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A model of market surprises

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Abstract

This paper presents a theory to link improvements in transparency about monetary policy objectives to improvements in transparency about monetary policy actions and then to the conditional volatility of market expectations of policy rates. Crucially, policy announcements act not just as an instrument but also as a beacon that can potentially communicate information to agents about the policymakers' reactions to shocks. When the objectives of policymakers are not made transparent, agents are more likely to interpret any accommodation to price shocks as indicating that policymakers are following their own unobserved suboptimal objectives. Policymakers in these regimes are therefore less inclined to be transparent in their explanations. Conversely when policy objectives are more clearly defined, policymakers become more transparent in their explanations too. Then, the less markets will be surprised by interest rate announcements. I show that happens at a diminishing rate: as transparency is improved further from already high levels, there is less of a reduction in the variance of market surprises. The reason is that agents know that they can rely more on the monetary policy beacon in very transparent regimes. Hence they become more active in their decision-making and policymakers take that extra sensitivity into account. The model illustrates the gains to having clearly defined policy objectives. It also explains how a continued occurrence of market surprises, after an initial large reduction, could be consistent with the greater transparency and more precisely formed inflation expectations.

Summary

The bulk of evidence suggests that some combination of improvements in the monetary policy making institutions (more transparency, enhanced credibility and stronger accountability), consolidation in fiscal policy, a more benign international economic environment and technological improvements in the dissemination of data releases has reduced interest rate volatility in the United Kingdom in the 1990s. But it is difficult to isolate the role of transparency by itself in reducing interest rate volatility. Still, arguably, the incidence of market surprises is greater than one might expect given the extent of these improvements. Might this be because transparency affects surprises differently when it has improved from low levels than when further improvements are made at high levels of transparency? To help answer this question, this paper presents a theory to link improvements in transparency to how well financial markets predict policy rates.

In the paper, policymakers may have a different interpretation to private agents as to what an economic shock means for interest rates, even though data is commonly available. There is then a role for policy announcements (both the interest rate decision and the surrounding explanations) to act as a beacon communicating information to agents about the policymakers' preferences. Policymakers take account of this feature when they determine first, how to set interest rates and second, in choosing how transparent they want to be in explaining that decision.

What determines how transparent policymakers want to be with their explanations? The paper shows that policymakers are more likely to be transparent in their explanations if they follow a transparent objective. The paper describes an improvement from a bad regime where policymakers are allowed to follow their own secret, unpredictable inflation objective to a good regime where the inflation target is publicly known and fixed. Policymakers in bad regimes will be inclined to also be less transparent in explaining their actions while policymakers in good regimes have a strong incentive to be transparent about their explanations.

Improving transparency in objectives typically lowers the volatility of market interest rates and implies less market surprises. But the paper also shows that this happens at a decreasing rate; improvements in transparency from already high levels have less effect on reducing the likelihood of market surprises than when transparency is improved from very low levels. At high levels of

transparency, agents rely more on the cleaner signal and this results in greater sensitivity of agents' expectations. This feeds back onto interest rates offsetting the effects of greater transparency. In general, though, improving transparency leads to more precisely formed inflation expectations. In this sense greater transparency is good for welfare.

1 Introduction

The bulk of evidence suggests that some combination of improvements in the monetary policy making institutions (more transparency, enhanced credibility and stronger accountability), consolidation in fiscal policy, and a more benign international economic environment has reduced interest rate volatility in the United Kingdom in the 1990s.[1] And technological improvements mean that data releases are ever more rapidly disseminated and more evenly distributed to market participants and policymakers alike. These changes would suggest that interest rate surprises, the extent to which market interest rates fail to predict monetary policy, should have become much less likely.

Haldane and Read (2000) were among the first to examine whether an improvement in the monetary framework made a difference. They compared the pre and post-Bank of England independence (6 May 1997) regimes using market interest rate data. Working with data from 1984 to 1997, they found that around 40%-50% of any change in UK official interest rates has been a surprise at the short end of the yield curve, and about 15% of any change was a surprise at the long end. But a dummy put in to separate out data since independence was significant at shorter maturities, suggesting that the effect of the new regime was to reduce the volatility of short-run surprises in financial data.

