Precommitment, Transparency and Monetary Policy

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Abstract

Conventional wisdom says that commitment eliminates the inflationary bias of monetary policy. However, this paper shows that the inflation bias can persist even when the central bank commits. A simple model is presented in which the central bank precommits by setting the policy instrument, and the subsequent adjustment of inflation expectations is part of the transmission mechanism. Generally there is still an inflation bias, despite the absence of a time-inconsistency problem. It is caused by uncertainty about the economic disturbances to which the central bank responds. Only perfect transparency about economic information completely eliminates the inflation bias.

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Zusammenfassung

Üblicherweise wird angenommen, dass ein Inflationsbias verschwindet, wenn sich eine Zentralbank glaubwürdig im voraus auf ihre Politik festlegt. Dieses Papier zeigt, dass ein Inflationsbias trotzdem fortbestehen kann. Es wird ein einfaches Modell dargestellt, in dem die Zentralbank im voraus ihre Instrumente festlegt und die anschließende Anpassung der Inflationserwartungen Teil des Transmissionsprozesses ist. Im allgemeinen existiert ein Inflationsbias weiter, obwohl kein Zeitinkonsistenzproblem mehr auftritt. Ursache ist die Unsicherheit über die ökonomischen Störungen, auf die die Zentralbank reagiert. Nur vollkommene Transparenz hinsichtlich der Informationen beseitigt vollständig den Inflationsbias.

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The optimal design of economic policy in the presence of rational expectations is a topic of active research. A prominent example is the inflationary bias of discretionary monetary policy that has dominated much of the literature on monetary policy since the influential work by Kydland and Prescott (1977). As is well known, the inflation bias arises when monetary policymakers are unable to commit themselves and aim to stimulate output beyond the natural rate. The socially optimal outcome is unattainable because the central bank takes the inflation expectations of the private sector as given, either strategically (in a Nash equilibrium), or due to the timing of events (when expectations are incorporated in contracts). From this literature it is easy to conclude that the inflation bias vanishes if the central bank commits itself every period by moving first, and people subsequently adjust their expectations.

This paper shows, however, that the inflationary bias of monetary policy typically persists even if the central bank first sets the policy instrument and the market then forms its inflation expectations. The reason is that the public does not know the policy outcome yet; it only observes the policy action. Although this provides a signal of the central bank's intentions, it also reflects economic disturbances. Uncertainty about the economic shocks to which the central bank responds makes the signal noisy, and provides scope for the central bank to create surprise inflation and boost output. The public anticipates this and increases its inflation expectations. The central bank takes this into account and pursues a higher level of inflation than socially optimal.

Greater transparency about the economic shocks reduces the opportunity for surprise inflation and therefore reduces the inflation bias. In the case of perfect economic transparency, the inflation bias vanishes. When the private sector has imperfect economic information, less transparency about the central bank's preferences also reduces the inflation bias. Intuitively, greater economic transparency and/or more preference uncertainty make the policy instrument a better signal of the central bank's intentions, so inflation expectations become more sensitive to it.

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Greater responsiveness of expectations gives the central bank a bigger incentive to mimic the behavior of a low-inflation type to reduce inflation expectations. As a result, an increase in the degree of economic transparency and/or a decrease in preference transparency reduces the inflation bias.

For the commonly adopted information structure in which the private sector perfectly observes the central bank's preferences but has imperfect information about the economic shocks, the inflation bias is in fact largest. Intuitively, the information asymmetry on the economic situation creates the opportunity to pursue surprise inflation, whereas complete preference transparency eliminates the possibility of mimicking.

The model is in the tradition of strategic monetary policy games. However, it constitutes a significant departure from the framework introduced by Kydland and Prescott (1977) and formalized by Barro and Gordon (1983*a*). The essence of these models is that the public's inflation expectations are fixed when the central bank determines monetary policy, and held constant while the central bank's actions take effect. Given the long lags associated with the effects of monetary policy, this implies that people's expectations are not adjusted for up to one or two years. This assumption seems unrealistic. Instead, this paper reverses the timing and assumes that people form their inflation expectations after the central bank sets the policy instrument. Thus, instead of the usual Nash equilibrium, this paper considers the extensive-form game in which the central bank is Stackelberg leader.

There is an extensive literature on the inflation bias. Kydland and Prescott (1977) suggest central banks should abandon discretionary policy and commit to rules. The contribution of this paper is to show that precommitment is *not* sufficient to eliminate the inflation bias when there is asymmetric information about the economic disturbances reflected in the policy instrument. The role of private information under commitment is also addressed by Canzoneri (1985). He analyzes flexible targeting rules that allow the central bank to respond to private information but reduce the inflation bias caused by dynamic inconsistency. Like Barro and Gordon (1983*b*), he relies on reputation effects generated by retaliating trigger strategies. This paper, however, analyzes how private information gives rise to an inflation bias when the central bank commits to a policy action every period, so there is no time-inconsistency problem. In addition, it follows the reputation literature of signaling and rational updating of people's expectations based on the central bank's actions (Backus and Driffill 1985, Barro 1986).

The paper also underscores the salient role of transparency. The effects of transparency on the inflation bias are similar to the results obtained in models with dynamic inconsistency. Faust and Svensson (2000) show that greater transparency on control errors which improves the interpretation of policy outcomes tends to reduce the inflation bias. Geraats (2000) analyzes transparency on the economic information reflected in policy actions, like the present paper.

The inflation bias in this paper can be eliminated by addressing its sources: the central bank's preferences or asymmetric information on the economy. To the extent that complete economic transparency is not feasible, society could appoint 'conservative' central bankers that put less weight on output stimulation (Rogoff 1985) or pursue a lower inflation target (Svensson 1997). Another possibility is to have incentive schemes or contracts for central bankers (Walsh 1995, Persson and Tabellini 1993).

