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The Equilibrium Degree of Transparency and Control in Monetary Policy*

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Abstract

We examine a central bank's endogenous choice of degree of control and degree of transparency, under both commitment and discretion. We argue that discretion is the more realistic assumption for the choice of control and that commitment is more realistic for the choice of transparency. For the choice of control, under discretion maximum degree of control is the only equilibrium. For the choice of transparency, under commitment, a sufficiently patient bank with sufficiently low average inflation bias will always choose minimum transparency. Thus, a maximum feasible degree of control with a minimum degree of transparency is a likely outcome. The Bundesbank and the Federal Reserve System are, arguably, examples of this.

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1 Introduction

Central banks have a reputation for secrecy. Policy boards of central banks generally deliberate in secret, like judicial panels. In sharp contrast with other policymaking and judicial bodies in most major democracies, however, central-bank policy is often implemented without any detailed justification and often with no announcement at all. The norm of secrecy has recently been rejected, most notably in inflation-targeting countries such as New Zealand, the U.K., and Sweden. In one way or another, these countries have made an explicit commitment to stable low inflation as their primary goal of monetary policy, and the central banks issue transparent inflation reports laying out inflation forecasts, explaining how policy will respond to various contingencies, and accounting for past errors.

Rationalizing transparency and openness is easy. Goodfriend [14] strongly criticized the Federal Reserve's arguments for secrecy in a famous court case, and Blinder [4] recently provided a strong case for openness and accountability, arguing that this makes independent central banking more consistent with democracy and improves the stabilization properties of monetary policy.[1] In the literature on inflation targeting, transparency has been motivated as a way of improving the incentives for central banks to pursue their announced goals, in addition to facilitating the implementation of monetary policy by increasing its predictability by the private sector (see, for instance, Svensson [26] and [27]).

Rationalizing the secrecy norm is not so easy. Milton Friedman argued that secrecy comes from central bankers' desires to minimize accountability and maximize prestige.[2] These desires (if they exist) are surely not limited to central bankers; thus, one is left to wonder why society sets up structures to indulge these desires of central bankers to a much larger degree than those of policymakers heading other policymaking agencies and bodies.

The seminal work by Cukierman and Meltzer [8] (CM) provides a different explanation of central-bank secrecy. CM build on the Kydland and Prescott [16] and Barro and Gordon [2] models of optimizing policy by adding a time-varying source of inflation bias and making this bias private information of the central bank. At certain times, the bank values employment particularly highly and would like to use inflation surprises to attain that goal. While the bank cannot, on average, surprise the public, CM shows that if control errors mask the true intention of the bank, the bank can use inflation surprises to raise output during the periods when it is most valuable. The most notable result in CM is that central banks might well choose deliberately imperfect control in order to mask their intentions. Faust and Svensson [9] (FS) recently extended CM in two ways, by clearly distinguishing the roles of transparency on the one hand and the degree of control on the other (transparency and control are in indistinguishable in CM) and by allowing a more realistic and standard quadratic loss function for the central bank (the loss function in CM is indifferent to output variability).

Transparency in FS and in this paper here refers to the degree to which central-bank intentions can be inferred by outside observers. Thus, more transparency makes it easier to assess whether central-bank intentions are consistent with announced goals or to what extent the central bank is instead pursuing idiosyncratic goals that differ from announced goals. The degree of *control* refers to the degree of congruence between the intended and actual outcome of policy actions by the central-bank. A central bank's *reputation* is a summary of what past observable actions of the bank imply about future its behavior.

FS is primarily focused on the question of whether issues like transparency and credibility remain important in the context of the apparent low and stable inflation equilibria that have been obtained recently in many countries. That paper showed, for example, that even when policy delivers inflation fluctuating in a narrow range less than five percent, the exogenously set degree of transparency can have modest but still important effects. However, throughout FS (as in CM), the degree of transparency and the degree of control are taken as exogenous, without any analysis of their determination in an equilibrium.

Given the potential importance of transparency and control even in low inflation equilibria, this paper takes up the endogenous choice of transparency and control under the Faust-Svensson extension of CM.[3] We consider the separate choices of transparency and control under both commitment and discretion. With regard to the degree of *control*, we argue that discretion is the relevant paradigm and find that under discretion the *maximum* degree of control is the only equilibrium for the standard loss function. The commitment equilibria seem less plausible, but then as in CM both maximum control and noisy control are consistent with arguably relevant parameters. With regard to the degree of *transparency*, we argue that commitment is the more plausible paradigm. We restate the FS result that under commitment a sufficiently patient bank with a sufficiently low average inflation bias will always choose *minimum* degree of transparency. Under discretion, both minimum and maximum transparency are possible equilibria.

If discretion over the degree of control and commitment over the degree of transparency are the most realistic assumptions, then our results suggest one would see maximum feasible control by very opaque central banks, which is arguably the result observed, say, for the Federal Reserve

System and the Bundesbank.

Section 2 presents the model. Section 3 discusses the choice of degree of control and section 4 examines endogenous announcements and the choice of degree of transparency. Section 5 presents some conclusions and the appendix supplies technical details.

2 The basic model and its solution

This section lays out the model and the elements of the equilibrium under fixed transparency and control that form the building blocks for understanding the endogenous choice of transparency and control.

2.1 The model

The model has two agents, the private sector and the central bank. The private sector's behavior is summarized by two relations. First, employment is generated by a standard Phillips curve,

$$l_t = (\pi_t - \pi_{t|t-1}) + \varepsilon_t, \tag{2.1}$$

where l_t is (log) employment in period t, and π_t is the inflation rate in period t (the change in the log price level between period $t-1$ and period t) and ε_t is an employment shock (a supply shock).[4] Private-sector expectations of inflation, $\pi_{t|t-1,}$ are rational in that they constitute the mathematical expectation, given available information.

In order to keep track of the asymmetric information, our conventions are that the expectations operator with respect to central-bank information is denoted by E, and the one with respect to private-sector information is denoted by E^p. Subscripts like $_{t|t-1}$ always indicate the private-sector conditional expectation of a variable in period t, given the information available in period $t-1$; thus, given the rational expectations assumption, $\pi_{t|t-1} \equiv \mathrm{E}^p_{t-1}\pi_t$.

