Transparency, Flexibility, and Inflation Targeting

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Three parallel and certainly not independent changes have occurred in central bank practices over the past fifteen years. The first is the spread of central bank independence, which is tied to the notion that even when the government plays a role in setting the goals of monetary policy, central banks should be free from political interference as they pursue those goals. A second trend is the adoption of inflation targeting. Beginning with New Zealand in December 1989, and followed by Chile in January 1991, over twenty countries have adopted some version of inflation targeting. Finally, the third trend among both inflation-targeting and non-targeting central banks is the adoption of greater transparency in the conduct of monetary policy. In fact, transparency is increasingly viewed as a standard and important component of best practices in central banking.

These three trends are closely related. In democratic societies, independence needs to be underpinned by accountability. Greater transparency is commonly viewed as an important means for achieving this accountability. It is also a natural outcome of the wide-spread adoption of inflation targeting by central banks in both developed and developing economies, since, at a minimum, inflation targeting involves the formal announcement of a target for the inflation rate. Even central banks that have not formally adopted inflation targeting have become more transparent in recent

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years. Eijffinger and Geraats (2006) provide an index of transparency for a set of developed economies that includes both inflation targeters (Australia, Canada, New Zealand, Sweden, and the United Kingdom) and non-targeters (Japan, Switzerland, and the United States). They find that between 1998 and 2002, transparency increased for virtually all the central banks they studied. Even the Federal Reserve, which has so far resisted calls to establish a formal inflation target, has moved to make its policy practices more transparent.

Recently, however, new questions have been raised about the value of having central banks provide more and better information to the public. Morris and Shin (2002) argue that providing more accurate public information can carry a cost when private agents have individual sources of information and must base decisions partly on what they expect others are expecting. In their model, private agents must forecast an underlying shock and attempt to forecast the forecasts of others. This creates a role for higher-order expectations (expectations of expectations of expectations...).[1] Agents may then overreact to public information, increasing the economy's sensitivity to any forecast errors in the public information.

The possibility that the private sector may overreact to central bank announcements captures a concern expressed by policymakers. For example, in discussing the release of Federal Open Market Committee (FOMC) minutes, Janet Yellen expresses the view that "financial markets could misinterpret and overreact to the minutes" (Yellen, 2005). Svensson (2006), however, argues that the Morris-Shin result is not a general one. He shows that welfare is increased by more accurate public information in the Morris-Shin model for all but unreasonable parameter values (and he therefore concludes that their message supports transparency after all).

Unfortunately, the existing research on the role of higher-order expectations and the welfare costs of public information does not employ the types of models that are standard in monetary policy analysis. In this paper, I employ a simple new Keynesian framework to investigate the role of transparency in the presence of private and diverse information. The framework can be used to address such questions as how the public information provided by interest rate movements alters the effectiveness of monetary policy; what benefits

1. Woodford (2003) also investigates the role of higher-order expectations in inducing persistent adjustments to monetary shocks in the Lucas-Phelps islands model. See also Hellwig (2002).

(and potential costs) are associated with releasing additional public information such as a short-run inflation target; whether it is always advantageous to announce targets; and whether central banks should widely publicize their targets.

My results show that a policy's impact on inflation is significantly affected by the way policy actions alter each individual price setter's expectations about the state of the economy. In the absence of central bank announcements, the direct impact on inflation of a contractionary policy move can be offset if private information is poor or the central bank's information is very precise. For example, firms may interpret an interest rate hike as a signal that the central bank believes the economy has been hit by a positive cost shock; inflation may rise as firms adjust their own beliefs about the cost shock. Announcements allow price setters to distinguish policy actions designed solely to offset demand shocks (which therefore should not affect inflation) from those actions designed to partially offset the inflation effects of cost shocks. Announcements can thereby prevent demand shocks from affecting inflation, but expectations can become more volatile in reaction to announcements. Inflation variability can increase when targets are announced.

If formal announcements heighten inflation variability, it may be advantageous for the central bank to make partial announcements of the type analyzed by Cornand and Heineman (2004). Partial announcements include, for example, speeches about the economy that may not be as widely reported as formal policy announcements. Speeches and other means of providing partial information play an important role in central banking practices, and these means of communication long predate the publication of inflation reports. The optimal degree of partial announcement depends on the relative weight the central bank places on inflation and output gap objectives. If the central bank's information about the aggregate economy is more accurate than the private information of price setters, neither inflation "nutters" (that is, strict targeters who focus exclusively on stabilizing inflation, even to the detriment of economic growth) nor central banks that place a large weight on output objectives will find it optimal to make any announcements. Central banks that are flexible inflation targeters will, however, find it optimal to be completely transparent. This may be why inflation targeters (who are not inflation nutters) are likely to implement highly transparent policy regimes.

I focus on the role of transparency for a central bank that already behaves as an inflation targeter and whose objectives are known and understood by the public. When a central bank has credibly established its reputation for maintaining low and stable inflation, the release of forecasts, output targets, and other information is a means of providing greater transparency about the central bank's assessment of the state of the economy. The next section briefly reviews the related literature; given the excellent survey by Geraats (2002), I focus on work that investigates issues of public information and transparency. Section 2 then discusses the role of the central bank's instrument as a public signal. I show how the behavior of inflation depends on the quality of both the central bank's and the private sector's information. Section 3 considers the case in which the central bank announces its target for the output gap, which provides a second source of public information. Partial announcement of the central bank's target are analyzed in section 4. This section also considers how announcements affect the optimal policy responses to cost and demand disturbances, as well as the optimal degree of transparency. Section 5 presents some extensions and explores lessons, while the appendix provides details of the model and derivations.

1. Policy and Public Information

As Issing notes, "Transparency is not an end in itself: a central bank is not established with the primary objective of communicating with the public" (Issing, 2005). Instead, the arguments in favor of greater transparency rest on two pillars—accountability and efficiency. The first stresses the importance of transparency for ensuring the public can hold policymakers accountable. This rationale for transparency resonates strongly among supporters of central bank independence. With independence comes accountability, and accountability requires transparency.

The second argument for transparency is that it improves economic efficiency, in terms of either the operation of financial markets or the implementation of policy. For example, in remarks at a 2001 conference on transparency in monetary policy held at the Federal Reserve Bank of St. Louis, Alan Greenspan expressed the view that transparency aids the functioning of financial markets: "Simply put, financial markets work more efficiently when their participants do not have to waste effort inferring the stance of monetary policy from diffuse signals generated in the day-to-day implementation of policy" (Greenspan, 2002).

Transparency may also improve the ability of monetary policy to achieve its goals by ensuring that private market expectations are consistent with the aims of central bank policy. In the forward-looking new Keynesian model that is widely used for monetary policy analysis, for example, the effectiveness of monetary policy depends on the policy's ability to affect expectations about the future path of interest rates (Woodford, 2003). A transparent policy—one that reduces uncertainty about future policy actions—can improve the trade-off between output and inflation objectives. According to King (2005), "Because inflation expectations matter to the behavior of the households and firms, the critical aspect of monetary policy is how decisions of the central bank affect those expectations." This focus on the public's expectations is mirrored in the detailed policy reports produced by many inflation-targeting central banks. The Central Bank of Chile, for example, states that one of the objectives of its Monetary Policy Report is "to provide information that can help guide economic agents' expectations regarding future inflation and output trends" (Central Bank of Chile, 2005, preface).

Both arguments in favor of transparency have been challenged. Critics of formal inflation targeting argue that any regime that holds a central bank accountable for a single objective—such as achieving an inflation target—may lead the central bank to ignore the effects of its actions on broader measures of economic welfare. This is a general problem in designing incentive mechanisms; a high powered incentive scheme works best when actions can be monitored closely.[2] Furthermore, some analysts argue that transparency may actually reduce the central bank's ability to engage in stabilization policies. This last argument is, perhaps, not surprising. Much of the academic literature examining transparency uses models in which monetary policy has real effects only to the extent that it can surprise the public. By creating an inflation surprise, the central bank is able to stimulate real output. Since the public cannot be systematically surprised under rational expectations, the attempt to engineer an economic expansion only leads to an average inflation bias. If transparency reduces the central bank's ability to generate surprises, it weakens the central bank's incentive to engage in expansionary policy and, as a result, lowers the equilibrium rate of inflation. Transparency would seem to be unambiguously advantageous (Faust and Svensson, 2002). However, if the central bank's scope for engaging in stabilization policies is also a function of its ability to generate surprise inflation, transparency reduces that ability.

2. See Walsh (2003) for an application of this principle to inflation targeting.

This limits the potential for policy to reduce economic fluctuations. Transparency may leave the central bank unable to cushion the real economy from macroeconomic shocks, a cost emphasized by Cukierman (2001).

