$. This condition is satisfied when θ_t is constant over time because in this case $Cov[\pi_t, \theta_t] = Var[\theta_t] = 0$. Intuitively, strategic announcements in this paper refer to those inflation announcements that misrepresent central bank's private information to offset the effect of the supply shock on inflation. Since the supply shock varies over time, strategic announcements should vary over time as well.

For disinflation periods we test the significance of the coefficient of correlation between $\pi_t - \theta_t$ and θ_t for each country. Results are reported in Table 1. At the 5% significance level only in one of the 19 countries (the Czech Republic) there is evidence that the correlation coefficient may be negative. Notice that Mexico, the country of the sample which starts with the highest level of inflation (52% in 1995), presents the strongest evidence of having a positive correlation coefficient. As explained before, a positive correlation coefficient is consistent with truthful inflation announcements in countries with high inflation or when the implicit target is correlated with the demand shock or the supply shock.

Unfortunately, the sample size is too small for some countries. This reduces the statistical power of the test i.e. increases the probability of failing to reject the null hypothesis when it is false. On the other hand, for most of the countries the conclusion is the same at much higher levels of significance. This fact enhances the power of the test. To increase confidence in the conclusion we test the joint hypothesis of whether

[16] $Cov[\pi_t - \theta_t, \theta_t] = -(1 + \lambda - z_2)(1 + \lambda)\sigma_s^2$.

[17] There are, on average, 7 observations per country, ranging from 3 (e.g. Romania) to 17 observations (Colombia).

Table 1: Test of correlation coefficients

$H_0 : \rho_{\pi-\theta,\theta} \geq 0$ $H_1 : \rho_{\pi-\theta,\theta} < 0$			
Country	Obs.	$\widehat{\rho}$	p-value
Brazil	8	-0.490	0.11
Canada	5	0.321	0.70
Chile	11	0.073	0.58
Colombia	17	0.121	0.68
Czech Rep.	8	-0.774	0.01*
Hungary	7	-0.671	0.05
Iceland	3	0.923	0.87
Indonesia	9	-0.580	0.05
Israel	12	-0.020	0.48
Korea	4	-0.307	0.35
Mexico	9	0.771	0.99
New Zealand	4	-0.187	0.41
Peru	9	0.069	0.57
Philippines	7	-0.439	0.16
Poland	7	-0.059	0.45
Romania	4	-0.499	0.25
Slovakia	3	-0.841	0.18
Spain	4	0.577	0.79
Turkey	3	-0.401	0.74

*Significant at 5%

Source: Table A.1, updated by the author.

the annual inflation target plays no role in explaining the difference between inflation and the inflation target itself in those countries for which the estimated correlation coefficient is negative (12 countries, from Table 1). We include individual effects to account for differences in the level of inflation among countries. The following equation is estimated, $\pi_{it} - \theta_{it} = \delta_{i0} + \delta_1\theta_{it} + \xi_{it}$, where the subscript i refers to the country and ξ is the error term. Poolability of δ_1 ($\delta_{i1} = \delta_1$, $\forall i$) is confirmed by conducting an F-test (p-value: 0.53). The following results are obtained

$$\widehat{\pi_{it} - \theta_{it}} = \widehat{\delta}_{i0} - \underset{(0.202)}{0.298}\theta_{it} \qquad R^2 = 0.322$$

Individual effects δ_{i0} are reported in Appendix D.1. The value reported in parenthesis corresponds to the estimated White period standard error which is robust to serial correlation and time-varying variances in the disturbances. From the estimates, it can be concluded that δ_1 is not significantly different from zero (p-value: 0.14). These results and the ones in Table 1 suggest that there is no evidence that central banks make strategic inflation announcements.

In concluding this section, we discuss another important implication from the analysis herein that can be empirically tested, namely, that the inflation target announcement is the best possible inflation forecast that can be constructed at the moment of announcement. This can be seen as follows. Section 3.2.2 shows that there is no rational expectations equilibrium with inflation announcements when the central bank intends to misrepresent private information. To avoid this problem, the same section argues that the central bank may announce the inflation target for period t when it does not yet have any information to anticipate economic shocks of the same period. From equation (34), we can see that the inflation target announcement is the best possible estimate of the implicit target for t, given the information available to the central bank in the second stage of period $t-1$, i.e. $\theta_t = E\left[\pi_t^* \mid I_{t-1(2)}^{cb}\right]$. Furthermore, using (34), (36) and the fact that $E\left[\varepsilon_t^k \mid I_{t-1(2)}^{cb}\right]$ for $\varepsilon \in \{s, d\}$, $k \in \{p,\ b,\ u\}$, it is easy to see that

