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SIGNALING AND COMMITMENT: MONETARY VERSUS INFLATION TARGETING

HANS GERSBACH
University of Heidelberg

VOLKER HAHN
University of Heidelberg

The article compares the social efficiency of monetary targeting and inflation targeting when central banks may have private information on shocks to money demand and the transparency solution is not feasible because of verifiability problems. Under inflation targeting and monetary targeting, central banks may have an incentive to signal their private information in order to influence the public's expectations about future inflation. We show that inflation targeting is superior to monetary targeting, as it makes it easier for central banks to commit to low inflation. Moreover, central banks that are weak on inflation prefer inflation targeting to monetary targeting.

Keywords: Central Banks, Inflation Targeting, Monetary Targeting, Signaling, Commitment

1. INTRODUCTION

Since the beginning of the 1990s, inflation targeting has been adopted in many countries, including New Zealand, the United Kingdom, Sweden, and Canada. Although it is too early to draw any final conclusions about the performance of inflation targeting, the experience of the last several years indicates that inflation targeting has been relatively successful. By contrast, the German Bundesbank[1] and the Swiss National Bank have long relied on monetary targeting, and both banks also have been successful in their attempt to achieve price stability and low inflation rates. Thus, deciding which monetary policy regime central banks should adopt is an important question. For instance, in the light of the start-up phase of the European Monetary Union, it is crucial to determine which monetary policy framework the ECB should choose. And some authors have argued that the

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Federal Reserve, which has been said to follow a "just do it" approach, should adopt inflation targeting as well [see Bernanke et al. (1999)].

The purpose of this paper is to compare the social efficiency of inflation targeting with that of monetary targeting when central banks wish to signal their competence and the nature of their private information about future money demand shocks. We consider a model in which inflation is affected by money growth and by other factors about which the central bank may only have incomplete knowledge. Here, the public faces two kinds of information asymmetry. First, it is unsure about the precision of the central bank's information on future inflation. For example, the central bank may be very confident about its projections. By contrast, the central bank may know that the quality of its data is rather poor or that the computer model it uses is outdated and delivers poor forecasts. This knowledge about the precision of the central bank's information and forecasts may be available to the central bank, but not to the public. Second, if the central bank does in fact possess that competence, the public is unsure about the nature of the central bank's information on the future link between money growth and inflation.

Our major finding is that in social terms inflation targeting is superior, or at least equivalent, to monetary targeting, as inflation targets are better suited for the central bank to commit to low inflation. This may seem somewhat paradoxical as we assume that the central bank can commit perfectly to a certain value of money growth under monetary targeting, which might at first sight enable the central bank to overcome the time-inconsistency problem. By contrast, under inflation targeting, the central bank cannot perfectly commit to a certain target value, as there may be unforeseen shocks affecting the future value of inflation.

Why is monetary targeting inferior to inflation targeting? Inflation targets are more closely related to future inflation and thus make it easier for the central bank to commit to low inflation.

The relation between announced targets and future inflation is closer in the following sense. Under monetary targeting, an uninformed central bank has the potential to create output gains by making the public believe that it has received a negative shock. Under inflation targeting, this is not possible for an uninformed central bank, as its announced inflation target must equal inflation on average. Thus, the rather tight link between the announced target and future inflation makes a commitment to low inflation easier under inflation targeting. Although a common argument in favor of inflation targeting is that it is informationally efficient to aim at a final target, such as inflation, and not at an intermediate target, such as monetary growth,[2] our paper makes the new point that in the presence of information asymmetries it also may make the commitment to low inflation easier.

However, under both targeting regimes, the complete elimination of the time-inconsistency problem may be impossible unless the central bank is rather conservative, because a central bank aiming to stimulate output may withhold information on shocks that might render inflation rather high. Consequently, the inflation bias cannot be completely eliminated, even under inflation targeting.

The paper is organized as follows: In the next section we review the related literature, proceeding in Section 3 to develop the model. A benchmark solution is proposed in Section 4, whereas the results for inflation targeting and monetary targeting are derived in Sections 5 and 6, respectively. In Section 7, we compare the results for monetary targeting and inflation targeting. Then we analyze the factors determining the size of the parameter b, which plays a crucial role in our model. Section 9 discusses the underlying assumptions of our model and the implications for the robustness of the results. Section 10 presents our conclusions.

2. REVIEW OF THE LITERATURE

The pros and cons of monetary targeting versus inflation targeting and the historical performance of these two targeting regimes have been discussed in many important contributions in the last decade.[3] The main advantages of inflation targeting have been identified as the use of all available information and the promotion of transparency and credibility. First, inflation targets are easily understandable for the public. Second, inflation targeting implies accountability to the public and thus can help to discipline monetary policy [see, among others, Bernanke et al. (1999), Mishkin (1999), and Svensson (1997, 1999)].

Inflation targeting, by contrast, has been criticized as not being operational because the central bank's control of the inflation rate is relatively tenuous and only takes effect after long time lags. Moreover, in the event of large supply-side shocks, an exclusive focus of policy on inflation could lead to an unstable economy [see, e.g., McCallum (1999) and Mishkin (1999)].

The advantages of monetary targeting are therefore associated with two main arguments. First, monetary growth rates are closely related to the instruments of monetary policy and thus more easily controllable than inflation itself. Second, monetary targets may be more transparent to the public than inflation targets because only one indicator is used [cf., e.g., Mishkin (1999) and von Hagen (1995, 1999)].

In this paper, we first demonstrate that both monetary targeting and inflation targeting pose considerable communication problems when the relationship between money growth and inflation is affected by shocks. We then show that the signaling costs associated with monetary targeting are higher than those associated with inflation targeting.

A different set of communication problems has been examined by Laubach (2003). He considers asymmetric information in terms of the degree of commitment of central banks, concluding that inflation targeting is not inferior for communicating the central bank's objectives. The present paper suggests that under inflation targeting the costs of communicating competence are lower than under monetary targeting.

3. MODEL

We consider a simple one-period model with two players, a central bank and the public. The government acts as a delegated monitor for the public. The public is unsure about the precision and the nature of the central bank's information about future inflation.

Let π denote inflation realized at the end of the period, π^e the private sector's expectation of inflation, and y output growth. The natural rate of output is denoted by y_0. The private sector's behavior is summarized by a standard Phillips curve:

$$y = y_0 + (\pi - \pi^e). \tag{1}$$

The relation between inflation π and the monetary growth rate m chosen by the central bank is:

$$\pi = m + \epsilon, \tag{2}$$

where ϵ denotes shocks to money demand:

$$\epsilon = \begin{cases} +\delta & \text{w.p.} \quad \frac{1}{2} \\ -\delta & \text{w.p.} \quad \frac{1}{2}\,. \end{cases} \tag{3}$$

Equation (2) takes into account that inflation is determined by money growth as well as temporarily by other factors beyond the central bank's control [see also Laubach (2003)]. Note that the choice of m can be observed by the public.

We assume that the private sector's expectations are rational, that is, π^e is the correct expectation of the public, given its information set.

The central bank observes a signal of the demand shock with probability $\lambda \in]0, 1[$. For simplicity's sake we assume that this signal is not noisy, that is, if the central bank recognizes the signal, it is able to completely determine inflation by choosing the appropriate value for m. Thus, with probability λ, the central bank becomes fully informed about the value of ϵ and, with probability $1-\lambda$, the central bank will remain ignorant and there is nothing it can do to achieve its preferred rate of inflation with certainty.

The public therefore faces three types of central banks:

$CB^+ \rightarrow$ CB has observed $\epsilon = +\delta$ (prob. $\frac{\lambda}{2}$)
$CB^- \rightarrow$ CB has observed $\epsilon = -\delta$ (prob. $\frac{\lambda}{2}$)
$CB^0 \rightarrow$ CB has not observed the signal (prob. $1 - \lambda$)

We assume that the signal is private information available only to the central bank and not verifiable for the public. The central bank's assessments about the future developments in an economy may involve a certain amount of judgment and experience of the decision-making body and may thus be unverifiable private information.

Our central assumption is that there is a chance that central banks have superior information. There is a large literature suggesting that central banks obtain information about the future course of the economy earlier than the public.[4] The assumption has recently received empirical support by Peek et al. (1999, 2003) and Romer and Romer (2000). Our assumption is weaker since we consider a case when there is only a positive probability that at some time the central bank will have more accurate forecasts than the public. Moreover, some recent arguments support the view that there is a positive chance that central banks may temporarily have more information than the public. We will review these arguments in detail in Section 9 when we discuss the significance of our assumptions.

The central bank's loss function is given by

$$L = E[\pi^2 + a(y - y^*)^2] + \mathcal{P}, \tag{4}$$

where y^* is the log output target. It is above the natural level y_0 and given by $y^* = y_0 + \Delta$ with $\Delta > 0$.[5] Δ may be positive as a result of frictions, such as distortionary taxes or wage bargaining by unions, which lower the natural rate of output below its socially optimal level. An inflation bias also may result from the central bank's uncertainty about the natural rate, thus inducing it to experiment and raise money growth until inflation rises [cf. Reis (2003)]. E denotes the expectation given the information set of the central bank, and $\mathcal{P}$ a possible penalization.