Since then more evidence on the recent UK experience has accumulated from a set of studies that have used high frequency data to compare the volatility of interest rate surprises around announcement days to when there was no announcement, the idea being to isolate the incidence of surprises from other reasons why volatility has fallen over the 1990s.[2] Clare and Courtenay (2001) compared the volatility of reactions of short sterling and long gilt contracts pre and post-independence to monetary policy announcements (interest rate announcements and publication of the MPC *Minutes*) using data from January 1994 up to June 1999. They compared volatilities on announcement days relative to non-announcements, and thus adjusted for shifts in

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(1) See Geraats (2002) for a summary of the evidence on improved transparency in the 1990s. Benati (2004) presents evidence on the fall in volatility of shocks hitting GDP deflator inflation and real GDP and Lildholdt and Vila Wetherilt (2004) estimate the breakpoint in lower interest rate volatility in the 1990s.
(2) For examples of studies on the US see Kuttner (2000); Moore and Austin (2002); Faust, Swanson and Wright (2004); Poole, Rasche and Thornton (2002); Bernanke and Kuttner (2003); Goldberg and Leonard (2003); Lange, Sack and Whitesell (2003); and Swanson (2004). Perez-Quiros and Sicilia (2002) study the euro area. Coppel and Connolly (2003) discuss the Australian experience and Parent (2003); Siklos (2003) and Moessner, Gravelle and Sinclair (2004) tackle the Canadian experience for example.

the underlying volatility over the years. Their key finding was that after about ten minutes, the volatility — when measured by mean absolute returns — is less post-independence compared to pre-independence, although not significantly so.[3]

Moessner *et al* (2004) matched the reactions of short sterling and long spot gilts (at two, five and ten year maturities) to interest rate changes from January 1993 to August 2000. They did find that the reaction of both short sterling and long-term gilts to interest rate changes was less following independence at all maturities, but again not significantly so.

Lasaosa's (2005) work took the data set up to June 2001. As with Clare and Courtenay, she measured the excess volatility of announcement days compared to non-announcement days, and test for differences pre and post-independence. But like Moessner *et al*, she restricted her interest rate announcements to those when interest rates were changed. She found that although the short-term interest rate surprises were not significantly different pre and post-announcement, the volatility in long-term gilts futures was higher. Splitting the post-independence period into two did not reveal that this volatility diminishes in later post-independence years.

One reason put forward for why surprises continue to occur is that it takes time for markets to learn about these changes in monetary policy institutions. Lasaosa's study (the most recent) takes the data up to June 2001, which is four years after Bank of England independence. So even if more learning dynamics have still to take place following the regime change, that process would seem to be protracted. This would suggest that an analysis of market surprises would need to model why agents have to learn, and allow for asymmetries in information.

Another possible explanation is that aspects of the UK monetary policy framework (decision-making by committee and individual accountability) have acted to make surprises more likely. Some econometric evidence is provided by Siklos (2003), who regressed implied volatilities and spreads on dummies of when MPC minutes reflect a unanimous decision compared to a close decision.

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(3) But the immediate reactions of short sterling and long gilts to monetary policy announcements are significantly greater post-independence.

He found that the expression of a divergence of views lowers implied volatilities and makes no difference to spreads. [4]

In summary, we cannot be sure whether or not the granting of independence to the Bank of England significantly reduced the likelihood of revisions to market interest rates following policy announcements. It is difficult to separately identify the effect of the different structural changes that occurred during these years. Many improvements in the UK monetary policy regime were carried out prior to independence following sterling's exit from the Exchange Rate Mechanism in September 1993 — see Bowen (1995) — and so Bank independence may not be the only break point in the data. But there does not seem to have been as great a fall in the volatility of market surprises following Bank independence as one might have expected, and this is the starting point for the analysis in this paper.

To answer these questions, I present a model that describes how improvements in transparency affects market expectations. There are two sources of asymmetric information: on the policymakers' objectives and on their interpretation of the shock. Agents and policymakers form expectations using their knowledge of the distribution (the means and variances) of different sources of uncertainty; hence this is a signal-noise framework. Given the nature of the inflation objective and their information constraints, policymakers make their decisions on the policy stance while endogenising how transparent they want to be in their explanations.