Most of the literature has considered strategic monetary policy games in which the private sector and the central bank move either simultaneously, or sequentially with the private sector acting first. An exception is Goodhart and Huang (1998) who analyze an infinite-horizon model with policy lags, output persistence and/or overlapping wage contracts. They implicitly assume preference uncertainty but economic transparency. They show that a model with merely monetary policy lags eliminates the inflation bias. The present paper explains that this no longer holds when there is some economic uncertainty.

An exception to the usual Nash strategy in monetary policy games is presented by Başar and Salmon (1990). They adopt the model by Cukierman and Meltzer (1986), a repeated simultaneous-move game with private information on the central bank's preferences, but analyze the Stackelberg solution in which the central bank acts as the (strategic) leader. Simultaneity of actions implies that the private sector cannot use the policy instrument to update its expectations in the same period. But in the Stackelberg solution, the central bank takes into account the effect of its policy rule on inflation expectations, so the inflation bias is zero on average. Their analysis presumes that every period, the central bank can precommit to a policy rule that depends on its unobservable type. In contrast, this paper features an extensive-form game in which the central bank commits through a policy action. Although the central bank is the Stackelberg leader, the presence of asymmetric information on economic disturbances makes the policy action a noisy signal and gives the central bank an incentive to create excessive inflation.

The basic model in which commitment gives rise to an inflation bias is presented in section 1. The appendix formally analyzes some special cases. In addition, it presents a variation on the basic model, which features a monetary, Lucas-type transmission mechanism, and shows that using a mechanism based on the real interest rate leads to the same qualitative conclusions. The results are discussed in section 2. Section 3 concludes that in the presence of policy lags, central banks do not need policy rules to eliminate the inflation bias. Instead, economic transparency about the shocks to which they are responding suffices while maintaining complete flexibility.

1 Model

The central bank has the objective function

$$W = -\frac{1}{2}\left(\pi - \tau\right)^2 + \beta\left(y - \bar{y}\right), \tag{1}$$

where π is inflation, τ the central bank's inflation target, y real output, $\bar{y}$ the natural rate of output, and β the relative weight on output stimulation ($\beta > 0$). The central bank's inflation target τ is stochastic: $\tau \sim N\left(\bar{\tau}, \sigma_\tau^2\right)$ with $\sigma_\tau^2 > 0$. The economic structure is determined by the quantity equation

$$\pi = m + \varepsilon_v \tag{2}$$

and the Lucas supply equation

$$y = \bar{y} + b\left(\pi - \pi^e\right) + \varepsilon_s \tag{3}$$

where m denotes money supply growth and π^e the market's inflation expectations; ε_s is a supply shock and ε_v can be interpreted as a velocity shock. The economic disturbances are stochastic: $\varepsilon_s \sim N\left(0, \sigma_s^2\right)$ and $\varepsilon_v \sim N\left(0, \sigma_v^2\right)$, with $\sigma_s^2 > 0$ and $\sigma_v^2 > 0$; τ, ε_s and ε_v are assumed to be independent. The parameter b is the extent to which surprise inflation stimulates output.

The timing is as follows. Nature draws the central bank's inflation target τ and the economic shocks ε_s and ε_v, which are only known to the central bank. The central bank sets the money supply growth m. Subsequently, the public observes money supply growth, and it forms its inflation expectations π^e. Finally, inflation π and output y are realized.

There is asymmetric information about the central bank's preferences. So, the public uses the money supply m to infer the central bank's type τ. This is complicated by the presence of asymmetric information about the economic disturbances ε_s and ε_v. It is assumed that people have rational expectations. Formally, the information set available to the public when it forms its inflation expectations π^e equals $\{m, \Omega\}$, where $\Omega \equiv \{\beta, b, \bar{y}, \bar{\tau}, \sigma_\tau^2, \sigma_s^2, \sigma_v^2\}$ summarizes the structure and parameters of the model.

To find the solution to this game, it is crucial to know how the public's inflation expectations π^e are affected by the central bank's actions m. It is postulated that

$$\pi^e = u_0 + u_m m. \tag{4}$$

It is shown below that this is consistent with rational expectations. The central bank maximizes the objective function (1) with respect to m subject to (3) and (2), and incorporating the updating of inflation expectations (4). The first order condition with respect to m implies

$$m = \tau + (1 - u_m)\,\beta b - \varepsilon_v. \tag{5}$$

Money supply is increasing in the central bank's inflation target τ and decreasing in the velocity shock ε_v. It does not depend on the supply shock ε_s because the central bank does not aim to stabilize output with its objective (1). Using (2) gives

$$\pi = \tau + (1 - u_m)\,\beta b. \tag{6}$$

The economic interpretation of this equation is that it equalizes the marginal costs and benefits of an increase in the money supply m. The marginal cost in terms of higher inflation is $\pi - \tau$; the marginal benefit from the stimulation of output equals $\beta b\,(\mathrm{d}\,\pi/\,\mathrm{d}\,m - \mathrm{d}\,\pi^e/\,\mathrm{d}\,m) = \beta b\,(1 - u_m)$.

Notice that the usual inflationary bias of discretionary monetary policy in the Kydland and Prescott (1977) and Barro and Gordon (1983*a*) model, $\pi = \tau +$

βb, obtains if $u_m = 0$. This could be because the central bank is myopic in the sense that it fails to incorporate the effect of its actions m on the public's inflation expectations π^e. Alternatively, the public may not be able to use the policy instrument to update its inflation expectations, like in a simultaneous-move game, so that $\mathrm{d}\,\pi^e/\,\mathrm{d}\,m = 0$. In the case of commitment to a money supply rule, the public adjusts its inflation expectations fully, $\mathrm{d}\,\pi/\,\mathrm{d}\,m = \mathrm{d}\,\pi^e/\,\mathrm{d}\,m = 1$, so there is no inflation bias.