The cost function builds on the natural rate model introduced by Barro and Gordon (1983) and Kydland and Prescott (1977). These preferences represent an explicit zero inflation target and an output target. There is a trade-off between the desire for low inflation and the incentive to create higher output by surprise inflation. The weight on the output target is given by $a \in [0, \infty[$. We assume that the central bank's objectives are representative of the public's preferences. The central bank's loss function minus the possible punishment $\mathcal{P}$ stands for social losses.

$\mathcal{P}$ represents a penalty imposed by the government if it can verify that the central bank has not attempted to meet its target levels.[6] Let the announced targets of the central bank under inflation targeting and monetary targeting be denoted by π_T and by m_T, respectively. We will use additional indices to specify the type of bank that announces the target. For example, π_T^+ represents an inflation target announced by a central bank of type CB^+. Because the central bank can completely control its target under monetary targeting, the punishment rule is simply given by:

$$\mathcal{P} = \begin{cases} 0 & \text{if } m = m_T \\ \infty & \text{otherwise.} \end{cases} \tag{5}$$

Under inflation targeting, the penalty rule is only slightly more complicated because an uninformed bank cannot control inflation exactly. But m is observable by the government and can be used to control the behavior of the central bank. Thus, under inflation targeting $\mathcal{P}$ is given by:

$$\mathcal{P} = \begin{cases} 0 & \text{if } m = \pi_T \text{ or } \pi = \pi_T \\ \infty & \text{otherwise.} \end{cases} \tag{6}$$

An uninformed central bank must choose $m = \pi_T$, which means that its best estimate of inflation equals the target. A competent central bank can control inflation exactly and therefore achieve $\pi = \pi_T$ or it can mimic an uninformed

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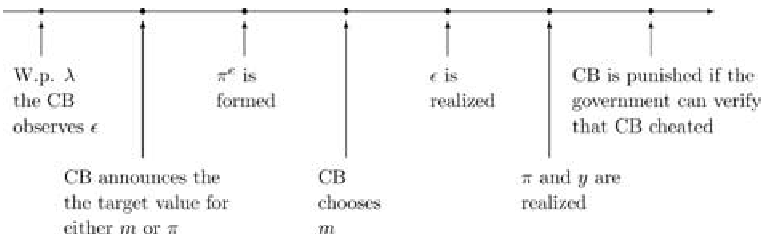

FIGURE 1. Sequence of events.

bank and choose $m = \pi_T$, which implies an inflation rate of $\pi_T - \delta$ or $\pi_T + \delta$, respectively. All other choices imply that the central bank has tried to deceive the public and will therefore lead to severe punishment.

We introduce a punishment mechanism in our model as the target announcements would otherwise be meaningless. It is not necessary for the punishment to amount to ∞, it is sufficient for the punishment to be strong enough to prevent deviations. Of course, we are using a highly stylized mechanism enabling the central bank to commit itself to targets. Weaker assumptions that would allow for small deviations from announced targets would only complicate the analysis and probably lead to similar results.[7]

Within the period in question, the sequence of events is as follows: At the beginning of the period, the central bank has the possibility of observing a signal about the monetary demand shocks occurring in this period. Subsequently, the central bank announces either an inflation target or a monetary target. Then the public forms inflation expectations based on the announcement and locks into nominal contracts for the remainder of the period. Subsequently, the central bank chooses its monetary policy. Finally, after the monetary demand shock has occurred, inflation and real output are realized. If the government is able to prove that the central bank has deliberately failed to achieve the target, it will impose major punishments on the central bank, for example, fire the central bank manager. Thus, the central bank will never want to deviate from its announcement if the government can verify afterward that the bank did not do its best to achieve the target. We summarize the sequence of events in Figure 1.

The government has no possibility of observing whether the central bank was informed in the first stage of the game since the information is not verifiable. Because of the shock, an uninformed bank announcing an inflation target will not be able to reach its goal with certainty. This means that an informed central bank can choose a monetary policy, resulting in an inflation rate that differs from the announced target. If there is a difference between actual and announced inflation, the bank can claim that this gap occurred because it did not have information on the monetary demand shock.

Under monetary targeting, there are no discretionary powers for the central bank because the government is always able to detect whether the central bank has fulfilled its obligation and has chosen the announced rate of monetary growth m.

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There are, however, other communication problems with monetary targeting. Under the monetary targeting scenario, the public knows for sure which choice of monetary growth m the central bank will make. But the public may be unsure which inflation rate will be realized after observing a particular money growth rate because different types of central banks may choose the same or different money growth rates.

The model will later be elaborated for two different cases: inflation targeting and monetary targeting (in Sections 5 and 6, respectively). In the next section, we establish a benchmark case.

4. SOCIALLY EFFICIENT MONETARY POLICY RULES

Let us assume that a social planner exists who can verify the information of the central bank. Ex ante, the planner can impose exact rules concerning how the central bank should behave given the observed signal, that is, in every contingency CB^-, CB^0, CB^+. Hence, problems because of information asymmetries or dynamic inconsistency cease to exist. The social planner enforces a monetary policy that guarantees expected inflation to be zero. The choice of a particular target rule is irrelevant. Hence we obtain:

PROPOSITION 1. *The socially efficient solutions under both monetary policy rules are given by*:

$$\begin{aligned} CB^+ &: \pi_T^+ = m_T^+ + \delta = 0 \\ CB^- &: \pi_T^- = m_T^- - \delta = 0 \\ CB^0 &: \pi_T^0 = m_T^0 \qquad = 0. \end{aligned} \tag{7}$$

Thus, losses for an informed bank are given by:

$$L^I := L^+ = L^- = a\Delta^2. \tag{8}$$

However, expected losses for an uninformed central bank are larger, because it cannot perfectly control inflation:

$$L^0 = a\Delta^2 + (1+a)\delta^2. \tag{9}$$

Because a central bank is informed with probability λ and a bank of type CB^0 occurs with probability $1-\lambda$, we can now derive the expected overall losses in the benchmark case using equations (8) and (9):

$$L = \lambda L^I + (1-\lambda)L^0 = a\Delta^2 + (1-\lambda)(1+a)\delta^2. \tag{10}$$

Not surprisingly, expected overall losses decrease with λ. The greater the likelihood that the central bank is informed about shocks, the smaller the expected losses are because inflation variability can be avoided by stabilizing money demand shocks.

Another way to implement the socially optimal solution is a transparency requirement which forces the central bank to truthfully reveal all private information.[8] In our model, we assume that this is impossible, as the public is not able to verify the central bank's private information.

5. INFLATION TARGETING

Let us first consider inflation targeting as the monetary policy rule. From the punishment scheme [equation (6)], it follows that CB^+ can create inflation that exceeds its target level by δ if it chooses $m = \pi_T$. But CB^- and CB^0 cannot deviate from their targets by creating larger inflation than announced. Therefore, there may be incentives for CB^+ to imitate the banks CB^- and CB^0. The latter may want to signal their types by announcing higher inflation targets than would be optimal without the risk of imitation. This can create extra losses.

The following definition will greatly simplify the analysis:

$$b := a(2\Delta/\delta - 1). \tag{11}$$

We will now show that both under inflation targeting and under monetary targeting the characteristics of possible equilibria crucially depend on the value of b.[9] A classification according to $b \leq 1$ and $b \geq 1$ is reasonable for both scenarios. In Section 8, we will discuss the factors determining the size of b.

We will now show that under inflation targeting a simple pooling equilibrium exists for $b \leq 1$. We prepare the ground for our findings with the following observation about the behavior of CB^+ in the case where the public knows the central bank's type. In the appendix we show:

PROPOSITION 2. *Assume the type of central bank is known to be CB^+. If the inflation target is below a critical level π_c*

$$\pi_T < \pi_c := \frac{b-1}{2}\delta, \tag{12}$$

then $\pi^e = \pi = \pi_T + \delta$ for a central bank of type CB^+. If $\pi^e = \pi = \pi_T$, then $\pi_T > \pi_c$ necessarily holds.

The reasoning behind Proposition 2 is as follows: If CB^+ announces a very high inflation rate, the additional losses for choosing an inflation rate that is even higher ($\pi = \pi_T + \delta$) may outweigh the relatively small benefits from the higher output possibly created by surprise inflation. An inflation target above the critical value is always credible. Because $\pi_c < 0$ for large values of δ, we obtain a pooling equilibrium for $b \leq 1$:

PROPOSITION 3. *Assume $b \leq 1$ (i.e. $\pi_c = \delta(b-1)/2 < 0$), then a pooling equilibrium exists with $\pi_T = \pi^e = 0$ for all types of banks. The beliefs of the public are given by*:

$$\pi^e(\pi_T) = \begin{cases} \pi_T + \delta & \text{for } \pi_T \leq \pi_c \\ \pi_T & \text{for } \pi_T > \pi_c. \end{cases} \tag{13}$$

Expected overall losses are the same as in the benchmark case.