There is more than one definition of credibility in the monetary policy literature. Here it is assumed that less credible monetary policy makers are those that pursue their own stochastic, idiosyncratic inflation target. This inflation target is not known to agents, they only know its distribution. The stochastic movements in this target are suboptimal. Imagine that these less credible policymakers were very transparent about their actions. Then agents could perceive that inflationary shocks are being accommodated to pursue this idiosyncratic inflation goal and inflation expectations will be destabilised. Less credible policymakers, therefore, have an incentive not to be transparent in explaining their actions. Conversely once the inflation goal is made transparent and credible, the incentive is, generally, to be transparent in explanations also.

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(4) This result confirms earlier work by Chadha and Nolan (2001). Experimental evidence presented in Lombardelli, Proudman and Talbot (2002) and Blinder and Morgan (2000) suggests that decision-making by committee could be better than individual decision-making. In a theoretical model where committee members have different sources of information, Gerlach-Kristen (2004) shows how deliberation by committee can improve outcomes even if members can only absorb each other's views imperfectly, assuming members do not act strategically.

This is a key mechanism in the model.

The aim is to capture how transparency might be instilled into the system. For example one could argue that the institutional changes put in place after exit from the Exchange Rate Mechanism in the United Kingdom made a significant difference in that they dispelled much uncertainty surrounding the long-run inflation target. Once that change became credible, revisions in financial market participants' expectations of shocks seemed less likely to affect their views of expected outturns for long-run nominal variables (inflation or interest rates).[5]

Another defining feature of the model is that interest rate decisions (or associated information releases — the model makes no attempt to distinguish between words and actions) act through two channels. First, monetary policy makers might surprise markets by being able to react to shocks in a way that markets cannot fully anticipate. This is the **active instrument** function of interest rate surprises. But there is another role for interest rates: they act as a **beacon** when the interest rate announcement steers agents' inflation expectations by giving them useful information about what monetary policy makers think is going on in the economy. I show that this can be true even if policymakers internalise the effect that their announcements have on agents' beliefs.

Some, for example Romer and Romer (2000), have argued that policy announcements convey information because monetary policy makers have better access to data.[6] However raw data is now very widely available, and so it seems plausible that any such advantage should have been eroded. The interpretation I rather favour is that monetary policy makers process raw (and publicly available) information differently when coming up with their own interest rate decision and that is why their announcements contain some news.[7] After all, many aspects of their objectives (the

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(5) See Haldane and Read (2000) and also Tucker (2004). Gürkaynak *et al* (2005) confirm that the response of long-term forward rates in the United Kingdom to surprises in macroeconomic data outturns following Bank independence is much less when compared to the United States (where no inflation target is announced) and when compared to pre-independence. Kohn and Sack (2003) compared the extra effect of Fed talk (FOMC statements, and congressional testimonies and major speeches by Chairman Greenspan) over and above unexpected policy changes between January 1989 and April 2003. They found that while near-term interest rates are affected, other financial variables, such as ten-year yields or longer than two-year forwards, equity prices and the exchange rate, are less affected.

(6) Recently Faust *et al* (2004) tested and rejected the possibility that the Fed has private information about either inflation or GDP.

(7) This interpretation of transparency focuses on asymmetries of information processing rather than in raw data, as in Geraats (2002). '*This definition of transparency focuses on information that agents actually have, not on the act of disclosing information. The reason is that public availability of data need not suffice to achieve transparency. If manipulation of data is required to extract useful information and agents are constrained by limited resources, then asymmetric information could persist.*' Geraats (2002, page 2).

risks to the forecast, the weight placed on those risks in setting rates, output costs and the optimal horizon) are sensitive to the mix of structural shocks that are hitting the economy. As the objective cannot be fully pre-specified in the remit, much still depends on the monetary policy makers' interpretation and discretion round by round, even when raw data is rapidly disseminated.[8]

Putting these two elements together, the model is calibrated so that improving transparency about the inflation goal at low levels of transparency leads to a greater transparency in explanations and less market surprises. I show that this happens at a decreasing rate: the variance of interest rates falls by less when transparency is improved further from already high levels than when it is improved from low levels. The reason is that the beaconing function of policy announcements can be enhanced under more transparent regimes. More transparency raises the sensitivity of short-term inflation expectations to fundamental shocks and that extra sensitivity feeds back onto interest rate setting. So the continued occurrence of surprises could be consistent with greater transparency. As in general improving transparency tends to lead to more precisely formed inflation expectations, transparency is, in this sense, good for welfare.