$$\theta_t = E\left[\pi_t \mid I_{t-1(2)}^{cb}\right] \tag{43}$$

In the second stage, the inflation target announced is equal to the central bank's inflation forecast as we wanted to show.[18] This would not the case if the central bank announced when it has information about economic shocks, independent of whether it announces the implicit target truthfully or strategically. In the case of commitment to truthful communication, the reason is that unlike the inflation forecast the inflation target does not incorporate some available information, specifically, the effect of anticipated shocks on inflation. In the case of strategic behaviour, all of the available information is incorporated into the announcement but in such a way that the effect of shocks on inflation is not truthfully revealed.

Diron and Mojon (2008) find evidence to support that inflation targets announced by 7 industrialised inflation-targeting countries and by the ECB outperform standard forecasting models and the mean of inflation forecasts constructed by professional forecasters (surveyed by Consensus Economics Inc.). Since it is implausible that the central bank's informational advantage can be large enough to allow the inflation target announcement to be such a good forecast while some private information is misrepresented, Diron and Mojon's (2008) results add to the evidence of truthful communication of inflation targets.

5 Conclusion

Transparency and communication with the public have gained relevance in the conduct of monetary policy. The increased interaction between the central bank and the public brings attention to the effect of policy announcements on private sector expectations. To assess the economic impact of monetary policy transparency, previous literature has assumed that the monetary authority commits to truth-telling. However, even if the central bank prefers truthful over no communication, it may still find it optimal to

[18] Equation (43) does not hold if there is persistence in the supply shock unless such persistence also affects the optimal rate of inflation and hence affects π_t^*.

attempt to misguide inflation expectations so as to reduce economic volatility. To complement earlier work, the present paper analyses the scenario in which the policymaker communicates information about inflation targets or output and inflation forecasts so as to maximise society's welfare, and therefore central bank announcements may not conform to truth. The paper shows that, for a very standard setup with a stochastic expectations augmented Phillips curve, there is no equilibrium under rational expectations with inflation announcements when the central bank intends to misrepresent private information.

The paper also shows that this problem can be solved by announcing at stages in which just incentives to tell the truth are present. The central bank may announce when inflation expectations, of the period in which the announcement is made, are already formed and there is not yet information about future shocks. In this case, there are no incentives to mislead the public in order to reduce future economic volatility. Furthermore, despite being announced late in the period, inflation announcements are still useful because they are informative about the central bank's intentions for future periods. Therefore, an equilibrium exists and truthful communication is the optimal strategy for the central bank and also welfare-improving for society.

Empirical data on the annual inflation target setting is examined and no evidence is found against the hypothesis that central banks announce truthfully rather than strategically.

APPENDIX

A No-announcements case. First period

In period two, the public estimates η_1 using three different signals that can be constructed from three variables observed in period one, namely, the policy instrument m_1 and two outcomes, inflation π_1 and output y_1. This represents a signal extraction problem. Assuming that shocks η_1 and ε_1^k for $\varepsilon \in \{s, d\}$ and $k \in \{b, u\}$ are normally distributed, the estimator takes the following form

$$\widehat{\eta}_{1|2} = \phi_m x(m_1) + \phi_\pi x(\pi_1) + \phi_y x(y_1) \tag{44}$$

where ϕ_j for $j \in \{m, \pi, y\}$ are constant parameters and $x(.)$ stands for the signal constructed from the corresponding variable inside the parenthesis. From equations (3) and (4), π_1 and y_1 depend on m_1, π_1^e and aggregate shocks. Inflation expectations π_1^e also depend on aggregate shocks s_1^p, d_1^p. We can then consistently assume that $\widehat{\eta}_{1|2}$ can be expressed as

$$\widehat{\eta}_{1|2} = \psi_0 + \psi_m m_1 + \psi_{d^p} d_1^p + \psi_{d^b} d_1^b + \psi_{d^u} d_1^u + \psi_{s^p} s_1^p + \psi_{s^b} s_1^b + \psi_{s^u} s_1^u \tag{45}$$

where ψ_0, ψ_m and ψ_{ε^k} for $\varepsilon \in \{s, d\}$ and $k \in \{p, b, u\}$ are constants to be determined.