Rational expectations imply that $\pi^e = \mathrm{E}\left[\pi|m,\Omega\right]$. Substituting (2) gives

$$\pi^e = m + \mathrm{E}\left[\varepsilon_v|m,\Omega\right]. \tag{7}$$

Although the public forms its inflation expectations after the central bank moves, the policy action m is not fully informative about the policy outcome π because the public does not observe the velocity shock ε_v. However, the public realizes that the money supply reflects the central bank's knowledge of the shock, and it tries to infer the velocity shock ε_v from the money supply m. Since m has a normal distribution by (5), (7) produces

$$\pi^e = \mathrm{E}\left[\varepsilon_v|\Omega\right] + \left(1 + \frac{\mathrm{Cov}\left\{\varepsilon_v, m|\Omega\right\}}{\mathrm{Var}\left[m|\Omega\right]}\right) m - \frac{\mathrm{Cov}\left\{\varepsilon_v, m|\Omega\right\}}{\mathrm{Var}\left[m|\Omega\right]}\mathrm{E}\left[m|\Omega\right]. \tag{8}$$

Note that (8) corresponds to the postulated updating equation (4), so this is a rational expectations equilibrium. It follows from (5) that $\mathrm{Cov}\left\{\varepsilon_v, m|\Omega\right\} = -\sigma_v^2$ and $\mathrm{Var}\left[m|\Omega\right] = \sigma_\tau^2 + \sigma_v^2$. Matching coefficients with (4) yields

$$u_m = \frac{\sigma_\tau^2}{\sigma_\tau^2 + \sigma_v^2},$$

so $0 < u_m < 1$.[2] The updating coefficient u_m suggests that the signal extraction problem can be recast in another way. Inflation π depends on the unknown inflation target τ by (6). To form its inflation expectations, the public uses the noisy signal m to infer τ. The updating coefficient u_m is positive as people ascribe a higher money supply to a higher inflation target and therefore expect a higher level of inflation. The magnitude of the updating coefficient reflects the accuracy of the signal m and is increasing in the signal-to-noise ratio σ_τ^2/σ_v^2.

[2]For completeness, $u_0 = \frac{\sigma_v^2}{\sigma_\tau^2+\sigma_v^2}\bar{\tau} + \left(\frac{\sigma_v^2}{\sigma_\tau^2+\sigma_v^2}\right)^2 \beta b$.

Using (5) and (8), gives the public's inflation expectations

$$\pi^e = \bar{\tau} + \frac{\sigma_\tau^2}{\sigma_\tau^2 + \sigma_v^2} (\tau - \bar{\tau}) - \frac{\sigma_\tau^2}{\sigma_\tau^2 + \sigma_v^2} \varepsilon_v + \frac{\sigma_v^2}{\sigma_\tau^2 + \sigma_v^2} \beta b. \tag{9}$$

A central bank with a higher inflation target τ causes higher inflation expectations, but not to the full extent because the money supply is considered a noisy signal. An increase in the velocity shock ε_v reduces inflation expectations because the decrease in the money supply is partly attributed to a lower inflation target.

Substituting u_m into (6) gives the level of inflation

$$\pi = \tau + \frac{\sigma_v^2}{\sigma_\tau^2 + \sigma_v^2} \beta b. \tag{10}$$

Clearly, there is an inflation bias even though there is no time-inconsistency problem. Although the central bank moves first, it is still able to cause surprise inflation because of the presence of asymmetric information about the velocity shock. People anticipate this and increase their inflation expectations for any level of the money supply. To prevent a drop in output, the central bank has to increase the money supply, which gives rise to the inflation bias.

Finally, using (10), (9) and (3), output equals

$$y = \bar{y} + \frac{\sigma_v^2}{\sigma_\tau^2 + \sigma_v^2} b (\tau - \bar{\tau}) + \frac{\sigma_\tau^2}{\sigma_\tau^2 + \sigma_v^2} b \varepsilon_v + \varepsilon_s. \tag{11}$$

A central bank that has a higher than expected inflation target ($\tau > \bar{\tau}$) succeeds in boosting output. However, rational expectations ensure that the expected value of output equals the natural rate: $\mathrm{E}[y|\Omega] = \bar{y}$.

It follows from (10) that the inflation bias in this Stackelberg game has its source in (a) the objective to stimulate output beyond the natural rate ($\beta > 0$), just like in the Nash game; and (b) asymmetric information on the economic disturbances that affect the policy instrument, or simply lack of 'economic transparency'.[3] In the presence of some economic uncertainty ($\sigma_v^2 > 0$), the degree of

[3]Note that only velocity shocks (σ_v^2) matter and that uncertainty about the supply shock (σ_s^2) is immaterial. The reason is that the policy instrument m is not affected by supply shocks ε_s, so they do not create any noise. However, this is specific to the transmission mechanism in this model. For the real-interest rate mechanism analyzed in appendix A.3, uncertainty about supply shocks does matter.

preference uncertainty (σ_τ^2) also matters. So, let us analyze how they affect the inflation bias.

A lower variance of velocity shocks σ_v^2 reduces the inflation bias since there is less opportunity for surprises. An alternative explanation is that a reduction in the uncertainty about the economic disturbances that affect the central bank's actions makes the policy instrument a more accurate signal of the inflation target. So, people adjust their inflation expectations more in response to the policy instrument. This makes it more beneficial for the central bank to mimic the behavior of a low-inflation type. As a result, the inflation bias is lower. This argument is analogous to the effect of reputation in dynamic monetary policy games: The central bank changes its current actions to affect (future) inflation expectations and obtain a more favorable output-inflation trade-off.