Economists now have a great appreciation for the role that systematic, predictable policy can have on the real economy. It is not just surprises that matter. The effects of transparency may differ considerably when the predictability of policy, rather than its unpredictability, is important in determining its real impact on the economy.[3]

Morris and Shin (2002) develop a different argument for why providing public information can carry a cost. They show that the provision of more accurate public information can, in some circumstances, have a detrimental effect by leading private agents to rely too little on private sources of information.[4] Just as the earlier literature focuses on the role of monetary surprises rather than systematic policy actions to analyze issues of transparency, the Morris-Shin analysis is conducted within a framework that fails to capture important aspects of actual monetary policy. Thus, any potential limits to transparency need to be reexamined in a setting that better captures important aspects of monetary policy and its implementation. For example, the public information in the Morris-Shin study is a signal on an exogenous disturbance. In fact, most of the monetary policy debate on transparency focuses on the endogenous signals a central bank might release. By announcing its inflation forecast, the central bank provides a public signal, but the signal is dependent on policy objectives, as well as on the central bank's assessment of economic conditions. That is, how strongly (or weakly) the central bank reacts to its estimate of an inflation shock affects the information about the central bank's assessment of the economy that can be gleaned from any policy action.

Even in the absence of explicit policy announcements about targets or forecasts, central banks that employ a short-term interest rate as their policy instrument automatically provide public information, as markets can see and react immediately to any change in the policy

3. The reliance on models in which surprises are the key to the real effects of monetary policy may be one reason that Carpenter (2004) finds only a limited set of lessons for policymakers to learn from the academic literature on transparency.

4. As noted previously, Svensson (2006) argues that the Morris-Shin result is not a general one, a conclusion supported by Hellwig (2004).

rate.[5] In addition to the direct impact on spending, the interest rate setting signals to firms the central bank's beliefs about the state of the economy. A rise in the interest rate may imply that the central bank is forecasting a rise in the Wicksellian real rate, or it may signal the forecast of a positive cost shock. Thus, the efforts of private agents to infer what the central bank knows and what other agents think the central bank might know can play a role, even if explicit announcements are not made.

Amato and Shin (2003) cast the Morris-Shin analysis in a more standard macroeconomic model. In their model, the central bank has perfect information about the underlying shocks. This ignores the uncertainty that policymakers themselves face in assessing the state of the economy. Similarly, Amato and Shin do not allow the private sector to use observations on the policy instrument to draw inferences about the central bank's information. In fact, market speculation about policy actions often focuses on what a policy change says about the central bank's assessment of the economy; the nominal interest rate may be the primary public signal about monetary policy that a central bank provides. In this case, the information in the public signal is a direct function of the central bank's policy actions.

Amato and Shin (2003) further assume one-period price setting and represent monetary policy by a price-level targeting rule. In Hellwig (2004), prices are flexible and policy is given by an exogenous stochastic supply of money; private and public information consists of signals on the nominal quantity of money. In contrast, I employ a standard Calvo-type model of imperfect price flexibility, with the modification that firms adjusting each period must do so before observing the actual aggregate price level. The need to infer what other firms are doing is thus present, as in Amato and Shin and in Hellwig, but the approach is consistent with standard new Keynesian models.

Hellwig provides a more microeconomic-based analysis and shows that this can be important for assessing the welfare effects of better information. My interest is in investigating the role of announcements, not just the provision of less noisy exogenous signals. I focus on the

5. In Faust and Svensson (2002) and Jensen (2002), an exogenous control error is present in the link between the central bank's instrument and the output gap. They assume that the central bank is unable to affect or react to this control error, but it can provide the public with accurate information on some fraction of the actual control error. Transparency is then interpreted as a decrease in the volatility of the unannounced component.

implications for inflation and output gap volatility, as these are the most common measures used to assess macroeconomic performance. Some comments on how results might differ if a welfare-based measure were used are discussed in the concluding section.

2. The Policy Instrument as a Source of Public Information

To study the informational role of policy instruments and announcements, I employ a simple new Keynesian model. The details of the model are spelled out in the appendix. The model features a continuum of firms of measure one, each producing a differentiated product using an identical technology. Firms face a Calvo-type fixed probability of adjusting their price each period. In the standard new Keynesian model, firms have complete and common information about current shocks and about current aggregate equilibrium endogenous variables when setting prices. I assume instead that firms do not observe current shocks or the prices set by other firms until the period is over. Since any firm that is setting its price is concerned with its price relative to those of other firms, it needs to form expectations about the factors that determine its optimal relative price and about the behavior of other firms. This need to forecast the behavior of others introduces the role for public information stressed by Morris and Shin. Each period, private firms and the central bank receive noisy signals on aggregate shocks. Each firm's signal is private information to that firm, so individual firms have different information. The central bank sets its policy instrument and may make an announcement about its output gap target.[6] I assume that firms that do adjust their price in period t do so after observing the central bank's instrument.

Suppose firm j is setting its price in period t. Let $p_{j,t}{}^*$ denote the log price it chooses. It is convenient to treat $\Pi_{j,t}{}^* \equiv p_{j,t}{}^* - p_{t-1}$ as the choice variable, where p_{t-1} is last period's aggregate log price level. Let $\bar{\pi}_t^*$ be the average of $\Pi_{j,t}{}^*$ across the firms adjusting in period t, and let Π_t be the aggregate inflation rate. As shown in the appendix, the firm's decision depends on its expectations regarding $\bar{\pi}_t^*$, the output gap (denoted x_t), future inflation, and a cost shock (s_t). Specifically,

6. In the model, this is equivalent to announcing an inflation target. Give the structure of the model, it is somewhat more straightforward to view any announcement as an announcement about the output target.

$$\pi^*_{j,t} = (1-\omega)E^j_t\bar{\pi}^*_t + (1-\omega\beta)\kappa E^j_t x_t + \left(\frac{\omega\beta}{1-\omega}\right)E^j_t\pi_{t+1} + (1-\omega\beta)E^j_t s_t\,, \tag{1}$$

where E^j_t denotes the expectation at time t based on firm j's information, ω is the fraction of firms that do not adjust their price in a given period, and β is a discount factor.[7] The parameter κ is the output elasticity of marginal cost. The cost shock, s_t, arises as a result of stochastic fluctuations in the wedge between flexible-price output and the economy's efficient level of output (see Benigno and Woodford, 2004). Since a fraction of all firms $(1 - \omega)$ adjusts their prices, while the fraction ω does not, aggregate inflation is given by

$$\pi_t = (1-\omega)\bar{\pi}^*_t\,.$$

I represent monetary policy by the central bank's choice of an instrument, x_t^I, and by any announcements the central bank might make. I assume that x_t^I is observed at the start of the period, so that any firm that sets its price in period t can condition its choice on x_t^I. Because the most interesting policy trade-offs are generated by cost shocks and not by demand shocks, I model the monetary transmission mechanism from the central bank's instrument to the output gap in the simplest way possible. Specifically, let

$$x_t = x^I_t + v_t\,, \tag{2}$$

where v_t is a demand shock.

The model includes two primitive shocks: s, representing cost factors that generate inefficient inflation fluctuations for a given output gap and expectations of future inflation, and v, an aggregate demand disturbance. Each is assumed to be serially and mutually uncorrelated, and the central bank and price-setting firms must act before learning the actual realizations of the shocks. However, each firm receives an idiosyncratic private signal about s_t:

$$s_{j,t} = s_t + \phi_{j,t}\,.$$

The noise term, ϕ_j, is identically and independently distributed across firms. These signals are private in the sense that they are

7. In the case of common information, the appendix shows that equation (1) leads to the standard new Keynesian inflation adjustment relation.

unobserved by any other agent. The central bank receives private signals on the two disturbances:

$$s_{cb,t} = s_t + \phi_{cb,t} \text{ and}$$

$$v_{cb,t} = v_t + \xi_{cb}.$$

The noise terms, ϕ_{cb} and ξ_{cb}, are assumed to be independently distributed and to be independent of ϕ_j for all j and t. All stochastic variables are assumed to be normally distributed.[8]

I consider optimal policy in section 4. For now, I assume the central bank sets policy in a manner that would be optimal in the standard new Keynesian model if the central bank's objective is to minimize, under discretion, a standard quadratic loss function in inflation and the output gap. In this case, the optimal policy insulates x_t from any predictable demand shocks, while allowing the output gap and inflation to fluctuate in response to cost shocks. In particular, the central bank sets

$$x_t^I = \alpha E_t^{cb} s_t - E_t^{cb} v_t, \tag{3}$$

where $\alpha \le 0$. This implies an output gap target of $x_t^T = \alpha E_t^{cb} s_t$. Equation (1) implies that

$$\pi_t^T \equiv E_t^{cb}\pi_t = \Delta(1 + \alpha\kappa)E_t^{cb} s_t,$$

where $\Delta = (1 - \omega)(1 - \omega\beta)/\omega$. The parameter α characterizes the manner in which the central bank is willing to trade off inflation and output gap fluctuations. Thus, α governs the relative volatility of the central bank's targets for the output gap and inflation.

As equation (3) shows, observing the central bank's instrument imperfectly reveals the central bank's forecasts of demand and cost shocks. A rise in x^I could reflect the central bank's belief that a negative cost shock has occurred, or it could indicate that a negative demand shock has occurred. The actual realization of the output gap is

$$x_t = x_t^I + v_t = x_t^T + v_t - E_t^{cb} v_t.$$

8. Therefore, if E_t^{cb} denotes the expectations operator based on the central bank's information set at time t, then $E_t^{cb} s_t = \theta_s^{cb} s_t^{cb}$, where $\theta_s^{cb} = \sigma_s^2/(\sigma_s^2 + \sigma_{cb}^2)$ and σ_{cb}^2 is the variance of $\phi_{cb,t}$. Similarly, $E_t^{cb} v_t = \theta_v^{cb} v_t^{cb}$, where $\theta_v^{cb} = \sigma_v^2/(\sigma_v^2 + \sigma_\xi^2)$.