In the third stage of period one, the central bank minimises the discounted value of the expected loss in periods one and two with respect to m_1. Using (3), (4) and the fact that the policymaker cannot anticipate d_1^u and s_1^u, the expected loss (18) can be re-expressed in the following form

$$\begin{array}{c} \lambda\left(m_1+d_1^{cb}\right)^2+(\pi_1^e-\pi_1^*+m_1+d_1^{cb}+s_1^{cb})^2+(1+\beta)\left[(1+\lambda)\,\sigma_{d^u}^2+\sigma_{s^u}^2\right] \\ +\beta\frac{\lambda}{1+\lambda}\left\{(1+\lambda)^2\,\sigma_{s^p}^2+\sigma_{s^b}^2+\sigma_\eta^2+\alpha^2E\left[\left(\widehat{\eta}_{1|2}-\eta_1\right)^2\mid I_{1(3)}^{cb}\right]\right\} \end{array} \tag{46}$$

Substituting (45) into (46) and minimising with respect to m_1 implies

$$\begin{aligned} m_1 \;=\; & \frac{1}{1+\lambda+\omega\psi_m^2}\left[\omega\psi_m\left(\eta_1-\psi_0-\psi_{d^p}d_1^p-\psi_{d^b}d_1^b-\psi_{s^p}s_1^p-\psi_{s^b}s_1^b\right)\right. \\ & \left.+\pi_0^*-\pi_1^e-(1+\lambda)\,d_1^{cb}+\eta_1-s_1^{cb}\right] \end{aligned} \tag{47}$$

where, for ease of exposition, we have collected some terms, $\omega=\beta\alpha^2\frac{\lambda}{1+\lambda}>0$. Substituting (47) and (4) into (3) and using rational expectations we obtain

$$\pi_1^e=\pi_0^*+\lambda s_1^p+\omega\psi_m\left[\psi_0+(\psi_m+\psi_{s^p})\,s_1^p+(\psi_m+\psi_{d^p})\,d_1^p\right] \tag{48}$$

Using this result together with (47), (3) and (4) we can obtain expressions for signals of η_1:

$$\begin{aligned} \eta_1-\frac{(1+\omega\psi_m\psi_{s^b})\,s_1^b+(1+\lambda+\omega\psi_m\psi_{d^b})\,d_1^b}{1+\omega\psi_m} &= \\ \frac{\left(1+\lambda+\omega\psi_m^2\right)(d_1^p+m_1+s_1^p)}{1+\omega\psi_m} &\equiv x\left(m_1\right) \end{aligned} \tag{49}$$

$$\begin{aligned} \eta_1+\frac{\left(1+\lambda+\omega\psi_m^2\right)(d_1^u+s_1^u)+\omega\psi_m\left[(\psi_m-\psi_{d^b})\,d_1^b+(\psi_m-\psi_{s^b})\,s_1^b\right]+\lambda s_1^b}{1+\omega\psi_m} &= \\ \frac{\left(1+\lambda+\omega\psi_m^2\right)(\pi_1^e-\pi_1)}{1+\omega\psi_m} &\equiv x\left(\pi_1\right) \end{aligned} \tag{50}$$

$$\begin{aligned} \eta_1+\frac{\omega\psi_m\left(\psi_m-\psi_{d^b}\right)d_1^b+\left(1+\lambda+\omega\psi_m^2\right)d_1^u-(1+\omega\psi_m\psi_{s^b})\,s_1^b}{1+\omega\psi_m} &= \\ \frac{\left(1+\lambda+\omega\psi_m^2\right)(y_1+s_1^p)}{1+\omega\psi_m} &\equiv x\left(y_1\right) \end{aligned} \tag{51}$$

Notice that the left-hand side of each equality represents a signal of η_1. These are noisy signals because they include information about variables that cannot be observed by the public, and therefore it is not possible to extract the exact value of η_1. The right-hand side of each equality provides the way in which each signal can be defined using variables that are observed by the public.