The central bank has imperfect control over inflation,

$$\pi_t = i_t + \eta_t, \tag{2.2}$$

where i_t is the central bank's *intended inflation* and η_t is a mean-zero control error. Note that i_t is not the central bank's instrument, which is usually easily observable. This equation sweeps under the rug all issues of how the central bank's intended inflation is imperfectly implemented through the manipulation of its instruments. In our baseline case, the central bank's intended inflation is not observed by the public, and (2.2) captures the realistic feature that outcomes observed by the public do not fully reveal central-bank intentions.[5] For example, when inflation crested five percent briefly in the U.S. in 1990, the value of the interest rate instrument did not fully reveal to the public how the Fed would tradeoff the perceived cost and benefits of unemployment required to bring inflation down.[6]

The novel features of the model stem from the fact that central-bank preferences vary through time and, due to a lack of transparency (that is, due to private information), the private sector must try to deduce what the central bank is likely to do. The central bank's loss function at the end of period $t-1$ is

$$\mathrm{E}_{t-1} \sum_{j=t}^{\infty} \beta^{j-t} L_j, \tag{2.3}$$

where β $(0 < \beta < 1)$ is a discount factor, and where the period t loss function is

$$L_t \equiv \frac{1}{2} \left[\pi_t^2 + (l_t - l_t^*)^2 \right]. \tag{2.4}$$

The central bank's total employment target, l_t^*, fulfills

$$l_t^* = l^* + z_t, \tag{2.5}$$

$$z_t = \rho z_{t-1} + \theta_t, \tag{2.6}$$

where $l^* \geq 0$ is the long-run employment target, z_t is a time-varying preference parameter that we call the employment target, $0 \leq \rho < 1$, and θ_t is a shock to the target. We take z_t as unobservable to the public.

These preferences can be interpreted as representing a central bank with an explicit zero inflation target, and an implicit, unobservable, and time-varying employment target. We interpret the stochastic portion of the loss function as arising from shifts in the way the central banking structure aggregates heterogeneous and shifting societal views regarding employment.[7] As in FS, we are most interested in the case in which $l^* = 0$ and in which z_t is persistent with low variance so that the target fluctuates slowly in a narrow range around zero.

For comparison purposes, we also present results for the CM loss function,

$$L_t^{\mathrm{CM}} = \frac{1}{2} i_t^2 - (l^* + z_t)(l_t - \varepsilon_t) \tag{2.7}$$

(expressed in our notation). This differs from the standard loss function in two ways. First, only intended inflation figures in the first term; inflation due to the control error does not enter. Second, this loss function is linear in employment.[8] These two features mean that the bank is indifferent to any inflation generated by control error variance. Furthermore, the bank would accept arbitrary increases in employment variance in return for arbitrarily small decreases in average inflation. Both these features are at odds with our understanding of the objectives of actual central banks.

Following Cukierman and Meltzer [7] (CM2), we also allow the central bank to make an announcement at the end of each period $t-1$, before the expectations for period t have been fixed. The announcement is made as a single number, ξ_t.

The central bank has full information about its preferences and, at the end of period t, it has full information about all period t shocks. The private sector does not observe the central bank's employment target and intended inflation. The timing within in each period is as follows. At the end of period $t-1$, the private sector forms its expectations of period t variables. The central bank observes these expectations. At the beginning of period t (called $t-$), the central bank observes its employment target, z_t, and the supply shock, ε_t, and chooses its intended inflation, i_t. Next, the control error, η_t, is realized, giving π_t. The private sector observes π_t and ε_t, and sets l_t. Next, the central bank announces ξ_t to the private sector. Then the cycle begins again. All shocks in the model are jointly normal, mutually uncorrelated, and have zero means and fixed positive variances. The variance of any shock ζ_t is denoted σ_ζ^2.

2.2 Solving the model taking the degree of control and transparency as exogenous

FS show how to solve this model when transparency and control are exogenous and the results for endogeneity follow fairly directly from those results. We study equilibria that arise under two assumptions that keep the problem linear. First, the private sector believes that the central bank's intended inflation is a linear function of the relevant variables,

$$i_t = k_0 + k_1\varepsilon_t + k_2 z_t + k_3 z_{t|t-1}, \tag{2.8}$$

for some coefficients k_0, ..., k_3 that remain to be determined.

And second, the private sector further believes—and, unless otherwise noted the central bank behaves such that—the announcement ξ_t is generated according to[9]

$$\xi_t = \eta_t + \nu_t, \tag{2.9}$$

where ν_t is noise with variance σ_ν^2. The variance σ_ν^2 determines the quality of the announcement.

It is convenient to express signal quality in terms of the parameter

$$\tau \equiv \frac{\sigma_\eta^2}{\sigma_\eta^2 + \sigma_\nu^2}, \tag{2.10}$$

which is the squared correlation of η_t and ξ_t. We refer to τ as the degree of transparency. When $\tau = 1$ (maximum transparency), $\sigma_\nu^2 = 0$ and ξ_t fully reveals η_t; when $\tau = 0$ (minimum transparency), $\sigma_\nu^2 = \infty$ and ξ_t is a useless signal (recall that $\sigma_\eta^2 > 0$).[10] An announcement of the form (2.9) should be interpreted as an incomplete or fuzzy account by the bank of the most recent control error.[11] Since the private sector at the end of t attempts to determine whether a given inflation surprise $(\pi_t - \pi_{t|t-1})$ was an intentional action by the bank or was due to the control error, the private sector will use this information optimally in updating its estimate of the bank's employment target.[12]