Similarly, greater uncertainty about the central bank's preferences σ_τ^2 increases the responsiveness of inflation expectations to the money supply. This reduces the payoff of increasing the money supply and leads to a lower inflation bias. In the limit, as $\sigma_\tau^2 \to \infty$, the inflation bias completely vanishes. On the other hand, for $\sigma_v^2 \to \infty$ the money supply becomes so unreliable that people no longer pay attention to it. As a consequence, the simultaneous-move outcome obtains: $\pi = \tau + \beta b$.

It is interesting to consider the limiting cases of perfect economic transparency ($\sigma_v^2 \to 0$) and preference transparency ($\sigma_\tau^2 \to 0$).[4] In the case of economic transparency, the policy instrument is a perfect signal of the central bank's type, so $u_m = 1$. This provides the maximum incentive for the central bank to reduce the money supply to lower inflation expectations. It appears that the disadvantage of higher inflation expectations exactly offsets the temptation to boost output by creating surprise inflation. As a result, there is no inflation bias. Alternatively, the absence of economic uncertainty eliminates the possibility of surprise inflation and thereby the inflation bias.

In the case of preference transparency, the private sector directly observes the central bank's inflation target τ. When there is some economic uncertainty, the

[4]Note that the information set available to the public changes in these cases. See appendix A.1 and A.2 for formal derivations of the outcomes. In particular, it should be mentioned that in the case of economic transparency, $\mathrm{E}[\varepsilon_v|\Omega] = \varepsilon_v$ so that (9) and (11) reduce to $\pi^e = \tau$ and $y = \bar{y} + \varepsilon_s$, respectively.

public no longer relies on the noisy policy instrument to update its expectations on τ, so $u_m = 0$. This means that the outcome is the same as in the simultaneous-move game: $\pi = \tau + \beta b$.[5] Intuitively, the central bank realizes that people do not pay attention to its policy actions, so it feels tempted to generate inflation surprises. However, the public anticipates this and increases its inflation expectations accordingly. The result is the full inflation bias. From an economic perspective, the central bank can no longer benefit from the reputation effect of a reduction in the money supply, so there is nothing to counteract the incentive to create surprise inflation.

Finally, there is the case of perfect economic and preference transparency. Given that merely economic transparency gives no inflation bias, but merely preference transparency gives the full bias, this really is a knife-edged case.[6] It appears that the combination of economic and preference transparency eliminates the inflation bias. Intuitively, although preference transparency removes the possibility of mimicking, the presence of economic transparency makes inflation surprises impossible.

However, it should be noted that this outcome of no inflation bias is extremely sensitive to the assumptions made. Introducing the slightest economic uncertainty, the Stackelberg outcome turns into the worst case of a full inflation bias. Or, assuming the public incurs tiny costs associated with the verification of a state variable also gives the worst outcome.[7] The only way in which the result is robust is that introducing some preference uncertainty does not affect the outcome.

To summarize, when the central bank commits to a policy action, there is still an inflation bias whenever there is lack of economic transparency in the sense that the private sector is uncertain about the economic disturbances to which the central bank responds. In that case, greater transparency about the central bank's preferences actually increases the inflation bias. On the other hand, greater economic transparency reduces the inflation bias, and it completely vanishes in the case of perfect economic transparency.

[5] One may be tempted to argue that preference transparency in this model implies that the public has perfect foresight and cannot be fooled ($\pi^e = \pi$), so that the central bank maximizes $W = -\frac{1}{2}(\pi - \tau)^2$ and $\pi = \tau$. Appendix A.2 explains why this reasoning is incorrect.

[6] See Appendix A.2 for a formal analysis.

[7] See appendix A.2 for the formal arguments.

2 Discussion

The monetary policy game introduced in this paper assumes that the central bank precommits itself and moves first through a policy action. This reflects the implicit assumption of policy lags, which are considered to be significant in monetary policy. This gives the private sector the opportunity to respond to the central bank's actions, which in turn affects the policy outcome. Thus, the model captures the important feature that policymakers need to incorporate the effect of their policy actions on the public's expectations. In contrast to previous literature on reputation in a multi-period context, it is assumed that the adjustment of expectations influences the effect of *current* policy actions on the policy outcome. In other words, the response of private sector expectations is considered an integral part of the policy transmission mechanism.

The model starts from the usual premise in the time-inconsistency literature that the central bank has an objective function that is (at least locally) increasing in output. Furthermore, it is assumed that there is asymmetric information between the central bank and the private sector. In the basic model of section 1 there are two information asymmetries. First, the private sector is uncertain about the central bank's preferences. This could be interpreted as a fundamental credibility problem inherent to the impossibility to observe intentions directly. However, the inflation bias under commitment is not caused by preference uncertainty. Second, there is asymmetric information about economic disturbances. This is the driving force of the inflation bias. Romer and Romer (2000) provide evidence for such asymmetric information. They show that (confidential) Federal Reserve forecasts of inflation are superior to those of commercial forecasters, even at a short horizon of one or two quarters ahead. This suggests that central banks may indeed have private information about the economy. However, it should be emphasized that the results in this paper do not rely on the central bank having superior information. The only thing that matters is that there is uncertainty about the economic information that the central bank uses for its policy decisions.

The model in section 1 adopts a monetary, Lucas-type transmission mechanism in which the central bank directly controls inflation through its instrument, money supply growth. Output can only be affected through inflation surprises. However, the signaling intuition suggests that the results do not depend on the need for inflation surprises to stimulate output; instead, they are driven by the rewards of investing in 'reputation' in the form of lower inflation expectations. Appendix A.3 shows that the same effects apply to a real interest rate mechanism. The policy instrument is the nominal interest rate, which allows the central bank to influence the ex ante real interest rate and thereby output. Inflation is controlled only indirectly through the output gap and it is affected by the public's inflation expectations. The same conclusions hold as before. Economic uncertainty, in this case about the demand and supply shocks that are reflected in the interest rate, creates an inflation bias that exacerbates as the uncertainty increases; political uncertainty reduces the inflation bias.