Price-setting behavior by firm *j* depends on four factors: the firm's expectations of what other firms are doing ($E_t^j \bar{\pi}_t^*$); what the firm thinks the central bank believes is the current cost shock, since that affects the firm's expectation of the output gap; the firm's expectation of future inflation; and the firm's expectation of the current cost shock. Thus, two new aspects of the decision are present that are missing from previous analysis. Not only must the firm form expectations about what other firms are expecting (as in Amato and Shin, 2003), but it must also form expectations about the central bank's output gap target, which implicitly involves forming expectations about the central bank's expectation of the cost shock (and implicitly, therefore, about what other firms are expecting that the central bank is expecting). Because firm *j* has private information on the cost shock, its expectation of *s* may differ from what it thinks the central bank's expectation is; that is, $E_t^j(E_t^{cb}s_t) \neq E_t^j s_t$. The problem is to guess what the central bank thinks, not simply to guess what the cost shock is. Moreover, the firm must be forward-looking in assessing future inflation.[9]

When the public can observe the central bank's instrument, but no announcements are made by the central bank, the relevant information set of firm *j* consists of its private signal, $s_{j,t}$, and the central bank's instrument setting, x_t^I. Given that the firm must assess the likely value of the output gap (since that is related to real marginal cost), observing x_t^I provides a noisy signal on x_t^T and therefore on x_t. It also provides information relevant for forecasting the cost shock itself. The informational content of this signal depends on the policy parameter α. This contrasts with Amato and Shin (2003) and Hellwig (2004), who model the public signal as exogenous. Here, the setting of the policy instrument is the public signal, and it depends on the policymaker's preferences.

Firm *j*'s expectations of s_t and x_t conditional on $s_{j,t}$ and x_t^I can be written as $E_t^j s_t = \Gamma_{11}s_{j,t} + \Gamma_{12}\, x_t^I$ and $E_t^j x_t = \Gamma_{21}s_{j,t} + \Gamma_{22}\, x_t^I$. In Morris and Shin, Amato and Shin, and Hellwig, the weights placed on private and public information in the individual firm's forecast are independent of any aspect of the central bank's policy decisions. This is not the case here, as the public signal is the central bank's instrument; $\Gamma_{i,j}$ generally depends on α. For example, if α is very small, then movements in x_t^I are due primarily to the central bank's attempt to offset demand

9. The presence of a signaling effect of policy will alter the central bank's incentives in setting policy; see Geraats (2002). In this and the next section, I ignore this by simply taking equation (3) as the description of policy. Section 4 considers optimal policy.

shocks. Private firms therefore place little weight on x_t^I in forming their expectations about the cost shock.

An equilibrium strategy for firm *j* is a linear function of its private signal and the policy instrument. This strategy is derived in the appendix. Aggregating over all adjusting firms and multiplying by $1 - \omega$ to obtain the aggregate inflation rate, equilibrium inflation can be written as

$$\pi_t = (1-\omega)\bar{\pi}_t^* = \gamma_1 s_t + \gamma_2 x_t^I \,. \tag{4}$$

The appendix shows that

$$\gamma_1 = (1-\omega)\left[\frac{(1-\omega\beta)(\Gamma_{11}+\kappa\Gamma_{21})}{1-(1-\omega)\Gamma_{11}}\right]$$

and

$$\gamma_2 = \frac{(1-\omega)(1-\omega\beta)\kappa\Gamma_{22}}{\omega} + \frac{(1-\omega)(1-\omega\beta)\Gamma_{12}}{\omega} + \frac{(1-\omega)^2\gamma_1\Gamma_{12}}{\omega} \,. \tag{5}$$

Equation (5) divides γ_2, the impact of the policy instrument on inflation, into three distinct terms, each of which represents a different channel through which the policy instrument affects inflation. The first term is the direct (and standard) effect of the instrument on the expected output gap and, therefore, on inflation. Because firms must set prices before they know the current level of production, it is the expected output gap that affects inflation.[10] A unit increase in x_t^I causes firms to expect a rise in the output gap of Γ_{22}, and the output gap elasticity of inflation is $(1 - \omega)(1 - \omega\beta)\kappa/\omega$. The second term arises when a change in the central bank's instrument leads firms to alter their own expectations of the cost shock. A rise in the instrument will be interpreted (partially) as indicating a negative cost shock ($\Gamma_{12} \leq 0$ because $\alpha \leq 0$). This tends to reduce inflation, partially offsetting the direct positive impact that a rise in xtI has on inflation. Finally, the third term captures the Morris-Shin effect. The public nature of the instrument causes the firm to alter not only its assessment of the cost shock, but also its expectations of what other firms expect.

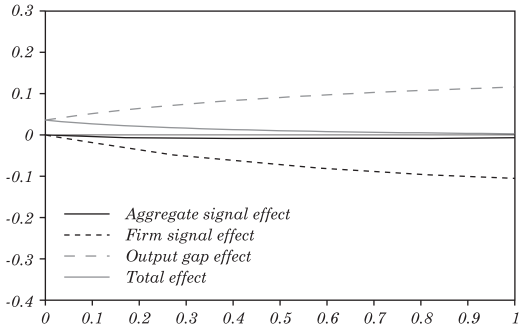
10. In the absence of demand shocks, $x_t^I = x_t$ and $\Gamma_{22} = 1$, so that $\gamma_2 = (1-\omega)(1-\omega\beta)\kappa/\omega$. One thus obtains the standard result in the literature that the output gap elasticity of inflation is $(1 - \omega)(1 - \omega\beta)\kappa/\omega$.

To assess the components of γ_2 and how they vary with the quality of private and public information, I numerically solve the model. To do so, I set $\omega = 0.5$, $\kappa = 2.0$, and $\beta = 0.99$. A value of 0.5 for ω is consistent with evidence on the frequency of price adjustment in the United States (Bils and Klenow, 2004). In microeconomic-founded models, κ is the sum of the coefficient of relative risk aversion and the inverse of the wage elasticity of labor supply. Values of one for each of these parameters are not uncommon, yielding $\kappa = 2.0$. The value chosen for the discount factor, β, is typical when dealing with quarterly data. In the standard common-information case, optimal policy under discretion would imply that $\alpha = -(\kappa\Delta)^2/[(\kappa\Delta)^2 + \lambda]$, so I use this value for α. For the variances of the different stochastic shocks, I set the variances of the cost and demand shocks equal to each other and normalize so that $\sigma_s^2 = \sigma_v^2 = 1$. Following Amato and Shin, I assume for the benchmark case that the private sector noise variance is equal to 0.2. While Amato and Shin assume the central bank has perfect information on the shocks, I assume the noise variances in the central bank's signals also equal 0.2, so for the baseline case, $\sigma_{\phi,j}^2 = \sigma_{\phi,cb}^2 = \sigma_\xi^2 = 0.2$.

Figure 1 illustrates how the quality of the private sector's information affects the net impact of the policy instrument on inflation. The curve labeled "total effect" gives the effect of a one-unit increase in the policy instrument on inflation as a function of the variance of the noise in the private signal on the cost shock. A rise in x_t^I that reflects a rise in x_t^T is associated with an increase in the output gap and would be expected to increase inflation. When $\sigma_{\phi,j}^2 = 0$, firms are able to observe the cost shock without error; observing the central bank's instrument setting conveys no further information about s_t. In this case, policy operates on inflation only through the standard direct effect on the output gap. As the quality of private information deteriorates, however, firms increasingly use x_t^I in forming expectations about the cost shock. The line labeled "firm signal effect" shows the impact on inflation when firm's alter their own expectations about the cost shock once they observe x_t^I (operating through the second term in equation (5)). Recall that x_t^I is decreasing in the central bank's signal on the cost shock. Firms interpret an increase in x_t^I as partly reflecting a decrease in the central bank's forecast of the cost shock. Firms, lower prices in anticipation of a negative cost shock. The direct output gap effect becomes larger for a parallel reason: changes in x_t^I generate larger changes in firms' expectations of the cost shock and, therefore, of the expected output gap.[11]

11. The firm signal effect and the output gap effect essentially cancel each other, because $\kappa\alpha \approx -1$ in the simulations.

Figure 1. The Quality of Private Sector Information and the Policy Instrument's Impact on Inflation[a]



Source: Author's computations.
a. The impact on inflation of a change in the central bank's policy instrument declines as the quality of the private sector's information falls.

The line in the figure labeled "aggregate signal effect" is the contribution of the Morris-Shin effect—the channel working through the firm's expectations of other firms' expectations. Consistent with Svensson's finding in the original Morris-Shin model, this effect contributes little to the overall impact on inflation of a change in the central bank's instrument.