When these assumptions are consistent with rational expectations equilibrium, the private sector's learning problem about z_t is optimally solved by the Kalman filter,

$$z_{t+1|t} = (\rho - gk_2)\, z_{t|t-1} + gx_t, \tag{2.11}$$

$$x_t \equiv \pi_t - k_0 - k_1\varepsilon_t - k_3 z_{t|t-1} - \tau\xi_t. \tag{2.12}$$

where g is the Kalman gain, which depends on k_2, σ_η^2, σ_ν^2 and σ_θ^2.[13] Equation (2.12) is the measurement equation, and under the private sector's belief in (2.8) and (2.9), straightforward substitution reveals that

$$x_t = k_2 z_t + (\eta_t - \tau\xi_t), \tag{2.13}$$

so that x_t is equal to scaled z_t plus noise. Under the assumptions, then, equilibrium dynamics are,

$$\pi_t = k_0 + k_1\varepsilon_t + k_2 z_t + k_3 z_{t|t-1} + \eta_t \tag{2.14}$$

$$\pi_{t|t-1} = k_0 + (k_2 + k_3)\, z_{t|t-1} \tag{2.15}$$

$$\pi_t - \pi_{t|t-1} = k_1\varepsilon_t + k_2(z_t - z_{t|t-1}) + \eta_t \tag{2.16}$$

$$l_t = (1 + k_1)\varepsilon_t + k_2(z_t - z_{t|t-1}) + \eta_t \tag{2.17}$$

$$l_t - l_t^* = (1 + k_1)\varepsilon_t + k_2(z_t - z_{t|t-1}) + \eta_t - l^* - z_t \tag{2.18}$$

FS shows how to verify that (2.8) is the optimal reaction of the central bank in this economy and derives some facts about the optimal ks in the reaction function. Here we review one portion of this derivation that is useful in understanding the results.

The economy has two state variables z_t and $z_{t|t-1}$: z_t is the bank's employment target, and $z_{t|t-1}$ is the private sector's best estimate of the target. We call $z_{t|t-1}$ the bank's *reputation* since it completely summarizes the private sector's view of how past policy behavior reflects on future behavior. We recursively define the central bank's value function as

$$V(z_{t|t-1}, z_{t-1}) \equiv \mathrm{E}_{t-1} \min_{i_t} \mathrm{E}_{t-} \left[L_t + \beta V(z_{t+1|t}, z_t) \right], \tag{2.19}$$

where E_{t-} denotes the expectations of the central bank given its information at the *beginning* of period t, after it has observed ε_t and θ_t, but before η_t, π_t, ξ_t, and l_t have been realized.

In period t, the central bank's problem is to solve

$$\min_{i_t} \mathrm{E}_{t-} \left[L_t + \beta V(z_{t+1|t}, z_t) \right]. \tag{2.20}$$

In equilibrium, i_t must satisfy the first-order condition

$$-\mathrm{E}_{t-} \frac{\partial L_t}{\partial i_t} = \beta \mathrm{E}_{t-} \frac{\partial V(z_{t+1|t}, z_t)}{\partial z_{t+1|t}} \frac{\partial z_{t+1|t}}{\partial i_t}. \tag{2.21}$$

On the left side of (2.21) is the marginal net benefit in period t of a period-t positive inflation surprise: $\partial L_t / \partial i_t$ involves higher employment through the Phillips curve which is good when z_t is high and involves higher inflation which is bad when inflation is positive. The right side gives the discounted marginal cost from period $t+1$ onward of the surprise. We call these reputation costs since they are scaled by the effect of the surprise on reputation, $\partial z_{t+1|t} / \partial i_t$.

The aspects of the solution that are of importance for this paper are reported in the following proposition proved in FS,[14]

Proposition 2.1. *When the private sector believes* (2.8) *and* (2.9) *and the central bank follows* (2.9) *for a given* τ, $0 \leq \tau \leq 1$, *the solution to the bank's decision problem for* i_t *has the form* (2.8).

(i) *For the standard loss function:* $0 < k_0 < l^*$, $k_1 = -\frac{1}{2}$, $0 < k_3 \leq k_2 < \frac{1}{2}$, $g > 0$, $\rho - gk_2 > 0$, *and* $\partial \mathrm{E}_{t-} V(z_{t+1|t}, z_t) / \partial \mathrm{E}_{t-} z_{t+1|t}^2 > 0$.

(ii) *For the CM loss function:* $0 < k_0 < l^*$, $k_1 = k_3 = 0$, $0 < k_2 < 1$, *and* $\partial \mathrm{E}_{\mathrm{t}-} V(z_{t+1|t}, z_t) / \partial \mathrm{E}_{t-} z_{t+1|t}^2 = 0$.

Some explanation of the key results is useful. For both loss functions, average inflation, k_0, is between zero and l^*, the average employment target. Thus, when l^* is zero, there is no average inflation bias. As usual under the standard loss function, $k_1 = -1/2$ so that the effect of supply shocks is spread evenly between employment and inflation.[15] Under the CM loss, the bank does not care about employment variance and ignores the supply shock. Under both loss functions, k_2 is positive, implying that a higher employment target leads to higher choice of inflation.

Finally, under the standard loss, all else equal the bank is averse to rises in the variance of its reputation (because variability of reputation results in variability of employment via variability of inflation expectations). For the CM loss function, the bank ignores its reputation in forming policy ($k_3 = 0$), and the variance of its reputation does not affect its loss.

3 Choosing the degree of control with exogenous degree of transparency

We consider the choice of control-error variance under discretion and then briefly mention some results under commitment, arguing that the commitment paradigm is implausible in this context. We are not here concerned with transparency and the announcement, so we fix τ and maintain the assumption that the central bank must generate ξ_t, according to (2.9). (For the CM loss function, we set $\tau = 0$, so there is no useful signal.)

3.1 Choosing control-error variance under discretion

Suppose that the central bank can choose the variance of the control error each period before choosing i_t. We discuss possible interpretations of this choice below.

Proposition 3.1. *If the central bank chooses $\sigma_\eta^2 \geq 0$ at the beginning of each period t (that is, at time $t-$), before it chooses its intended inflation for period t.*

(i) *For the standard loss function, $\sigma_\eta^2 = 0$ is the only equilibrium. If there is a positive lower bound on control error variance, this lower bound value is the only equilibrium.*

(ii) *For the CM loss function, any value of $\sigma_\eta^2 \geq 0$ is an equilibrium.*

The proposition is proved in appendix B. Part (ii) illustrates the peculiar results that follow when the central bank is indifferent to the variance of employment and to inflation variance stemming from poor control. Under the CM loss function, the bank is totally indifferent to the noise level and will be willing to deliver any value of noise (and, hence, any variance of employment and inflation) expected by the private sector.