It is obvious that there is no profitable deviation for either type of bank. Intuitively, because CB^+ can only create surprise inflation by the size of the shock and because the parameter δ increases with decreasing b, $b \leq 1$ means that the possible surprise inflation is so large that the losses caused by the high inflation rate outweigh the benefits from surprise inflation.

For $b \geq 1$, we obtain the following proposition, which is proved in the Appendix:

PROPOSITION 4. *Assume $b \geq 1$. Then a semiseparating equilibrium exists with announcements*

$$\begin{aligned} \pi_T^+ &= -\delta \\ \pi_T^0 &= \pi_T^- = (\sqrt{b} - 1)\delta > 0. \end{aligned} \tag{14}$$

The equilibrium and out-of-equilibrium beliefs of the public are given by:

$$\pi^e(\pi_T) = \begin{cases} \pi_T + \delta & \text{for } \pi_T < \pi_T^0 \\ \pi_T & \text{for } \pi_T \geq \pi_T^0. \end{cases} \tag{15}$$

Inflation rates amount to:

$$\pi = \begin{cases} 0 & \text{for } CB^+ \\ \pi_T^0 & \text{for } CB^- \\ \pi_T^0 \pm \delta & \text{for } CB^0. \end{cases} \tag{16}$$

Expected overall losses are:

$$L = a\Delta^2 + (1 - \lambda)(1 + a)\delta^2 + \left(1 - \frac{1}{2}\lambda\right)(\sqrt{b} - 1)^2\delta^2. \tag{17}$$

The equilibrium satisfies the intuitive criterion.[10]

Hence, CB^0 and CB^- announce the same positive inflation rate. CB^+ is separated because of a negative inflation target.[11] The properties of the equilibrium are illustrated in Figure 2. On the left side of Figure 2, the equilibrium targets and the resulting inflation rates are displayed. The right side shows the inflation expectations of the public depending on the announced target.

Let us take a close look at L in Proposition 4. The first and second summand are precisely the losses in the benchmark case. The last summand represents positive signaling costs for CB^0 and CB^-. The probability for a bank to be either of type CB^0 or CB^- is exactly $1 - \lambda/2$. Overall losses are decreasing in λ, but always exceed the benchmark losses because even for $\lambda \to 1$ there are signaling costs for CB^-.

We have already noted in the proof of Proposition 4 that in any separating equilibrium π_T^+ must be $-\delta$. Hence, if other separating equilibria exist, the difference can only be due to higher values for π_T^0. But obviously these equilibria would not

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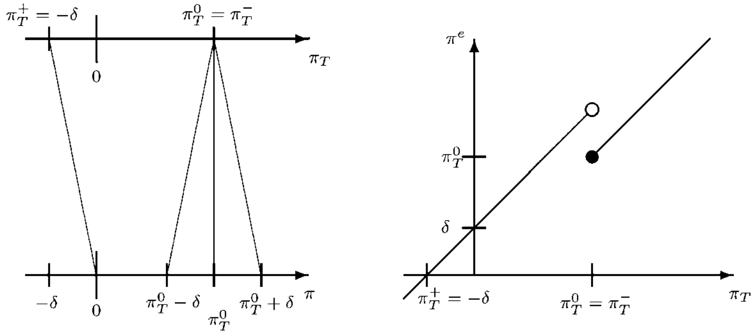

FIGURE 2. Separating equilibrium under inflation targeting for $b \geq 1$.

satisfy the intuitive criterion, as every $\pi_T > \sqrt{b} - 1$ is equilibrium dominated for CB^+ by construction. We obtain:

PROPOSITION 5. *The equilibrium of Proposition 4 is the only separating equilibrium that satisfies the intuitive criterion.*

We next look at pooling equilibria for $b \geq 1$. In the Appendix, we will prove the following proposition:

PROPOSITION 6. *No pooling equilibrium exists for $b \geq 1$ that satisfies the intuitive criterion.*

Hence, the equilibrium in Proposition 4 is unique if we use the intuitive criterion that is the most widely applied refinement in signaling games.

Note that for $b = 1$, the results obtained for both assumptions $b \geq 1$ and $b \leq 1$ yield the same inflation rates and social losses.

6. MONETARY TARGETING

In this section, we focus on monetary targeting. The central bank announces a target value m_T. The public knows that the central bank will always choose the announced monetary growth rate, as any deviation would cause punishment and infinite losses [according to equation (5)]. But in order to predict inflation, the public must form expectations about the type of central bank announcing a particular money growth target m_T. Given the announcement m_T, any of the values $m_T - \delta$, m_T and $m_T + \delta$ might be the inflation rate expected by the central bank. Because of this uncertainty, there are several incentives for central banks to mimic other types of banks and to signal a particular type to the public. CB^0 could gain from imitating the behavior of CB^- because surprise inflation would be possible if the public believed that CB^0 was CB^-. And CB^+ might elect to imitate CB^0 and perhaps even CB^- because this would create space for moderate or even very high surprise inflation. Because the danger of being imitated pushes up inflation expectations, both CB^0 and CB^- may want to signal their types. Thus, there is the

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possibility of even larger signaling costs compared to the outcome under inflation targeting.

As a result of the punishment scheme for monetary targeting [equation (5)], $m_T = m$ holds in any equilibrium. Hence, we will omit the index t in the following.

For $b \leq 1$, we obtain results that are similar to the outcomes under inflation targeting. In the Appendix, we prove the following proposition:

PROPOSITION 7. *Assume $b \leq 1$. Then the following fully separating equilibrium exists. The monetary policy chosen in equilibrium is*: $m^+ = -\delta$, $m^- = +\delta$, *and* $m^0 = 0$. *The equilibrium and out-of-equilibrium expectations of the public are given by*:

$$\pi^e(m) = \begin{cases} m + \delta & \text{for } m < 0 \\ m & \text{for } 0 \leq m < \delta \\ m - \delta & \text{for } m \geq \delta. \end{cases} \tag{18}$$

Inflation rates amount to:

$$\pi = \begin{cases} 0 & \text{for } CB^+ \text{ and } CB^- \\ \pm\delta & \text{for } CB^0. \end{cases} \tag{19}$$

Expected overall losses are the same as in the benchmark case.

Proposition 7 indicates that where b is sufficiently small, we obtain the benchmark outcome as in the case of inflation targeting.

Let us now examine the solution for $b \geq 1$. In the Appendix, we show:

PROPOSITION 8. *Assume $b \geq 1$. Then the following separating equilibrium exists. The monetary policy chosen in equilibrium is*:

$$\begin{aligned} m^0 &= (\sqrt{b} - 1)\,\delta > 0 \\ m^- &= \sqrt{2b - 2\sqrt{b} + 1}\;\delta > \delta \\ m^+ &= -\delta. \end{aligned} \tag{20}$$

The equilibrium and out-of-equilibrium beliefs of the public are given by:

$$\pi^e(m) = \begin{cases} m + \delta & \text{for } m < m^0 \\ m & \text{for } m^0 \leq m < m^- \\ m - \delta & \text{for } m^- \leq m. \end{cases} \tag{21}$$

Inflation rates amount to:

$$\pi = \begin{cases} 0 & \text{for } CB^+ \\ m^0 \pm \delta & \text{for } CB^0 \\ m^- - \delta > m^0 & \text{for } CB^-. \end{cases} \tag{22}$$

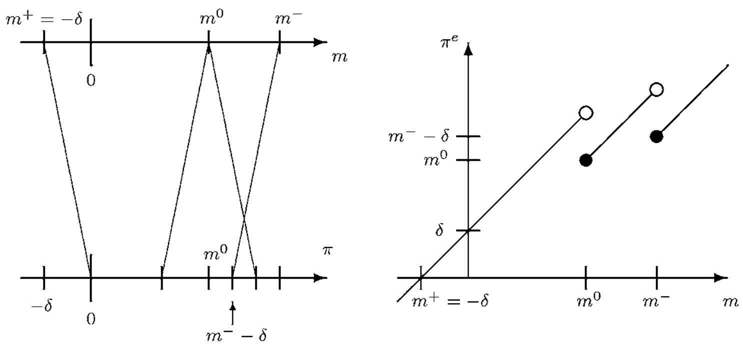

FIGURE 3. The separating equilibrium under monetary targeting for $b \geq 1$.

Overall expected losses are:

$$L = a\Delta^2 + (1-\lambda)(1+a)\delta^2 + (1-\lambda)(\sqrt{b}-1)^2\delta^2 + \frac{\lambda}{2}(\sqrt{2b-2\sqrt{b}+1}-1)^2\delta^2. \tag{23}$$

The equilibrium for monetary targeting differs from the equilibrium for inflation targeting in one way. Under monetary targeting, there are three types of banks, whereas in the preceding section there were effectively only two types. As we will prove, this leads to increased signaling costs and therefore to higher expected overall losses. The properties of the equilibrium are illustrated in Figure 3. On the left side of Figure 3, the chosen equilibrium targets and the resulting inflation rates are displayed. The right side shows the inflation expectations of the public depending on the announced target.