By expressing x_t^I in terms of the underlying shocks, one can express aggregate inflation as

$$\pi_t = (\gamma_1 + \gamma_2 \alpha \theta_s^{cb}) s_t + \gamma_2 \alpha \theta_s^{cb} \phi_{cb,t} - \gamma_2 \theta_v^{cb} (v_t + \xi_t), \tag{6}$$

and the output gap as

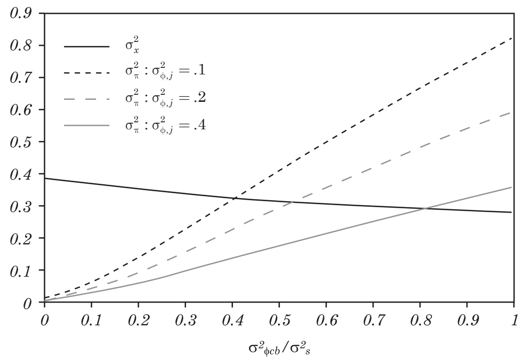
$$x_t = \alpha \theta_s^{cb} (s_t + \phi_{cb,t}) - (1 - \theta_v^{cb}) v_t - \theta_v^{cb} \xi_t . \tag{7}$$

If the central bank has complete information on the demand shock, so that $\xi_t \equiv 0$ and $\theta v^{cb} = 1$, the output gap is insulated from the demand shock. Nevertheless, demand shocks do affect inflation, because equation (6) contains the term $-\gamma_2 v_t$, arising from the effects of demand shocks on the central bank's instrument. If the central bank observes a positive v_t, it lowers x_t^I. Private firms interpret this fall in the policy instrument as reflecting the central bank's belief that the economy has experienced a positive cost shock. Individual firms that are adjusting their price then increase their estimate of the cost shock and believe that other firms will do the same. Lack of transparency about the central bank's estimate of demand shocks causes inflation to fluctuate in response to demand shocks, even though the central bank has prevented these shocks from affecting the output gap.

In the literature building on Morris and Shin, the precision of the central bank's announcements is often treated as a policy choice. While x_t^I is not an announcement but rather a policy action observed by all firms, its informational content is affected by the precision of the signals received by the central bank. Before examining the role of announcements, I explore the effects on output and inflation variability of more precise central bank information, in the form of a decline in the variance in the central bank's signal on either the cost shock or the demand shock. Morris and Shin argue that an increase in the precision of the public signal could lower welfare, essentially by making the economy more sensitive to public forecast errors. Amato and Shin (2003) find that the variance of the price level increases as the public signal becomes more accurate.

Figure 2 plots the variances of annualized inflation and the output gap as functions of the quality of the central bank's signal on the cost shock. Amato and Shin's result does not hold when the public signal is the central bank's instrument and the central bank's forecast of the cost shock becomes more accurate. As $\sigma^2_{\phi,cb}$ falls, so too does the variance of inflation. Because the central bank's forecast errors affect inflation, an improvement in the central bank's ability to forecast leads

Figure 2. The Accuracy of the Central Bank's Forecast and the Volatility of Inflation and the Output Gap[a]



Source: Author's computations.

a. As the central bank's forecast becomes less accurate, inflation becomes more volatile and the output gap becomes less volatile.

to more stable inflation. Inflation is also more stable if private sector information is less accurate (higher $\sigma^2_{\phi,j}$). When the quality of private information is low, private sector expectations—and thus the prices firms set—are less sensitive to private information. The volatility of the output gap does increase somewhat as $\sigma^2_{\phi,cb}$ falls. When the central bank can forecast more accurately, it responds more aggressively to its signal on the cost shock, leading to greater output gap movements.

Standard quadratic loss functions used to represent the objectives of monetary policy typically include both inflation and output gap volatility. Because more accurate central bank information makes the output gap more volatile while reducing the volatility of inflation, the net gain from the perspective of the central bank depends on the relative weight placed on these two objectives. Figure 2 suggests that only a central bank that placed little weight on its inflation objective would want less accurate forecasts.

3. Central Bank Announcements about Its Targets

While the impact of policy can depend on the informational content of the policy action, discussions of transparency generally focus on actions by the central bank that are designed explicitly to provide information. For example, the publication of the central bank's inflation or output forecasts or its announcement of short-run targets for inflation increase transparency. As noted earlier, a key objective of policymakers is to influence private sector expectations. The market, however, uses central bank announcements for two purposes. Private agents use announcements to better understand and forecast the intentions of the central bank, and they also try to infer from any announcement something about the central bank's assessment of the state of the economy. This means that errors in the central bank's assessment of the economy will infect private sector forecasts and expectations. This may introduce undesirable volatility into private sector expectations.

Suppose the central bank announces its target for the output gap.[12] Since the central bank's target for the output gap depends solely on its forecast of the cost shock, the announcement of x^T reveals $E_t^{cb}s_t$, and firms no longer need to infer the central bank's cost shock forecast from its instrument setting. The announcement of x_t^T does affect each firm's

12. As noted previously, this is equivalent to announcing an inflation target.

estimate of the cost shock itself, and it therefore also affects individual firm's beliefs about the actions that other firms will undertake. Firms can also use the observation of x^I and the announcement of x^T to infer the central bank's forecast of the demand disturbance.[13] However, this information is not relevant for their pricing decision (in the present model), since private forecasts of the output gap simply equal x_t^T.[14]

Intuitively, one would expect that announcing the target would improve economic outcomes. Since private firms are now able to distinguish between interest rate movements that are simply designed to offset demand disturbances from those reflecting the central bank's estimate of the cost shock, demand shocks will no longer cause fluctuations in the inflation rate. At the same time, releasing information on x_t^T in no way hampers the central bank's ability to achieve its output gap target. Greater transparency should thus improve welfare.

This intuition, however, is not necessarily correct, for reasons similar to those discussed by Morris and Shin. While greater transparency about the central bank's output gap target ensures that instrument changes designed to offset demand shocks no longer lead to fluctuations in inflation expectations, private sector expectations become more sensitive to the announced target than they were to the instrument. Consequently, the central bank's forecast errors in estimating the cost shock generate greater volatility in the inflation rate than they did prior to the introduction of announcements. If this channel dominates the reduction in volatility that occurs because demand shocks no longer affect inflation, loss can actually rise when targets are announced. Whether transparency reduces or increases loss depends on the quantitative characteristics of the economy.

When all firms observe x_t^T, equation (1) becomes (again, assuming serially uncorrelated shocks)

$$\pi^*_{j,t} = (1-\omega)E_t^j\overline{\pi}_t^* + (1-\omega\beta)(\kappa x_t^T + E_t^j s_t).$$

In this case, firm j no longer needs to infer the central bank's estimate of the cost shock. Instead, it must only assess what it

13. Recall that $x_t^T - x_t^I = E_t^{cb} v_t$. The information structure here differs from that employed in Geraats (2005), who studies a model in which the public is uncertain about the central bank's inflation target, as well as the underlying demand and supply shocks. Simply announcing an output gap target was not sufficient, in her model, to reveal the central bank's information about the underlying shocks.

14. This follows because $E_t^j x_t = E_t^j(x_t^I + v_t) = x_t^T + E_t^j(v_t - E_t^{cb} v_t) = x_t^T$.

believes the cost shock is and what it expects other adjusting firms will do. The announcement of the target output gap, which reveals the central bank's estimate of the cost shock, also provides information that the firm may wish to combine with its private signal in forming an estimate of s_t.

Let π_t^A denote the equilibrium inflation rate when x_t^T is announced. The appendix shows that

$$\pi_t^A = \bar{\gamma}_1 s_t + \bar{\gamma}_2 x_t^T = (\bar{\gamma}_1 + \alpha\bar{\gamma}_2\theta_s^{cb})s_t + \alpha\bar{\gamma}_2\theta_s^{cb}\phi_{cb,t}. \tag{8}$$

The output gap is given by

$$x_t = x_t^T + v_t - E^{cb}v_t = \alpha\theta_s^{cb}(s_t + \phi_{cb,t}) + (1 - \theta_v^{cb})v_t - \theta_v^{cb}\xi_{cb,t}. \tag{9}$$

Comparing these with equations (6) and (7) reveals that the behavior of the output gap is unaffected by the central bank's announcement. The announcement has no effect on the central bank's information set and therefore does not affect either the instrument choice or the behavior of the output gap. This follows from the assumption that the central bank directly controls the gap (up to a forecast error). Hence, the more interesting comparison is between equations (6) and (8).

Inflation is insulated from demand shocks when the central bank announces its output target. This does not necessarily mean, however, that inflation will be more stable. Because the information provided by the central bank is no longer contaminated by demand shocks, public expectations about the cost shock will respond more strongly to the announced value of x_t^T. As a consequence, $|\bar{\gamma}_2| > |\gamma_2|$, so that inflation is affected more by any errors the central bank makes in forecasting the cost shock; the coefficient on $\phi_{cb,t}$ is larger in absolute value in equation (8), the equilibrium expression for inflation with a target announcement, than it is in equation (6), the equilibrium inflation rate without announcements.

Table 1 shows the percent change in the variance of inflation that results from announcing the output gap target as a function of the noise variances in both the private and central bank signals on the cost shock. When private information is very accurate ($\sigma_{\phi,j}^2 = 0.1$), announcements cause inflation to become more variable unless the central bank's information is equally accurate. With private sector information quite precise, the central bank's instrument contains little useful information in the absence of the announcement of an output gap target, so γ_2 is very small. The central bank's forecast errors thus have little impact on inflation. When the target is announced, however, more weight is assigned to it, since it now provides direct information on the central bank's forecast of s_t. If central bank forecast errors have a large variance, inflation volatility increases.

