# Announcements and the Role of Policy Guidance

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**Abstract**

By providing guidance about future economic developments, central banks can affect private sector expectations and decisions. This can improve welfare by reducing the effects of asymmetric information and by leading to smaller forecast errors. But it can also magnify the impact of noise in the central bank's forecasts. I employ a model of heterogeneous information to compare outcomes under opaque and transparency policies. While *better* central bank information is always welfare improving, *more* central bank information may not be.

## 1 Introduction

Standard models used for monetary policy analysis typically assume private agents and the central bank share a common information set, yet actual policy decisions are taken in an environment in which asymmetric information is the norm and can play an important role in affecting the way policy affects the economy. Policy decisions depend on the central bank's objectives and on its view of the economy, and private agents may be uncertain about the former and hold different views about the latter. Transparency in the conduct of policy can help to reduce asymmetric information. Inflation targeting central banks, for example, invest significantly in attempting to reduce uncertainty about the objectives of policy, while the release by many

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central banks of detailed inflation and output projections can serve to ensure the public shares the central bank's information about future economy developments. By being transparency about its objectives and its outlook for the economy, central banks help provide the public with guidance about the future.

But providing guidance about the future carries with it risks. As Poole (2005) has expressed it,

> ...for me the issue is whether under normal and routine circumstances forward guidance will convey information or whether it will create additional uncertainty.

Since any forecast released by the central bank is subject to error, being more transparency may simply lead private agents to react to what was, in retrospect, just noise in the forecast. The possibility that the private sector may overreact to central bank announcements does capture a concern expressed by some policy makers. For example, in discussing the release of FOMC minutes, Janet Yellen expressed the view that "Financial markets could misinterpret and overreact to the minutes" (Yellen 2005).

In this paper, I explore the role of economic transparency – specifically, transparency about the central bank's assessment of future economic conditions – in altering the effectiveness of monetary policy. I do so in a framework in which central bank projections may convey useful information but may also introduce inefficient fluctuations into the economy.

A focus on economic transparency seems appropriate for understanding the issues facing central banks such as the Federal Reserve and the ECB. The recent concerns about the implications of the subprime mortgage market reflect, in part, private sector uncertainty about the Fed's view of the economic outlook and the way the outlook for inflation and real economic activity may be affected by financial market conditions. Very little of the debate focused on whether the Fed or the ECB were committed to low inflation. The uncertainty in financial markets in recent months and its implications for broader macroeconomic performance illustrates clearly the significant differences that can arise between the central bank and private market participants. This is a classic example of asymmetric information about the economy. Much of the debate has been focused on the question of future interest rate cuts, but the underlying issues appear to be chiefly related to differing views among private forecasters and between private forecasters and the Fed over the likely impact of financial market disturbances on the real economy and the likelihood of a future recession.

The next section discusses the two goals of transparency Bill Poole (2005) has stressed – accountability and policy effectiveness. Then, section 3 develops a model of asymmetric and heterogenous economic information that can be used to model the implications of two different levels of transparency. In the first, the public observes the central bank's instrument choice, but the central bank provides no further information to the public. In the second, the central bank releases its underlying information on disturbances expected to affect the economy. The welfare implications of these regimes are discussed in section 4. Within each regime, better quality central bank information is always welfare improving (the pro-transparency aspect of Morris and Shin 2002 emphasized by Svensson 2006). However, across regimes, more central bank information has ambiguous effects. Based on simulations of the calibrated model, a central bank with relatively poor quality information about the economy should announce its forecasts of economic shocks, while a central bank with high quality information about all the fundamental disturbances should be opaque. However, if the central bank has poor information on disturbances to the gap between output and the efficient level of output, it should always be transparent. Section 5 concludes.

## 2 The goals of transparency

Transparency requires asymmetric information, but the nature of this asymmetry can take many forms. In fact, Geraats (2002) has classified five types of transparency – political, procedural, economic, policy, and operational. Briefly, these correspond to transparency about objectives, about the internal decision making process, about the central bank's forecasts and models, about the central bank's communications about its policy actions, and about its instrument setting and control errors. Each of these dimensions of transparency are important and have been studied extensively (see Geraats 2002 for a survey),

In recent years, central banks have become more transparency along all these dimensions, and levels of transparency that would have been viewed as exceptional twenty years ago are today accepted as best practice among modern central banks. (Eijffinger and Geraats 2006, Dincer and Eichengreen 2007). The trend towards central bank independence with explicit mandates assigned to central banks and the wide-spread adoption of inflation targeting has contributed greatly to political transparency. The Bank of England is among the most procedurally transparent central banks, publishing minutes and individual votes of its Monetary Policy Committee discussions. Central banks such as the Federal Reserve that were formerly reluctant to communicate policy actions directly now do so clearly, timely, and directly. The most transparent central banks, such as the Bank of Norway, publish their projections for the policy interest rate. The use of a short-term interest rate as the instrument of policy has greatly enhanced operational transparency. But while most central banks today are transparency about their policy stance and operational procedures – something hard to avoid when using a short-term market interest rate as the instrument of policy – there is much greater variation in the extent to which central banks are transparency about their decision making process, their internal forecasts, and their policy objectives.

But what is the point of being transparent? As noted earlier, Poole has articulated two goals of transparency two goals of transparency: to meet the Fed's "responsibility to be politically accountable" and "to make monetary policy more effective." The next two subsections discuss each of these goals.

### 2.1 Transparency and accountability

Economic transparency is clearly important for accountability, though the role transparency plays in supporting accountability can differ depending on whether the ultimate objectives of monetary policy are observable or unobservable. For example, suppose the objectives of monetary policy are, ex post, clearly measurable and observable. For concreteness, assume inflation is the only objective of the central bank. And not only is there agreement about the importance of inflation, but there is also agreement on the appropriate measure of inflation that the central bank should control. In this environment, it is in principle straightforward to ensure accountability. Observing the ex post rate of inflation would provide a simple means for judging the performance of the central bank. However, even under the conditions specified (a single measurable objective), simply observing the ex post realization of inflation is not sufficient to serve as an effective performance measure. The reason is that inflation is not directly controllable – even under an optimal policy (so that the central bank is doing exactly what it should be doing), the realized inflation rate can differ from the desired value. This difference may be small, but as long as there is any random variation that is beyond the ability of the central bank to eliminate, public accountability based solely on inflation outcomes will punish some good central bankers and reward some lucky ones.

Transparency can help promote accountability by allowing the public to base its evaluation of the central bank not just on observed inflation but on the information that was available to the central bank when it had to make its policy decision. Having access to internal bank forecasts, for example, allows outsiders to evaluate the decisions made by the central bank. This can mitigate some of problems associated with evaluations based solely on realized inflation. Having access to the information on which decisions were based helps remove the influence of random uncontrollable events that affect inflation and therefore supports a better system of accountability.[1]

In general, however, policy objectives are not directly observable, and they may even be inherently unmeasurable. Certainly recent theoretical models, which have emphasized the use of the welfare of the representative agent as the appropriate objective of policy, have defined optimal policy in terms of unmeasurable objectives. It is not clear that we could reach agreement on the correct way to measure welfare, as that depends on the specific model we believe characterizes the economy, even if we could agree on how to define welfare. It certainly is not observable.

Transparency can be especially critical when objectives are unobserved. Assessing, or holding accountable, an economic agent when objectives are unobservable is not a situation unique to monetary policy and central banks. Perhaps the most prominent case in which public policy must deal with this situation is in the education field, where the objectives are high quality education and teaching but there exists wide disagreement over how to define and measure these qualities.

Since social welfare does depend on inflation, and inflation can be observed, one might use inflation as a type of performance measure, holding the central bank accountable for achieving a low and stable inflation rate. Inflation targeting can be thought of as defining such a performance measure for the central bank. The critical issue in choosing any performance measure, however, is how powerful one wants to make the incentives. If accountability is based strictly on realized inflation, and the consequences of missing the target are large, then the central bank will naturally focus on achieving the target even if this means sacrificing other, more difficult to measure, aspects of social welfare. The concern that inflation targeting produces too much of a focus on inflation control is at the heart of most criticisms of inflation targeting in the United States.

But this is where transparency becomes particularly important. Greater transparency can lessen the need to rely on a single easily measured performance indicator. When the public is able to assess the information about

[1] As Tim Harford pointed out in a recent "Dear Economist" column (*Financial Times,* 9/1/2007), it might seem sensible for an company to judge its ice cream sales force on total sales, but having information about the weather allows for a better assessment of the contribution of the sales team to actual sales.

the economy on which the central bank based policy decisions, it is no longer necessary to base accountability just on inflation outcomes. Less weight can be placed on inflation outcomes in evaluating the central bank (and holding it accountability) when there is greater transparency about what information the central bank had at the time it made its policy decisions (Walsh 1999).

## 2.2 Transparency and the effectiveness of monetary policy

Poole's second goal of transparency, promoting policy effectiveness, has received much greater attention recently than has the issue of accountability. Improving policy effectiveness through transparency requires that private sector decisions be influenced, and influenced systematically, by the information central banks provide. With the development of new Keynesian models and their emphasis on the importance of forward-looking behavior, managing expectations to improve policy effectiveness has taken on a new importance. Woodford (2005) has gone so far as to state that "For not only do expectations about policy matter, but, at least under current conditions, very little *else* matters."[2]

The intuition for Woodford's statement is straightforward – when agents are forward looking, current decisions depend on both current and expected future policy. Policy makers control directly only a short-term interest rate. Yet rational agents are forward looking and so base their spending and pricing decisions on their assessment of future interest rates, not just current rates. The recognition that expectations matter is not confined to academics; a recent article in the *Financial Times* states that "What really matters, both for the markets and the economy, is not the current policy rate but the expected path of future rates."[3]

Transparency and its relationship to policy effectiveness played a key role in a large literature within the context of the Barro-Gordon tradition, where the primary focus was on the average inflation rate bias that could arise under optimal discretionary policy. By and large, this literature focused on political and operational transparency, and it employed models in which policy surprises were the source of the real effects of monetary policy. Geraats (2002) provides an excellent survey of the literature.

In these models, the central bank's preferences were generally treated as stochastic and unknown. The policy instrument was also taken to be

[2] Italics in the original.