The expression for L in Proposition 8 may seem rather complicated, but it is in fact easy to interpret. The first and second terms are the benchmark losses, with the second term representing the losses because of the imperfect controllability of inflation for uninformed banks. Note that the probability for the emergence of an uninformed bank is $1 - \lambda$. The third and the fourth terms represent the signaling costs of banks CB^0 and CB^-, respectively. Note that the probability for CB^0 is $1 - \lambda$ and $\lambda/2$ for CB^-.

Whether losses are increasing or decreasing in λ under monetary targeting depends on the parameter values. For some parameter constellations, poor knowledge of the central bank about future shocks might be socially more beneficial than accurate forecasts.

In the Appendix we show that, as with inflation targeting, pooling equilibria can be ruled out by the intuitive criterion.[12]

PROPOSITION 9. *Assume $b \geq 1$. No pooling equilibrium exists if we apply the intuitive criterion.*

7. MONETARY TARGETING VERSUS INFLATION TARGETING

Let us compare monetary targeting and inflation targeting for $b > 1$. For both monetary policy rules, CB^+ incurs no signaling costs because CB^+ would choose

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the same targets if the public knew the central bank's type. Under monetary targeting, the signaling costs of CB^0 are exactly the same as under inflation targeting whereas the signaling costs for CB^- are higher. This is the case under monetary targeting because CB^0 could profit from imitating CB^- by creating unexpected inflation and, thus, output gains. This possibility does not exist under inflation targeting, as CB^0 does not want to create inflation exceeding the announced target.

Because of the increased signaling costs for CB^-, overall expected losses and expected inflation rates are higher under monetary targeting.

We can thus derive:

PROPOSITION 10. *The social losses under inflation targeting are either lower than or equal to those incurred under monetary targeting.*

1. *If* $b \leq 1$, *monetary targeting and inflation targeting are socially equivalent.*
2. *If* $b > 1$, *inflation targeting is socially preferable to monetary targeting. The difference in social losses, that is, social losses under monetary targeting minus social losses under inflation targeting, amounts to*:

$$\Delta L = \frac{1}{2}\lambda\delta^2(b - 2\sqrt{2b - 2\sqrt{b} + 1} + 1) > 0. \quad (24)$$

Although the possibility of creating surprise inflation exists both for $b \leq 1$ and for $b \geq 1$, condition $b \leq 1$ guarantees that the benefits of an increase in output because of surprise inflation are smaller than the losses created by a higher inflation rate. Therefore, under both monetary policy rules there is no necessity for signaling and the socially optimal results occur for $b \leq 1$.

Interestingly, under monetary targeting the public can exactly derive the central bank's type from the announced target; this is impossible under inflation targeting. Thus, the public is informed better under monetary targeting, albeit at the expense of inefficiently high costs.

Why is monetary targeting inferior to inflation targeting? Under monetary targeting an uninformed bank has the potential to create surprise inflation; this is not possible under inflation targeting. Let us consider monetary targeting and suppose that the central bank is uninformed. If the public expects a negative shock, then the public's inflation expectations are below the uninformed central bank's inflation expectations. This means that the uninformed central bank expects beneficial output gains. A central bank that has observed a negative shock will, however, try to prevent imitation due to larger output gains if the public's expectations are above the actual inflation rate. It will therefore choose a high inflation rate to deter imitation. Now let us consider inflation targeting and suppose that the central bank is uninformed and announces an inflation target π_T. If the public expects a positive shock, inflation expectations will be $\pi_T + \delta$. If the public expects an uninformed bank, the public's expectations will equal π_T. If the public expects a negative shock, it will expect an inflation rate of π_T because a choice of $\pi_T - \delta$, although possible, is never beneficial for $b \geq 1$. All three cases imply that the public's inflation expectations are larger than or equal to the inflation rate expected by

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the central bank. There is no possibility for an uninformed central bank to create surprise inflation and output gains. Therefore, a central bank that has observed a negative shock has no reason to deter imitation at the expense of large inflation. This is why inflation targeting is superior to monetary targeting.

8. DISCUSSION OF PARAMETER *b*

We will now discuss the factors determining the size of b, which we have defined in equation (11). This is important because inflation targeting is superior to monetary targeting for $b > 1$, whereas both inflation targeting and monetary targeting yield the same social losses for $b \leq 1$. First, the parameter b is decreasing in a. Thus, for central banks that are hard on inflation, that is, for small a, both scenarios lead to the same outcomes. But for central banks that put very high emphasis on output targets, our model indicates that inflation targeting will be the better option. In our conclusions, we will return to this observation.

Second, b depends on the value of Δ. Δ is the difference between the output growth target and the natural rate of output. If the central bank targets the flexible-price output level, that is, the level that would obtain if any frictions such as distortionary taxes, imperfect competition in goods markets and labor markets were absent, then Δ is a measure of the frictions in the economy that lower output below its optimal level. Note that a high value of Δ increases the incentive for inflationary surprises.

Third, b also depends on δ. In a more general model, shocks to money demand could be divided into a commonly known component and a component that may only be known to the central bank. Thus, shock ϵ in our model represents the latter part of the whole shock, that is, δ should not be interpreted as the overall size of monetary disturbances but as the part of these shocks that is unknown to the public but may be known to the central bank. It is therefore appropriate to use δ as a measure of the potential informational advantage of the central bank vis-à-vis the public or as a measure of (the lack of) transparency. If δ is small, then the potential for asymmetric information is negligible and monetary policy is highly transparent. Note that a small value of δ, that is, a small potential informational advantage for the central bank, implies a large value of b and therefore that inflation targeting is superior. Thus, a central bank facing a well-informed public is more likely to adopt inflation targeting than monetary targeting, whereas if there are perhaps large information asymmetries a central bank will be indifferent as to the choice between the two monetary policy strategies. This may explain the current tendency toward inflation targeting. Information asymmetries may have been mitigated, and this makes inflation targeting more worthwhile for central banks.[13]

It may be interesting to get a feel for plausible values of b. For simplicity, we have used a Phillips curve $y = y_0 + \alpha(\pi - \pi^e)$ with α set to 1. It is straightforward to show that, in general, that is, for $\alpha \neq 1$, we would obtain $b = a\alpha^2(\frac{2\Delta}{\alpha\delta} - 1)$. Thus, in order to determine b, we have to calibrate α, which we approximate by the inverse of the sacrifice ratio.[14] We assume a value of $\alpha = 1/6.4$ [which corresponds to the choice of Gordon (1997), footnote 8]. Following Cecchetti et al. (2002), we set the weight on the output goal to $a \approx 1/3$.[15] For Δ a value of about 3% might seem reasonable. Because δ corresponds to the potential informational advantage of the central bank[16] for the inflation forecast over the relevant horizon of, say, approximately one year, it is unlikely to be much higher than $\delta = 0.3\%$. Inserting these values into our expression for b, we obtain $b \approx 1.03$. This result should, of course, be taken with great caution and is no more than an indication that a value for b of larger than 1 is not completely unrealistic. Thus, there may be more welfare gains from inflation targeting than monetary targeting.

9. DISCUSSION OF ASSUMPTIONS

In this section, we explore the plausibility of our main assumptions and their significance for our findings. We also discuss some possible modifications to our model. One of our assumptions is that the government imposes infinite losses on the central bank if it can verify that the central bank has deliberately failed to achieve the target. Because of time inconsistency, it may be uncertain whether the government will actually impose the penalty if a deviation is detected. In New Zealand, for instance, the Governor of the Reserve Bank can be fired for failing to achieve the inflation target. In 1996, inflation exceeded the upper ceiling of the target range, but the Governor stayed in office [cf., e.g., Bernanke et al. (1999)]. For our results to hold, it is not necessary for the central bank manager to be actually fired; it is sufficient for the central bank manager to estimate the likelihood of dismissal high enough to deter any detectable deviations. The sanctions also may arise without an actual punishment by the government. In particular, if we were to consider a dynamic version of our model with infinitely many subsequent stages of the game we have described, then these infinite losses could be interpreted as a loss of reputation.

If we dispense the assumption that the loss function of the central bank is representative of social losses, the conclusion that inflation targeting will perform either as well as or even better than monetary targeting still remains valid. Even if social losses were represented by a loss function with a different emphasis on the output goal $a' \neq a$, society should still prefer inflation targeting for $b > 1$. This follows from the fact that intentional surprise inflation can never be achieved in equilibrium.

One important assumption is that there is a positive chance that central banks will have superior information. Apart from the reasoning in the literature mentioned in Section 3, there are complementary arguments that central banks may have superior information. Wieland (2000) notes that under model uncertainty central banks may be inclined to change their instruments slightly in order to obtain information about the way the transmission channel works. Because only the central bank knows whether certain effects are a result of exogenous shocks or a result of its own experimenting, this may be a source of superior information. Goodfriend (1986) suggests that the widespread use of "Fed watchers" is an indication that the Federal Reserve has private information about monetary relationships. But, obviously, this also could be information about preferences or the intended path of future monetary policy. Recent claims that the ECB should publish internal forecasts [see Buiter (1999), among others] also may indicate that central banks have private information that is not available to outsiders. Peek et al. (1999, 2003) identify a possible source of superior information. They convincingly argue that part of the Fed's informational advantage stems from confidential data gained by banking supervision. Moreover, both the U.S. Federal Reserve System and the ECB through the 11 National Central Banks have large research departments and a strong regional presence and may be privy to information on aggregate or regional monetary shocks that are not readily available to outsiders.