The paper suggests which kind of transparency is needed to eliminate the inflation bias. A central bank should disclose the economic shocks that affect its policy decision. So, the relevant information depends on the policy instrument that the central bank adopts; velocity shocks in case of the money supply, and demand and supply shocks for the nominal interest rate. The latter could be conveniently conveyed through the publication of conditional central bank forecasts of output and inflation that are based on a constant level of the nominal interest rate and private sector inflation expectations.[8]

Notice that the model presumes that there is no private information about the structure of the economy. If there is asymmetric information about the economic model, the policy instrument typically becomes a noisy signal of the central bank's intentions and the inflation bias reappears. More generally, the inflation bias vanishes only when there is complete economic transparency, that is, symmetric information about the economic information (data, models, forecasts) on which policy actions are based.

In addition, the model assumes that the central bank is able to observe economic shocks perfectly; there are no forecast errors due to unanticipated shocks. Introducing such control errors does not affect any of the qualitative results. Furthermore, openness about control errors that affect the implementation of the central bank's policy actions, which could be called 'operational transparency', would be immaterial in the present model. The reason is that operational transparency is backward looking and gives clues about the central bank's past objectives, whereas economic transparency is forward looking and reveals the central

[8]This follows directly from (21) and (22).

bank's current intentions which determine future inflation.[9]

Finally, it is important to identify the crucial difference between precommitment to policy rules, and commitment in the form of a policy action in this paper. The central bank commits itself in the sense that it moves first. However, monetary policy is still discretionary since the central bank is not bound by a rule; every period, it decides about the policy action and has the opportunity to respond to shocks. The difference between policy rules and 'discretionary precommitment' lies in the information structure. In both cases, the public effectively observes the policy action before it forms its expectations and the policy instrument is a noisy signal of the policy outcome because of economic disturbances. But under discretionary precommitment, the central bank can exploit this noise to cover up expansionary policy, which leads to the inflation bias. Commitment eliminates the inflation bias only if the policy decision is made under symmetric information about the economic disturbances that affect the policy instrument. This can be obtained by rules that determine policy well in advance so that economic shocks cannot be anticipated, and/or for long enough periods so that the shocks average out. Alternatively, this can be obtained by discretionary policy in the presence of policy lags provided the central bank embraces economic transparency by sharing information on economic disturbances with the private sector.[10]

3 Conclusion

The time-inconsistency literature suggests that commitment eliminates the inflationary bias of discretionary monetary policy. This paper shows, however, that precommitment is no sure cure. A simple, static model is presented in which the central bank moves first by setting the policy instrument and the public subsequently forms its inflation expectations before the policy actions take effect.

[9] In a dynamic context with repeated games under economic opaqueness, greater operational transparency could be useful and reduce the inflation bias like in the model by Faust and Svensson (2000).

[10] This provides formal support for critics of the time-inconsistency literature, most notably, Blinder (1998) who states that the academic debate on rules versus discretion "has been barking up the wrong – or, rather, nonexistent – trees" and has made "insufficient contact with reality", and McCallum (1995, 1997) who argues that somehow central banks can 'just do it'.

Thus, the model captures an implicit policy lag. Moreover, it incorporates the private sector's response to policy actions into the policy transmission process.

The public uses the policy instrument to infer the central bank's intentions. However, economic disturbances make the instrument a noisy signal. This provides an opportunity for expansionary policy without detection and is the source of the inflation bias.

Greater transparency about the economic shocks to which the central bank responds makes the public pay closer attention to the central bank's actions to update its expectations. The central bank takes into account the effect of the private sector's inflation expectations on the policy outcome. This exerts discipline on the central bank's actions and reduces its incentive to stimulate output. Less economic uncertainty gives the central bank less scope to stray. In the case of perfect economic information, the feedback from private sector inflation expectations is so strong that it completely offsets the tendency to create an inflation bias.

Greater transparency about the central bank's preferences actually worsens the inflation bias because it reduces the need for the private sector to focus on the central bank's actions, and thereby loosens the grip on the central bank.

The implication for monetary policy is that greater openness should not focus on conveying the central bank's objectives, but on explaining its policy actions. Furthermore, the paper suggests that central banks don't necessarily need rules; instead, economic transparency suffices to eliminate the inflation bias, while maintaining discretionary flexibility. Perhaps, this explains why in practice, central banks that redesign their policy procedures do not commit to rules, but to inflation reports.

A Appendix

The appendix analyzes special cases and a variation on the basic model in section 1. Appendix A.1 looks at the case of economic transparency, appendix A.2 discusses preference transparency and appendix A.3 derives the results for a real-interest rate transmission mechanism.

A.1 Economic Transparency

This appendix derives the outcome of the basic model in section 1 for the special case of complete economic transparency. So, $\sigma_s^2 = \sigma_v^2 = 0$, and the information set available to the public when it forms its inflation expectations equals $\{m, \varepsilon_s, \varepsilon_v, \Omega\}$. Assume the following updating equation

$$\pi^e = u_0 + u_m m + u_s \varepsilon_s + u_v \varepsilon_v. \tag{12}$$

The central bank maximizes the objective function (1) subject to (3) and (2), and incorporating (12). The first order condition with respect to m yields

$$m = \tau + (1 - u_m)\,\beta b - \varepsilon_v \tag{13}$$

as before. So, using (2)

$$\pi = \tau + (1 - u_m)\,\beta b. \tag{14}$$

Rational expectations imply $\pi^e = \mathrm{E}\,[\pi | m, \varepsilon_v, \varepsilon_s, \Omega]$. Under economic transparency the public can use the policy instrument m to perfectly infer the inflation target τ from (13). Substituting this into (14) gives

$$\pi^e = m + \varepsilon_v.$$

This is consistent with the postulated updating equation (12) for $u_0 = 0$, $u_m = 1$, $u_s = 0$ and $u_v = 1$. So, this corresponds to a rational expectations equilibrium. Substituting $u_m = 1$, it follows that $m = \tau - \varepsilon_v$, $\pi^e = \tau$ and

$$\pi = \tau.$$

So, in the case of economic transparency there is no inflation bias. People correctly anticipate the level of inflation ($\pi^e = \pi$), so output equals $y = \bar{y} + \varepsilon_s$.