Part (i) was recognized by Goodfriend [14]. The intuition is as follows. At time $t-$, adding mean-zero noise to the reaction function cannot make the bank better off with respect to *average* inflation or employment: the noise has no effect on the mean outcome. It does, however, damage the bank by raising the *variance* of inflation and employment for period t. Similarly, adding mean-zero noise to the policy choice at t does not change average future reputation, $E_{t-}z_{t+1|t}$; it only raises the variance of future reputation, which is bad for the bank.

In the standard Kydland-Prescott-Barro-Gordon literature, we can think of the central bank promising zero inflation, but without commitment, the central bank has an incentive to renege on the promise and deliver higher inflation. Here the situation is analogous, but the effect is more virtuous. We can imagine the bank promising noisy control, but without commitment, the bank has an incentive to renege and use the best possible control.

3.2 Control-error variance and commitment

Following CM, we can imagine a central bank having a commitment mechanism and choosing the control-error variance, σ_η^2, once-and-for-all without any knowledge of the state variables. CM documented that the central bank would choose $\sigma_\eta^2 > 0$ for the vast majority of parameter values they examined. FS find that under the standard loss function the central bank would choose positive noise for a much smaller range of parameter values than under the CM loss, but it remains the case that both zero and positive noise variance can be supported by arguably reasonable parameterizations.

Intuitively, the positive noise equilibria arise because the noise slows the public learning about the employment target l_t^*: when a positive inflation surprise happens the public is more likely to attribute it to noise and is more moderate in revising up its estimate of l_t^*. This allows the central bank to benefit from a more sustained sequence of inflation surprises when l_t^* is persistently high.

The most important point from our perspective is that equilibria under commitment regarding control error variance are implausible. These equilibria rest on the assumption of the central bank being able to commit regarding the second moment of policy (the variance) but not with regard to the first moment (average policy behavior). Various factors that are often argued to facilitate sustainable commitment seem more relevant, however, when applied to the first than to the second moment. It is relatively easy to verify *ex post* that the central bank reacted as promised to nonstochastic elements of the rule. It is much more difficult to know whether the noise induced by the central bank had the proper variance. If we believe that central banks would and could cheat on their commitment to a policy rule, it seems much more likely that they would and could cheat regarding the variance of the noise added to the policy rule.

Goodfriend emphasizes the possibility of adopting operating procedures that generate noisy control. This is possible, but the choice, say, of a poor intermediate target does not fully determine a level of noise. Central banks have discretion over many techniques that could improve control, such as improving forecasting efforts or data construction and analysis. The difficulty for outside observers to verify whether or not the central bank is pursuing these options—together with the incentive of the bank to secretly improve control—would make the noisy-control equilibrium very fragile, in our view.

One particular example of deliberate noisy control is commitment to an inappropriate intermediate target, like a money-growth target or an exchange-rate target, when the true loss function involves stabilizing inflation.[16] The Bundesbank's emphasis on monetary targeting might, at first, be seen as an example of this. However, a number of observers have come to the conclusions that the Bundesbank followed monetary targeting only in words but inflation targeting in deeds. Therefore, the Bundesbank might be seen as an example of the difficulty of sustaining commitment to an inferior operating procedure.

A comment on robustness is warranted, since we have only considered a small range of the possible equilibria of the basic model—Markov equilibria with linear learning functions. We believe, however, that the main point of this section is of interest more generally.[17]

The results under discretion are driven by a simple principle: under discretion, the central bank will only follow a strategy involving randomizing (adding noise to the control or announcement) if it is indifferent among the random outcomes that may result. This is a very general principle from game theory (for instance, see Fudenberg and Tirole [12]) and it is easily understood: when the time comes to obey the random number generator, the central bank will cheat if some outcomes are preferred to others. Thus, when the bank's loss varies with the size of the realized control error, as seems most reasonable, deliberately poor control is unlikely to emerge in equilibrium.

4 Endogenous announcements and the degree of transparency

Up to now, we have put an unnatural restriction on the central bank: it cannot affect the degree of transparency, for instance by directly communicating with the private sector. If the bank would truthfully announce η_t, then any value of committing to $\sigma_\eta^2 > 0$ would be lost. In this section, we endogenize the announcement quality, allowing the central bank to choose the degree of transparency, τ, either once-and-for-all under commitment, or every period under discretion.[18]

To explore the role such announcements might play, we now fix a positive level of control-error variance (corresponding, say, to the minimum feasible control error variance discussed above), and consider the endogenous choice of the announcement, ξ_t, under the assumption that the private sector believes that the announcement is equal to the control error plus noise, (2.9).[19] Recall from (2.10) that the degree of transparency is measured by τ, the squared correlation between the announcement, ξ_t and the control error, η_t. The higher this correlation (the higher the signal-to-noise ratio), the more precise will be the private sector's inference about i_t and, hence, z_t. For simplicity, we only consider the standard loss function and not the CM loss function in this section. The results for the two loss functions differ for the same reasons as already explained above.

With regard to transparency, we believe that the existence of a commitment mechanism is a more subtle issue than with regard to control error noise. There are clearly commitment mechanisms that facilitate commitment to low transparency. The Federal Reserve and other central banks have elaborate internal rules about secrecy and the release of information, and there are legal and administrative punishment mechanisms that are used in the case of leaks. At each time t, the bank may have an incentive to enact a one-time deviation from such rules, but there are legislative and administrative barriers to such rapid rule changes.

There are also ways of committing to high transparency.[20] The prime current examples of a high degree of transparency are the high-quality *Inflation Reports* regularly issued by inflation-targeting central banks, notably Reserve Bank of New Zealand, Bank of England and Sweden's Riksbank. Creating such reports requires substantial resources, organization and planning. A system for producing regular inflation reports is probably difficult to reverse. Further, once the system is in place, it would be a most dramatic action for a central bank to suddenly dismantle it; such an action would have very severe consequences for the bank's reputation and might invite a legislative response.[21]

Because we conclude that commitment is plausible, we emphasize the commitment results, but since we do not see commitment as the only outcome we also briefly consider the results under discretion.