Table 1. Effect of announcing x_t^T
Percent change in inflation variance

	$\sigma^2_{\phi,cb}$				
$\sigma^2_{\phi,j}$	*0.1*	*0.3*	*0.5*	*0.8*	*1.0*
0.1	−18.08	25.32	32.41	30.87	28.55
0.3	−40.95	−30.42	−17.07	−7.41	−4.23
0.5	−26.49	−41.50	−31.65	−21.48	−17.26
0.8	7.08	−41.47	−38.17	−29.98	−25.79
1.0	32.27	−37.06	−38.47	−32.18	−28.34

Source: Author's computations.

The other situation in which announcements can raise inflation variability occurs when the central bank has relatively precise forecasts of the cost shock, while private information is very noisy. When private information is poor, price-setting firms place a very large weight on the central bank's announcement, particularly if the central bank has accurate information. Even though $\sigma^2_{\phi,cb}$ is small, the announcement has such a large weight on private expectations that inflation becomes more volatile.

4. Partial Announcements

In the previous section, I assumed that everyone receives (and uses) the central bank's announcement about its output gap target. As noted in the introduction, however, central banks often release information through speeches and other public venues that reach a selective, rather than a universal, audience. Financial markets closely follow and monitor central bank announcements, but this is unlikely to be the case for the wider public audience. Central banks renowned for their transparency, such as the Bank of England, the Reserve Bank of New Zealand, or the Swedish Rijksbank, produce glossy publications that explain their policy framework and forecasts in great detail, yet the readership of these materials is unlikely to extend very far. Even though mass newspapers report on central bank policies and forecasts, I suspect that only the broad contours of policy reach the proverbial person on the street.

Using a framework similar to the Morris-Shin model, Cornand and Heinemann (2004) demonstrate that the partial release of information can be useful. The basic intuition for Cornand and Heinemann's result is straightforward. The wide release of public information serves to coordinate expectations, and this can make the economy sensitive to noise in the public information; this is the cost of announcements. The gain is that announcements provide information that helps the public form more accurate expectations. When the general announcement of the central bank's information may be costly, it may still pay to release information to some members of the public. If only a few agents receive the central bank's information, private sector expectations will, on average, be more accurate. Since only a few agents receive the information, however, it has little effect on the typical agent's expectations of what others are expecting.

To consider the partial release of information, suppose the central bank announces x_t^T in a manner such that only a fraction, P, of all firms receive the information.[15] As $P \rightarrow 1$, and all firms learn x_t^T, the effects of expected demand shocks on inflation are eliminated, but inflation becomes more responsive to $\phi_{cb,t}$. This may limit how widely the central bank wants to broadcast an announcement of x^T.

This creates three classes of firms in each period: those that do not receive an opportunity to adjust their price, those that do adjust but do not receive the central bank's announcement, and those that adjust and receive the announcements. Consider first the adjusting firms that receive information about x_t^T, corresponding to P. For these firms, their expectation of the current cost shock depends on their private information, $s_{j,t}$, and on the announced target output gap.[16] For the adjusting firms that do not observe x_t^T (corresponding to $1 - P$), expectations can be based only on private signals and the central bank's instrument. These firms must also forecast the central bank's output gap target. Firms that adjust prices in period t must form expectations about what other firms are expecting, and this now

15. This partial release of information can be interpreted in terms of the notion of rational inattention emphasized by Mankiw and Reis (2002): perhaps all firms observe the announcement, but only a fraction, P, actually incorporate the new information into their decisions. The assumption here is not that the central bank selectively provides information to some firms but not others; all firms have an equal probability of obtaining the information.

16. Given the assumptions about policy, the instrument x_t^I provides no relevant information once x_t^T is known. This follows because $x_t = x_t^T v_t - E_t^{cb} v_t$, and x_t^I provides no information about $v_t - E_t^{cb} v_t$. The equilibrium strategy of a firm that observes x_t^T depends on x_t^I, since the firm's expectations about what other firms expect must take into account the behavior of firms that do not observe x_t^T.

depends on the fraction of firms that receive information about the central bank's output gap target. The resulting equilibrium inflation rate with partial announcements, π_t^P, takes the form

$$\pi_t^P = \mu_s(P)s_t + \mu_I(P)x_t^I + \mu_T(P)x_t^T,$$

where the coefficients μ_j depend on P. These coefficients also depend on the policy rule followed by the central bank.

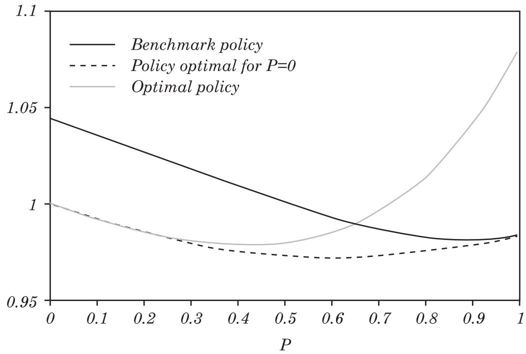
At this point, it is useful to assume a loss function that allows one to assess the effects of partial announcements and to derive optimal policy. I assume the central bank's objective is to minimize a standard quadratic loss function that depends on inflation variability and output gap variability.[17] Specifically, let loss be given by

$$L = \sigma_\pi^2 + \lambda\sigma_x^2, \tag{10}$$

where σ_i^2 denotes the variance of i. For the benchmark simulations, I set $\lambda = 1$ when the inflation rate is expressed at an annual rate.

The solid line in figure 3 shows loss as a function of P for the benchmark policy rule of equation (3). Loss is lower when $P = 1$ (complete announcements) than when $P = 0$ (no announcement), but not fully announcing the output target still generates a small gain. For this policy rule, the minimum loss occurs when $P = 0.9$.

Figure 3. Loss as a Function of *P* for Different Policy Rules



Source: Author's computations.
a. Loss is relative to the optimal policy with P = 0.

17. In section 5 I discuss how conclusions might be affected by using a loss function that is directly related to the welfare costs of fluctuations in the model. Hellwig (2004) provides a welfare-based analysis of the accuracy of public information.

While a policy rule of the form assumed in equation (3) is optimal in a standard new Keynesian model of monetary policy (under discretion), the standard framework assumes symmetric information on the part of firms and the central bank. The central bank's policy instrument thus plays no role in affecting expectations. When the policy instrument also conveys information about the central bank's assessment of the state of the economy, the central bank's incentives are altered. The central bank must now take into account the informational impact its policy choice has on private sector behavior. This incentive effect of information can distort policy. In the context of the model of the previous section, for example, the central bank may not fully adjust its instrument to offset demand shocks, since the movements in x^I necessary to do so would cause the private sector to alter their expectations about the cost shock. Greater transparency in the form of an explicit announcement about the central bank's output gap target would allow the central bank to fully offset demand shocks without affecting private sector expectations about the cost shock. Greater transparency thus improves policy flexibility.[18]

The desirability of announcements depends critically on the policy rule followed by the central bank. For example, suppose the central bank implements a policy rule of the form

$$x_t^I = \alpha_1 E_t^{cb} s_t^{cb} + \alpha_2 E_t^{cb} v_t^{cb}. \qquad (11)$$

This rule allows the central bank to let demand shocks affect the output gap target if $\alpha_2 \neq -1$. Suppose further that it chooses α_1 and α_2 to be optimal in the absence of announcements (that is, when $P = 0$).[19] Loss as a function of P with this policy rule is shown by the line labeled "policy optimal for $P = 0$." In this case, loss is lower when no announcements are made than it is with a complete announcement. The optimal P for this rule is 0.42; that is, the output gap target should be conveyed to less than half the private sector. Failure to adjust policy when announcements are made can lead to significant deterioration in loss, as illustrated by the large increase in loss for $P = 1$ when the policy that was optimal in the absence of announcements continues to be followed (see the dashed line). The

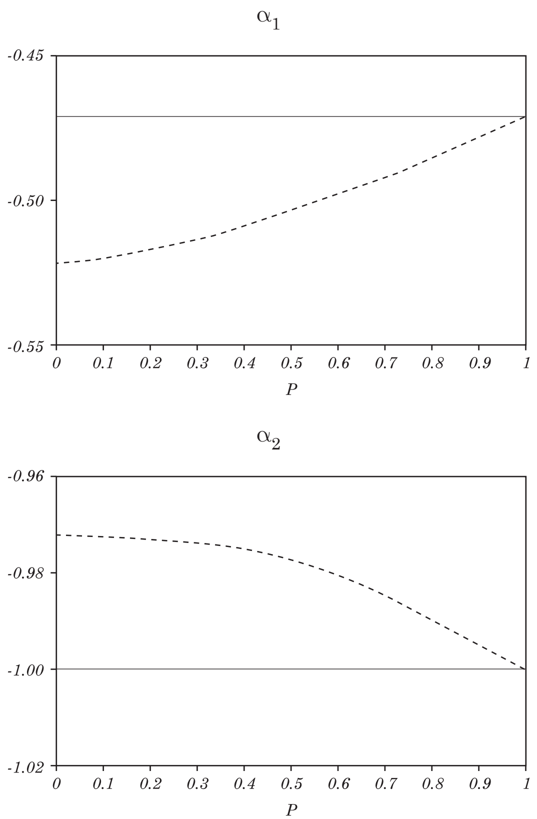
18. Walsh (1999) and Geraats (2005), among others, explore the incentive effect of announcements in different monetary policy contexts. See Geraats (2002) for further references.