A.2 Preference Transparency

This appendix analyzes the outcome of the model in section 1 in the case of preference transparency. First, consider the special case of complete information. So, $\sigma_\tau^2 = \sigma_s^2 = \sigma_v^2 = 0$, and the information set available to the public when it forms its inflation expectations equals $\{\tau, m, \varepsilon_s, \varepsilon_v, \Omega\}$. It will prove useful to adopt a solution approach that is similar to the one in section 1 and appendix A.1. So, postulate the updating equation

$$\pi^e = u_0 + u_\tau \tau + u_m m + u_s \varepsilon_s + u_v \varepsilon_v. \tag{15}$$

The central bank maximizes the objective function (1) subject to (3) and (2), and incorporating (15). The first order condition with respect to m yields

$$m = \tau + (1 - u_m) \beta b - \varepsilon_v \tag{16}$$

as before. So, using (2)

$$\pi = \tau + (1 - u_m) \beta b. \tag{17}$$

Rational expectations imply $\pi^e = \mathrm{E}[\pi | \tau, m, \varepsilon_v, \varepsilon_s, \Omega]$. Clearly, the public is able to perfectly forecast inflation. It can do so in (infinitely) many ways: using τ directly; or, using m to solve τ from (16) as in appendix A.1; or, any combination of both methods. More formally, one can write

$$\pi^e = \mu (\tau + (1 - u_m) \beta b) + (1 - \mu)(m + \varepsilon_v) \tag{18}$$

where $0 \leq \mu \leq 1$. This is consistent with the postulated updating equation (15) and the outcomes obtained by matching coefficients correspond to rational expectations equilibria. This gives $u_0 = \mu (1 - u_m) \beta b$, $u_\tau = \mu$, $u_m = 1 - \mu$, $u_s = 0$ and $u_v = 1 - \mu$. Note that every way of constructing inflation expectations leads to perfect foresight:

$$\pi^e = \pi. \tag{19}$$

The private sector has rational expectations, so its implicit objective is to maximize

$$W_P = -\frac{1}{2} \mathrm{E}\left[(\pi^e - \pi)^2 | \Omega_P \right] \tag{20}$$

where $\Omega_P = \{\tau, m, \varepsilon_v, \varepsilon_s, \Omega\}$ denotes the information set available to the private sector. This means that the private sector is completely indifferent among the methods $\mu \in [0, 1]$.

The central bank realizes this and it has the advantage of moving first. So, it chooses to focus on the method μ that maximizes its objective (1). Substituting (3), using (19), (17) and $u_m = 1 - \mu$, produces

$$W = -\frac{1}{2} (\mu\beta b)^2 + \beta\varepsilon_s.$$

As a result, the central bank settles on $\mu = 0$, or $u_m = 1$. Therefore the Stackelberg equilibrium in the case of perfect economic and preference transparency is no inflation bias:

$$\pi = \tau.$$

However, this outcome is not very robust. The source of this sensitivity lies in the private sector's indifference among all methods μ. Introducing small changes to the information structure or the payoff can easily shift the outcome from the best to the worst outcome. First, the effect of small costs associated with the verification of a state variable is discussed. Subsequently, a (slight) information asymmetry about economic disturbances is analyzed.

Suppose the public experiences a small cost γ for each state variable it uses ($\gamma > 0$). This could arise from costs of data collection or information processing. Let $s(\mathcal{S})$ denote the number of state variables that the public decides to include in its information set $\Omega_P(\mathcal{S})$, where $\mathcal{S} = \{\tau, m, \varepsilon_s, \varepsilon_v\}$ denotes the set of state variables. Assume that the public's objective is to minimize the sum of the mean square forecast error and the information costs: $W_P^c = -\frac{1}{2} \operatorname{E}\left[(\pi^e - \pi)^2 | \Omega_P(\mathcal{S})\right] - \gamma s(\mathcal{S})$. Since the public is able to forecast inflation perfectly ($\pi^e = \pi$) for any method μ, it chooses the method that relies on the smallest number of state variables.[11] So, the public prefers $\mu = 1$ ($u_0 = \beta b$, $u_\tau = 1$, $u_m = u_s = u_v = 0$) and only uses the inflation target τ. As a result, the outcome is $\pi = \tau + \beta b$. Notice that this even holds for tiny costs $\gamma > 0$. It appears that this minor change in the public's payoff has a big effect on the Stackelberg equilibrium; it goes from the best to the worst possible outcome.

Consider the case in which there is some uncertainty about the velocity shock ($\sigma_v^2 > 0$). This means that ε_v is no longer in the public's information set $\Omega_P =$

[11] This amounts to the minimum state variable condition that McCallum (1983) proposes in the case of multiple rational expectations equilibria.