[3] "Debate unfolds on likely impact of cut in US interest rates" by Krishna Guha, *Financial Times*, September 6, 2007, p. 2.

observed with error or subject to a control error. For example, the central bank might control nonborrowed reserves but this allowed only imperfect control of the money supply.[4] This aspect was relevant when central banks employed a monetary aggregate as its instrument, but is not likely to be relevant when a nominal interest is the explicit instrument of monetary policy. Observing money growth would not provide enough information for the public to disentangle the effects of control errors from shifts in central bank preferences. Thus, there is opaqueness about political objectives and operational implementation. Transparency was typically modelled as a reduction in the noise in the signal on the policy instrument. The optimal degree of transparency balanced the gains from greater transparency in allowing the public to more quickly learn when the central bank's preferences had shifted against the cost in terms of stabilization as the ability of the central bank to create surprises is reduced with greater transparency. Cukierman and Meltzer (1986) show that the central bank may prefer to adopt a less efficient operating procedure than is technically feasible (i.e., not reduce the control error variance to its minimum possible level).[5]

As emphasized in recent discussions of transparency, however, new Keynesian models imply that it is predictable monetary policies, not surprises, that are most effective in achieving policy goals. In such an environment, transparency, rather than reducing the efficacy of policy can actually increase it. Announcements about future policy actions, or about the central bank's assessment of future economic developments, can affect private sector expectations of future interest rates, inflation, and economic activity. With spending and pricing decisions dependent on these expectations, using announcements to influence expectations gives the central bank an additional policy instrument. As such, it serves to make policy more effective. The argument that transparency can increase the effectiveness of monetary policy is certainly more consistent with the practice of central banks which has been uniformly to move in the direction of greater transparency.

But providing information to the public may have potential costs. These costs are associated with the conditional nature of any forecast. Some commentators[6] have worried that the public will not understand the distinction between a conditional and an unconditional forecast. Particularly when

[4] See, for example, Cukierman and Meltzer (1986) and Faust and Svensson (2002).

[5] See also Faust and Svensson (2002) who show that, when the choice of transparency is made under commitment, patient central banks with small inflation biases will prefer minimum transparency. They argue that this result might account for the (then) relatively low degree of transparency that characterized the U.S. Federal Reserve.

[6] Add references.

reputational considerations are important, deviating from a previously announced policy path may be interpreted by the public as a deviation from a commitment equilibrium rather than as an appropriate response based on new information. If a central bank fails to raise interest rates after signalling that it planned to, private agents may believe the bank has become less concerned about inflation, causing inflation expectations to rise. Financial market participants may underestimate the conditionality of the announced rate path and so view deviations as introducing unwarranted uncertainty into financial markets. These factors may make the central bank reluctant to adjust rates, producing a lock-in effect that would reduce flexibility and limit policy effectiveness.

Even when the public understands the conditional nature of the guidance provided by the central bank, announcements may introduce new sources of volatility. The influential paper by Morris and Shin (2002) has highlighted one channel through with central bank announcements may have a detrimental effect. Unlike standard models which assume all private agents share the same information, Morris and Shin focus on the case of heterogenous private information and in which each private agent must attempt to forecast what others are expecting. When private agents have individual sources of information, Morris and Shin have argued that there can be a cost to providing more accurate public information.[7] Agents may overreact to public information, making the economy more sensitive to any forecast errors in the public information.

Subsequent research (e.g., Hellwig 2004, Svensson 2006) has suggested that the Morris-Shin result is not a general one and that better, more accurate, central bank information is welfare improving.[8] However, just as the earlier literature on transparency employed models at odds with current policy frameworks (only surprises mattered, money supply was the instrument), the analysis of Morris and Shin is conducted within a framework that fails to capture important aspects of actual monetary policy. For example, the issue facing most central banks is not whether to provide more accurate forecasts. Instead, the issue is whether or not to announce forecasts. And even in the absence of explicit announcements or guidance, central banks already provide information through the setting of the policy instrument.

[7] Woodford (2003) has investigated the role of higher order expectations in inducing persistent adjustments to monetary shocks in the Lucas-Phelps islands model. See also Hellwig (2002).

[8] Svensson (2006) has argued 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. A similar result is found by Hellwig (2004).

When private agents observe a change in the central bank's instrument or receive announcements about the central bank's inflation forecast, they are obtaining public signals that depend on both the central bank's policy objectives and its assessment of economic conditions. The impact of a change in the policy instrument will depend, in part, on the information that it conveys about the central bank's views of the economy.

The work by Morris and Shin on heterogenous information and the quality of public information has been extended by Amato and Shin (2003) who cast the Morris-Shin analysis in a more standard macro model. In their model, the central bank has perfect information about the underlying shocks. This ignores the uncertainty policy makers themselves face in assessing the state of the economy. Nor do Amato and Shin allow the private sector to use observations on the policy instrument to draw inferences about the central bank's information. They also 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.

The potential costs and benefits of releasing central bank forecasts have been analyzed by Geraats (2005). However, she assumes also agents do not observe the bank's policy instrument prior to forming expectations and she employs a traditional Lucas supply function. Her focus is on reputational equilibria in a two-period model with a stochastic inflation target. Thus, the model and the issues addressed differ from the focus on the role of information in a Morris-Shin-like environment.

Rudebusch and Williams (2006) and Gosselin, Lotz, and Wyplosz (2007) both focus specifically on the provision of future interest rate projections. Rudebusch and Williams explore the role of interest rate projections in a model of political transparency – the asymmetry of information pertains to policy preferences and the central bank's inflation target. transparency is modeled as a reducing in the noise in the central bank's projection. In contrast to the model I develop, Rudebusch and Williams incorporate learning, finding that the public's ability to learn, and welfare, increase when interest rate projections are provided.

Gosselin, Lotz, and Wyplosz (2007) adopt a quite different approach and focus on what they characterize as creative opacity. In their model, the private sector learns from the information released by the central bank, but the central bank also learns about private sector information by observing long-term interest rates. By providing its projection for the short-term interest rate, the central bank is able to recover private sector information from the long-term rate. This aligns expectations but may require the central bank to distort its current interest rate setting to achieve the desired long-term rate. If the central bank's information is poor, it may be better to remain opaque. While the role of central bank learning is a critical one, I ignore it in the model of section 3 in order to focus on the why the provision of information by the central bank that is used by the private sector affects inflation and output.

Thus, several questions remain unresolved concerning the role of transparency within the context of an environment in which agents have heterogenous information and central bank actions and announcements constitute common information. Specially, how does the information conveyed by the central bank's instrument alter the effectiveness of policy? Current models often assume the instrument cannot be observed and therefore does not have direct information effects. What is the effect of more information as opposed to better information? And are concerns about the added uncertainty of greater transparency warranted? These question are addressed in the model of section 3.

#### 2.2.1 Anchoring versus steering

Accepting that expectations matter – even that very little else matters – does not fully articulate the lessons that should be drawn for the implementation of monetary policy. Expectations may be critically important but, if the central bank operates in a discretionary environment, it may be unable to effectively influence them. Alternatively, if credible commitments are possible, the central bank's set of potential instruments is vastly expanded since in can effectively influence expectations of inflation at all points in the future. Most central banks would probably view themselves as able to affect expectations to some degree but certainly lacking the degree of control availability in a commitment environment. However, central banks can only imperfectly manage expectations. And managing expectations can mean many things, so it is useful to distinguish between managing in the sense of *anchoring* expectations and managing in the sense of *steering* expectations.

The lessons of the 1970s and 1980s have been well learned by central banks. Allowing inflation to rise and, more critically, allowing the public to begin to expect high inflation, creates economic distortions and forces costly adjustments to bring inflation back down. Today, central bankers universally accept the importance of ensuring the economy has a nominal anchor, and the current anchor of choice is inflation targeting. Establishing a credible low inflation target serves to anchor private sector inflation expectations.

Achieving a stable rate of inflation requires that inflation expectations be consistent with the central bank's inflation target, so expectations must be anchored consistently with the medium term target. This can ensure long-run inflation remains under control, but it also opens the potential for the central bank to actively engage in short-run policies aimed at promoting real stability even if these policies produce short-run variation in inflation.

Despite agreement on the need for a nominal anchor, disagreement does exist over the appropriate anchor. When inflation rates in industrial economies were high, it was clear that bringing down inflation had to be the primary objective. Today, with inflation rates generally low, some[9] have argued that an anchor that allows for nonstationary drift in the price level is not really an anchor after all, and that central banks should focus on price level targeting.

Anchoring expectations should be distinguished from managing expectations as a means of increasing the effectiveness of monetary policy. The standard new Keynesian model, with its implication that current inflation depends on expected future inflation, has been one factor accounting for the stress on expectations management. As emphasized for example, by Woodford (2003), a central bank able to commit is able to improve the short–run output gap inflation volatility trade-off it faces by affecting expected future inflation. Within the context of that model, in the face of a positive cost shock, the central bank is able to limit the rise in inflation relative to target by engineering the expectation of a future decline in inflation below target. This more active role of expectations – using them essentially as an additional policy instrument might be best characterized as steering expectations to contrast it from anchoring expectations.[10]

There are potential concerns raised by the notion of steering. First, steering conjures up the image of actively adjusting policy to manage the economy. It therefore can become a modern guise for fine-tuning, though this may operate via the management of expectations rather than through the direct manipulation of current interest rates. As such, it is open to the inherent dangers of fine-tuning. Specifically, to usefully steer expectations, policy makers must understand the linkages between their actions and announcements and the actions taken by private agents. Thus, unlike the notion of anchoring expectations, policies based on steering expectations are likely to be very model dependent.

[9] Add references.

[10] As Woodford has expressed it, central banks need "to successfully steer private-sector expectations" (Woodford 2003, p. 45).

Setting aside the issue of whether central banks can successfully steer expectations, relatively little focus has been placed on quantifying the potential gains from such steering. One example of an attempt to do so is provided by the work of Dennis and Söderström (2006). They employ three small-scale estimated models to compare the results under optimal discretion and optimal commitment. Since commitment policies in forward looking models rely on the ability of the central bank to affect future expectations, this comparison provides some insights into the potential gains from steering expectations. Dennis and Söderström find that the gains from commitment can vary significantly, depending on the model, but they conclude that "for quite plausible, data-consistent, macroeconomic models, the welfare gains from precommitment can be large."