Although the role of monetary policy announcements as a beacon has been relatively less explored, this paper is related to an existing literature, and in particular, work by Faust and Svensson (2001, 2002) and Mukand and Kutsoati (2004). There are differences, though. Faust and Svensson (2001, 2002) do not allow policymakers to internalise the effects of their announcements on agents' expectations, although they do allow for transparency to affect the transmission of policy as I do. Mukand and Kutsoati (2004) allow for asymmetries in information between the policymakers and agents over whether the economy is in a 'good' or 'bad' state. They do not derive the effects of greater transparency. Kozicki and Tinsley (2004) explore the effect of asymmetries in information in a signal-noise framework, but they discuss asymmetries in knowledge about the policymakers' preferences (such as the long-run inflation target, the weight on output stabilisation, or the long-run employment goal). They do not allow for the interest rate to provide a useful signal. Canzoneri (1985), Ellingsen and Söderström (2001), Jääskelä and McKeown (2005a, b) for example, all discuss the implications of private information on shocks

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(8) In other words the contract is incomplete (Vickers (1998)) especially when policymakers are faced by shocks whose monetary policy impacts require interpretation, rather than those whose implications are straightforward and understood by all. See also King (2001, page 378). Winkler (2000) emphasises that monetary policy transparency is about achieving a common understanding, and may be constrained by the fact that monetary policy decisions can be complex and uncertain and so difficult to formulate in precise terms. He argued that another constraint might be when decisions are transmitted from multiple senders (when there is a committee) to multiple receivers.

but not in a signal-noise framework, where agents do not know the variances of the disturbance processes.

It might be important to clarify how different concepts of monetary policy transparency modelled here relate to what has been discussed in the literature. Geraats (2002) explains that monetary policy transparency concerns the removal of asymmetries in information between monetary policy makers and economic decision-makers. But there are different possible types of transparency corresponding to the different type of information that can be asymmetrically distributed and the different ways of modelling how that asymmetry is diminished. She distinguishes asymmetries in knowledge and interpretation on the state of the economy and the transmission mechanism (economic and operational transparency) from other types of information asymmetries: on monetary policy makers' objectives (political transparency); the process by which monetary policy makers make decisions (procedural transparency) and statements about the future course of policy (transparency). Economic transparency is when the central bank discloses more of its private information whereas operational transparency is when it achieves a reduction of control error. In this set-up, political transparency is related to economic and operational transparency. The underlying structural change is that there is more transparency about the inflation objective (political transparency). But this has implications for the transparency that the policymakers choose to attach to their policy actions (economic and operational transparency).[9]

The paper is structured as follows. Section 2 presents the model. In Section 3 the model is solved and the main results presented as propositions. Section 4 presents some illustrative numerical results for particular parameter values and Section 5 concludes.

2   A model of market surprises when interest rates act as a beacon

2.1   The transmission mechanism

The description of the transmission mechanism is very simple. The hope is that results derived from this simple model will be borne out in more complicated realistic structures. The transmission of interest rates onto macroeconomic variables — given inflation expectations — is

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[9] As in Woodford (2005), economic and operational transparency are inextricably linked. That is simply because agents' expectations are what drive macroeconomic variables, for example through asset prices. Hence the transmission of monetary policy is itself dependent on agents' understanding of how policymakers interpret the macroeconomic environment.

kept down to three equations: an accelerationist Phillips curve for inflation, Δp,

$$\Delta p = E\left[\Delta p \mid I_p\right] + \beta y + e \tag{1}$$

an IS equation for output, y,

$$y = -\alpha r \tag{2}$$

and a definition of the market real interest rate (r) as real rate derived from agents' observation of the noise-free interest rate signal (i^P):

$$r = E\left[i^P \mid I_p\right] - E\left[\Delta p \mid I_p\right] \tag{3}$$

The shock is distributed normally as

$$e \sim N\left(0, \sigma_e\right)$$

$\left[z \mid I_p\right]$ describes agents' expectations of a variable z formed using the information set I_p. At this stage, values for the parameters are not specified but we can note that in most standard calibrations $\beta > 0$ and $\alpha > 0$.

Equation **(1)** can be derived from a Lucas-type supply-side model. Although this is a very tractable inflation equation, it contains none of the dynamics that seem to describe the true inflation process. The IS curve, equation **(2)**, is also shorn of dynamics so as to be easy to manipulate. As in Goodhart, Clark and Huang (1999) it is the real interest rate formed on expectations of current inflation that matters.