$\{\tau, m, \varepsilon_s, \Omega\}$, so it must be that $u_v = 0$.[12] Note that $\mathrm{E}[\varepsilon_v|\Omega_P] = 0$ and $\mathrm{Var}[\varepsilon_v|\Omega_P] = \sigma_v^2$. The public knows that given its updating equation (15), optimization by the central bank implies (16) and (17). Substituting this into (20) gives

$$W_P = -\frac{1}{2}\left(u_0 + (u_\tau + u_m - 1)\tau + u_s\varepsilon_s - (1-u_m)^2\beta b\right)^2 - \frac{1}{2}u_m^2\sigma_v^2.$$

Since $\sigma_v^2 > 0$, the private sector sets $u_m = 0$. Regarding the other coefficients, the updating equation should hold for any value of τ and ε_s, so the private sector's objective W_P is maximized for $u_0 = \beta b$, $u_\tau = 1$ and $u_s = 0$. As a consequence, the updating equation becomes $\pi^e = \tau + \beta b$. In other words, the public decides to ignore the money supply m because a noisy variable ε_v is required to interpret it. Instead, it relies on the central bank's inflation target, but this gives the central bank an incentive to create unexpected inflation to boost output, and leads to an inflation bias.[13]

The result that the inflation bias rears its ugly head again if there is some economic uncertainty may seem surprising. After all, the public has perfect foresight: $\pi^e = \pi$. One may think that the central bank therefore maximizes $W = -\frac{1}{2}(\pi - \tau)^2$ so that $\pi = \tau$ and there is no inflation bias. However, this argument is incorrect. The reason is that the central bank does not set the policy outcome π, but a (noisy) policy instrument m. Suppose, counterfactually, that $\pi = \tau$ and $\pi^e = \tau$ is the equilibrium outcome. As the Stackelberg leader, the central bank incorporates the public's response $\pi^e = \tau$. So, the central bank sets the policy instrument m to maximize $W = -\frac{1}{2}(m + \varepsilon_v - \tau)^2 + \beta b(m + \varepsilon^v - \tau)$, which yields $m = \tau + \beta b - \varepsilon_v$. This corresponds to $\pi = \tau + \beta b$, contradicting the initial claim that $\pi = \tau$ is the equilibrium outcome.

[12] It seems that ε_v could be solved from m and τ using (16). However, when the public decides on the optimal updating coefficients, u_m is a variable. So, ε_v cannot be inferred ex ante, only ex post.

[13] Similarly, one can verify the results obtained in section 1 and appendix A.1. Uncertainty about τ with $\Omega_P = \{m, \varepsilon_s, \varepsilon_v, \Omega\}$, gives $(u_\tau = 0)$ $u_m = 1$, $u_s = 0$, $u_v = 1$ and $u_0 = 0$. Unobservability of the money supply (like in a simultaneous-move game) with $\Omega_P = \{\tau, \varepsilon_s, \varepsilon_v, \Omega\}$, gives $(u_m = 0)$ $u_\tau = 1$, $u_s = 0$, $u_v = 0$ and $u_0 = \beta b$. When only the money supply is observed so that $\Omega_P = \{m, \Omega\}$, the private sector maximizes $W_P = -\frac{1}{2}\left(u_0 + (u_m - 1)\bar{\tau} - (1-u_m)^2\beta b\right)^2 - \frac{1}{2}(u_m - 1)^2\sigma_\tau^2 - \frac{1}{2}u_m^2\sigma_v^2$. This gives $u_m = \frac{\sigma_\tau^2}{\sigma_\tau^2 + \sigma_v^2}$ and $u_0 = \frac{\sigma_v^2}{\sigma_\tau^2+\sigma_v^2}\bar{\tau} + \left(\frac{\sigma_v^2}{\sigma_\tau^2+\sigma_v^2}\right)^2\beta b$. Uncertainty about the supply shock ε_s is immaterial because the private sector always sets $u_s = 0$.

The reason that there is an inflation bias is that the public does not directly observe the policy outcome π, but instead a policy action m that is an imperfect signal because of the presence of unobservable velocity shocks ε_v. The private sector is not able to tell whether a high level of the money supply m is due to a low velocity shock ε_v or bound to lead to high inflation π. This gives the central bank the opportunity to create surprise inflation, which it exploits in an attempt to stimulate output. The private sector anticipates that the central bank faces this temptation and expects an inflation bias. The central bank must follow suit to prevent a reduction in output.

When there is perfect transparency about the economic disturbances, however, there is no scope for surprise inflation. The public can use the money supply m and the velocity shock ε_v to forecast inflation. In that case, the central bank incorporates $\pi^e = m + \varepsilon_v$ and the objective (1) reduces to $W = -\frac{1}{2}\left(m + \varepsilon_v - \tau\right)^2$, so that $\pi = \tau$. Instead, the public could ignore the money supply and use the inflation target, in which case it expects the inflation bias, $\pi^e = \tau + \beta b$. In either case, the private sector is able to forecast inflation perfectly ($\pi^e = \pi$), so it is indifferent. The central bank moves first and it decides to behave according to the former case because it is more beneficial; the public has no reason not to comply, so that the Stackelberg outcome is $\pi = \tau$.

The striking result that even the slightest economic uncertainty has such a sharp, negative effect when there is perfect transparency about the central bank's preferences reflects a more general property of Stackelberg outcomes. Bagwell (1995) shows that the first-mover advantage that prevails in games of perfect information vanishes when the follower observes the leader's action with even a slight amount of imprecision.

A.3 Real Interest Rate Transmission

This section analyzes the basic model in section 1 under a different transmission mechanism. Instead of the monetary, Lucas-type mechanism, it employs the real interest rate transmission. The structure of the economy is summarized by the IS relation

$$y = \bar{y} - a\left(i - \pi^e - \bar{r}\right) + \varepsilon_d \tag{21}$$

and the price-adjustment equation

$$\pi = \pi^e + \frac{1}{b}(y - \bar{y}) - \frac{1}{b}\varepsilon_s \tag{22}$$

where i is the nominal interest rate, $\bar{r}$ the long run real interest rate, ε_d a demand shock, and a the sensitivity of output to the ex ante real interest rate ($a > 0$). Assume that $\varepsilon_d \sim N(0, \sigma_d^2)$, $\varepsilon_s \sim N(0, \sigma_s^2)$ and $\tau \sim N(\bar{\tau}, \sigma_\tau^2)$, and that ε_d, ε_s and τ are independent.