4.1 Choosing the degree of transparency under commitment

Choosing the degree of transparency is different from choosing the control-error variance in a fundamental way. The control-error variance directly enters the loss function by feeding into inflation and employment variance, whereas the degree of transparency does not directly affect the economy. One might suppose that the central bank would be more in favor of imprecise announcements than imprecise control. This intuition receives some support.

Since the complexity of the equilibrium prevents analytical results, we follow CM in numerically exploring which parameter values lead to $\tau < 1$ being optimal. As in FS, we explore a "large" and a "small" parameter space. The large parameter space is $(\beta, \rho) \in [0,1]^2$, $(\sigma_\eta^2, \sigma_\varepsilon^2, \sigma_\theta^2, l^*) \in [0,10]^4$. The small parameter space is the same except that the discount factor is $\beta = 0.99999$ and the average employment target is $l^* = 0$. Thus, the small space only considers patient banks with no average inflation bias. We compute the optimal τ for 100,000 points chosen uniformly from each parameter space and then report the share of parameter values that lead to optimal transparency being minimal, maximal, or in between.[22]

Proposition 4.1. *Suppose that the central bank, with the standard loss function, chooses τ once-and-for-all with no knowledge of the state of the economy.*

(i) *For the full parameter space, maximum transparency ($\tau = 1$) is preferred by the central bank for* 79.5 *percent of the parameter space, whereas minimum transparency ($\tau = 0$) is preferred for* 18.6 *percent. An intermediate degree of transparency is preferred for* 1.9 *percent.*

(ii) *For the small parameter space, minimum transparency is always preferred by the central bank.*

For most of the full parameter space, the central bank prefers to be as transparent as possible. While we have few general results about the roles of the parameters in generating the optimal τ, the results for the small parameter space shed important light on the role of β and l^*. As indicated in part (ii), when we make the bank more patient, $\beta \approx 1$, and set the mean employment target to zero, $l^* = 0$, the central bank uniformly prefers minimum transparency.

This case of a patient bank with small average bias seems like the most relevant one to us, and it is worth examining where the preference for secrecy comes from. When $l^* > 0$, marginally lowering transparency from full transparency leads to a marginal increase in average inflation, k_0, which hurts the bank. This is because, all else equal, the fall in transparency masks the bank's motives, giving it an incentive to generate positive inflation surprises on average. This cannot occur in equilibrium and equilibrium average inflation, k_0, must rise to offset the incentive for inflation surprises. When $l^* = 0$, $k_0 = 0$ independent of τ. Thus, a major marginal cost to the bank of lowering transparency is eliminated and the bank finds low transparency more attractive.

To understand how the higher β contributes to a preference for low transparency, we recall that the bank (as examined in section 2) each period chooses its intended inflation each period under discretion. A value of $\beta \approx 1$ maximizes the relative weight the bank places on the future costs and benefits of reputation. This makes the bank's behavior in each period closer to minimizing the unconditional loss function under commitment.[23] Intuitively, we can view the reputation effect as a punishment mechanism, and note that this mechanism is more effective with higher β. When the public has a more effective punishment mechanism for inflation surprises, it need not respond to a fall in transparency with as large a rise in k_0: rather than deterring the bank from surprises ex ante with an average bias, it can deter it ex post with degraded reputation. Thus, the marginal cost to the bank of lowering transparency is reduced, and secrecy becomes optimal for a broader range of parameters.

4.2 Choosing the degree of transparency and the announcement under discretion

In the commitment discussion, we implicitly envisioned the bank committing regarding two features, (a) it could commit to making the announcement equal to the truth plus noise (as in (2.9)), and (b) it could commit regarding the correlation between the announcement ξ and η_t. In the following proposition we first relax both of these, then just (b).

Proposition 4.2. *Assume that the private sector believes that the announcement ξ_t is generated according to* (2.9).

(i) *If the bank cannot commit regarding* (a) *or* (b) *and, thus, chooses ξ_t freely at t, then only minimum transparency* ($\tau_t = 0$) *is consistent with equilibrium.*

(ii) *If the central bank can commit as in* (a) *to announce according to* (2.9), *but selects the degree of transparency τ_t each period then only minimum* ($\tau_t = 0$) *and maximum* ($\tau_t = 1$) *transparency are consistent with an equilibrium.*

The proposition is proved in appendix B. It is straightforward to see that $\tau_t = 0$ is an equilibrium in both parts. When $\tau_t = 0$, the announcement is useless and will be ignored by the private sector. If the private sector ignores the announcement, the bank is indifferent about the announcement and will follow $\tau_t = 0$.

For both parts, it is also clear that intermediate values of τ_t are not consistent with equilibrium. If the public expects an announcement according to $\tau_t \in (0, 1)$, the bank has an incentive to deviate and announce according to $\tau_t = 1$. This deviation will not affect the average announcement or any average outcome in the economy; the deviation only reduces mean zero noise. As emphasized above, the bank does not like variance and, hence, will prefer the deviation.[24] This same logic implies that $\tau_t = 1$ is an equilibrium in (ii): if the public expects $\tau_t = 1$, the central bank's only deviation is to reduce τ_t, which has a cost of adding variance without any beneficial affect on mean outcomes. By limiting deviations from truth-telling to actions that are costly, we support a fully revealing equilibrium.

In part (i), by contrast, the central bank can ignore (2.9) and make deviations that are deterministic. This removes the variance cost just discussed and makes the announcements into *cheap talk* and a standard result applies: truth telling (full transparency) is not an equilibrium (e.g., [6]).[25]

In summary, we find the commitment paradigm to be most relevant regarding transparency. Under commitment, minimum transparency is the only equilibrium for the small parameter space, which is arguably the most relevant part of the parameter space. Maximum transparency is more likely to be observed where the average inflation bias is higher and, say, political considerations raise the central bank's discount rate. Under discretion minimal transparency is generally an equilibrium, and maximal transparency may also be an equilibrium if deviations from truth telling involve are inherently costly to the bank.