As the inflation equation features no persistent nominal rigidities, demand shocks are easily accounted for by monetary policy. Supply-side cost-push shocks on the other hand do create a dilemma for monetary policy by raising inflation at the same time as lowering output. So we restrict ourselves to the case of a cost-push supply shock and derive explicit expressions to explain the role of beaconing and the effects of improvements in transparency with this one shock impact only. [10] i^P is the noise-free interest rate signal in nominal terms, and will be defined formally below. But briefly, it is the economic (noise-free) component of that announcement that policymakers make. This reflects that it is market expectations about the news component of policy announcements, and not the announcement itself, that matters for economic decisions. [11]

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[10] Ravenna and Walsh (2005) provide some justification for these cost-push shocks.
[11] It follows that a more rigorous approach would be to model the term structure in a dynamic setting, as in Ellingsen and Söderström (2001) and (2004), who discuss the effect of information asymmetry on the term premium.

2.2 Monetary policy setting

The description of policy is not far removed from what one would find in most illustrative monetary policy models. The loss function of policymakers is given by their expectations of the weighted average of unconditional variances of the output gap and inflation. Assuming that the target inflation rate that they follow, τ, is stochastic, [12] this loss function is written as

$$L = \frac{\left(E\left[y \mid I_{mp}\right]\right)^2}{2} + \gamma \frac{\left(E\left[(\Delta p) \mid I_{mp}\right] - \tau\right)^2}{2} \qquad (4)$$

There are four reasons why the outcome is not equivalent to maximising social welfare. First, policymakers are constrained by not having full information. Second, to the extent that policymakers are not credible, they follow their own inflation objective (τ) and third, may also support this by not being transparent in their explanations. And finally one could question whether social welfare should be captured by a loss function expressed only in terms of *unconditional* variances of inflation and output. [13] What is absent from this popular format is the welfare benefit of agents forming *more precise* expectations on their economic decision-making, which seems crucial, at least when assessing the role of transparency.

In what follows, the policymakers internalise the effects of their actions on agents' expectations. This means that optimal policy takes explicit account of higher-order beliefs, [14] as suggested by Svensson (2003a). Consider the alternative, a discretionary solution, where policymakers take the agents' expectations as exogenous, as in Clarida, Gali and Gertler (1999) for example. [15] Although that discretionary solution would be a Nash equilibrium it would not be subgame perfect. If policymakers and agents somehow inherit a state off the equilibrium path then it would not be optimal for agents to form expectations as independent of the policymakers' choices and it would not be optimal for policymakers to ignore that.

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(12) As this is a static model, we ignore the discount rate.

(13) See Woodford (2003, 2005) for example.

(14) In the asymmetric information literature, the belief that agent A forms about what another agent B believes that agent A is believing about B and so on, is called a higher-order belief. As in our model, higher-order beliefs are of interest when agents do not share the same information set. See Phelps (1983) and Amato, Shin and Morris (2003) for example. Here I introduce noise frictions in making higher-order beliefs.

(15) Goodhart, Clark and Huang (1999) compare the discretionary and commitment solutions in a model of asymmetric information with inflation dynamics. They do not tackle this in a signal-noise framework: agents in their model do not use information on the second-order moments of the shocks. For a comparison in a signal-noise framework, see Faust and Svensson (2002).

2.3 The sequence of events and the information sets

The sequence of events in the story is as follows:

- First agents form their expectations prior to receiving any signal from monetary policy makers. The information set of agents in this counterfactual state is defined as $I_{p0} = [\chi]$ and comprises only the parameters of the model including the distribution of the error processes,

$$\chi \in \left[\alpha, \beta, \gamma, \sigma_s^2, \sigma_\tau^2, \sigma_q^2, \sigma_e^2\right]$$

- Then the shock, e, happens. Policymakers observe a noisy signal, s, of that shock. They announce their beacon as to the course of monetary policy, i, based on common information (χ), their own private interpretation of the shock (s), and their own objective (τ). The beacon is set optimally in all but one aspect. The policymakers may choose to send out a signal which does not reflect directly their own interpretation of the shock (s) but rather some blurred version. That blurring reflects a lack of transparency and is represented by a noise term q. This is deliberate. But policymakers remain ignorant of its exact consequences: they do not observe q although they know its variance. This captures how a lack of transparency impairs information both for the receiver and the sender. The policymakers' information set is therefore defined as $I_{mp} = [\chi, s, \tau]$.