We then proceed to verify that all of the three signals provide useful information, and therefore $\phi_j\neq 0$ for $j\in\{m,\pi,y\}$ in equation (44). If one of the signals can be expressed as a linear combination of the others, plus some independent error term, then this signal is redundant. Let $\boldsymbol{A}$ be the 3×3 matrix formed by the coefficients of variables s_1^b, d_1^b and d_1^u in the left-hand side of equalities in (49)-(51)

$$\boldsymbol{A} = -\frac{1}{1+\omega\psi_m}\begin{pmatrix} (1+\omega\psi_m\psi_{s^b}) & (1+\lambda+\omega\psi_m\psi_{d^b}) & 0 \\ \omega\psi_m(\psi_{d^b}-\psi_m) & \omega\psi_m((\psi_{s^b}-\psi_m)-\lambda) & -\left(1+\lambda+\omega\psi_m^2\right) \\ (1+\omega\psi_m\psi_{s^b}) & \omega\psi_m(\psi_{d^b}-\psi_m) & -\left(1+\lambda+\omega\psi_m^2\right) \end{pmatrix}$$

The coefficient of s_1^u is not included because it is an independent disturbance which appears only in one signal, $x(\pi_1)$. To check if all of the three signals provide useful information we examine if $\boldsymbol{A}$ is full rank. By Gauss-Jordan elimination we can reduce this matrix to the identity matrix of size 3 and therefore $rank[\boldsymbol{A}] = 3$.

Substituting (3), (4), (48) and the right-hand side of (49)-(51) into (44) and comparing the result to (45) we obtain a system of equations to express ψ_0, ψ_m and ψ_{ε^k} for $\varepsilon \in \{s,d\}$ and $k \in \{p,b,u\}$ in terms of coefficients ϕ_j for $j \in \{m,\pi,y\}$. The expression for ψ_m can be obtained from

$$\psi_m = \frac{\left(1+\lambda+\omega\psi_m^2\right)\left(\phi_m+\phi_\pi+\phi_y\right)}{1+\omega\psi_m}$$

and the rest of the coefficients in (45) can be expressed in terms of ψ_m and ϕ_j for $j \in \{m,\pi,y\}$:

$$\begin{aligned} \psi_0 &= 0 \quad , \quad \psi_{d^p} = \psi_{s^p} = \psi_m \\ \psi_{d^b} &= \tfrac{\phi_\pi+\phi_y}{\phi_m+\phi_\pi+\phi_y}\psi_m \quad , \quad \psi_{d^u} = \psi_{d^b} \\ \psi_{s^b} &= \tfrac{\phi_\pi}{\phi_m+\phi_\pi+\phi_y}\psi_m \quad , \quad \psi_{s^u} = \psi_{s^b} \end{aligned} \tag{52}$$

Finally, substituting (47), (48) and (52) into (3) and (4) we obtain equations (19) and (20):

$$\pi_1 = \pi_0^* + \lambda s_1^p + d_1^u + s_1^u + c_1 d_1^b + c_2 s_1^b + c_3\eta_1$$
$$y_1 = -s_1^p + d_1^u + c_1 d_1^b - (1-c_2)\, s_1^b + c_3\eta_1$$

where $c_1 = \frac{\omega\psi_m\left(\psi_m-\psi_{d^b}\right)}{1+\lambda+\omega\psi_m^2}$, $c_2 = \frac{\omega\psi_m\left(\psi_m-\psi_{s^b}\right)+\lambda}{1+\lambda+\omega\psi_m^2}$, $c_3 = \frac{1+\omega\psi_m}{1+\lambda+\omega\psi_m^2}$.

Proposition 3 *In the model with no announcements and with a central bank that cannot perfectly anticipate the demand shock (and hence $\sigma_{d^u}^2 > 0$), inflation π_1 and the output gap y_1 are strictly increasing in the anticipated demand shock d_1^b, (i.e. $c_1 > 0$).*

Proof.

(i) c_1 is nonnegative.

Let Φ be the vector of ϕ_j for $j \in \{m,\pi,y\}$, i.e. $\Phi \equiv \left[\phi_m\ \phi_\pi\ \phi_y\right]'$. For the signal extraction problem presented in this appendix, in which we estimate η_1 given signals