5 Conclusions

Results about the endogenous choice of control and transparency seem to be more sensitive to assumptions about details of loss functions, commitment mechanisms and available strategies than has previously been emphasized. For example, the CM result that central bankers may choose noisy control in order to obscure its policy is weakened or overturned under a more standard loss function or more plausible assumptions about commitment mechanisms.

We argue that discretion is more plausible for the choice of the degree of control and that commitment is more plausible for the choice of the degree of transparency. This combination implies that maximum feasible control by minimum-transparency central banks is likely to be observed in practice.

We believe that both Bundesbank and the Federal Reserve System provide examples of this. With regard to inflation control, Bundesbank's performance in the post-War era is legendary; the Fed's performance has been similarly strong since the mid 1980s. The Fed arguably has a record of low transparency, however (see for instance Blinder [4]).[26] While the Bundesbank's framework of monetary targeting may appear to be a model of transparency, several analysts (for instance, Neumann [19], von Hagen [29], Bernanke and Mihov [3] and Clarida, Gali and Gertler

[5][27]) have concluded that the Bundesbank has systematically given priority to inflation control when conflicts arise between the inflation target and the monetary target. Thus, Svensson [27] and [28] has argued that the Bundesbank's framework is inflation targeting in disguise, that is, inflation targeting in deeds and monetary targeting in words only. Under this view, the Bundesbank's framework is also one of low transparency.

The recent emergence of inflation-targeting central banks with a high degree of transparency, may constitute a puzzling contradiction of these results. In some cases, notably the Reserve Bank of New Zealand and the Bank of England, the high degree of transparency is imposed on the central bank by the government, which is consistent with our results. One could argue, however, that this imposition was actively promoted and enthusiastically accepted by those central banks. Furthermore, some inflation-targeting central banks, notably the Riksbank, have voluntarily established high standards of transparency, albeit at a gradual pace.

What accounts for these exceptions from the general prediction? Since we believe that commitment is the relevant paradigm for the choice of transparency, the model accommodates this result only if these banks are not described by parameters in the small parameter space. There is some reason to take this view: high-transparency inflation targeting tends to emerge in countries with a bad inflation history. This is consistent with the view that the average inflation bias in these countries historically has been sufficiently large to support maximum transparency as an equilibrium.

A The equivalence with the Kalman filter in FS

In FS, we assume

$$\begin{aligned} \eta_t &= \tilde{\xi}_t + \tilde{\nu}_t, & \text{(A.1)} \\ \sigma^2_{\tilde{\xi}} &= \tilde{\tau}\sigma^2_\eta, & \text{(A.2)} \\ \sigma^2_{\tilde{\nu}} &= (1-\tilde{\tau})\sigma^2_\eta, & \text{(A.3)} \end{aligned}$$

where the tildes are added to differentiate the FS specification from that of this paper. In FS, we assume that the private sector observes $\tilde{\xi}_t$ and, at the end of period t, constructs the variable

$$\tilde{x}_t \equiv \pi_t - k_0 - k_1\varepsilon_t - k_3 z_{t|t-1} - \tilde{\xi}_t.$$

Then under the private sector's belief in (2.8) and (A.1), the variable $\tilde{x}_t$ fulfills

$$\tilde{x}_t = k_2 z_t + \tilde{\nu}_t. \tag{A.4}$$

This is the measurement equation in FS. Obviously, it is equivalent to the measurement equation (2.13) under the assumption that

$$\sigma^2_{\tilde{\nu}} = \text{Var}[\eta_t - \tau\xi_t] = \text{Var}[\eta_t - \tau(\eta_t + \nu_t)] = (1-\tau)\sigma^2_\eta, \tag{A.5}$$

where we have used (2.10) and (2.9). Since by (2.10), $(1-\tau)\sigma^2_\eta = \tau\sigma^2_\nu$, we get

$$\sigma^2_{\tilde{\nu}} = \tau\sigma^2_\nu. \tag{A.6}$$

Furthermore, by (A.3) and (A.5), we have

$$\tilde{\tau} = \tau. \tag{A.7}$$

Thus, under the assumption (A.6), the Kalman filter problems in FS and this paper are identical, and the degree of transparency τ has the same interpretation in both papers. It follows that the Kalman gain g in (2.11) is given by the same equation as in FS, except that $\tau\sigma^2_\nu$ is substituted for σ^2_ν.

B Proofs

Proof of Proposition 3.1

In this proof, we use the fact that the value function, V, will be quadratic in the state variables since the loss function is quadratic and the two state variables evolve linearly:

$$V(z_{t|t-1}, z_{t-1}) \equiv \delta_0 + \delta_1 z_{t|t-1} + \frac{1}{2}\delta_2 z^2_{t|t-1} + \delta_3 z_{t-1} + \frac{1}{2}\delta_4 z^2_{t-1} + \delta_5 z_{t|t-1} z_{t-1}, \tag{B.1}$$

for some coefficients δ_0, ..., δ_5. We also use the fact, from Proposition 2.1, that $\delta_2 > 0$.

Part (i). Suppose, contrary to the result, that some $\bar{\sigma}^2_\eta > 0$ is an equilibrium. We show that a one-period deviation to $\sigma^2_\eta = 0$ reduces the loss to the bank. If $\bar{\sigma}^2_\eta$ is an equilibrium independent of the state, the choice of i_t in each period will be as in the baseline case. Call the intended policy action $\hat{\imath}_t$. The loss associated with allowing the error to be drawn with variance $\bar{\sigma}^2_\eta$, seen from the end of period $t-1$, can be written

$$V(z_{t|t-1}, z_{t-1}) = \text{E}_{t-1}\frac{1}{2}\left[(\hat{\imath}_t + \eta_t)^2 + (\hat{\imath}_t + \eta_t - \pi_{t|t-1} + \varepsilon_t - l^* - z_t)^2\right] + \beta \text{E}_{t-1} V(z_{t+1|t}, z_t) \tag{B.2}$$

The expected loss from using the same $\hat{\imath}_t$, but setting $\sigma_\eta^2 = 0$ at t before returning to $\sigma_\eta^2 = \bar{\sigma}_\eta^2$ from $t+1$ onward is

$$V_r(z_{t|t-1}, z_{t-1}) = \mathrm{E}_{r,t-1}\frac{1}{2}\left[\hat{\imath}_t^2 + (\hat{\imath}_t - \pi_{t|t-1} + \varepsilon_t - l^* - z_t)^2\right] + \beta \mathrm{E}_{r,t-1} V(z_{t+1|t}\ z_t), \tag{B.3}$$

where the r subscripts indicate that this is the value when the bank *reneges* on the equilibrium for one period. The value function for period $t+1$ onward is the same in (B.2) and (B.3). The value taken will be different in the two cases, however, since the state variable $z_{t+1|t}$ will take different values for period t onward (depending upon the realizations of η_t under different variances).