19. For the benchmark parameter values, this involves $\alpha_1 = -0.5221$ and $\alpha_2 = -0.9726$.

line labeled "optimal policy" shows the relation between the extent of announcements and loss when policy adjusts to be optimal for each *P*. The lowest loss is now achieved with *P* = 0.6; the announcement of the output gap target should be made to reach most but not all firms.

Figure 4 shows how the policy coefficients vary with the extent of the announcement. The horizontal solid line in each panel shows the value of the coefficient for the standard optimal discretionary policy. The top panel shows that the central bank should react more strongly to a cost shock (α_1 is larger in absolute value) when the bank is less transparent (when P is smaller). The lower panel, in turn, shows that demand shocks should be fully offset in the standard case ($\alpha_2 = -1$).

Figure 4. Optimal Policy Coefficients as a Function of *P*



Source: Author's computations.

In contrast, the central bank's optimal response to its estimate of the demand shock is muted when $P < 1$. This reflects the incentive effect that arises when the central bank is not fully transparent (Geraats, 2002). This is easiest to understand when $P = 0$. Private agents observe only the policy instrument in this case, and they attempt to infer the central bank's cost shock estimate from the instrument. Reacting more strongly to demand shocks adds more noise to the signal provided to the private sector. Errors in the central bank's demand forecast influence inflation, and this also leads to a more muted response to $E_t^{cb}v_t$. As $P \to 1$, the central bank can adjust its policy instrument to fully offset demand shocks, since private agents are able to distinguish between movements in the instrument stemming from cost shocks and those stemming from demand shocks.

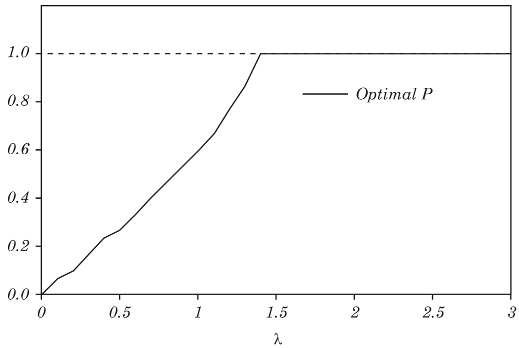
The discussion so far has held λ, the relative weight on the output gap objective in the loss function, fixed. A standard exercise is to vary this weight to map out an efficiency frontier that identifies the minimum inflation variance associated with a given output gap variance. By comparing this frontier for $P = 0$ and for $P = 1$, one can assess the effects of announcing the output gap target on the trade-off faced by the central bank. One can also examine how the frontier for the optimal P compares to the trade-offs for $P = 0$ and $P = 1$ for each λ.

Figure 5 shows the optimal P as a function of λ for the benchmark parameters.[20] Complete transparency ($P = 1$) is only optimal for central banks that place a large weight on output gap volatility relative to inflation volatility. With $P = 1$, the central bank can set $\alpha_2 = -1$; that is, it will completely insulate the output gap from any forecasted demand shock. The gain from setting $\alpha_2 = -1$ is larger for central banks that place a correspondingly large weight on stabilizing the output gap. However, if λ is small, so that the central bank cares primarily about inflation stability, then the optimal P is less than one. By setting $P < 1$, the central bank ensures that private firms do not overreact to its instrument or to the announcement. It will be optimal, in this case, not to fully offset demand shocks, but the resulting increase in output gap volatility leads to only a small impact on the loss function when λ is small.

For the benchmark value of $\sigma^2_{\phi,j}$, the critical value of λ at which it becomes optimal to fully announce targets decreases as the quality of the central bank's information about the cost shock rises. With more accurate information on the cost shock, the central bank is less concerned that its forecast errors will create excessive inflation

20. The values of λ are based on inflation being expressed at annual rates.

Figure 5. The Optimal Extent of Announcements as a Function of λ: $\sigma^2_{\phi,j} = \sigma^2_{\phi,cb} = 0.2$

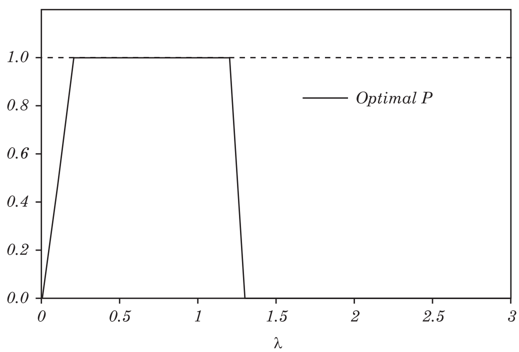


Source: Author's computations.

volatility. As suggested by table 1, however, if private information is very poor, announcements can increase inflation volatility and the optimal *P* will fall.

As discussed earlier, the benchmark calibration, in which the firm's private information and the central bank's information about the aggregate cost shock are equally noisy, may overstate the accuracy of the private information that an individual firm is likely to have about aggregate conditions. Figure 6 shows the effects of

Figure 6. The Optimal Extent of Announcements as a Function of λ: $\sigma^2_{\phi,j} = 0.4,\ \sigma^2_{\phi,cb} = 0.1$



Source: Author's computations.

instead assuming $\sigma^2_{\phi,j} = 0.4$ and $\sigma^2_{\phi,cb} = 0.1$. When the central bank has relatively more accurate information about any aggregate cost shock, then it is optimal to widely announce the output gap target as long as some weight (but not a large weight) is placed on output gap volatility in the loss function. The figure offers an interesting perspective on the rise of central bank transparency. If inflation-targeting central banks are viewed as focusing primarily on inflation objectives while still caring about output fluctuations, such that λ is small but still positive, they are most likely to find a policy of complete transparency to be optimal.

5. Lessons and Extensions

In this paper, I have investigated the role of transparency when private information is diverse and the central bank provides public information either implicitly, by setting its policy instrument, or explicitly, by making announcements about its short-run targets. In the absence of explicit announcements, the impact the policy instrument has on inflation depends critically on the information the instrument conveys to the public about the state of the economy. By announcing its short-run output gap target (equivalently, its short-run inflation target), the central bank reveals information on its forecast of demand and cost shocks. This provides more accurate public information to price-setting firms, but it also makes private sector decisions more sensitive to the central bank's forecast errors. As a result, inflation may become more volatile when the central bank announces its short-run target. For most combinations of the relative accuracy of private and central bank information, however, the net result of making announcements is to reduce inflation variability. When no announcement is made, the central bank will not fully neutralize the impact of demand shocks on the output gap and inflation. The signaling effect of policy actions constrains the central bank's response to its forecasts of demand shocks. By making announcements, the central bank can respond more flexibly and stabilize the output gap from demand disturbances.

Being transparent is seldom an all-or-nothing proposition. Partial announcements provide one means of investigating how widely central banks should disseminate information about their targets. If central banks have more accurate information about aggregate disturbances than private firms do (that is, $\sigma^2_{\phi,j} > \sigma^2_{\phi,cb}$), then inflation targeters should be very transparent (that is, $P = 1$). Only inflation nutters or central banks that place a large weight on output gap stability would find it optimal to make no announcements.

By assuming serially uncorrelated shocks, I was able to ignore the role of expectations about future inflation, considering only the case in which the private sector observes the central bank's current instrument setting, while some (or all) private firms may observe the current output gap target. The basic framework, however, can be used to consider the implications of announcements about future instrument values or targets. First, consider a situation in which the central bank announces its expected future output gap target.[21] If disturbances are serially uncorrelated, expected future targets and instruments would all equal zero, and their announcement would convey no further information to the public. Assume then that cost and demand shocks do display some degree of persistence. Unless the central bank has additional information that would help it forecast future innovations, the announcements of the future target conveys no additional information, once the current target is announced.

The Federal Reserve has, in recent years, phrased its press releases after FOMC meetings to give markets a strong signal about the likely future direction of interest rates. In terms of the present model, this can be interpreted as providing information about $x^I{}_{t+1} + 1$. Suppose the central bank announces its expected future instrument setting. In this case, the public obtains information on

$$x_t^I = \alpha_1 \theta_s^{cb} s_t^{cb} + \alpha_2 \theta_v^{cb} v_t^{cb} \text{ and}$$

$$E_t^{cb} x_{t+1}^I = \alpha_1 E_t^{cb} s_{t+1}^{cb} + \alpha_2 E_t^{cb} v_{t+1}^{cb}.$$

As long as cost and demand disturbances are characterized by differing degrees of serial correlation, the private sector is able to infer both central bank signals, s_t^{cb} and v_t^{cb}, from the announced information. Announcing the future path of the policy instrument thus represent an alternative to announcing the policy targets.