$x(m_1)$, $x(\pi_1)$ and $x(y_1)$, we can obtain an expression for each ϕ_j (in terms of $\sigma^2_{\varepsilon^k}$, ψ_m and ψ_{ε^k} for $\varepsilon \in \{s,d\}$ and $k \in \{b,u\}$) from the following equation

$$\Phi = \sigma^2_\eta \mathbf{1}_3' \boldsymbol{V}_x^{-1} \tag{53}$$

where $\mathbf{1}_3$ represents a vector of ones and size three and $\boldsymbol{V}_x$ is the covariance matrix of the signals, i.e. the left-hand side of equalities in (49)-(51). Using the resulting expressions from (53), it can be shown that $\frac{\phi_\pi+\phi_y}{\phi_m+\phi_\pi+\phi_y} = \frac{\left(1+\lambda+\omega\psi_m\psi_{d^b}\right)q}{1+\lambda+\omega\psi_m^2}$ where $q \equiv \frac{1}{1+\sigma^2_{d^u}/\sigma^2_{d^b}}$. We then substitute this result into the expression for ψ_{d^b} in (52) and solve for ψ_{d^b}. Finally the result is substituted into the expression for c_1 above to obtain $c_1 = \frac{(1-q)\left(1+\lambda+\omega\psi_m^2\right)\psi_m^2}{1+\lambda+(1-q)\omega\psi_m^2} \geq 0$.

(ii) $c_1 \neq 0$.

From the result in (i), since $\omega > 0$ and $q > 0$, $c_1 = 0$ if and only if $\psi_m = 0$. If $\psi_m = 0$, from (52), all of the coefficients in (45) are zero. This implies that no useful information can be extracted from π_1, y_1 or m_1. However, even if $\psi_0 = 0$, $\psi_m = 0$ and $\psi_{\varepsilon^k} = 0$ for $\varepsilon \in \{s,d\}$ and $k \in \{p,b,u\}$ matrix $\boldsymbol{A}$ is still full rank. ■

When $\sigma^2_{d^u} = 0$, $rank\,[\boldsymbol{A}] = 2$ and any two of the three signals are relevant. In this case, the central bank fully offsets the effect of d_1^b (and hence $c_1 = 0$) without affecting the information that private agents obtain from the signals.

B Equivalence of the multi-period case and the one-period case with announcements

The present appendix shows that if there is an equilibrium in the multi-period model with announcements, it has to be equal to the equilibrium in the one-period setup. As in section 3.2.2, given the assumption that $\pi_t^* - \widehat{\pi}^*_{t(0)}$ and s_t^b are normally distributed, inflation expectations are linear in all of the relevant pieces of information and therefore follow (26):

$$\pi_t^e = a_0 + a_\theta \theta_t + a_s s_t^p + a_{\pi^*} \widehat{\pi}^*_{t(0)} \tag{54}$$

where $\widehat{\pi}^*_{t(0)} = \alpha \widehat{\pi}^*_{t-1|t(0)} + (1-\alpha)\pi_0^* + \widehat{\eta}_{t-1|t(0)}$. Moreover, assume that there exist values for parameters a_i for $i \in \{0, \theta, s, \pi^*\}$ such that there is an equilibrium under rational expectations.

B.1 Finite periods

In this case we start by solving the problem in the final period, T. It can be seen that the optimal inflation announcement is (cf. (27) for the one-period setup)

$$\theta_T = \frac{\left(\pi_T^* - \widehat{\pi}^*_{T(0)}\right) - a_0 - (1+a_s)\,s_T^p - s_T^b + (1-a_{\pi^*})\,\widehat{\pi}^*_{T(0)}}{a_\theta} \tag{55}$$

Substituting (5), (54) and (55) into (4) and (6) yields

$$\pi_T = \pi_T^* + s_T^u + d_T^u \tag{56}$$

$$y_T = d_T^u \tag{57}$$

Substituting (56) and (57) into (1) and taking the unconditional expected value, the expected loss function for period T is

$$E\left[\Gamma_T\right] = (1+\lambda)\,\sigma_{d^u}^2 + \sigma_{s^u}^2$$

Since this expression does not depend on lagged variables, the expected loss in T is not affected by decisions made in $T-1$. Therefore in $T-1$, the central bank acts as if it were the last period and the solution again takes the same form. By backward induction it can be seen that the same is true for any other period, and therefore if there is an equilibrium for the finite-period model it will be equal to the equilibrium for the one-period case.