## 3 Welfare effects of opaqueness and transparency

As the earlier quotation from Poole notes, transparency by the central bank both conveys information and potentially creates additional uncertainty. One way in which this can happen has been highlighted by Morris and Shin (2002). They consider an model in which agents have private information and must forecast a fundamental disturbance. However, they must also attempt to forecast what others are forecasting. For example, a firm setting its price cares about its relative price, so it must forecast the prices being set by other firms. If common information is introduced – and an announcement by the central bank would represent common information available to all firms – Morris and Shin show that agents may overreact to this common information. If the central bank's information about the economy is subject to error, these errors can then introduce excessive volatility into expectations – Poole's "additional uncertainty."

While transparency may promote effectiveness but add uncertainty, new Keynesian models suggest a third factor that can be affected by the information the central bank provides. With stagged price adjustment, the welfare costs of inflation variability arise from the dispersion of relative prices it creates (Rotemberg and Woodford 1995, Woodford 2003a). Relative price dispersion is also generated if firms have asymmetric information. If the central bank provides information by making announcements, this information is available to all firms. Common information reduces the dispersion of relative prices by reducing the variation of private sector expectations. Essentially, the central bank's announcement serve as a focal point; when each firm combines this common information with their own private information, the result is to cause expectations to become more similar across firms. Of course this potential benefit will depend on the quality of the central bank's information and therefore on the accuracy of the information it announces.

A final additional factor – one discussed in the earlier literature on transparency but absent from much of the recent literature – is the role informational asymmetries can play in affecting the incentives faced by a policy maker operating in a discretionary environment. The incentive effects of information was a central theme in work on transparency within the context of Barro-Gordon models (see Geraats 2002). Under discretion, the incentives faced by the central bank is influenced by the information the policy maker releases to the public.[11]

### 3.1 The value of announcements

To investigate the role of economic transparency, I employ a simple model motivated by new Keynesian models based on Calvo-type pricing adjustment by monopolistic firms and by Morris and Shin's demonstration of the role asymmetric information can play.[12] Firms receive private signals on the fundamentals shocks affecting the economy. Each period, a fraction of firms adjust their prices. In doing so, they care about their relative price and so must attempt to forecast what other price-adjusting firms are doing. But this requires the individual firm to predict what other firms are predicting about the shocks hitting the economy. Hence, higher order expectations will matter, as in Morris and Shin.

Like Gosselin, Lotz, and Wyplosz, I assume the central bank's preferences are known. Unlike their model, however, I incorporate the common knowledge effect central to the Morris and Shin model. However, I focus on how private agents learn from the information provided by the central bank and ignore the reverse inference problem of the central bank inferring the private sector's information that is key to the model of Gosselin, Lotz, and Wyplosz.

The basic model is similar to the one employed in Walsh (2006, 2007a). In this earlier work, only demand and cost shocks were present, so it was only necessary to make a single projection (of inflation or the output gap) to fully reveal the central bank's information (since the public also observed

[11] In Walsh (2007b), I show that this incentive effect under discretion can make it socially optimal to appoint a Rogoff-conservative central banker, that is, a central banker who places less weight on output gap stabilization that society does.

[12] As noted earlier, in the basic Morris-Shin model, Svensson (2006) shows that for almost all parameter values, better central bank information is welfare improving.

the policy instrument). The primary focus was also on partial transparency in the sense of Cornand and Heinmann (2006). The chief contributions of the present paper are to enrich the information structure, to account fully for the welfare costs of relative price dispersion created by information heterogeneity, and to assess transparency in terms of both quantity (the role of providing more information) and quality( the effect of better information).

The central bank, like individual firms, is assumed to receive potentially noisy information on the fundamental economic shocks. I consider two policy regimes. In the first, the opaque regime and denoted by superscript $o$, the central bank makes no announcements. However, even in this regime, the central bank reveals something about its information when it sets its policy instrument. In the absence of other information, private agents combing the observation on the instrument with their own private information in forming expectations. A rise in the policy interest rate, for example, will be interpreted partially as reflecting the central bank's attempt to offset a projected positive demand shock and partially as a move to contract real out to offset a positive cost shock. Because the instrument conveys information, the central bank needs to take into account how the public will interpret its actions in setting its instrument.

The second regime corresponds to full transparency and is denoted by superscript $f$. In this regime, the central bank releases its information on the fundamental shocks. That is, rather than use its signals to form projections of inflation and the output gap and then publicizing these projections, the central bank simply releases the values of the signals. In this case, the actual setting of the instrument conveys no additional information. No information effects exist that could alter the incentives faced by the central bank. The benefits of this regime are that private sector forecasts are improved and, because there is more common information across firms, relative price dispersion is reduced. The potential costs is that central bank forecast errors affect inflation, and expectations can become more volatile.

A third potential regime is one in which the central bank releases inflation and output gap projections. However, from these projections and the value of the instrument setting, the public can infer relevant central bank signals in a rational expectations equilibrium. As the model will contain three fundamental shock on which the central bank receives noisy signals, the two projections plus the observed instrument setting will sufficient (in general) to reveal the central bank's private information. Thus, this regime would be the same as a regime of full transparency.

While I assume the central bank operates in a discretionary manner in setting its policy instrument, I assume it can commit to its regime (opaque or transparent).

### 3.2 The basic model

As is standard in optimal monetary policy models in which the policy instrument is an interest rate, the key constraint facing the central bank is provided by the Phillips curve linking inflation and real economic activity. To keep the model simple, therefore, I represent the demand side of the model in a very stylized, reduced form manner and instead focus on the nature of price adjustment and the informational structure that gives rise to a role for transparency.

The underlying model of price adjustment is based on Calvo, combined with the timing assumptions of Christiano, Eichenbaum, and Evans (2005) and the addition of firm-specific information. The Christiano, Eichenbaum, and Evans timing implies that firms who adjust their price for period $t$ do so based on $t-1$ information. Expressed alternatively, firms in period $t$ make decisions about their prices for period $t+1$. Because information differs across firms, price setting firms will not all set the same price as in the standard common information framework that is employed in most models. In addition, because firms care bout their relative price, they must forecast the aggregate $t+1$ price level when they set their individual price for that period. This also differs from standard specifications in which firms setting their price are assumed to know the aggregate equilibrium price level.

The basic timing is as follow:

1. At the end of period $t$, the central bank observes signals about $t+1$ shocks and sets its policy instrument $\theta_t$.

2. Firms observe $\pi_t$, $x_t$, and $\theta_t$ as well as individual specific signals about $t+1$ shocks. Firms may also observe announcements made by the central bank.

3. Those firms that can adjust their price set prices for $t+1$.

4. Period $t+1$ actual shocks occur and $\pi_{t+1}$ and $x_{t+1}$ are realized.

Three types of shocks are considered: 1) costs shocks that are firm specific and assumed to represent inefficient volatility in real marginal costs; 2) aggregate demand shocks; and 3) shocks to the gap between the economy's flexible price equilibrium output and its efficient level of output. These latter will be referred to as welfare gap shocks. Individual firms and the central bank receive noisy and private signals on each of these shocks. The model differs from standard new Keynesian models in that information is not common and firms must set prices before observing the current realizations of shocks.

A randomly choose fraction $1-\omega$ of firms optimally set their price for period $t+1$. If $\beta$ is the discount factor, one can show that (see Walsh 2007b)

$$\pi^*_{j,t+1} = (1-\omega)E^j_t\bar{\pi}^*_{t+1} + (1-\omega\beta)\kappa E^j_t x_{t+1} + (1-\omega\beta)E^j_t e^s_{t+1} + \left(\frac{\omega\beta}{1-\omega}\right)E^j_t \pi_{t+2}, \tag{1}$$

where $\pi^*_{j,t+1}$ is the log price firm $j$ sets for period $t+1$ relative to the period $t$ average log price level (i.e, $p^*_{j,t+1} - p_t$), $E^j_t\bar{\pi}^*_{t+1}$ is firm $j's$ expectation about the average $\pi^*_{i,t+1}$ being set by other adjusting firms, $E^j_t x_{t+1}$ is firm $j's$ expectation about the output gap in $t+1$, $e^s_{t+1}$ is the aggregate, common cost shock, and $E^j_t\pi_{t+2}$ is firm $j's$ expectation about future inflation. For simplicity, I assume (1) is linearized around a zero-inflation steady state.

Monetary policy is represented by the central bank's choice of an instrument $\theta_t$ and by any announcements the central bank might make. I assume the instrument setting is observed at the start of the period so that any firm that sets its price in period $t$ can condition its choice on the central bank's policy action. The output gap is then equal to

$$x_{t+1} = \theta_t + e^v_{t+1}, \tag{2}$$

where $e^v_{t+1}$ is a demand shock. While I will call $\theta_t$ the central bank's instrument, it essentially represents the central bank's intended output gap.

#### 3.2.1 Information

As noted, there are three fundamental disturbances in the model: $e^s_t$ representing cost factors that, for a given output gap and expectations of future inflation, generate inefficient inflation fluctuations; $e^v_t$, the aggregate demand disturbance; and $e^u_t$, a shock to the gap between the flexible-price output gap and the efficiency output gap. I assume each is serially correlated of the form

$$e^i_{t+1} = \rho_i e^i_t + \psi^i_{t+1}.$$

Firms in setting prices and the central bank in setting its policy instrument must act before learning the actual realizations of the aggregate shocks. Firm $j$'s idiosyncratic information $e^i_{j,t+1}$ for $i = s, v, u$ is related to the aggregate shock according to

$$e^i_{j,t+1} = e^i_{t+1} + \phi^i_{j,t+1},\ i = s,\ v,\ u.$$

The terms $\phi^i_{j,t+1}$are identically and independently distributed across firms and time. These signals are private in the sense that they are unobserved by other agents. For convenience, each $\phi^i_{j,t+1}$ will be referred to as a noise term, even though $\phi^s_{j,t+1}$ is actually the idiosyncratic component of the firm's cost shock. Further, assume all agents observe the actually realizations of the aggregate shocks at the end of each period. Define $\gamma^i_j = \sigma^2_i / \left(\sigma^2_i + \sigma^2_{i,j}\right)$, where $\sigma^2_i$ is the variance of $\psi^i$ and $\sigma^2_{i,j}$ is the variance of $\phi^i_j$. From the distributional assumptions about firms' information, $E^j_t e^i_{t+1} = \left(1 - \gamma^i_j\right) \rho_i e_t + \gamma^i_j e^i_{j,t+1}$.