An important future extension of the analysis will be to examine the case of unobservable state variables. The estimation problem facing both the private sector and the central bank is greatly complicated when shocks are serially correlated and unobserved. Svensson and

21. This is equivalent in the present model to announcing a future inflation target.

Woodford (2004) consider the case of optimal policy with unobserved states and asymmetric information between the private sector and the central bank. As in the standard literature, however, they assume that all private sector information is common information, and they further assume that the private sector has full information about aggregate states.

While some of the effects of transparency could be assessed by examining the implications for inflation volatility, a loss function was required to determine the optimal extent to which information should be made public. I employed a standard quadratic loss function. This can be misleading, as Hellwig (2004) demonstrates, and it tends to undervalue the gains from transparency. The reason is based on the underlying distortion that makes inflation costly in new Keynesian models. The welfare costs of inflation are due to the increase in price dispersion across firms that inflation generates. When firms have private information, this introduces a new source of price dispersion and exacerbates the welfare costs of inflation. The central bank can reduce the extent of price dispersion by providing information that is common to all firms. This represents a welfare gain and increases the advantages of adopting a transparent policy regime. In terms of the model of partial announcements, employing an explicit welfare criterion is likely to increase the optimal degree of transparency.

Appendix

This appendix provides details of the model underlying the discussion in the text The probability that a firm does not have the opportunity to adjust its price is ω. The log price of firm i in period t is $p_{i,t}$, and p_t is the aggregate log price level. Denote by $p_{i,t}{}^*$ the price chosen by firm i if it adjusts its price in period t. Then,

$$p_t = (1-\omega)\bar{p}_t^* + \omega p_{t-1}\,, \tag{12}$$

where $\bar{p}_t^* = \int_0^1 p_{i,t}^* di$. Equation (12) implies that $\bar{p}_t^* - p_t = \omega(\bar{p}_t^* - p_{t-1})$ and

$$\pi_t = p_t - p_{t-1} = (1-\omega)(\bar{p}_t^* - p_{t-1}) = \left(\frac{1-\omega}{\omega}\right)(\bar{p}_t^* - p_t). \tag{13}$$

Let φ denote real marginal cost, and assume a steady-state inflation rate of zero. If firm j can adjust its price in the period, it sets its current price equal to the expected discounted value of current and future nominal marginal cost, φ + p. Future marginal cost is discounted by the probability that the firm has not received another opportunity to adjust ω and by the discount factor, β. In addition, I assume price is affected by a mean zero aggregate cost shock, s_t, that alters the firm's desired price. Hence,

$$p_{j,t}^* = (1-\omega\beta)\sum_{i=0}^{\infty}(\omega\beta)^i\,(E_t^j\varphi_{t+i} + E_t^j p_{t+i} + E_t^j s_{t+i}). \tag{14}$$

where E_t^j denotes the expectations based on the information available to firm j. The key assumption in equation (14) is that prior to setting its price, the firm does not observe the aggregate price level or the realization of either the current marginal cost or the cost shock.

Individual firms may set different prices because they base their expectations on different information sets. To simplify, I assume that all information is revealed at the end of each period. This implies that

$$E_t^j p_{j,t+1}^* = E_t^j \bar{p}_{t+1}^*\,.$$

Each firm expects that if it can adjust in t + 1, it will set the same price as other adjusting firms.

Using equation (13) and defining $\pi_{j,t}{}^* = p_{j,t}{}^* - p_{t-1}$ one obtains, after some manipulation,

$$\pi^*_{j,t} = (1-\omega)E^j_t\bar{\pi}^*_t + (1-\omega\beta)E^j_t\varphi_t + (1-\omega\beta)E^j_t s_t + \left(\frac{\omega\beta}{1-\omega}\right)E^j_t\pi_{t+1}, \qquad (15)$$

where $\bar{\pi}^*_t = \bar{p}^*_t - p_{t-1}$. Hence, firm j adjusts its price based on its expectations of what other adjusting firms are choosing ($E^j_t\bar{\pi}^*_t$), its expectations about current marginal costs and the cost shock, and its forecast of next-period aggregate inflation. Assume real marginal cost is linearly related to an output gap measure, x_t: $\varphi_t = \kappa x_t$. Then,

$$\pi^*_{j,t} = (1-\omega)E^j_t\bar{\pi}^*_t + (1-\omega\beta)\kappa E^j_t x_t + (1-\omega\beta)E^j_t s_t + \left(\frac{\omega\beta}{1-\omega}\right)E^j_t\pi_{t+1}. \qquad (16)$$

It is interesting to contrast this equation with the standard case in which all firms have identical information sets and are able to observe the current disturbances. In the standard Calvo model, $\pi^*_{j,t} = \bar{\pi}^*_t$ for all j, so equation (15) becomes

$$\pi^*_t = \left(\frac{1-\omega\beta}{\omega}\right)\kappa x_t + \left(\frac{1-\omega\beta}{\omega}\right)s_t + \left(\frac{\beta}{1-\omega}\right)E_t\pi_{t+1}.$$

Then, using equation (13), this becomes

$$\pi_t = (1-\omega)\pi^*_t = \left[\frac{(1-\omega)(1-\omega\beta)}{\omega}\right](\kappa x_t + s_t) + \beta E_t\pi_{t+1},$$

which differs from the standard from only in the coefficient on the cost shock. This is due to the fact that I include the shock in the equation for the firm's optimal price (equation 14), rather than just adding it on at the end.

No Announcements

In the absence of announcements, the information available to firm j is derived from its private signal, $s_{j,t}$, and from observing the policy instrument, x^I_t. These are related to the cost shock innovation and the output gap according to

$$\begin{bmatrix} s_t \\ x_t \end{bmatrix} = \begin{bmatrix} s_{j,t} \\ x^I_t \end{bmatrix} + \begin{bmatrix} \phi_{s,t} \\ v_t \end{bmatrix}.$$

Let $\Gamma = V_{ou}V_{oo}^{-1}$, where V_{ou} is the covariance matrix between the observed signals $[s_{j,t}, x^I_t]$ and the unobserved variables $[s_t, x_t]$ and

V_{oo} is the covariance matrix of the observed signals. Then, firm *j*'s expectation of $[s_t \; x_t]$ conditional on $s_{j,t}$ and x_t^I is

$$E_t^j \begin{bmatrix} s_t \\ x_t \end{bmatrix} = \Gamma \begin{bmatrix} s_{j,t} \\ x_t^I \end{bmatrix}.$$

Let $\Gamma_{i,j}$ denote the i,j^{th} element of Γ. Then $E_t^j s_t = \Gamma_{11} s_{j,t} + \Gamma_{12} x_t^I$, and $E_t^j x_j^T = \Gamma_{21} s_{j,t} + \Gamma_{22} x_t^I$. Generally, $\Gamma_{i,j}$ depends on the policy parameter, α (see equation (3)).

Firm *j*'s price setting is now given by

$$\begin{aligned} \pi_{j,t}^* = {} & (1-\omega) E_t^j \bar{\pi}_t^* + (1-\omega\beta)\kappa(\Gamma_{21} s_{j,t} + \Gamma_{22} x_t^I) \\ & + (1-\omega\beta)(\Gamma_{11} s_{j,t} + \Gamma_{12} x_t^I), \end{aligned} \tag{17}$$

where the assumption of serially uncorrelated shocks has been used to set $E_t^j \pi_{t+1} = 0$. An equilibrium strategy for firm *j* will take the form

$$\pi_{j,t}^* = \tilde{\gamma}_1 s_{j,t} + \tilde{\gamma}_2 x_t^I. \tag{18}$$

In forming expectations about the pricing behavior of other firms adjusting in the current period, firm *j*'s expectation of $\bar{\pi}_t^*$ is given by

$$E_t^j \bar{\pi}_t^* = \tilde{\gamma}_1 E_t^j s_{j,t} + \tilde{\gamma}_2 x_t^I = \tilde{\gamma}_1 \Gamma_{11} s_{j,t} + (\tilde{\gamma}_1 \Gamma_{12} + \tilde{\gamma}_2) x_t^I.$$

Substituting this into equation (17) yields

$$\begin{aligned} \pi_{j,t}^* = {} & \left[(1-\omega)\tilde{\gamma}_1 \Gamma_{11} + (1-\omega\beta)(\Gamma_{11} + \kappa\Gamma_{21})\right] s_{j,t} \\ & + \left[(1-\omega)(\tilde{\gamma}_1 \Gamma_{12} + \tilde{\gamma}_2) + (1-\omega\beta)(\Gamma_{12} + \kappa\Gamma_{22})\right] x_t^I. \end{aligned}$$

When I equate coefficients in this expression to those in equation (18), it follows that

$$\tilde{\gamma}_1 = \frac{(1-\omega\beta)(\Gamma_{11} + \kappa\Gamma_{21})}{1-(1-\omega)\Gamma_{11}} \text{ and}$$

$$\tilde{\gamma}_2 = \frac{(1-\omega)\tilde{\gamma}_1 \Gamma_{12} \, (1-\omega\beta)(\Gamma_{12} + \kappa\Gamma_{22})}{\omega}. \tag{19}$$

Aggregating over all adjusting firms yields equation (4) of the text:

$$\pi_t = (1-\omega)\bar{\pi}_t^* = \gamma_1 s_t + \gamma_2 x_t^I ,$$

where $\gamma_1 = (1-\omega)\tilde{\gamma}_1$ and $\gamma_2 = (1-\omega)\tilde{\gamma}_2$.