B.2 Infinite horizon

For the infinite-horizon case, following the dynamic programming optimization approach, the central bank solves

$$Min \;\; E\left[\Gamma_t + \beta V_{t+1} \mid I_t^{cb}\right]$$

where V is the value function for which we do not yet know the functional form. Given (54), we know from section 3.2.2 that (5) for m_t and (27) for θ_t are the optimal actions of the central bank in the one-period setup. From the analysis for the finite-period case, we know that for the one-period model $\pi_t = \pi_t^* + s_t^u + d_t^u$ and $y_t = d_t^u$. Substituting these expressions into (1) and taking the expected value conditional on I_t^{cb}

$$E\left[\Gamma_t \mid I_t^{cb}\right] = (1+\lambda)\,\sigma_{d^u}^2 + \sigma_{s^u}^2$$

which is the minimum possible value that the central bank could attain for the expected loss of a single period, given that s_t^u and d_t^u cannot be anticipated. Therefore, if every period the central bank follows (5) and (27), in the infinite horizon problem the value function for period t would be $V_t = (1+\lambda)\,\sigma_{d^u}^2 + \sigma_{s^u}^2 + \beta E\left[V_{t+1} \mid I_t^{cb}\right]$. Since this is true for any period and $E\left[\Gamma_t \mid I_t^{cb}\right]$ is not affected by lagged variables, the minimum expected loss for every single period is attainable without affecting the same possibility for future periods. Consequently,

$$V = \left[(1+\lambda)\,\sigma_{d^u}^2 + \sigma_{s^u}^2\right]\sum\nolimits_{j=0}^{\infty}\beta^j = \frac{(1+\lambda)\,\sigma_{d^u}^2 + \sigma_{s^u}^2}{1-\beta}$$

The value function for any period is constant and independent of decisions made in the past, and therefore if there is an equilibrium for the infinite-horizon model it will be equal to the equilibrium for the one-period case.

C Late announcements, infinite horizon

This section extends the model with late inflation announcements to the infinite horizon. The analysis is based on the case in which the central bank announces an inflation target. In the case of forecasts the analysis is similar.

Based on the expressions for the two-period model, we start by assuming a specific form for the value function of the infinite horizon problem. We then verify that the assumed form is right and determine the value of its coefficients. From equation (33), using the fact that $E\left[\pi_2^* \mid I^p_{2,\theta_{2|1}}\right] = \theta_{2|1}$ and taking the expected value conditional on the information set of the central bank in the third stage of period one,

$$\begin{aligned} E\left[\Gamma_2 \mid I^{cb}_{1(3)}\right] &= (1+\lambda)\left(\sigma^2_{d^u} + \lambda\sigma^2_{s^p}\right) + \sigma^2_{s^u} + \frac{\lambda}{1+\lambda}\left(\sigma^2_{s^b} + \sigma^2_{\eta}\right) + \\ &\quad \frac{\lambda}{1+\lambda}\left(E\left[\pi_2^* \mid I^p_{2,\theta_{2|1}}\right] - \alpha\pi_1^* - (1-\alpha)\,\pi_0^*\right)^2 \end{aligned}$$

Based on this result, we then assume that the value function V_{t+1} for the infinite horizon problem takes the form

$$V_{t+1} = A_0 + A_1\left(E\left[\pi^*_{t+1} \mid I^p_{t+1,\theta_{t+1|t}}\right] - \alpha\pi_t^* - (1-\alpha)\,\pi_0^*\right)^2 \tag{58}$$

As in the two-period model, private agents can consistently assume that there is truthful communication. They follow $E\left[\pi^*_{t+1} \mid I^p_{t+1,\theta_t}\right] = \theta_{t+1|t}$. The problem of the central bank in the third stage of period t is

$$\underset{m_t}{Min} \quad E\left[\Gamma_t + \beta V_{t+1} \mid I^{cb}_{t(3)}\right] \tag{59}$$

Since V_{t+1} does not depend on m_t the solution for the monetary instrument in terms of expected inflation is equal to (5). Substituting (5) into (59) we can state that the problem for the central bank, in the second stage, is minimising

$$E\left[(1+\lambda)\,\sigma^2_{d^u} + \sigma^2_{s^u} + \frac{\lambda\left(\pi^e_t - \pi^*_t + s^{cb}_t\right)^2}{1+\lambda} + \beta V_{t+1} \;\;\middle|\;\; I^{cb}_{t(2)}\right] \tag{60}$$

with respect to $\theta_{t+1|t}$. The loss function of period t does not depend on the announcement $\theta_{t+1|t}$, and hence the solution to the problem is equivalent to minimising (58). Since $E\left[\pi^*_{t+1} \mid I^p_{t+1,\theta_t}\right] = \theta_{t+1|t}$, this implies

$$\theta_{t+1|t} = \alpha\pi^*_t + (1-\alpha)\,\pi^*_0 \tag{61}$$

This result implies, from (58), that for the optimal value of $\theta_{t+1|t}$, $V_{t+1} = A_0$. Substituting (4) and (5) into (3) and using rational expectations we obtain

$$\pi^e_t = E\left[\pi^*_t \mid I^p_{t,\theta_{t|t-1}}\right] + \lambda s^p_t \tag{62}$$