Let us now discuss the special form of loss function we are considering here. One might argue that no central bank in industrial countries has recently tried to stimulate economy by creating surprise inflation. Hence, the output goal in the loss function might seem artificial. But this observation does not contradict our model because the model predicts that surprise inflation does not occur in equilibrium. Another form of loss function often encountered in the literature [e.g. in Laubach (2003)] is linear in the output goal and not quadratic, as is assumed in our model. One can show that the results stay essentially the same for this modified loss function.

We have derived our results assuming a very simple distribution of shocks. In the Appendix, we illustrate for completeness that our results would still hold if we considered a richer setup in which shocks are uniformly distributed on a symmetric interval around zero.

Our results strengthen if we change the sequence of events. If the central bank chooses m before the public forms its inflation expectations π^e, nothing changes under monetary targeting because, as a result of our punishment scheme, m_T and m are always equal.[17] Thus, m does not reveal any new information to the public. But under inflation targeting the situation is different. Because the public observes both m and π_T, this means that CB^- can signal its type without cost. This further improves the performance of inflation targeting. The same arguments imply that, compared to losses under inflation targeting and monetary targeting, the central bank's expected losses will be lower if it announces two targets simultaneously. If the central bank announces both a monetary target and an inflation target, then the central bank that observes a negative shock can signal its type without cost. The uninformed bank, however, can still be imitated by CB^+ and will signal its type by choosing the same targets as under inflation and monetary targeting.

One also might ask how our findings would have to be adapted for a dynamic setting in which our basic game would be repeated many (possibly infinitely many) times. Let us consider two polar cases. First, the central bank's competence may be constant over time, implying that a central bank that receives information about ϵ in the first period also will obtain information in all future periods. Then the public could learn over time whether the central bank is informed or uninformed. An uninformed central bank could always commit to an optimal policy with zero

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inflation on average, no matter whether it was pursuing inflation targeting or monetary targeting. However, if the central bank were known to be informed, then one might expect that although it could not risk deviating from announced targets under inflation targeting, the signaling problems inherent in our model would not disappear completely under monetary targeting. CB^+ would have an incentive to mimic CB^-, which would induce CB^- to choose a relatively high money growth in its bid to signal its type. Also note that the equilibrium choices of the central bank do not depend on λ in our paper. This implies that the equilibria constructed in this paper would continue to exist even when the public would have learned the central bank's type with very high, albeit not perfect, precision.[18]

Second, if there was no perfect correlation between the precision of the central bank's past information and the precision of its information today, then the iterated equilibrium of our basic game also would be an equilibrium of the repeated game. One might argue that the central bank could overcome the time-inconsistency problem by building up a reputation. However, in our framework this is much harder than in the standard model, as an uninformed central bank may unintentionally create inflationary surprises that may cause a loss in reputation. Hence, inflation targeting is likely to remain superior in a dynamic setting.

10. CONCLUSIONS

Our main finding is that, as inflation targets involve a closer link between the announced target and future inflation,[19] inflation targeting makes it easier to overcome the problem of time-inconsistency. However, even under inflation targeting, the link between the announced target and future inflation is not perfectly tight. An interesting implication of our model is that transparency, that is, the publication of central banks' private information concerning macroeconomic shocks, is beneficial if the private information can be verified by the public, because it reduces the leeway between announced targets and future inflation. If δ, which is a measure of the central bank's informational advantage, decreases, then welfare increases under monetary targeting and under inflation targeting, as a very low value for δ makes it easier for the central bank to commit to a low-inflation policy by announcing target values. For $\delta = 0$ there is a very tight relationship between the announced target and the realized inflation rate, implying that the central bank can always commit to an optimal monetary policy. In brief, this model's recommendation for central banks is to publish all verifiable information concerning macroeconomic shocks. Non-verifiable information transparency, though desirable, is not feasible because truthful revelation is not in the central bank's interest.[20]

Let us now discuss what would happen if the central bank could choose freely whether to adopt inflation or monetary targeting as its monetary policy framework. This is an important issue in the current start-up phase of the European Central Bank (ECB). Our results indicate the following choices. If the central bank were able to choose its target variable ex ante, that is, before it realizes the shock, it would prefer inflation targeting for $b > 1$ because this implies lower expected losses.

For any of the three contingencies CB^+, CB^0, and CB^-, losses under inflation targeting are either as large as under monetary targeting or smaller. But for $b \leq 1$ the central bank would be indifferent, as expected losses and inflation rates are the same for both monetary policy rules. Inflation targeting is thus especially attractive for countries where credibility is a major issue, that is, where the value of b is relatively high, which implies that the temptation for surprise inflation is large.

As a corollary, our model may provide an explanation why many countries suffering from rather large inflation rates in the past have adopted inflation targeting. According to our model, inflation targeting enables central banks to commit themselves to low inflation rates more easily than with monetary targeting.[21] The countries that have adopted inflation targeting may have had considerable deficiencies with respect to credibility, which is reflected by a high value of b in our model. They may have used inflation targeting as a device to surmount these problems.

The mirror image of the argument might explain why the central banks in Germany and Switzerland did not switch policies from monetary to inflation targeting for a long period of time. Both central banks can be thought of as hard on inflation. This implies small weights a on output targets and therefore comparably small values for b. Hence, there have been smaller incentives to implement inflation targeting compared to other central banks.[22] But if we assume that the ECB starts with a higher value of a than the Bundesbank and the Swiss National Bank, or at least that the public assumes that a is larger [see also Illing (1998)], then inflation targeting should be the policy of choice.

NOTES

1. The Bundesbank, a central bank that has officially claimed to pursue monetary targeting, has recently been discussed as pursuing a hybrid strategy, that is, a mixture of inflation targeting and monetary targeting [see Bernanke et al. (1999)].

2. See the discussion of the literature in Section 2.

3. See Bernanke et al. (1999), Cabos et al. (2001), Cukierman (1995, 1997), Friedman and Kuttner (1996), Goodhart and Viñals (1994), Laubach (2003), Leiderman and Svensson (1995), McCallum (1999), Mishkin (1999), Svensson (1997, 1999), Taylor (1996), von Hagen (1995, 1999), and Wagner (1998).

4. The idea has been introduced by Canzoneri (1985) and also by Goodfriend (1986). For extensive discussion, see Cukierman (1992) and Romer and Romer (1997). Recent examinations of central banks with private information include Berger and Thum (2000), Garfinkel and Oh (1995), Laubach (2003), and Schaling (1995).

5. Additionally, we assume that $\Delta > 2\delta$, which will guarantee that realized output y is always smaller than the target y^*.

6. For a discussion of the enforcement of such arrangements and the nature of penalties, see Garfinkel and Oh (1993), Persson and Tabellini (1993), Rogoff (1985), and Walsh (1995a,b). For instance, Walsh (1995a) shows how the threat of dismissal can cause the central banker to pursue a desired policy.

7. Berger and Thum (2000) note that it may be relatively easy for a competent central bank to pretend to be uninformed. Pretending to be uninformed simply requires withholding information. By contrast, falsely pretending to have a certain kind of information requires the faking of data, which

may be much more difficult. In our model, it is never necessary for the central bank to actually forge information. Under monetary targeting, the central bank simply announces a money growth target which can be controlled exactly. The punishment is completely independent of the observed shock. Under inflation targeting, competent central banks may claim to be uninformed, but a central bank will never have to fake information.

8. Cf. Section 9 for a more detailed discussion.

9. Note that from $\Delta > 2\delta$ it follows that $b > 0$.

10. The intuitive criterion provides a means to check the plausibility of out-of-equilibrium beliefs. Suppose a central bank were expected to be of type $T \in \{CB^-, CB^0, CB^+\}$ if it chose a certain target that is not chosen in equilibrium. If a central bank of type T would never benefit from choosing this out-of-equilibrium strategy, whereas a central bank of type $T' \neq T$ would, then the out-of-equilibrium beliefs about the central bank's type can be ruled out as implausible. See Cho and Kreps (1987) for the precise definition of the intuitive criterion.

11. Note our assumption that the government cannot penalize CB^+ for creating higher inflation than announced, even though the type of central bank becomes apparent as a result of the signal created by the announced target. One reason might be that the central bank has the "right to be irrational." An uninformed central bank is allowed to choose an inflation target of $-\delta$, although this would not be optimal. Another reason might be that a punishment would imply the use of the public's expectations, which might not be verifiable in court.

12. It is unlikely that there are other equilibria, such as semiseparating equilibria, where two types pool as the third type of central bank chooses a different equilibrium strategy, which would satisfy the intuitive criterion.

13. Note that under transparency, that is, for $\delta = 0$, deliberate deviations from target values are not feasible for central banks. We obtain the benchmark results under monetary targeting and inflation targeting, as the central bank can commit to low inflation. But often the information is not verifiable, so transparency, although desirable, may be impossible [see Goodfriend (1986)].