The timing is as follows. Nature draws the central bank's inflation target τ and the economic shocks ε_d and ε_s, which are only known to the central bank. Then, the central bank sets the interest rate i. Subsequently, the public observes the interest rate, and it forms its inflation expectations π^e. Finally, output y and inflation π are realized. Formally, the information set available to the public when it forms its inflation expectations π^e equals $\{i, \Omega_r\}$, where $\Omega_r \equiv \{\beta, a, b, \bar{y}, \bar{r}, \bar{\tau}, \sigma_\tau^2, \sigma_d^2, \sigma_s^2\}$.

Again, the updating of inflation expectations based on the policy instrument i plays a crucial role. It is postulated that

$$\pi^e = u + vi, \tag{23}$$

which appears to be consistent with a rational expectations equilibrium. The central bank maximizes its objective (1) subject to (21) and (22), and incorporates the effect of its policy actions on the public's inflation expectations through (23). The first order condition implies

$$\begin{aligned} i \quad = \quad & \frac{a+b}{(1-v)a - vb}u + \frac{a}{(1-v)a - vb}\bar{r} - \frac{b}{(1-v)a - vb}\tau \\ & - \frac{a\beta b^2(1-v)}{((1-v)a - vb)^2} + \frac{1}{(1-v)a - vb}\varepsilon_d - \frac{1}{(1-v)a - vb}\varepsilon_s. \end{aligned} \tag{24}$$

Substituting this into (23), (21) and (22), gives the level of inflation

$$\pi = \tau + \beta b \frac{(1-v)a}{(1-v)a - vb}. \tag{25}$$

The usual inflation bias, $\pi = \tau + \beta b$, arises if the policy instrument i has no effect on inflation expectations ($v = 0$).

Rational expectations imply that $\pi^e = \mathrm{E}[\pi | i, \Omega]$. Substituting (25) and using the fact that i is normally distributed by (24),

$$\pi^e = \mathrm{E}[\tau|\Omega] + \frac{\mathrm{Cov}\{\tau, i|\Omega\}}{\mathrm{Var}[i|\Omega]}(i - \mathrm{E}[i|\Omega]) + \beta b \frac{(1-v)a}{(1-v)a - vb}.$$

Using (24), $\text{Cov}\{\tau, i|\Omega\} = \frac{-b}{(1-v)a-vb}\sigma_\tau^2$ and $\text{Var}[i|\Omega] = \frac{1}{((1-v)a-vb)^2}\left(b^2\sigma_\tau^2 + \sigma_d^2 + \sigma_s^2\right)$. Matching coefficients with (23) and rearranging gives the updating coefficient in the rational expectations equilibrium[14,15]

$$v = -\frac{ab\sigma_\tau^2}{\sigma_d^2 + \sigma_s^2 - ab\sigma_\tau^2}.$$

The sign of the updating coefficient depends on the relative uncertainty about economic disturbances. When there is a lot of economic uncertainty ($\sigma_d^2 + \sigma_s^2 > ab\sigma_\tau^2$), the nominal interest rate is a poor signal of the central bank's inflation target, so inflation expectations are not very responsive. This means that an increase in the nominal interest rate leads to a higher ex ante real interest rate, which reduces inflation. As a result, there is a negative relation between the nominal interest rate and inflation expectations ($v < 0$). When there is relatively little economic uncertainty ($\sigma_d^2 + \sigma_s^2 < ab\sigma_\tau^2$), a higher nominal interest rate is associated with a higher inflation target which induces an increase in inflation expectations ($v > 0$).[16,17]

Substituting v into (25) produces

$$\pi = \tau + \frac{\sigma_d^2 + \sigma_s^2}{\sigma_d^2 + \sigma_s^2 + b^2\sigma_\tau^2}\beta b.$$

So, under economic opaqueness, there is an inflation bias, but it is smaller than with the conventional timing of Kydland and Prescott (1977)

in which case inflation equals $\pi = \tau + \beta b$. Observe that less economic uncertainty (smaller σ_d^2 and σ_s^2) reduces the inflation bias. In the limit, $\sigma_d^2, \sigma_s^2 \to 0$, the inflation bias is completely eliminated like in the model in section 1 with perfect economic transparency.

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[14] Note that in the special case in which $\sigma_d^2 + \sigma_s^2 = ab\sigma_\tau^2$, no (pure-strategy) rational expectations equilibrium exists.

[15] For completeness, $u_O = (1-v)\bar{\tau} - v\bar{r} + a\beta b\frac{(1-v)^2}{(1-v)a-vb}$.

[16] In fact, $v > 1$ for $\sigma_d^2 + \sigma_s^2 > 0$. Inflation expectations are so responsive that they rise by more than the nominal interest rate and depress the ex ante real interest rate. The latter equals $r \equiv i - \pi^e = (1-v)\,i - u$, so $\partial r/\partial i > 0$ for $v < 1$, and $\partial r/\partial i \leq 0$ for $v \geq 1$.

[17] For the quadratic objective function $W = -\frac{1}{2}(\pi-\tau)^2 - \frac{1}{2}\beta(y-\bar{y})$ one can show that $0 < v < 1$ for reasonable parameter values. This implies that an increase in the nominal interest rate leads to a higher ex ante real interest rate and is associated with contractionary monetary policy, while it causes an *increase* in inflation expectations. This is consistent with empirical findings for the United States reported by Romer and Romer (2000) and could explain the paradoxical fact that long-term interest rates tend to rise in response to tighter monetary policy.

Also note that the limiting case of political certainty ($\sigma_\tau^2 \to 0$) leads to the full inflationary bias: $\pi = \tau + \beta b$. In the case of both political certainty ($\sigma_\tau^2 \to 0$) and economic transparency ($\sigma_d^2, \sigma_s^2 \to 0$) there is no inflation bias: $\pi = \tau$. However, the same caveat applies as in appendix A.2.

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