Since η_t is independent of all other stochastic elements in the model, it is clear that the loss for period t must be lower in (B.3) than in (B.2). For period $t+1$ onward, expand the difference in the expectation of the value function as

$$\begin{aligned}(\mathrm{E}_{t-1} - \mathrm{E}_{r,t-1})V(z_{t+1|t}, z_t) &= \delta_1(\mathrm{E}_{t-1} - \mathrm{E}_{r,t-1})z_{t+1|t} + \frac{1}{2}\delta_2(\mathrm{E}_{t-1} - \mathrm{E}_{r,t-1})z_{t+1|t}^2 \\ &\quad + \delta_5(\mathrm{E}_{t-1} - \mathrm{E}_{r,t-1})z_{t+1|t}z_t.\end{aligned}$$

The only difference between the two expectations is the variance of η_t and this variance only depends on the second term on the right side. Since reputation, $z_{t|t-1}$, evolves according to (2.11)

$$(\mathrm{E}_{t-1} - \mathrm{E}_{r,t-1})V(z_{t+1|t}, z_t) = \frac{1}{2}\delta_2 g^2(1-\tau)\bar{\sigma}_\eta^2,$$

since

$$(\mathrm{E}_{t-1} - \mathrm{E}_{r,t-1})z_{t+1|t}^2 = (\mathrm{E}_{t-1} - \mathrm{E}_{r,t-1})g^2(\eta_t - \mathrm{E}[\eta_t|\xi_t])^2 = g^2(1-\tau)\bar{\sigma}_\eta^2.$$

This is positive in our case, since $\delta_2 > 0$ (from proposition 2.1).

Part (ii). Suppose that any fixed $\bar{\sigma}_\eta^2 > 0$ is an equilibrium. We can follow the argument of the proof of part (i). The two differences are that the period t loss is unaffected by the control-error variance. Furthermore, since $\delta_2 = 0$ in the CM case, the choice of σ_η^2 in period t does not affect the expected value of the loss from period $t+1$ onward either.

Proof of Proposition 4.2

The argument that $\tau_t = 0$ is an equilibrium in (i) and (ii) is given in the text. Now, we show that no $\tau_t \in (0,1)$ is an equilibrium in (i) and, by direct extension, in (ii). Suppose some $\tau_t \in (0,1)$ were an equilibrium. Consider the point in time at $t+$ when the period-t economy has been resolved but the announcement, ξ_t, has not yet been given. If τ_t is an equilibrium, the bank's optimum will be described by the value function

$$\mathrm{E}_{t+}V(z_{t+1|t}, z_t) = \mathrm{E}_{t+}\left[\delta_0 + \delta_1 z_{t+1|t} + \frac{1}{2}\delta_2 z_{t+1|t}^2 + \delta_3\rho z_t + \frac{1}{2}\delta_4 z_t^2 + \delta_5 z_{t+1|t}z_t\right],$$

where the only random term is $z_{t+1|t}$. Following the proof of proposition 3.1, consider the value of using $\tau = 1$ for one period before returning to the proposed equilibrium τ_t. Since $z_{t+1|t}$ evolves according to (2.11) under either strategy, the expectation of $z_{t+1|t}$ is the same under either τ. Since z_t is known at $t+$, the only difference between the value of the loss function in the two cases is, as in the above proof, δ_2 times the difference in $\mathrm{E}_{t+}z_{t+1|t}^2$ in the two cases. Since the two means are the same, the variance is higher under $\tau < 1$, and $\delta_2 > 0$ (by proposition 2.1), the loss must be lower for $\tau = 1$.

$\tau_t = 1$ is an equilibrium in part (i): Assume that the private sector expects $\tau_t = 1$. The bank must use some $\tau_t \in [0, 1]$, and by the argument just given, using any $\tau < 1$ will raise the loss function.

$\tau_t = 1$ is not an equilibrium in part (ii): Assume $\tau_t = 1$ is an equilibrium. Following the argument in the text, we need only show that the bank's loss is not minimized at $\xi_t = \eta_t$. Since the bank's welfare is quadratic in z_t and a given z_t can occur with any η_t, it is clear that $\xi_t = \eta_t$ cannot minimize loss for all z_t and η_t.

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Notes

[1]Both quote Karl Brunner for support: "Central banking [has been] traditionally surrounded by a peculiar and protective political mystique... The mystique thrives on a pervasive impression that Central Banking is an esoteric art. Access to this art and its proper execution is confined to the initiated elite. The esoteric nature of the art is moreover revealed by an inherent impossibility to articulate its insights in explicit and intelligible words and sentences" (as quoted in Goodfriend [14]).

[2]See Friedman quoted in Fischer [11], footnote 52.

[3]Several papers, including Andersen [1], Cukierman and Meltzer [7], Persson and Tabellini [21], Muscatelli [18] and Walsh [31] examine how announcements by central banks may potentially reveal private information about the goals of the banks or the state of economy, but they do not consider central banks' endogenous choice of transparency.

[4]The average rate of employment, $\mathrm{E}[l_t]$, is normalized to equal zero.

[5]At the expense of added mathematical complication and positing an additional transient shock to central bank preferences, we could add an instrument that the central bank manipulates and that is observed by the public but whose value does not directly reveal intentions.

[6]We provide a more complete argument on this point in FS.