Substituting $V_{t+1} = A_0$, (2) and (62) into (60), and taking the expected value conditional on the information of the central bank in the third stage of period $t-1$, we can obtain the value function

$$V_t = \beta A_0 + E\left[\Gamma_t^{LA}\right] + \frac{\lambda}{1+\lambda}\left(E\left[\pi_t^* \mid I^p_{t,\theta_{t|t-1}}\right] - \alpha\pi_{t-1}^* - (1-\alpha)\,\pi_0^*\right)^2$$

where $E\left[\Gamma_t^{LA}\right]$ is equal to the expected loss in the second period of the two-period case (the right-hand side of (38)). This confirms that the assumption about the functional form of the value function V is consistent. We can then easily determine coefficients for the value function: $A_0 = \frac{E\left[\Gamma_t^{LA}\right]}{1-\beta}$ and $A_1 = \frac{\lambda}{1+\lambda}$. For any period t, inflation expectations, realised inflation and the output gap follow the same expressions obtained in section 3.2.3, (35)-(37). The total expected loss for the infinite horizon is equal to $\frac{E\left[\Gamma_t^{LA}\right]}{1-\beta}$. The conclusion that society is better off with late announcements than without them remains unchanged for the infinite horizon. The explanation is the same. With late announcements the central bank has an additional instrument to reveal the best estimation of π_t^* without compromising its ability to respond optimally to economic shocks.

D Empirical Section

D.1 Individual Effects

Table D1: Individual Effects

Country	$\widehat{\delta}_{i0}$	Std. Error
Brazil	3.649	1.137**
Czech Rep.	-0.650	0.794
Hungary	2.807	0.836**
Indonesia	4.580	1.395**
Israel	1.538	1.395
Korea	0.355	0.882
New Zealand	0.220	0.555
Philippines	2.021	0.951*
Poland	1.303	1.161
Romania	3.024	1.024**
Slovakia	2.022	0.387**
Turkey	6.313	0.874**

*Significant at 5% **Significant at 1%

D.2 Strategic announcements, general case

Assume that expectations are described by (26), for given parameters a_i $i \in \{0, \theta, s, \pi^*\}$. The central bank announces strategically following (27). Substituting (5), (26) and (27) into (6) yields $\pi_t = \pi_t^* + s_t^u + d_t^u$. Using this equation, (27) and the fact that $E\left[\widehat{\pi}_{t(0)}^*\right] = E\left[\pi_t^*\right]$, we find that

$$\begin{aligned} Cov\left[\pi_t - \theta_t, \theta_t\right] &= -\frac{1}{a_\theta^2}\left\{a_0^2 + \left(1 + a_s\right)^2 \sigma_{s^p}^2 + \sigma_{s^b}^2 + \left(1 - a_\theta\right) MSE\left[\widehat{\pi}_{t(0)}^*\right] \right. \\ &\quad \left. + \left(1 - a_\theta - a_3\right)\left(1 - a_{\pi^*}\right) Var\left[\widehat{\pi}_{t(0)}^*\right]\right\} \end{aligned}$$

where $MSE\left[\widehat{\pi}_{t(0)}^*\right]$ and $Var\left[\widehat{\pi}_{t(0)}^*\right]$ are the mean square error and the variance of the estimator $\widehat{\pi}_{t(0)}^*$, respectively. A sufficient condition to make the right-hand side of the equation negative is that coefficients on $MSE\left[\widehat{\pi}_{t(0)}^*\right]$ and $Var\left[\widehat{\pi}_{t(0)}^*\right]$ be positive, and therefore

$$a_\theta \leq 1 \text{ and } \left(1 - a_\theta - a_{\pi^*}\right)\left(1 - a_{\pi^*}\right) \geq 0 \tag{63}$$

This condition allows for a great variety of cases and values of coefficients. It does not restrict neither the intercept a_0 nor the coefficient on the anticipated supply shock a_s. With regard to a_θ and a_{π^*}, it allows for very plausible cases, for instance, the one mentioned in section 4 in which private agents take a weighted average of the inflation announcement θ_t and their own estimation of the implicit target $\widehat{\pi}_{t(0)}^*$ (i.e. $a_\theta + a_{\pi^*} = 1$). Furthermore, it allows for linear combinations of θ_t and $\widehat{\pi}_{t(0)}^*$ in which there could be negative values of coefficients. Negative values of a_θ allow to include cases in which private agents consider the fact that the central bank may announce a very low (high) inflation target to try to offset the effect of an inflationary (deflationary) shock. Moreover, since the condition above is sufficient but not necessary, the set of cases for which $Cov\left[\pi_t - \theta_t, \theta_t\right] < 0$, includes but is not limited to those in which (63) is satisfied.