In a similar manner, the central bank receives private signals on the three aggregate disturbances:

$$e^i_{cb,t} = e^i_{t+1} + \phi^i_{cb,t},\ i = s,\ v,\ u.$$

The noise terms $\phi^i_{cb}$ are assumed to be independently distributed and to be independent of $\phi^i_j$ for all $i$, $j$ and $t$. All stochastic variables are assumed to be normally distributed. The central bank is also assumed to observe the actually realizations of the aggregate shocks at the end of each period. Define $\gamma^i_{cb} = \sigma^2_i / \left(\sigma^2_i + \sigma^2_{i,cb}\right)$, where $\sigma^2_{i,cb}$ is the variance of $\phi^i_{cb}$. From the distributional assumptions about the central bank's information, $E^{cb}_t e^i_{t+1} = \left(1 - \gamma^i_{cb}\right) \rho_i e_t + \gamma^i_{cb} e^i_{cb,t+1}$.

The central bank's objective is to minimize, under discretion, a standard quadratic loss function that depends on inflation variability and output gap variability. Specifically, loss is given by

$$L^{cb}_t = E_t \sum_{i=0}^{\infty} \beta^i \left[\pi^2_{t+i} + \lambda_x \left(x_{t+i} - e^u_{t+i}\right)\right], \tag{3}$$

where $e^u_t$ is equal to stochastic variation in the gap between the flexible price gap ($x$) and the welfare-maximizing output gap.

Social loss, in contrast to (3), is affected by relative price dispersion, and this can arise from inflation (because of staggered price adjustment) and because of informational asymmetries across firms. Social loss is given by

$$L^{cb}_t = E_t \sum_{i=0}^{\infty} \beta^i \left[\pi^2_{t+i} + \lambda_I z_{t+i} + \lambda_x \left(x_{t+i} - e^u_{t+i}\right)\right], \tag{4}$$

where $z_t$ is relative price dispersion arising from asymmetric information across individual firms. If social loss is represented by a second order approximation to the welfare of the representative agent, inflation is costly because it is associated with a dispersion of relative prices (Woodford 2003a). This dispersion is affected if information differs across firms. It can be shown (see the appendix) that the variance of relative prices across firms depends on $\pi_t^2$ and on the noise in the signals received by individual firms, with the appropriate weight on this last source relative to $\pi_t^2$ given by

$$\lambda_I = \frac{(1-\omega)^2}{\omega}.$$

The loss associated with information dispersion can be reduced if the central bank provides more information. However, it is not affected by the period-by-period policy choice the central bank makes in setting its instrument (conditional on the policy regime that defines the type of announcements the central bank makes). This, under discretion, the central bank takes the term $z_t$ in (4) due to informational dispersion as given and minimized (3).

In regime $o$, firms observe their own private signals and the central bank's instrument. In regime $f$, the central bank provides its signals directly to the public. Alternatively, the central bank could announce its inflation and output gap forecasts; combined with the observed instrument setting, these announcements would fully reveal the central bank's signals.

Let $\Omega_{j,t+1}$ denote the vector of private signals received by firm $j$, and let $\Omega_{t+1} = \int \Omega_{j,t+1}$ be the information aggregated over firms. Let $\Omega_{cb,t+1}$ denote the innovation to the central bank's information set. Let $Z_t' = \begin{bmatrix} e_t^s & e_t^v & e_t^u \end{bmatrix}$ and $\psi_t' = \begin{bmatrix} \psi_t^s & \psi_t^v & \psi_t^u \end{bmatrix}$. Then we can write

$$Z_{t+1} = \rho Z_t + \psi_{t+1},$$

where $\rho$ now denotes the three by three matrix with diagonal elements $\rho_i$, and $E_t^{cb}\psi_{t+1} = \Gamma_{cb}\Omega_{cb,t+1}$, where

$$\Gamma_{cb} = \begin{bmatrix} \gamma_{cb}^s & 0 & 0 \\ 0 & \gamma_{cb}^v & 0 \\ 0 & 0 & \gamma_{cb}^u \end{bmatrix}.$$

We can now evaluate equilibrium under each of the policy regimes.

### 3.3 Equilibrium under the opaque regime

In the absence of central bank announcements, firm $j's$ new information is given by its private signals and the policy instrument. Let $\tilde{\theta}_t$ denote the value of $\theta_t$ unforecastable based on past information. Then new information available to firm $j$ consists of $\Omega_{j,t+1}$ and $\tilde{\theta}_t$. Assume beliefs about monetary policy are

$$\theta_t = D_1^o Z_t + D_2^o E_t^{cb} \psi_{t+1} = D_1^o Z_t + D_2^o \Gamma_{cb} \Omega_{cb,t+1},$$

where $D_1^o$ and $D_2^o$ are each $1 \times 3$. These beliefs are consistent with a rational expectations equilibrium under a discretionary monetary policy. Note that the new information in the policy instrument is $\tilde{\theta}_t = D_2 \Gamma_{cb} \Omega_{cb,t+1}$. In a standard model, one would have the central bank only responding to its forecasts of the underlying shocks; it would respond to $E_t^{cb} Z_{t+1} = \rho Z_t + \Gamma_{cb} \Omega_{cb,t+1}$, which would imply, for example, that the first element of $D_1^o$ would equal $\rho_s$ times the first element of $D_2^o$. However, certain equivalence does not hold in this model in the opaque regime.

Define $\Theta^o = \left[ \begin{array}{cc} \Theta_1^o & \Theta_2^o \end{array} \right]$ such that $\Theta_1^o$ is $3 \times 3$ and $\Theta_2^o$ is $3 \times 1$ where the $ij^{th}$ element of $\Theta_1^o$ gives the effect of the firm's $j^{th}$ signal on its forecast of the $i^{th}$ shock. Similarly, the $i^{th}$ element of $\Theta_2^o$ is the effect of $\tilde{\theta}_t$ on the firm's forecast of the $i^{th}$ shock. Because the firm's signals on the different shocks are uncorrelated, $\Theta_1^o$ would, in the absence of the observation of $\tilde{\theta}_t$, consist of a diagonal matrix with the signal to noise ratios along the diagonal. The off-diagonal elements of $\Theta_1^o$ can be non-zero when the firm combines its own information with $\tilde{\theta}_t$ to forecast the shocks. For example, suppose $\tilde{\theta}_t > 0$. This might indicate a response by the central bank to a negative demand shock, a negative cost shock, or a positive welfare gap shock. If the firm's signal on the demand shock is positive, then given $\tilde{\theta}_t$, this makes it less likely the central bank is reacting to a negative demand shock. The firm will therefore alter its forecast of cost and target shocks. Firm $j's$ expectation of $Z_{t+1}$ is

$$E_t^j Z_{t+1} = \rho Z_t + E_t^j \psi_{t+1} = \rho Z_t + \Theta_1^o \Omega_{j,t+1} + \Theta_2^o \tilde{\theta}_t.$$

The appendix shows that the equilibrium strategy for firm $j$ will take the form

$$\pi_{j,t+1}^* = a^o Z_t + b^o \Omega_{j,t+1} + b_\theta \tilde{\theta}_t, \tag{5}$$

where $a^o$ and $b_o$ are $1 \times 3$. Under both regimes, the expressions for the coefficients on $Z_t$ and $\Omega_{j,t+1}$ in the firm's equilibrium strategy take the same form, and the ones for $a^o$ and $b^o$ are given in the appendix.[13]

[13] Of course their values differ under the two regimes to the extent information available to firms differs.

Finally, the impact of the instrument on an individual firm's pricing decision is

$$b_\theta = \left(\frac{1-\omega\beta}{\omega}\right)\kappa + \left(\frac{1}{\omega}\right)\left[(1-\omega)b^o + (1-\omega\beta)\left(\iota_1+\kappa\iota_2\right)+\omega\beta a^o\right]\Theta_2^o, \quad (6)$$

where $\iota_i$ is a $3 \times 1$ vector of zeros with a one in the $i^{th}$ place.

Equation (6) illustrates the channels through which a policy action affects the pricing decisions of firms. The first term, $(1-\omega\beta)\kappa/\omega$ is the standard effect operating through the output gap. Since inflation is $(1-\omega)$ times the pricing decision of the individual firm in a standard new Keynesian model, the effect on aggregate inflation operating through this terms would be $(1-\omega)(1-\omega\beta)\kappa/\omega$, which is the normal coefficient on the output gap in a new Keynesian model based on Calvo pricing.

The remaining terms on the right side in (6) represent the informational effects of policy actions. For example, the effect of an expected cost shock operates through its direct impact on firm expectations about cost and demand shocks, the term $(1-\omega\beta)\left(\iota_1+\kappa\iota_2\right)$ and via its effect on individual pricing decisions through a firm's expectations of what other firms are expecting, the $(1-\omega)b_1^o$ term.

Equilibrium inflation is given by

$$\pi_{t+1} = (1-\omega)\bar{\pi}^*_{t+1} = (1-\omega)\left(a^o Z_t + b^o\Omega_{t+1} + b_\theta\tilde{\theta}_t\right) \quad (7)$$

and

$$\frac{\partial \pi_{t+1}}{\partial \tilde{\theta}_t} = (1-\omega)b_\theta.$$

The informational channels can significantly alter the impact of the central bank's instrument on inflation. I calibrate the model using standard values for the basic parameters ($\omega = 0.75$, $\beta = 0.99$, and $\kappa = 1.8$). These values imply $(1-\omega)(1-\omega\beta)\kappa/\omega = 0.1545$. The standard deviations of all shocks is set equal to one. Figure 1 shows how $(1-\omega)b_\theta$ varies with the quality of private sector information, as measured by the signal to noise ratio $\gamma_j^i$.[14] When firms have perfect information on the shocks, the policy instrument conveys no information, and the elasticity of inflation with respect to $\theta$ equals 0.1545. However, when $\theta$ also conveys information, its impact on inflation is significantly reduced. When private information is poor, movements in $\theta$ are partially attributed to the central bank's response to demand

[14] The figure is constructed for the case of serially uncorrelated disturbances and $\gamma_{cb}^i = 0.9$.