14. The sacrifice ratio is the amount of output lost for a reduction in the inflation rate.

15. Salemi (1995) also estimates the Fed's preferences, using inverse-control theory.

16. Cf. the discussion in Section 8.

17. There is usually a long time lag between the monetary policy measure and its maximum effect. So there is a chance that the central bank may have already chosen a monetary policy but at a given time, when, for example, wages are determined, the monetary policy has not yet become effective [for a discussion of the transmission channels of monetary policy and the respective time lags see, e.g., Svensson (1999)].

18. One also might suspect that the central bank learns over time. Accordingly, the probability of the central bank being informed could increase. Nevertheless, the central bank may not be informed with certainty.

19. See Section 1.

20. Cf. Section 9 for a discussion.

21. In a dynamic context with many periods, it might be possible for central banks to gain a reputation for being tough on inflation and thus solve the credibility problem inherent in the framework of Barro and Gordon (1983). But building reputation by keeping inflation low may take time and is often costly at the outset.

22. Clearly, there are other potential explanations why different countries have adopted different targeting approaches for central banks. For instance, the decision for monetary targeting could be interpreted as an attempt to signal a small value of a because, according to our model, only central banks with a small value of a would choose monetary targeting.

23. We only consider equilibria in pure strategies.

24. We will omit the conditions for the existence of pooling equilibria here. We can however establish that these conditions can be satisfied for sufficiently large values of a. The inflation expectations [equation (A.1)] lead to costs for a central bank's deviations. These costs are increasing in a. Therefore, pooling equilibria exist for large a.

25. Obviously, e does not necessarily exist, that is, e^2 may be negative. But this is not essential because the proposition holds trivially if e does not exist. This follows because of the next condition ${\pi'_T}^2 < f^2$. For example, $\pi_T{}' = 0$ is always a solution when $e^2 < 0$.

26. This separating equilibrium is the only separating equilibrium that satisfies the intuitive criterion. The arguments are essentially the same as in the proof of Proposition 5.

27. If the root on the left side of the first inequality does not exist, this condition must be omitted.

28. For a central bank that has observed a negative shock or that is uninformed, no profitable deviation from the constructed equilibrium can exist. But there is one possible deviation left to be checked. A central bank that has observed a positive shock could choose $\pi = \pi_T$ instead of $m = \pi_T$. It is however not easy to derive the resulting condition for the existence of the equilibrium (which would correspond to the condition $b \geq 1$ derived for only two possible shocks) because the equilibrium choice of π_T cannot be solved analytically as a function of the observed shock.

29. The public is, however, unable to distinguish an uninformed central bank from a bank that has observed a shock of size zero because both central banks will choose the same monetary targets, which amount to π^0.

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APPENDIX

Proof of Proposition 2. Let us consider only the behavior of CB^+. Assume $\pi^e(\pi_T) = \pi_T$. According to our rational-expectations assumption it follows that CB^+ has no incentive to create surprise inflation, that is, to choose $\pi = \pi_T + \delta$ given $\pi^e = \pi_T$. Equilibrium losses for CB^+ are:

$$L^+ = \pi_T^2 + a\Delta^2.$$

Losses for CB^+ when creating surprise inflation would amount to:

$$L^{+'} = (\pi_T + \delta)^2 + a(\delta - \Delta)^2.$$

Thus, surprise inflation is not profitable if

$$\begin{aligned} L^+ &\leq L^{+'} \\ \pi_T^2 + a\Delta^2 &\leq (\pi_T + \delta)^2 + a(\delta - \Delta)^2 \\ \pi_T &\geq \frac{2a\Delta - (1+a)\delta}{2} = \frac{b-1}{2}\delta =: \pi_c. \end{aligned}$$

Let us briefly summarize our arguments: if $\pi^e(\pi_T) = \pi_T$, then $\pi_T \geq \pi_c$ holds. If $\pi_T < \pi_c$, then $\pi^e(\pi_T) \neq \pi_T$ must hold for a central bank of type CB^+. ■

Proof of Proposition 4. Let us now check whether the proposed equilibrium actually exists.

1. First, assume that we can neglect the behavior of CB^- and that it will simply imitate CB^0. Hence, we will only consider two types of bank. This assumption will be justified later.
2. Now we derive some properties of the expectations of the public $\pi^e(\pi_T)$. This function must be a step function with possible values of $\pi^e = \pi_T$, $\pi^e = \pi_T + \frac{1}{2}\lambda\delta$ or $\pi^e = \pi_T + \delta$, representing the different possible beliefs of the public about the type of central bank.[23] Suppose a separating equilibrium in pure strategies exists. The inflation target chosen by CB^+ and CB^0 is denoted by π_T^+ and π_T^0, respectively. Then, in equilibrium, we must have $\pi^e(\pi_T^0) = \pi_T$ and $\pi^e(\pi_T^+) = \pi_T + \delta$. Note that $\pi^e(\pi_T)$ must be constant in an open interval around π_T^+. Otherwise CB^+ could change π_T by an infinitesimal amount and thereby reduce its losses. But this means that π_T^+ must equal $-\delta$, as only at this point CB^+ does have no incentive to change π_T, provided the expectations of the public are $\pi^e = \pi_T + \delta$. From these first results, we also can derive the value π_T^0.
3. CB^+ has no incentive to mimic CB^0, that is, to choose $\pi_T = \pi_T^0$ (or even higher values of π_T). Equilibrium losses for CB^+ amount to:

$$L^+ = a\Delta^2.$$

If CB^+ chooses $\pi_T = \pi_T^0$, losses are:

$$L^{+'} = \left(\pi_T^0 + \delta\right)^2 + a(\delta - \Delta)^2.$$

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CB^{+} does not want to deviate if

$$L^{+'} \geq L^{+}$$
$$\left(\pi_T^0 + \delta\right)^2 \geq \delta(2\Delta - \delta).$$

Thus, the lowest level of π_T^0 consistent with this condition is given by:

$$\pi_T^0 = \sqrt{a\delta(2\Delta - \delta)} - \delta = (\sqrt{b} - 1)\delta.$$

4. It is not reasonable for CB^0 to choose $\pi_T > \pi_T^0$ because losses would increase. Now we show that CB^0 has no incentive to choose $\pi_T < \pi_T^0$ either. If this deviation were profitable, CB^0 would do best to choose $\pi_T = 0$. Equilibrium losses are:

$$L^0 = \left(\pi_T^0\right)^2 + a\Delta^2 + (1+a)\delta^2.$$

If CB^0 deviates, losses amount to:

$$L^{0'} = a(\delta + \Delta)^2 + (1+a)\delta^2.$$

The deviation is not profitable if

$$L^0 < L^{0'}$$
$$\left(\pi_T^0\right)^2 + a\Delta^2 < a(\delta + \Delta)^2$$
$$(\sqrt{b} - 1)^2 < b + 2a$$
$$\sqrt{b} > \frac{1}{2} - a.$$

Because by assumption $b \geq 1$ and $a > 0$, this inequality holds.

5. We will now justify our assumption concerning the behavior of CB^{-}. Obviously no profitable deviation $\pi_T' < \pi_T^0$ for CB^{-} exists because the best deviation $\pi_T' < \pi_T^0$ for CB^{-} is the same as the best deviation for CB^0 (i.e., $\pi_T = 0$ and therefore $\pi = 0$). Hence, the only deviation left to be checked is: CB^{-} chooses $\pi_T = \pi_T^0$ but selects a monetary policy that yields $\pi = \pi_T^0 - \delta$. This deviation is not profitable if

$$\left(\pi_T^0\right)^2 + a\Delta^2 < \left(\pi_T^0 - \delta\right)^2 + a(\Delta + \delta)^2$$
$$2\sqrt{b} < b + 2a + 3,$$

which always holds for $b > 1$ and $a > 0$.

6. Now we need to check whether $\pi_T^0 < \pi_c$. If not, there could be a contradiction between our assumptions on the inflation expectations $\pi^e(\pi_T)$ and Proposition 2.

$$\pi_T^0 < \pi_c$$
$$\sqrt{b} - 1 < \frac{b-1}{2}.$$

This is always true because $b \geq 1$. Thus, there is no contradiction to our assumption about $\pi^e(\pi_T)$.

7. Finally, we check whether the intuitive criterion is satisfied. We can be sure that $\pi_T \in]-\delta, \pi_T^0[$ is equilibrium dominated for CB^{+} because losses for CB^{+} definitely decrease if it chooses $\pi_T \in]-\delta, \pi_T^0[$ and the public believes $\pi^e = \pi_T$. Hence, the intuitive criterion is satisfied in the crucial region $\pi_T \in]-\delta, \pi_T^0[$.

Hence, the proposed equilibrium exists. ■

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Proof of Proposition 6. Whereas pooling equilibria may exist for special parameter values, we will now show that no pooling equilibrium for $b \geq 1$ satisfies the intuitive criterion.[24]

Assume a pooling equilibrium exists with inflation targets π_T^* for all types of banks. For this equilibrium to exist the public must make every deviation from this equilibrium inflation target unprofitable by expecting high inflation. Thus, for the expectations of the public we obtain:

$$\pi^e(\pi_T) = \pi_T + \begin{cases} \lambda\delta/2 & \text{for } \pi_T = \pi_T^* \\ \delta & \text{otherwise.} \end{cases} \qquad \textbf{(A.1)}$$

Pooling equilibria can be eliminated by applying the intuitive criterion if a deviation π_T' exists for every equilibrium inflation target π_T^*, which fulfills the following properties:

1. CB^+ does not want to select π_T' (independent of the beliefs of the public at π_T');
2. at π_T' CB^0 has losses lower than the equilibrium losses if the public expects the type of central bank to be CB^0 at π_T'.