References

Barro, R. and Gordon, D. (1983), 'A positive theory of monetary policy in a natural rate model', *Journal of Political Economy* **91**(4), 589–610.

Canzoneri, M. (1985), 'Monetary policy games and the role of private information', *American Economic Review* **75**(5), 1056–70.

Cukierman, A. (2001), Accountability, credibility, transparency and stabilization policy in the eurosystem, *in* C. Wyplosz, ed., 'The Impact of EMU on Europe and the Developing Countries', Oxford University Press, chapter 3, pp. 40–75.

Demertzis, M. and Hughes Hallett, A. (2007), 'Central bank transparency in theory and practice', *Journal of Macroeconomics* **29**(4), 760–789.

Dincer, N. N. and Eichengreen, B. (2007), Central bank transparency: Where, why, and with what effects?, Working Paper 13003, NBER.

Diron, M. and Mojon, B. (2008), 'Are inflation targets good inflation forecasts?', *Economic Perspectives* **32**(2), 33–45.

Eijffinger, S. and Van der Cruijsen, C. (2007), The economic impact of central bank transparency: A survey, CEPR Discussion Papers 6070, C.E.P.R. Discussion Papers.

Garfinkel, M. and Oh, S. (1995), 'When and how much to talk credibility and flexibility in monetary policy with private information', *Journal of Monetary Economics* **35**(2), 341–357.

Geraats, P. M. (2000), Why adopt transparency? the publication of central bank forecasts, Discussion Paper 2582, CEPR.

Geraats, P. M. (2002), 'Central bank transparency', *Economic Journal* **112**(483), 532–565.

Geraats, P. M. (2005), 'Transparency and reputation: The publication of central bank forecasts', *Topics in Macroeconomics* **5**(1), 1–26.

Geraats, P. M. (2006), 'Transparency of monetary policy: Theory and practice', *CESifo Economic Studies* **52**(1), 111–152.

Geraats, P. M. (2007), 'The mystique of central bank speak', *International Journal of Central Banking* **3**(1), 37–80.

Geraats, P. M. (2009), 'Trends in monetary policy transparency', *International Finance* **12**(2), 235–268.

Harvey, A. (1989), *Forecasting, Structural Time Series Models and the Kalman Filter*, Cambridge University Press.

Harvey, A. and De Rossi, G. (2006), Signal extraction, *in* K. Patterson and T. C. Mills, eds, 'Palgrave Handbook of Econometrics Vol.1', Palgrave MacMillan, chapter 27, pp. 970–1000.

Jensen, H. (2002), 'Optimal degrees of transparency in monetary policymaking', *Scandinavian Journal of Economics* **104**(3), 399–422.

Kydland, F. and Prescott, E. (1977), 'Rules rather than discretion: The inconsistency of optimal plans', *Journal of Political Economy* **85**(3), 473–491.

Mahadeva, L. and Sterne, G. (2002), 'Inflation targets as a stabilization device', *The Manchester School* **70**(4), 619–650.

Stein, J. C. (1989), 'Cheap talk and the Fed: A theory of imprecise policy announcements', *American Economic Review* **79**(1), 32–42.

Svensson, L. E. O. (2006), 'Social value of public information: Comment: Morris and shin (2002) is actually pro-transparency, not con', *The American Economic Review* **96**(1), 448–452.

Tarkka, J. and Mayes, D. (1999), The value of publishing official central bank forecasts, Research Discussion Papers 22/99, Bank of Finland.

Walsh, C. E. (1998), *Monetary Theory and Policy*, 1st edn, The MIT Press.

Walsh, C. E. (1999), 'Announcements, inflation targeting and central bank incentives', *Economica* **66**, 255–69.

Walsh, C. E. (2007), 'Optimal economic transparency', *International Journal of Central Banking* **3**(1), 5–36.