Announcements

When the central bank announces x_i^T,

$$E_t^j \begin{bmatrix} s_t \\ x_t \end{bmatrix} = \bar{\Gamma}_1 s_{j,t} + \bar{\Gamma}_2 x_t^T$$

where $\bar{\Gamma} = \bar{\mathbf{V}}_{ou}\bar{\mathbf{V}}_{oo}^{-1}$, in which $\bar{\mathbf{V}}_{oo}$ is the covariance matrix of the observed signals $[s_{j,t}, x_t^T]$, and is the covariance matrix between the observed and unobserved signals, s_t and x_t.

The equilibrium is derived following the same steps as in the previous section. Let $\bar{\Gamma}_{i,j}$ denote the j^{th} element of $\bar{\Gamma}_i$. Then equilibrium inflation is

$$\pi_t^A = \tilde{\gamma}_1 s_{j,t} + \tilde{\gamma}_2 x_t^T , \tag{20}$$

where

$$\tilde{\gamma}_1 = \frac{(1-\omega\beta)(\Gamma_{11} + \kappa\Gamma_{21})}{1-(1-\omega)\Gamma_{11}} \text{ and}$$

$$\tilde{\gamma}_2 = \frac{(1-\omega)\tilde{\gamma}_1\Gamma_{12}\,(1-\omega\beta)(\Gamma_{12} + \kappa)}{\omega}.$$

Partial Announcements

This subsection provides the solution in the general case of partial announcements and a policy that reacts to both cost and demand shocks. Specifically, assume

$$x_t^I = \alpha_1 E_t^{cb} s_t + \alpha_2 E_t^{cb} v_t ,$$

so that

$$x_t^T = \alpha_1 E_t^{cb} s_t + (1+\alpha_2) E_t^{cb} v_t .$$

In the previous sections, $\alpha_2 = -1$, so that the target gap was independent of the central bank's expected demand disturbance.

Consider first those adjusting firms that receive information about x_t^T (or π_t^T). There are a fraction, P, of such firms; let j index such firms. For these firms, $E_t^j s_t = H_1 s_{j,t} + H_2 x_t^T$ and $E_t^j x_t = x_t^T$. The pricing decision of such a firm satisfies

$$\pi_{j,t}^* = (1-\omega)E_t^j \bar{\pi}_t^* + (1-\omega\beta)\kappa x_t^T + (1-\omega\beta)(H_1 s_{j,t} + H_2 x_t^T). \tag{21}$$

Assume the equilibrium strategy for such a firm is

$$\pi_{j,t}^* = \alpha_1 s_{j,t} + \alpha_2 x_t^I + \alpha_3 x_t^T . \tag{22}$$

The instrument x_t^I appears because it provides information to firms observing x_t^T that is useful in assessing the expectations of firms that do not observe x_t^T.

For the $1 - P$ fraction of adjusting firms who do not observe x_t^T, expectations can be based only on private signals and the central bank's instrument. Let h index these firms. In addition, these firms must forecast both the cost shock and the output gap. Hence,

$$E_t^h s_t = \Gamma_{11} s_{j,t} + \Gamma_{12} x_t^I \text{, and}$$

$$E_t^h x_t = \Gamma_{21} x_{j,t} + \Gamma_{22} x_t^I .$$

The pricing decision of such a firm satisfies

$$\begin{aligned} \pi_{h,t}^* &= (1-\omega)E_t^h \bar{\pi}_t^* + (1-\omega\beta)\kappa(\Gamma_{21} s_{h,t} + \Gamma_{22} x_t^I) \\ &\quad + (1-\omega\beta)(\Gamma_{11} s_{h,t} + \Gamma_{12} x_t^I). \end{aligned} \tag{23}$$

Assume the equilibrium strategy for such a firm is

$$\pi_{h,t}^* = \alpha_1' s_{h,t} + \alpha_2' x_t^I . \tag{24}$$

Given the strategies of equations (22) and (24), for firms that observe x_t^T,

$$E_t^j \bar{\pi}_t^* = P(a_1 E_t^j s_t + a_2 x_t^I + a_3 x_t^T) + (1-P)(a_1' E_t^j s_t + a_2' x_t^I),$$

implying that

$$E_t^j \bar{\pi}_t^* = \left[Pa_1 + (1-P)a_1'\right]H_1 s_{j,t} + \left[Pa_2 + (1-P)a_2'\right]x_t^I$$
$$+ \left[Pa_1 H_2 + (1-P)a_1' H_2 + Pa_3\right]x_t^T.$$

Substituting this expression into equation (21) yields

$$\pi_{j,t}^* = (1-\omega)\left\{\left[Pa_1 + (1-P)a_1'\right]H_1 s_{j,t}\right\} + (1-\omega)\left[Pa_2 + (1-P)a_2'\right]x_t^I$$
$$+ (1-\omega)\left[Pa_1 H_2 + (1-P)a_1' H_2 + Pa_3\right]x_t^T$$
$$+ (1-\omega\beta)\kappa x_t^T + (1-\omega\beta)(H_1 s_{j,t} + H_2 x_t^T)$$
$$= \left\{(1-\omega)\left[Pa_1 + (1-P)a_1'\right]H_1 + (1-\omega\beta)H_1\right\}s_{j,t}$$
$$+ (1-\omega)\left[Pa_2 + (1-P)a_2'\right]x_t^I$$
$$+ \left\{(1-\omega)\left[Pa_1 H_2 + (1-P)a_1' H_2 + Pa_3\right] + (1-\omega\beta)(\kappa + H_2)\right\}x_t^T.$$

Equating coefficients with those in equation (22),

$$a_1 = (1-\omega)\left[Pa_1 + (1-P)a_1'\right]H_1 + (1-\omega\beta)H_1; \tag{25}$$

$$a_2 = (1-\omega)\left[Pa_2 + (1-P)a_2'\right]; \text{ and} \tag{26}$$

$$a_3 = (1-\omega)\left[Pa_1 H_2 + (1-P)a_1' H_2 + Pa_3\right] + (1-\omega\beta)(\kappa + H_2). \tag{27}$$

For firms that do not observe x_t^T,

$$E_t^h \bar{\pi}_t^* = P(a_1 E_t^h s_t + a_2 x_t^I + a_3 E_t^j x_t^T) + (1-P)(a_1' E_t^h s_t + a_2' x_t^I),$$

implying that

$$E_t^h \bar{\pi}_t^* = \left[Pa_1 \Gamma_{11} + (1-P)a_1' \Gamma_{11}\right]s_{h,t}$$
$$+ \left[Pa_1 \Gamma_{12} + (1-P)a_1' \Gamma_{12} + Pa_2 + (1-P)a_2'\right]x_t^I + Pa_3 E_t^h x_t^T.$$

For these firms, $E_t^h x_t^T = E_t^h x_t$. Hence,

$$E_t^h \bar{\pi}_t^* = \left[Pa_1 \Gamma_{11} + (1-P)a_1' \Gamma_{11} + Pa_3 \Gamma_{21}\right]s_{h,t}$$
$$+ \left[Pa_1 \Gamma_{12} + (1-P)a_1' \Gamma_{12} + Pa_2 + (1-P)a_2' + Pa_3 \Gamma_{22}\right]x_t^I.$$

Substituting this expression into equation (23) yields

$$E_t^h \bar{\pi}_t^* = (1-\omega)\left[Pa_1\Gamma_{11} + (1-P)a_1'\Gamma_{11} + Pa_3\Gamma_{21}\right]s_{h,t}$$
$$+(1-\omega)\left[Pa_1\Gamma_{12} + (1-P)a_1'\Gamma_{12} + Pa_2 + Pa_3\Gamma_{22}\right]x_t^I$$
$$+(1-\omega\beta)\kappa(\Gamma_{21}s_{h,t} + \Gamma_{22}x_t^I) + (1-\omega\beta)(\Gamma_{11}s_{h,t} + \Gamma_{12}x_t^I).$$

Equating coefficients with equation (24),

$$a_1' = (1-\omega)\left[Pa_1\Gamma_{11} + (1-P)a_1'\Gamma_{11} + Pa_3\Gamma_{21}\right] + (1-\omega\beta)(\kappa\Gamma_{21} + \Gamma_{11}); \quad (28)$$

$$a_2' = (1-\omega)\left[Pa_1\Gamma_{12} + (1-P)a_1'\Gamma_{12} + Pa_2 + (1-P)a_2' + Pa_3\Gamma_{22}\right] + (1-\omega\beta)(\kappa\Gamma_{22} + \Gamma_{12}). \quad (29)$$

Equations (25)–(27) and (28)–(29) can be solved jointly for $\alpha 1$, α_2, α_3, α'_1, and α'_2, and actual inflation is

$$\pi_t^P = (1-\omega)P(a_1 s_t + a_2 x_t^I + a_3 x_t^T) + (1-\omega)(1-P)(a_1' s_t + a_2' x_t^I)$$
$$= (1-\omega)\left\{\left[Pa_1 + (1-P)a_1'\right]s_t + \left[Pa_2 + (1-P)a_2'\right]x_t^I + Pa_3 x_t^T\right\}.$$

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