These two conditions yield two different inequalities:

1. Equilibrium losses for CB^+ amount to:

$$L^+ = \left(\pi_T^* + \delta\right)^2 + a[(1 - \lambda/2)\delta - \Delta]^2.$$

The deviation would be most profitable if the public believed the type to be CB^0 at π_T'. Thus, losses would amount to:

$$L^{+'} = (\pi_T' + \delta)^2 + a(\delta - \Delta)^2.$$

The deviation is not desirable if:

$$\begin{aligned} L^{+'} &> L^+ \\ (\pi_T' + \delta)^2 &> (\pi_T^* + \delta)^2 + a\{[(1 - \lambda/2)\delta - \Delta]^2 - (\delta - \Delta)^2\}. \end{aligned}$$

Reorganizing the second term of the right side

$$\begin{aligned} &a\{[(1 - \lambda/2)\delta - \Delta]^2 - (\delta - \Delta)^2\} \\ &\quad = a\delta\{[(1 - \lambda/2)^2 - 1]\delta + 2\Delta[1 - (1 - \lambda/2)]\} \\ &\quad = \lambda\delta a(-\delta + \lambda\delta/4 + \Delta) \\ &\quad = \lambda\delta^2 a\left[\frac{b + a}{2a} + a(\lambda/4 - 1)\right] \\ &\quad = \frac{\lambda\delta^2}{2}[b + a(\lambda/2 - 1)], \end{aligned}$$

we obtain the condition:[25]

$$(\pi_T' + \delta)^2 > (\pi_T^* + \delta)^2 + \frac{\lambda\delta^2}{2}[b + a(\lambda/2 - 1)] =: e^2 \qquad e > 0.$$

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2. The deviation must be profitable for CB^0 if the public believes the type is CB^0 at π_T'. Equilibrium losses are given by:

$$L^0 = \pi_T^{*2} + a(\lambda\delta/2 + \Delta)^2.$$

Losses for the deviation amount to:

$$L^{0'} = \pi_T'^{\,2} + a\Delta^2.$$

For the deviation to be profitable we must have:

$$\begin{aligned} L^{0'} &< L^0 \\ \pi_T'^{\,2} &< \pi_T^{*2} + a\delta(\lambda\Delta + \lambda^2\delta/4) \\ \pi_T'^{\,2} &< \pi_T^{*2} + \frac{\delta^2\lambda}{2}[b + a(1+\lambda/2)] =: f^2 \qquad f > 0. \end{aligned}$$

A sufficient condition for the existence of a π_T' satisfying the two inequalities is:

$$\delta + f > e$$

Inserting the expressions for e and f and simplifying the inequality yields:

$$\sqrt{\pi_T^{*2} + \frac{\delta^2\lambda}{2}[b + a(1+\lambda/2)]} > \pi_T^* - \frac{\lambda\delta a}{2}.$$

This inequality holds if either

$$\pi_T^* < \frac{\lambda\delta a}{2},$$

or

$$\begin{aligned} \pi_T^{*2} + \frac{\delta^2\lambda}{2}[b + a(1+\lambda/2)] &> \left(\pi_T^* - \frac{\lambda\delta a}{2}\right)^2 \\ \pi_T^* &> \frac{\delta}{2}\left(\frac{\lambda a}{2} - \frac{b}{a} - 1 - \frac{\lambda}{2}\right). \end{aligned}$$

But because the right side of the last inequality is smaller than $\lambda\delta a/2$, a deviation π_T' exists for every π_T^* that satisfies the two conditions enabling us to exclude the pooling equilibrium. Hence, any pooling equilibrium can be eliminated using the intuitive criterion. ■

Proof of Proposition 7. There are two candidate deviations (all other deviations are less attractive).

1. CB^0 chooses $m = \delta$. Losses would be:

$$L^{0'} = \delta^2 + a(\Delta - \delta)^2 + (1+a)\delta^2.$$

Equilibrium losses amount to:

$$L^0 = a\Delta^2 + (1+a)\delta^2.$$

For the deviation to be unprofitable $L^{0'} \geq L^0$ must hold and therefore

$$\begin{aligned} \delta^2 + a(\Delta - \delta)^2 &\geq a\Delta^2 \\ b &\leq 1, \end{aligned}$$

which corresponds to our assumption.

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2. CB^+ chooses $m = 0$. The computations are similar and yield the same result as in the first candidate deviation. Because CB^+ can control inflation exactly, the respective losses in this case, L^+ and $L^{+'}$, only differ from L^0 and $L^{0'}$ by the term $(1 + a)\delta^2$.

Because there is no profitable deviation, the proposed equilibrium exists. ■

Proof of Proposition 8. As a result of arguments similar to those established in the proof of Proposition 4, the money growth rate m^+ must equal $-\delta$ in any separating equilibrium. Having set the equilibrium value for m^+, we are able to derive the value of m^0, which must hold in equilibrium. Last but not least we can construct the equilibrium value for m^-. The following deviations have to be checked:

1. CB^+ has no incentive to mimic CB^0, that is, to choose $m = m^0$ or higher monetary growth rates. Equilibrium losses are:

$$L^+ = a\Delta^2.$$

If m^0 were chosen, losses would be:

$$L^{+'} = (m^0 + \delta)^2 + a(\delta - \Delta)^2.$$

Thus, $L^{+'} \geq L^+$ if and only if:

$$(m^0 + \delta)^2 \geq b\delta^2$$
$$m^0 \geq (\sqrt{b} - 1)\delta.$$

Hence, the lowest sustainable level of monetary growth is $m^0 = (\sqrt{b} - 1)\delta$, which corresponds to the proposed equilibrium. We next derive m^-.

2. There are two properties m^- must fulfill.
   (a) CB^0 has no incentive to choose m^-. Equilibrium losses are:

$$L^0 = (m^0)^2 + a\Delta^2 + (1 + a)\delta^2.$$

   Losses for the deviation $m = m^-$ are:

$$L^{0'} = (m^-)^2 + a(\delta - \Delta)^2 + (1 + a)\delta^2.$$

   For the equilibrium to exist $L^{0'} \geq L^0$ must hold, which implies:

$$(m^-)^2 + a(\delta - \Delta)^2 \geq (m^0)^2 + a\Delta^2$$
$$m^- \geq \sqrt{(m^0)^2 + b\delta^2}$$
$$m^- \geq \delta\sqrt{2b - 2\sqrt{b} + 1}.$$

   The lowest level of m^- consistent with this condition is:

$$m^- = \delta\sqrt{2b - 2\sqrt{b} + 1}.$$

   (b) CB^+ does not want to choose m^- as constructed under (a). Equilibrium losses for CB^+ are given by:

$$L^+ = a\Delta^2.$$

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Losses when CB^+ chooses m^- instead of $m^+ = -\delta$ amount to (choosing m^- results in huge surprise inflation):

$$L^{+'} = (m^- + \delta)^2 + a(2\delta - \Delta)^2.$$

Hence, the deviation is not profitable if $L^{+'} \geq L^+$, which yields:

$$(m^- + \delta)^2 \geq 4a\delta(\Delta - \delta)$$
$$(m^- + \delta)^2 \geq 2(b - a)\delta^2$$
$$1 + a + \sqrt{2b - 2\sqrt{b} + 1} \geq \sqrt{b}.$$

This inequality always holds for $a \geq 0$ and $b \geq 1$.

3. CB^0 does not want to deviate from m^0. The computations are the same as for inflation targeting (See the proof of Proposition 4). Therefore, they are omitted here.
4. Because CB^- incurs the highest losses in this equilibrium, there might be an incentive for CB^- to deviate. Two cases must be distinguished:
   (a) Assume $m^0 < \delta$, that is, $b < 4$. The candidate deviation that yields the lowest losses is $m' = \delta$. Equilibrium losses amount to:

$$L^- = (m^- - \delta)^2 + a\Delta^2.$$

   Losses when deviating are given by:

$$L^{-'} = a(\Delta + \delta)^2.$$

   We obtain the condition:

$$(\sqrt{2b - 2\sqrt{b} + 1} - 1)^2 < b + 2a.$$

   This inequality holds for $1 \leq b < 4$.