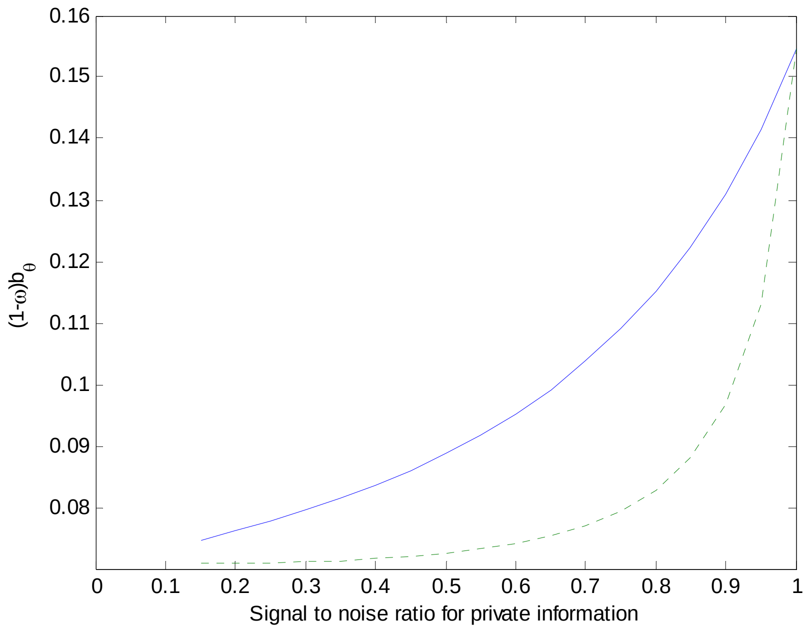


Figure 1: Elasticity of inflation with respect to the policy instrument in the opaque regime (solid line: $\gamma^i_{cb} = 0.5$, dotted line: $\gamma^i_{cb} = 0.9$)

shocks. A rise in $\theta$, for example, lowers firms' forecasts of demand shocks, so the net effect on the expected output gap, $\theta_t + E^j_t e^v_{t+1}$, and therefore the effect on price setting behavior and inflation, is less then the change in $\theta$. For a given quality of private sector information, the informational channel become more important as the central bank's information improves as private firms place more weight on the information conveyed by policy actions.

#### 3.3.1 Optimal discretionary policy in the opaque regime

Operating in a discretionary regime, the central bank sets policy optimally in each period as a function of $Z_t$ (if any shocks are serially correlated) and the current realizations of the signals it receives about the state of the economy. The first order condition for minimizing the expected value of the central bank's loss function (**??**) subject to (2) and (7) is given in the appendix. This first order condition can be solved for the optimal policy responses, and their values are also given in the appendix.

The solution to the model is obtained numerically by beginning with initial values for the policy coefficients, using these to obtain $\Theta^o$, $a^o$, $b^o$, and $b_\theta$, and then obtaining new policy coefficients from (8) - (13). This process continues until convergence. Once the equilibrium values of $a^o$, $b^o$, $b_\theta$ and the policy coefficients are obtained, aggregate inflation is given by

$$\pi_{t+1} = (1-\omega)\left[a^o Z_t + (b^o + b_\theta D_2 \Gamma_{cb})\,\psi_{t+1} + b_\theta D_2 \Gamma_{cb}\phi_{cb,t+1}\right],$$

while the welfare gap is

$$\begin{aligned} x_{t+1} - e^u_{t+1} &= \theta_t + e^v_{t+1} - e^u_{t+1} \\ &= D_1 Z_t + D_2 \Gamma_{cb} \Omega_{cb,t+1} + (\iota_2 - \iota_3)\left(\rho Z_t + \psi_{t+1}\right) \\ &= (D_1 + \iota_2\rho - i_3\rho)\, Z_t + (D_2 \Gamma_{cb} + \iota_2 - \iota_3)\,\psi_{t+1} + D_2 \Gamma_{cb}\phi_{cb,t+1}. \end{aligned}$$

## 3.4 Equilibrium with full transparency

I interpret full transparency as a regime in which the central bank shares its information on the economy. Within the context of the model, this would mean that the central bank publishes its signals on the various disturbances so that $\Omega_{cb,t+1}$ becomes known to all firms. In this case, the instrument no longer is a source of information to the private sector. This alters the impact of $\theta_t$ on inflation and so will affect the central bank's incentives in setting policy. When the central bank provides its information to the public, the central bank's information set is a subset of the public's information set. In this context, Svensson and Woodford (2002) have shown that certainly equivalence holds with respect to the central bank's policy problem. In particular, this implies that the optimal policy will be independent of the quality of either the central bank's information or the private sector's information.

Let $\Theta^f = \left[\begin{array}{cc} \Theta^f_1 & \Theta^f_2 \end{array}\right]$ be the appropriate $3 \times 6$ coefficient matrix such that

$$E^j_t \psi_{t+1} = \Theta^f_1 \Omega_{j,t+1} + \Theta^f_1 \Omega_{cb,t+1}.$$

The appendix shows that the equilibrium strategy for price setting firms takes the form

$$\pi^*_{j,t+1} = a^f Z_t + b^f \Omega_{j,t+1} + c^f \Omega_{cb,t+1} + h^f \theta_t.$$

where $a^f$ and $b^f$ take the same form as $a^o$ and $b^o$ (except with $\Theta^f_1$ replacing $\Theta^o_1$ in the expression for $b^f$, see the appendix). While the formulas for $a^f$

and $b^f$ are the same as for the opaque regime, the values of $b^o$ and $b^f$ will differ as $\Theta^f \neq \Theta^o$. The effect of the central bank's information is given by

$$c^f = \left(\frac{1}{\omega}\right)\left[(1-\omega)b + (1-\omega\beta)\left(\iota_1 + \kappa\iota_2\right) + \omega\beta a\right]\Theta_2^f,$$

and

$$h^f = \frac{(1-\omega\beta)}{\omega}\kappa.$$

Inflation will equal $(1-\omega)\bar{\pi}^*_{t+1}$, so

$$\frac{\partial \pi_{t+1}}{\partial \tilde{\theta}_t} = (1-\omega)h = \frac{(1-\omega)(1-\omega\beta)\kappa}{\omega}$$

and is independent on any informational effects. The optimal policy coefficients for this case, giving the policy response to each signal, are given in the appendix.

# 4 The value of releasing information

We can now compare the effects of providing information by comparing outcomes under the opaque regime and the transparent regime. To assess outcomes under the two regimes, the model is solved using calibrated parameters. For the structural parameters, I use standard values: $\beta = 0.99$, $\omega = 0.75$, $\sigma = 1$, $\eta = 0.8$. I set the variances of all shocks equal to 1. I also simply by assuming the shocks are serially uncorrelated. For the loss function, I set $\lambda_x = 1/16$, reflecting the use of quarterly inflation rates.

Table 1 shows the loss under each regime for different combinations of the signal to noise ratios for both the private sector and the central bank. The first thing to note is the loss is increasing in the quality of private sector information (moving across row from left to right) and decreasing in the quality of the central bank's information (comparing the top panel to the bottom panel). Better private information makes expectations more sensitive to signals and so increases the volatility of expectations and therefore inflation. This is welfare decreasing. Better central bank information is welfare improving because it allows the central bank to engage in more effective stabilization policies that reduce the volatility of inflation and the output welfare gap. While Morris and Shin (2002) suggest that improved common information could reduce welfare, the results in Table 1 are consistent with Hellwig (2004) and Svensson (2006) who argue that better central bank information generally improves welfare.

When $\gamma_j^i = 1$, firms observe the true shocks perfectly. In this case, the release of information or projections by the central bank is irrelevant and the loss is the same under both regimes.

Table 1: Loss under alternative regimes

| | | | $\gamma_{cb}^i = 0.5$ | | |
|---|---|---|---|---|---|
| $\gamma_j^i$ | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 |
| $o$ | 11.47 | 11.74 | 12.02 | 12.30 | 12.67 |
| $f$ | 11.25 | 11.43 | 11.67 | 12.05 | 12.67 |
| | | | $\gamma_{cb}^i = 0.9$ | | |
| $o$ | 2.31 | 2.59 | 2.89 | 3.20 | 3.48 |
| $f$ | 3.18 | 3.19 | 3.20 | 3.24 | 3.48 |

When central bank information is relatively poor (the signal and the noise have equal variances so that $\gamma_{cb}^i = 0.5$), the top panel of Table 1 suggest that the transparent regime dominates the opaque regime. The poor quality of the information means that it does not receive much weight in private sector expectations, particularly if private information is good. However, it does lead to some convergence of private sector expectations and this reduces relative price dispersion.

In addition, transparency allows the central bank to more efficiently neutralize the effects of expected demand shocks. This can be seen by comparing the policy reaction coefficients under the two regimes. These are shown in Table 2. Under regime $f$, expected demand shocks are completely offset (i.e., $d_2^v = -1$) regardless of the quality of private sector or central bank information. Under the opaque regime, $d_2^v = -1$ only when private agents have perfect information on the shocks. Otherwise, $d_2^o$ is less than one in absolute value and demand shocks are not fully offset.

Table 2: Optimal policy coefficients

| | $\gamma^i_{cb} = 0.5$ | | | | | |
|---|---|---|---|---|---|---|
| | $\gamma^i_j = 0.4$ | | | $\gamma^i_j = 0.8$ | | |
| | $\delta^s_2$ | $\delta^v_2$ | $\delta^u_2$ | $\delta^s_2$ | $\delta^v_2$ | $\delta^u_2$ |
| $o$ | −0.0339 | −0.9479 | 0.8868 | −0.0957 | −0.9792 | 0.8070 |
| $f$ | −0.1535 | −1.0000 | 0.7236 | −0.1535 | −1.0000 | 0.7236 |
| | $\gamma^i_{cb} = 0.9$ | | | | | |
| | $\delta^s_2$ | $\delta^v_2$ | $\delta^u_2$ | $\delta^s_2$ | $\delta^v_2$ | $\delta^u_2$ |
| $o$ | −0.0295 | −0.9536 | 0.9005 | −0.0727 | −0.9827 | 0.8518 |
| $f$ | −0.1535 | −1.0000 | 0.7236 | −0.1535 | −1.0000 | 0.7236 |

Under the opaque regime, the public will confuse movements in the instrument designed to offset forecasted demand shocks with movements associated with responds to either cost or welfare gap shocks. As a consequence, instrument moves aimed at offsetting demand shocks can affect inflation expectations and actual inflation to fluctuate as the public attributes part of the instrument chance as due to these other shocks. This makes it optimal to fail to fully move the instrument to offset demand shocks completely. Once the public can infer the central bank's estimate of demand shocks, as it can under regime $f$, there is no longer any reason not to fully react to insulate the output gap and inflation fully from projected demand shocks, so $\delta^v_2 = -1$ under regime $f$.