[7]It might seem natural to have l^* fixed but have the relative weights on the inflation and employment terms vary stochastically. Under this formulation, however, the solution to the problem is not a linear decision rule and the model becomes intractable. Note that l_t^* need not be seen as a deliberate deviation of the employment target from the natural rate; it might reflect private central views regarding the unobservable natural rate which fluctuates as different views reflected on the policy board come to have more prominence.

[8]In the CM loss function, $l_t^* = l^* + z_t$ is interpreted as a marginal benefit of more employment, rather than as an employment target.

[9]Alternatively, we could interpret ξ_t as a noisy observation of the control error available to the private sector.

[10]Note that the signal-to-noise (variance) ratio, $s \equiv \sigma_\xi^2/\sigma_\nu^2$, fulfills $s = 1/(1-\tau)$.

[11]We briefly take up the case in which the central bank cannot commit to an announcement of the form (2.9) in section 4. We believe that the central bank can commit, say, to truthfully revealing a proper subset of its information about the economy. If the subset of the information constitutes a noisy signal of the variable of interest (η in our case) this would lead to our formulation (in the linear case with normal shocks).

[12]Our formulation of the announcement is slightly different from CM2. In the CM2 formulation, the announcement comes after the central bank has observed θ_t, but before private-sector inflation expectations for t are formed. The only substantive difference is that in CM2, the announcement can reveal something about both the ρz_{t-1} and the θ_t portions of z_t, whereas in our formulation, the information is only about ρz_{t-1}.

[13]The parameterization of the signal in this paper differs slightly from FS. The equivalence and mapping between the parameterizations are shown in appendix A. The interpretation of τ is the same in either case.

[14]For the CM loss function, CM shows that the rational expectations equilibrium is unique. For the standard loss function, FS finds strong numerical evidence of uniqueness, but have no formal proof. The statements about the equilibrium for the standard loss function hold at any rational-expectations equilibrium under the assumptions.

[15]More generally, we could have different weights on employment and inflation in the loss function and the standard result for that case would occur in this model. None of the questions we address here would be substantially altered by shifting this weight.

[16]See Svensson [26] and [27] and Rudebusch and Svensson [23], for instance, for demonstrations that money-growth targeting is inefficient in minimizing a standard loss function of the form $L_t = \frac{1}{2}[(\pi_t - \pi^*)^2 + \lambda l_t^2]$, $\lambda \geq 0$.

[17]The set of equilibria that would emerge if we suspended assumptions (2.8) and (2.9), which keep the equilibria linear, and allowed a general signalling framework, might be quite large. Rogoff [22] has made this point with regard to CM. Palmqvist [20] incorporates explicit signalling in a simplified variant of FS.

[18]Cukierman and Meltzer [7] (CM2) incorporate communication by forcing the central bank to make an announcement of a fixed, imperfect quality. In terms of our notation, CM2 assume that the control-error variance σ_η^2 and the noise variance in the announcement σ_ν^2 are constrained by $\sigma_\eta^2 = k_2^2\bar{\sigma}_\eta^2$ and $\sigma_\nu^2 = k_2^2\bar{\sigma}_\nu^2$, where $\bar{\sigma}_\eta^2$ and $\bar{\sigma}_\nu^2$ are fixed positive constants. Thus, the degree of transparency in CM2 is fixed by $\tau = \frac{\bar{\sigma}_\eta^2}{\bar{\sigma}_\eta^2+\bar{\sigma}_\nu^2}$.

[19]One might also consider a fuzzy announcement about z_t directly. Formally, this would complicate the learning problem significantly. Of course, z_t and ξ_t announcements are closely related. For example, in this model the central bank can fully reveal z_t in equilibrium through the announcement of xi with $\tau = 1$. This result would not necessarily generalize, however.

[20]While commitment to very high and very low transparency seems quite plausible to us, commitment to moderate levels (intermediate τ) perhaps is less so. As noted above, the real world analog to commitment to moderate τ would probably involve rules that mandate accurate reporting of some clearly defined subset of the central bank's information.

[21]It remains true, however, that there would sometimes be incentives to hide or even manipulate facts and forecasts in these reports, either to rationalize a policy action or obfuscate an embarrassing lack of understanding of the economy. On the other hand, the standardized format and the high degree of scrutiny makes temporary obfuscation without detection and embarrassment quite difficult, certainly much more difficult than without the system.

[22]Judd [15] discusses this sort of numerical analysis of theoretical models more fully. While this share must be viewed as an estimate, with 100,000 draws it is estimated with great precision. In particular, if we call the true share x and the simulated share $\hat{x}$, using the normal approximation, we have $\sqrt{n}(\frac{\hat{x}-x}{\sqrt{x(1-x)}}) \sim N(0,1)$, where n is the number of draws. It follows that a 95 percent confidence interval for x is given by $\hat{x} \pm 1.96\sqrt{x(1-x)}10^{-5/2} = \hat{x} \pm 0.0062\sqrt{x(1-x)}$, if x is known. Since $\sqrt{x(1-x)}$ is bounded by 0.5, an upper bound for a 95 percent confidence interval is $\hat{x} \pm 0.0031$, that is, $\pm$ 0.31 percentage points.

[23]This point is developed further in FS.

[24]The bank is about to generate the announcement, $\xi_t = \eta_t + \nu_t$, where the variance of ν_t is determined by τ_t, $\sigma_\nu^2 = [(1-\tau_t)/\tau_t]\sigma_\eta^2$. Setting $\tau_t = 1$ reduces the variance of ν_t to zero without affecting the mean announcement.

[25]The fact that a fully revealing announcement is not an equilibrium—it is not subgame perfect—without restrictions of the sort in part (i) that make deviations costly is the starting point of Stein's [25] and Garfinkle and Oh's [13] application of Crawford and Sobel [6] to monetary policy. We discuss the applications of Crawford and Sobel more fully in an earlier version of this paper [10]. As we discuss, those papers more fully consider strategic communication, but in a more limited framework. We consider the results of this paper to be complementary to those results.

[26]See also Goodfriend [14] and Rudebusch and Walsh [24].

[27]Note an unfortunate and essential typo in Clarida, Gali and Gertler [5], table 1, p. 1045: The coefficient in the row for monetary policy and the column for ξ should be 0.07 instead of 0.7.