   (b) Assume $m^0 \geq \delta$, that is, $b \geq 4$. There are two potentially profitable deviations. First, CB^- chooses $m' = \delta$. But, in this case, inflation expectations are 2δ higher than actual inflation. Equilibrium losses and losses for the deviation are:

$$L^- = (m^- - \delta)^2 + a\Delta^2$$
$$L^{-'} = a(\Delta + 2\delta)^2.$$

   The deviation is not profitable for $L^{-'} \geq L^-$, which corresponds to

$$(\sqrt{2b - 2\sqrt{b} + 1} - 1)^2 < 2(b + 3a),$$

   which always holds for $b \geq 4$. Second, we have to check whether CB^- could benefit from setting $m' = m^0$. Losses for this deviation amount to:

$$L^{-'} = (m^0 + \delta)^2 + a(\Delta + \delta)^2.$$

   The deviation is not profitable for $L^{-'} > L^-$ and therefore

$$(\sqrt{2b - 2\sqrt{b} + 1} - 1)^2 < 2(b + a),$$

   which holds for $b \geq 4$.

Thus, we have proved the existence of the separating equilibrium.[26] ■

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Proof of Proposition 9. We will show that for every pooling equilibrium monetary growth rate m^* a deviation m' exists

1. that is profitable for CB^- if the public believes the deviating bank is CB^- and,
2. that is never profitable for either CB^0 or CB^+.

First, we derive the condition for CB^-,

$$\begin{aligned} L^- &= (m-\delta)^2 + a(\delta+\Delta)^2 \\ L^{-\prime} &= (m'-\delta) + a\Delta^2 \\ L^{-\prime} &< L^- \\ (m'-\delta)^2 &< (m-\delta)^2 + \delta^2(b+2a), \end{aligned}$$

then the condition for CB^+,

$$\begin{aligned} L^+ &= (m+\delta)^2 + a(\Delta-\delta)^2 \\ L^{+\prime} &= (m'+\delta)^2 + a(\Delta-2\delta)^2 \\ L^{+\prime} &> L^+ \\ (m'+\delta)^2 &> (m+\delta)^2 + \delta^2(b-2a), \end{aligned}$$

and, finally, the condition for CB^0:

$$\begin{aligned} L^0 &= m^2 + a\Delta^2 + (1+a)\delta^2 \\ L^{0\prime} &= m'^2 + a(\Delta-\delta)^2 + (1+a)\delta^2 \\ L^{0\prime} &> L^0 \\ m'^2 &> \delta^2 b + m^2. \end{aligned}$$

Sufficient conditions for the existence of a deviation m' satisfying the preceding three conditions are (where we have set $\delta = 1$, without loss of generality):

$$\begin{aligned} \sqrt{(m+1)^2 + b - 2a} &< \sqrt{(m-1)^2 + b + 2a} + 2 \\ \sqrt{b+m^2} &< \sqrt{(m-1)^2 + b + 2a} + 1. \end{aligned}$$

Tedious calculations yield that these two inequalities hold for any value of m, any $a > 0$ and any $b > 1$.[27] Thus, we have proved that we can eliminate all pooling equilibria for $b > 1$ by applying the intuitive criterion. ■

GENERALIZATION FOR UNIFORMLY DISTRIBUTED SHOCKS

The distribution of shocks in our model may seem artificial because only two types of shocks are possible, that is, $\epsilon \in \{-\delta, +\delta\}$. We will now briefly demonstrate that the proposed results do not depend on this assumption. For both monetary and inflation targeting we will derive equilibria which are similar to those in Propositions 4 and 8.

Suppose the shocks are uniformly distributed on the interval $[-\delta, +\delta]$. The punishment schemes implied by equations (5) and (6) can still be applied.

Let us consider inflation targeting first. As with our previous assumption on the distribution of shocks, only central banks that have observed a positive shock can profit from imitating other central banks. We will now construct an equilibrium where the public can infer the exact type of any central bank that has observed a positive shock from the announced inflation target while the other types of central banks pool, that is, choose the same inflation targets.

Losses for a central bank that observes a positive shock and chooses $m = \pi_T$ are given by:

$$L = (\pi_T + \epsilon)^2 + a(\pi_T + \epsilon - \pi^e(\pi_T) - \Delta)^2.$$

Differentiating this equation with respect to π_T yields the following differential equation:

$$\pi_T + \epsilon + a(\pi_T + \epsilon - \pi^e(\pi_T) - \Delta)(1 - \pi^{e\prime}(\pi_T)) = 0. \quad \textbf{(A.2)}$$

By assumption, the public can infer the central bank's signal from the inflation target. Thus, $\pi^e = \pi_T + \epsilon$ must hold. Using this equation, equation (A.2), and the border condition $\pi^e|_{\pi_T=-\delta} = 0$, we obtain the expectations of the public $\pi^e(\pi_T)$:

$$\pi^e(\pi_T) = a\Delta\left[1 - \exp\left(-\frac{\pi_T + \delta}{a\Delta}\right)\right]. \quad \textbf{(A.3)}$$

Note that the central bank that observes a shock of size zero will choose π^0 which is defined as the solution of $\pi^e(\pi_T) = \pi_T$. An uninformed bank and a central bank that has observed a

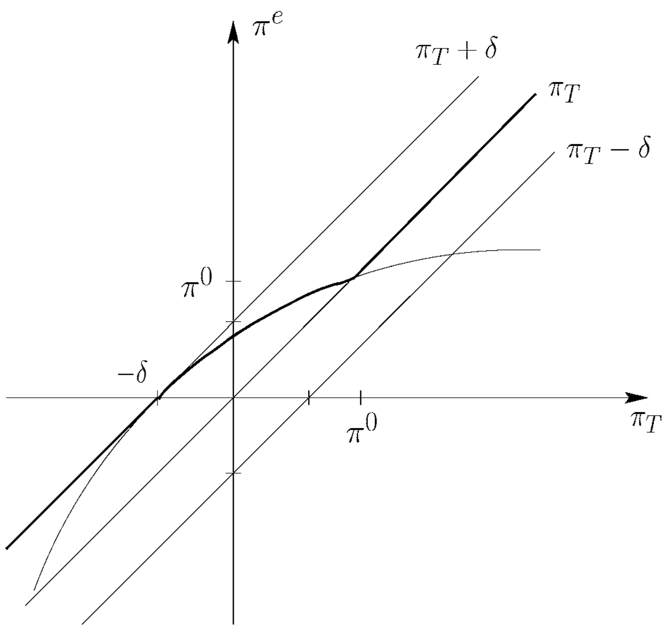

FIGURE A.1. Expectations of the public depending on the announced target value under inflation targeting.

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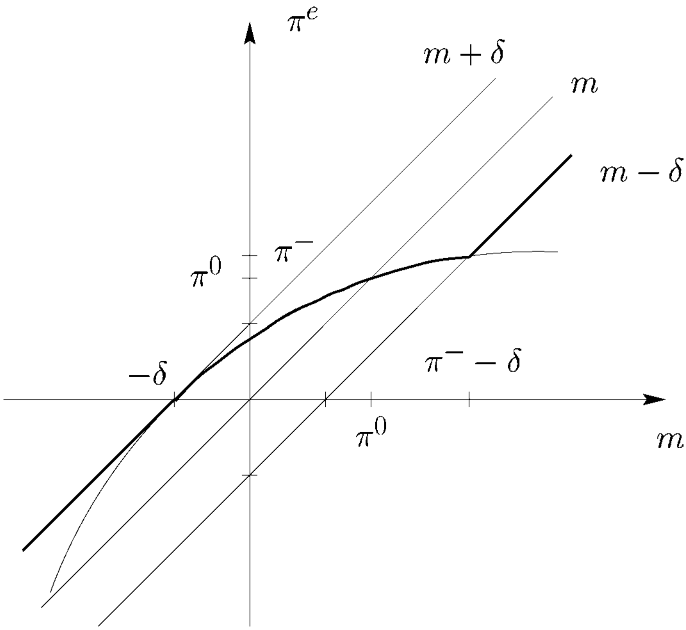

FIGURE A.2. Expectations of the public depending on the announced target value under monetary targeting.

negative shock will do the same (cf. Proposition 4). The bank that observed a positive shock of size δ chooses an inflation target $-\delta$ and an inflation rate 0. Central banks with shocks $\epsilon \in]-\delta, 0[$ choose inflation targets between $-\delta$ and π^0 which imply positive inflation rates up to π^0. It is reasonable to assume linear out-of-equilibrium expectations, i.e. for $\pi_T < -\delta$ and $\pi_T > \pi^0$, as there is a maximum possible amount of surprise inflation, δ, which cannot be exceeded. The expectations of the public are shown in Figure A.1.[28]

Under monetary targeting the results change slightly. The expectations $\pi^e(m)$ take the same form as $\pi^e(\pi_T)$ in equation (A.3). The only difference is that central banks observing a negative shock will signal their types in order to prevent imitation (cf. Section 6 for the intuition). For instance, the central bank observing $-\delta$, which is the smallest possible shock, will choose an inflation rate $\pi^- > \pi^0$ which is the solution of $\pi^e(m) = m - \delta$. The expectations of the public are shown in Figure A.2. Thus, we have constructed an equilibrium in which the public can always infer the precise size of the shock from the announced target m_T.[29]

We may conclude from this that central banks that are uninformed or have observed a positive shock will choose a policy resulting in the same inflation rates both under monetary and inflation targeting. But central banks observing negative shocks choose policies that produce higher inflation rates under monetary targeting. Hence, our main results remain valid if we consider uniformly distributed shocks. ■

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