The policy rule in the case of full transparency is invariant with respect to the quality of either the central bank's information or the private sector's information. This result follows from the demonstration by Svensson and Woodford (2002) that the central bank's decision problem satisfies the conditions for certainty equivalence if the private sector has more information than the central bank. This is the case in regime $f$ since private agents know both the central bank's signals and their own private signals.

The results in Table 1 varied firms' and the central bank's signal to noise ratios, but it did not allow these to differ across the different shocks; information quality was assumed to be the same for each shock. Table 3 reports results for the case in which the central bank has good information on cost and demand shocks but poor information on welfare gap shocks. Transparency is optimal. Thus, poor information on the welfare gap shock, arguably the type of shock central banks are least likely to understand and to have good information on, raises the value of transparency. This is not true of other shocks. Decreasing the quality of central bank information on cost and demand shocks, setting the signal to noise ratio for the other two shocks to 0.9, does not increase the desirability of transparency.

The reason information on the welfare gap shock affects the alternative regimes differently than do the other two shocks is because, from the perspective of private firms, welfare gap shocks simply introduce noise into monetary policy. Information on cost shocks is relevant for firms as they have a direct interest in forecast shock disturbances and because they need to forecast what other firms are forecasting about these shocks. The same is true of demand shocks since they affect firms' forecasts of the output gap. When policy is opaque, policy responses to welfare gap shocks simple make it harder for firms to extract useful information from the central bank's instrument.

Table 3: Loss under alternative regimes

| | $\gamma^s_{cb} = \gamma^v_{cb} = 0.9$, $\gamma^u_{cb} = 0.5$ | | | | |
|---|---|---|---|---|---|
| $\gamma^i_j$ | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 |
| $o$ | 6.83 | 6.88 | 6.87 | 6.99 | 5.89 |
| $f$ | 5.59 | 5.60 | 5.61 | 5.65 | 5.89 |

To assess the way transparency may introduce uncertainty, one can examine how the volatility of inflation, the welfare gap, and relative price dispersion depend on the regime and the quality of information. The variance of inflation due to noise in the central bank's information is shown in figure 2. Figure 3 expresses this same component of the variance of inflation as a percent of total inflation variability. Results for the opaque regime are indicated with +, those for the transparent regime by ×. The solid (dashed) lines denote the case of low ($\gamma^i_{cb} = 0.5$) and high ($\gamma^i_{cb} = 0.9$) quality central bank information respectively.

Except when private information is very good, figure 2 shows that transparency increases the volatility of inflation due to noise in the central bank's forecasts. This reflects the concern expressed by policy makers that greater transparency can increase uncertainty and the normal result that more information typically increases the volatility of expectations. The impact of central bank noise increases as private sector information becomes better. To understand why this is the case, start with the situation in which private agents have perfect information on the shocks ($\gamma^i_j = 1$) and consider the central bank's response to a signal on a shock. In response this signal, $\theta_t$ is changed, and fully translates into a change in the expected output gap since firms do not alter their forecast of demand shocks. However, as the quality of private agents' information falls, the impact of a change in $\theta_t$ in

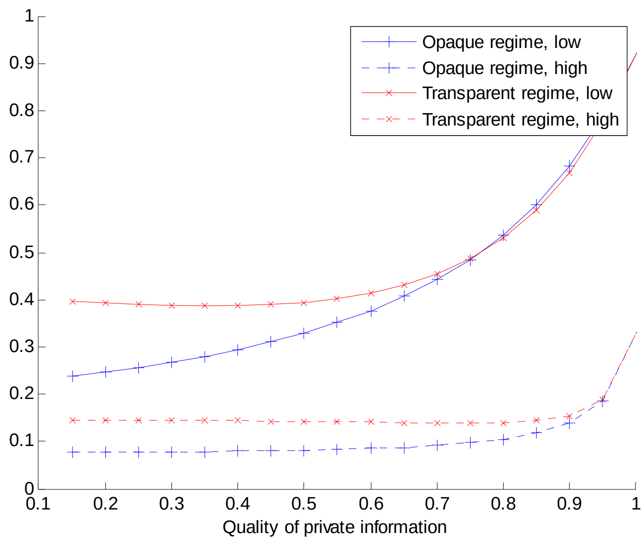


Figure 2: Variance of inflation due to central bank noise

the opaque regime falls (see figure 1) so the noise has a smaller impact on the expected output gap and inflation. Under the transparency regime, the impact of $\theta_t$ on the output gap and inflation is independent of information quality. However, as $\gamma_j^i$ falls, firms place more reliance on the central bank's announcements. A positive but noisy central bank signal on the cost shock, for example, leads the central bank to lower $\theta_t$ and causes firms to raise their forecast of the cost shock. This partially offsets the impact of $\theta_t$ on inflation, muting the consequences of the noise on inflation variability.

Under either regime when the central bank's information is poor, almost all of the variance of the welfare gap (not shown) is due to noise when the central bank's information is of poor quality, and almost none of the welfare gap variance is due to noise when the central bank's information is of high quality in the transparent regime.

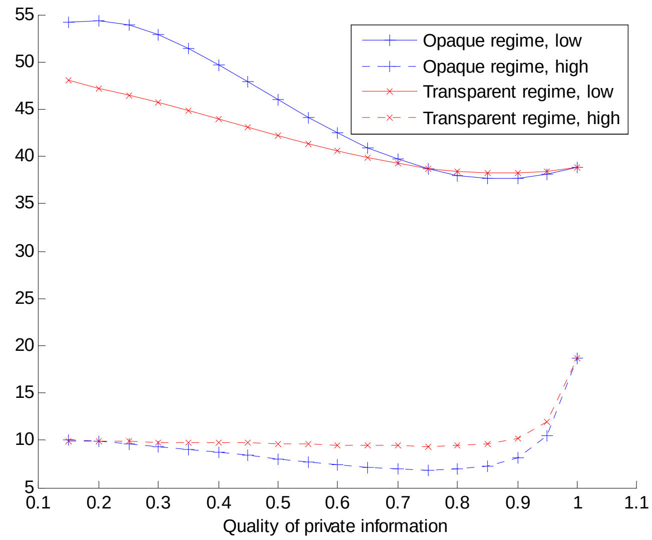


Figure 3: Inflation volatility due to central bank nosie as percent of total inflation variance

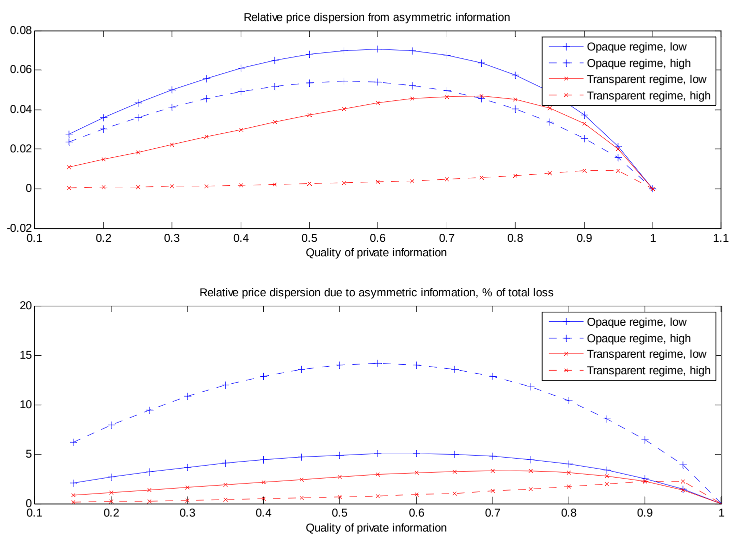


Figure 4: Relative price dispersion due to asymmetric information

In new Keynesian models, the welfare costs of inflation are due to the relative price dispersion that arises with staggered price adjustment. Heterogeneity in the information available to individual firms will also create relative price dispersion. Since information provided by the central bank is common information, it can help reduce relative price dispersion. The top panel of figure 4 shows the measure of relative price dispersion due to asymmetric information as a function of the quality of private sector information, while the bottom panel expressions the percentage contribution this makes to social loss. The solid lines correspond to the case of poor quality central bank information ($\gamma_{cb}^i = 0.5$) under the opaque regime (+) and the transparent regime ($\times$). The dashed lines show the case for high quality central bank information ($\gamma_{cb}^i = 0.9$).

When $\gamma_j^i = 1$, all firms share the same information, so dispersion due to heterogenous information goes to zero under either policy regime. However, relative price dispersion is increasing in $\gamma_j^i$ for low values of $\gamma_j^i$. When firms have very poor quality information, the level of informational heterogeneity is high, but because the information is of low quality, firms to not respond strongly to it. As information quality improves, firms do react more strongly to their own private information and this can increase the dispersion of prices.

Now consider the role of the quality of the central bank's information under the opaque regime. Relative price dispersion is lower when the central bank's information is good (top panel) than when it is poor, but this dispersion constitutes a larger fraction of total social loss (bottom panel). This is due to the better stabilization the central bank can achieve when it has better information on the economy. Not surprisingly, relative price dispersion is always lower under the corresponding transparency regime. For the same reason, better central bank information reduces relative price dispersion under the transparency regime.

## 5 Conclusions

In the traditional Barro and Gordon literature, Geraats (2002) discuss how the incentive effects of transparency can reduce the average inflation bias arising from discretion. I have focused on a model in which an average bias is absent, but policy incentives are still affected by the information provided to the public. Under complete transparency, private agents have access to the central bank's assessment of the economy. While firms still have heterogenous information, policy actions no longer provide any additional information and so the policy problem satisfies a form of certainty equivalence (Svensson and Woodford 2002). Optimal policy reactions to information about economic developments is independent of the quality of this information. Under an opaque policy regime, however, certainty equivalence does not hold, and the optimal policy responses to information will depend on the quality of both the central bank's information and the public's information. In a model of heterogeneous and asymmetric information, policy incentives are distorted under incomplete transparency.

Consistent with the work of Svensson (2006) and Hellwig (2004), better central bank information was found to improve welfare. In contrast, better private information reduced welfare. So while *better* central bank information is desirable, *more* central bank information may not be. When the central bank has very good information about future economic developments, providing that information can make expectations more volatile, particularly if firms have relatively poor information. However, transparency always acts to lower relative price dispersion across firms by expanding the set of common information.

When the central bank has relative good information about cost and demand shocks, but poor information about shocks to the welfare gap, guidance, in the forms of explicit provision by the central bank of its assessment of the economy, is likely to be desirable.

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## Appendix

**Welfare weight in information dispersion:** The weight on information dispersion: The costs of inflation variability in new Keynesian models arises from the inefficient dispersion of prices across firms that is generated. Let $p_{j,t}$ denote firm $j's$ price and let $\bar{P}_t$ be the aggregate price level. Then

$$\begin{aligned}\Delta_t &\equiv var_j\left(\log p_{j,t} - \bar{P}_{t-1}\right)\\ &= E_t\left(\log p_{j,t} - \bar{P}_{t-1}\right)^2 - \left(E_t \log p_{j,t} - \bar{P}_{t-1}\right)^2\\ &= E_t\left(\log p_{j,t} - \bar{P}_{t-1}\right)^2 - \left(\bar{P}_t - \bar{P}_{t-1}\right)^2.\end{aligned}$$

Using the assumptions of the Calvo model, the first term on the right can be written as

$$\omega E\left(\log p_{j,t-1} - \bar{P}_{t-1}\right)^2 + (1-\omega)E_t\left(\log p^*_{j,t} - \bar{P}_{t-1}\right)^2 = \omega\Delta_{t-1} + (1-\omega)E_t\left(\log p^*_{j,t} - \bar{P}_{t-1}\right)^2.$$

Now

$$\log p^*_{j,t} - \bar{P}_{t-1} = \log p^*_{j,t} - \log \bar{p}^*_t + \log \bar{p}^*_t - \bar{P}_{t-1},$$

where the first term on the right is zero in the standard new Keynesian model with common information across firms. Hence,

$$E_t\left(\log p^*_{j,t} - \bar{P}_{t-1}\right)^2 = E_t\left(\log p^*_{j,t} - \log \bar{p}^*_t\right)^2 + \left(\log \bar{p}^*_t - \bar{P}_{t-1}\right)^2$$

since the idiosyncratic noise is independence of the fundamental shocks. From the definition of inflation,

$$\pi_t = (1-\omega)\left(\log \bar{p}^*_t - \bar{P}_{t-1}\right),$$

so

$$E_t\left(\log p^*_{j,t} - \bar{P}_{t-1}\right)^2 = E_t\left(\log p^*_{j,t} - \log \bar{p}^*_t\right)^2 + \left(\frac{1}{1-\omega}\right)^2 \pi_t^2.$$

Combining these results,

$$\begin{aligned}\Delta_t &= \omega\Delta_{t-1} + (1-\omega)E_t\left(\log p^*_{j,t} - \log \bar{p}^*_t\right)^2 + \left(\frac{1}{1-\omega}\right)\pi_t^2 - \pi_t^2 \\ &= \omega\Delta_{t-1} + (1-\omega)E_t\left(\log p^*_{j,t} - \log \bar{p}^*_t\right)^2 + \left(\frac{\omega}{1-\omega}\right)\pi_t^2.\end{aligned}$$

It follows that

$$E_t\sum_{i=0}^{\infty}\beta^i\Delta_{t+i} = \left(\frac{\omega}{1-\omega}\right)\left(\frac{1}{1-\omega\beta}\right)E_t\sum_{i=0}^{\infty}\beta^i\left[\pi^2_{t+1} + \phi\left(\log p^*_{j,t+1} - \log \bar{p}^*_{t+1}\right)\right],$$

where $\phi = (1-\omega)^2/\omega$.

**The opaque regime**: Firm $j$'s price setting strategy is given by

$$\pi^*_{j,t+1} = (1-\omega)E^j_t\bar{\pi}^*_{t+1} + (1-\omega\beta)\kappa E^j_t x_{t+1} + (1-\omega\beta)E^j_t e^s_{t+1} + \left(\frac{\omega\beta}{1-\omega}\right)E^j_t\pi_{t+2}.$$

Let

$$\Sigma = \begin{bmatrix} \sigma^2_s & 0 & 0 \\ 0 & \sigma^2_v & 0 \\ 0 & 0 & \sigma^2_u \end{bmatrix},$$

$$\Sigma_j = \begin{bmatrix} \sigma^2_s + \sigma^2_{j,s} & 0 & 0 \\ 0 & \sigma^2_v + \sigma^2_{j,v} & 0 \\ 0 & 0 & \sigma^2_u + \sigma^2_{j,u} \end{bmatrix},$$

and

$$\Sigma_{cb} = \begin{bmatrix} \sigma^2_s + \sigma^2_{cb,s} & 0 & 0 \\ 0 & \sigma^2_v + \sigma^2_{cb,v} & 0 \\ 0 & 0 & \sigma^2_u + \sigma^2_{cb,u} \end{bmatrix}.$$

In the absence of central bank announcements, firm $j's$ new information is given by

$$\begin{bmatrix} \phi^s_{j,t+1} + \psi^s_{t+1} \\ \phi^v_{j,t+1} + \psi^v_{t+1} \\ \phi^u_{j,t+1} + \psi^u_{t+1} \\ \tilde{\theta}_t \end{bmatrix} = \begin{bmatrix} \Omega_{j,t+1} \\ \tilde{\theta}_t \end{bmatrix},$$

where $\tilde{\theta}_t$ is the new information contained in the instrument, $D_2\Gamma_{cb}\Omega_{cb,t+1}$. Define

$$\begin{aligned}\Theta^o &= \begin{bmatrix} \Sigma & \Sigma\Gamma'_{cb}D'_2 \end{bmatrix}\begin{bmatrix} \Sigma_j & \Sigma\Gamma'_{cb}D'_2 \\ D_2\Gamma_{cb}\Sigma & D_2\Gamma_{cb}\Sigma_{cb}\Gamma'_{cb}D'_2 \end{bmatrix}^{-1} \\ &= \begin{bmatrix} \Theta^o_1 & \Theta^o_2 \end{bmatrix},\end{aligned}$$

where $\Theta_1^o$ is $3 \times 3$ and $\Theta_2^o$ is $3 \times 1$. Thus, firm $j's$ expectation of $Z_{t+1}$ is

$$\begin{aligned} E_t^j Z_{t+1} &= \rho Z_t + E_t^j \psi_{t+1} \\ &= \rho Z_t + \Theta_1^o \Omega_{j,t+1} + \Theta_2^o \tilde{\theta}_t \\ &= \rho Z_t + \Theta_1^o \Omega_{j,t+1} + \Theta_2^o D_2 \Gamma_{cb} \Omega_{cb,t+1}. \end{aligned}$$

The aggregate information (i.e., aggregated over all firms) is

$$\begin{bmatrix} \Omega_{t+1} \\ \tilde{\theta}_t \end{bmatrix} = \begin{bmatrix} \psi_{t+1}^s \\ \psi_{t+1}^v \\ \psi_{t+1}^u \\ \tilde{\theta}_t \end{bmatrix}.$$

Defining $\iota_i$ as a $1 \times 3$ vector with a 1 in the $i^{th}$ place and zeros elsewhere, we can write a price-adjusting firms price change as

$$\begin{aligned} \pi_{j,t+1}^* &= (1-\omega) E_t^j \bar{\pi}_{t+1}^* + (1-\omega\beta)\kappa\theta_t + (1-\omega\beta)\left(\iota_1 + \kappa\iota_2\right) E_t^j Z_{t+1} + \left(\frac{\omega\beta}{1-\omega}\right) E_t^j \pi_{t+2} \\ &= (1-\omega) E_t^j \bar{\pi}_{t+1}^* + (1-\omega\beta)\kappa\left(\tilde{\theta}_t + D_1 Z_t\right) \\ &\quad + (1-\omega\beta)\left(\iota_1 + \kappa\iota_2\right)\left(\rho Z_t + \Theta_1^o \Omega_{j,t+1} + \Theta_2^o \tilde{\theta}_t\right) + \left(\frac{\omega\beta}{1-\omega}\right) E_t^j \pi_{t+2}. \end{aligned}$$

An equilibrium strategy for firm $j$ will take the form

$$\pi_{j,t+1}^* = a^o Z_t + b^o \Omega_{j,t+1} + b_\theta \tilde{\theta}_t,$$

where $a^o$ and $b_o$ are $1 \times 3$ and $\tilde{\theta}_t$ denotes the component of the instrument that was unforecastable based on $t-1$ information.

In forming expectations about the pricing behavior of other firms adjusting in the current period, firm $j$'s expectation of $\bar{\pi}_{t+1}^*$ is given by

$$\begin{aligned} E_t^j \bar{\pi}_{t+1}^* &= a^o Z_t + b^o E_{t+1}^j \Omega_{t+1} + b_\theta \tilde{\theta}_t \\ &= a^o Z_t + b^o E_{t+1}^j \psi_{t+1} + b_\theta \tilde{\theta}_t \\ &= a^o Z_t + b^o \left[\Theta_1^o \Omega_{j,t+1} + \Theta_2^o \tilde{\theta}_t\right] + b_\theta \tilde{\theta}_t \\ &= a^o Z_t + b^o \Theta_1^o \Omega_{j,t+1} + \left(b^o \Theta_2^o + b_\theta\right) \tilde{\theta}_t. \end{aligned}$$

Since

$$\pi_{t+1} = (1-\omega)\bar{\pi}_{t+1}^*,$$

it follows that

$$\begin{aligned} E_t^j \pi_{t+2} &= (1-\omega) E_t^j \bar{\pi}_{t+2}^* \\ &= (1-\omega) E_t^j \left[ a^o Z_{t+1} + b^o \Theta_1^o \Omega_{j,t+2} + (b^o \Theta_2^o + b_\theta) \tilde{\theta}_{t+1} \right] \\ &= (1-\omega) a^o E_t^j Z_{t+1} \\ &= (1-\omega) a^o \left( \rho Z_t + \Theta_1^o \Omega_{j,t+1} + \Theta_2^o \tilde{\theta}_t \right). \end{aligned}$$

Substituting these into the equation for $\pi_{j,t+1}^*$ and collecting terms,

$$\begin{aligned} \pi_{j,t+1}^* = \; & (1-\omega) a^o Z_t + (1-\omega\beta)(\iota_1 + \kappa \iota_2) \rho Z_t + \omega\beta a^o \rho Z_t + (1-\omega\beta)\kappa D_1 Z_t \\ & + (1-\omega) b^o \Theta_1^o \Omega_{j,t+1} + (1-\omega\beta)(\iota_1 + \kappa\iota_2) \Theta_1^o \Omega_{j,t+1} + \omega\beta a^o \Theta_1^o \Omega_{j,t+1} \\ & + (1-\omega\beta)\kappa \tilde{\theta}_t + (1-\omega)(b^o \Theta_2^o + b_\theta) \tilde{\theta}_t \\ & + (1-\omega\beta)(\iota_1 + \kappa\iota_2) \Theta_2^o \tilde{\theta}_t + \omega\beta a^o \Theta_2^o \tilde{\theta}_t. \end{aligned}$$

Equating coefficients with the proposed solution yields

$$a^o = \left( \frac{1-\omega\beta}{\omega} \right) \left[ \begin{array}{ccc} \rho_s + \kappa d_1^s & \kappa(\rho_v + d_1^v) & \kappa d_1^u \end{array} \right] (I_3 - \beta\rho)^{-1},$$

where $\rho$ is a $3 \times 3$ matrix with diagonal elements $\rho_i$, $i = s, v, u$, and

$$b^o = \left[ (1-\omega\beta)(\iota_1 + \kappa\iota_2) + \omega\beta a^o \right] \Theta_1^o \left[ I_3 - (1-\omega)\Theta_1^o \right]^{-1}.$$

The expression for $b_\theta^o$ is reported in the text.

The objective function under discretion involves minimizing

$$E_t^{cb} \left[ \pi_{t+1}^2 + \lambda_x \left( x_{t+i} - e_{t+1}^u \right)^2 \right]$$

subject to (2) and (7). Social loss is given by (4). The first order condition for the central bank decision problem under discretion is

$$(1-\omega) b_\theta E_t^{cb} \pi_{t+1} + \lambda_x \left( \theta_t + E_t^{cb} e_{t+1}^v - E_t^{cb} e_{t+1}^u \right) = 0.$$

From (7),

$$\begin{aligned} E_t^{cb} \pi_{t+1} &= (1-\omega) a^o Z_t + (1-\omega) b^o E_t^{cb} \Omega_{j,t+1} + (1-\omega) b_\theta \tilde{\theta}_t \\ &= (1-\omega) a^o Z_t + (1-\omega) b^o \Gamma_{cb} \Omega_{cb,t+1} + (1-\omega) b_\theta \tilde{\theta}_t \end{aligned}$$

since

$$E_t^{cb} \Omega_{j,t+1} = E_t^{cb} \psi_{t+1} = \Gamma_{cb} \Omega_{cb,t+1}.$$

Hence, the first order condition becomes

$$\begin{aligned}\lambda_x \theta_t + (1-\omega)^2 b_\theta^2 \tilde{\theta}_t &= (1-\omega) b_\theta E_t^{cb} e_{t+1}^u - (1-\omega)^2 b_\theta a^o Z_t \\ &\quad -(1-\omega)^2 b_\theta b^o \Gamma_{cb} \Omega_{cb,t+1} - \lambda_x E_t^{cb} e_{t+1}^v.\end{aligned}$$

This in turn implies that

$$\begin{aligned}\lambda_x D_1 Z_t + \left[\lambda_x + (1-\omega)^2 b_\theta^2\right] \tilde{\theta}_t &= -(1-\omega)^2 b_\theta \left[a^o Z_t + b^o \Gamma_{cb} \Omega_{cb,t+1}\right] \\ &\quad -\lambda_x \rho_v e_t^v + (1-\omega) b_\theta \rho_u e_t^u \\ &\quad + \begin{bmatrix} 0 & -\lambda_x & (1-\omega) b_\theta \end{bmatrix} \Gamma_{cb} \Omega_{cb,t+1},\end{aligned}$$

so

$$D_1 = \begin{bmatrix} 0 & -1 & (1-\omega)\left(\frac{b_\theta}{\lambda_x}\right) \end{bmatrix} \rho - (1-\omega)^2 \left(\frac{b_\theta}{\lambda_x}\right) a^o.$$

In terms of the individual coefficients,

$$d_1^s = -(1-\omega)^2 \left(\frac{b_\theta}{\lambda_x}\right) a_1^o \tag{8}$$

$$d_1^v = -\rho_v - (1-\omega)^2 \left(\frac{b_\theta}{\lambda_x}\right) a_2^o \tag{9}$$

$$d_1^u = \rho_u - (1-\omega)^2 \left(\frac{b_\theta}{\lambda_x}\right) a_3^o, \tag{10}$$

where $D_1 = \begin{bmatrix} d_1^s & d_1^v & d_1^u \end{bmatrix}$.

Finally,

$$\begin{aligned}\left[\lambda_x + (1-\omega)^2 b_\theta^2\right] \tilde{\theta}_t &= -(1-\omega)^2 b_\theta b^o \Gamma_{cb} \Omega_{cb,t+1} \\ &\quad + \begin{bmatrix} 0 & -\lambda_x & (1-\omega) b_\theta \end{bmatrix} \Gamma_{cb} \Omega_{cb,t+1},\end{aligned}$$

so

$$\tilde{\theta}_t = \left[\frac{\begin{bmatrix} 0 & -\lambda_x & (1-\omega) b_\theta \end{bmatrix} - (1-\omega)^2 b_\theta b^o}{\lambda_x + (1-\omega)^2 b_\theta^2}\right] \Gamma_{cb} \Omega_{cb,t+1}.$$

The individual coefficients are

$$d_2^s = -\left[\frac{(1-\omega)^2 b_\theta b_1^o}{\lambda_x + (1-\omega)^2 b_\theta^2}\right] \tag{11}$$

$$d_2^v = -\left[\frac{\lambda_x + (1-\omega)^2 b_\theta b_2^o}{\lambda_x + (1-\omega)^2 b_\theta^2}\right] \tag{12}$$

$$d_2^u = \left[\frac{\lambda_x - (1-\omega)^2 b_\theta b_2^o}{\lambda_x + (1-\omega)^2 b_\theta^2}\right], \tag{13}$$

where $D_2 = \left[\begin{array}{ccc} d_2^s & d_2^v & d_2^u \end{array}\right]$.

**Full transparency**: In regime $f$, the central bank announces its signals so that firms observe $\Omega_{cb,t+1}$ directly. Firm expectations now depend on $\Omega_{cb,t+1}$ and not directly on $\theta_t$.

Guess an equilibrium strategy of the form

$$\pi^*_{j,t+1} = a^f Z_t + b^f \Omega_{j,t+1} + c^f \Omega_{cb,t+1} + h^f \tilde{\theta}_t.$$

Then following the same procedures as used to solve the model without announcements, one finds that

$$a^f = \left(\frac{1-\omega\beta}{\omega}\right)\left[\left(\iota_1 + \kappa\iota_2\right)\rho + \kappa d_1\right]\left(I_3 - \beta\rho\right)^{-1}$$

$$b^f = \left[(1-\omega\beta)\left(\iota_1 + \kappa\iota_2\right) + \omega\beta a^f\right]\Theta_1^f\left[I_3 - (1-\omega)\Theta_1^f\right]^{-1}$$

$$c^f = \left(\frac{1}{\omega}\right)\left[(1-\omega)b + (1-\omega\beta)\left(\iota_1 + \kappa\iota_2\right) + \omega\beta a^f\right]\Theta_2^f.$$

$$h^f = \frac{(1-\omega\beta)}{\omega}\kappa.$$

Optimal policy in this regime satisfies the first order condition

$$(1-\omega)h^f E_t^{cb}\pi_{t+1} + \lambda_x\left(\tilde{\theta}_t + E\theta + E_t^{cb}e_{t+1}^v - E_t^{cb}e_{t+1}^u\right) = 0,$$

where $E\theta$ denotes the predictable part of policy. Note that

$$E_t^{cb}\pi_{t+1} = (1-\omega)\left[a^f Z_t + \left(b^f\Gamma_{cb} + c^f\right)\Omega_{cb,t+1} + h^f\tilde{\theta}_t\right]$$

since $E_t^{cb}\Omega_{j,t+1} = \Gamma_{cb}\Omega_{cb,t+1}$. Solving the first order condition yields

$$\theta_t = d_1 Z_t + d_2\Gamma_{cb}\Omega_{cb,t+1},$$

with

$$d_1^s = -\left[\frac{(1-\omega)^2 h^f}{\lambda_x}\right]a_1^f$$

$$d_1^v = -\rho_v - \left[\frac{(1-\omega)^2 h^f}{\lambda_x}\right]a_2^f$$

$$d_1^u = \rho_u - \left[\frac{(1-\omega)^2 h^f}{\lambda_x}\right] a_3^f$$

$$d_2^s = -(1-\omega)^2 h^f \left[\frac{(c_1^f/\gamma_{cb}^s) + b_1^f}{\lambda_x + \left(h^f\right)^2 (1-\omega)^2}\right]$$

$$d_2^v = -\left[\frac{\lambda_x + (1-\omega)^2 h^f \left[(c_2^f/\gamma_{cb}^v) + b_2^f\right]}{\lambda_x + \left(h^f\right)^2 (1-\omega)^2}\right]$$

$$d_2^u = \left[\frac{\lambda_x - (1-\omega)^2 h^f \left[(c_3^f/\gamma_{cb}^u) + b_3^f\right]}{\lambda_x + \left(h^f\right)^2 (1-\omega)^2}\right].$$