- Agents receive that signal, the monetary policy beacon, and then try to decode it. They do not know either the value of the supply-side shock impact (e), or the complete policy objective (τ) or the transparency noise (q). Neither can they know the current inflation outturn, else they could work out what the supply-side shock impact is. They form their expectations of the shock using only the beacon and their prior information on the variances, and make economic decisions on that basis. To summarise, their expectations at this stage are formed conditional on a with-beacon information set, $I_p = [\chi, i]$.

2.4 Agents' conjecture as to policy setting

Without knowing the exact values of its different components, the agents' conjecture is that the interest rate signal they receive arises from the following set of relationships:

$$i = c_1 s + \rho (1 - c_1) \tau + q \tag{5}$$

$$s = e + v \tag{6}$$

$$v \sim N\left(0, g_v \sigma_e\right), \tau \sim N\left(0, g_\tau \sigma_e\right) \text{ and } q \sim N\left(0, g_q \sigma_e\right) \tag{7}$$

$$c_1 = f\left((g_v)^2\right) \tag{8}$$

and

$$\left(g_q\right)^2 = g\left((g_v)^2, (g_\tau)^2\right) \tag{9}$$

Equation **(5)** contains the three crucial elements of the story. The first term, s, captures how interest rates are affected by the policymakers' imperfect observation of the true shock, e. v is a noise term representing the policymakers' ignorance. But the policymakers' idiosyncratic preferences over the inflation target (τ) also matters. This term enters in the objective of policymakers, equation **(4)**, but only its distribution and not its value is known to agents. When its variance is high ($(g_\tau \sigma_e)^2$ is much greater than zero) there is a justified lack of credibility surrounding the inflation target that the policymakers are aiming at. Finally, and crucially, q is the transparency noise that the policymakers deliberately introduce so that their announcement does not fully reflect information on either their interpretation of the shock or their objectives. v, τ and q are all independently normally distributed variables whose standard deviations are in proportion to that of the shock.[16]

Equations **(8)** and **(9)** are here to clarify that the coefficient c_1 and the function $f\left((g_v)^2, (g_\tau)^2\right)$ are consistent with the policymakers maximising their objectives and that in this sense these conjectures are correct in expectation. They will be derived explicit later on. Equation **(8)** reveals that the parameter c_1 in equation **(5)** is determined endogenously while ρ is imposed. Thus when policymakers with unclear and uncertain objectives accommodate the shock by not reacting to it, agents automatically assume they place more weight on their idiosyncratic objectives. When policymakers are credible, $(g_\tau \sigma_e)^2 \approx 0$, this constraint is slack. As I also show later this acts as a deterrent in preventing less credible policymakers from accommodating too much of the shocks, providing that ρ is set at a positive value (but is less than one to help ensure a solution exists). Equation **(9)** implies that the variance of transparency noise in explanations, $\left(g_q\right)^2$, is endogenous and a function of the uncertainty surrounding the objective and the policymakers' ignorance.

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(16) One could suppose that agents believe that policymakers also set policy on the basis of policymakers' expectations of agents' expectations, and hence also react to a term such as $E\left[E\left[e \mid I_p\right] \mid I_{mp}\right]$. However as policymakers' expectations of agents' expectations must be a function of variables in the policymakers' information set only (s and τ), that would give us exactly the same solution as we follow in the text.

2.5   Learning by recursive projection

I now need to explain how agents use their perception of policy interest rate setting (equation (**5**)) to form their expectations of the shock. Agents' expectations of the shock prior to receiving the signal is

$$E\left[e \mid I_{p0}\right] = 0 \qquad (10)$$

Agents use a *recursive projection formula* to update these prior beliefs with the signal.[17] To explain this let us consider how agents revise their prior expectations of a variable z. They first form a linear relationship that best (in the sense of minimising least squares) describes what information content surprises in the observed signal $\left(i - E\left[i \mid I_{p0}\right]\right)$ have for the expectational errors in that variable $\left(z - E\left[z \mid I_{p0}\right]\right)$ and then use that to revise expectations of the shock. The recursive projection updating rule can be summarised as

$$E\left[z - E\left[z \mid I_{p0}\right] \mid i - E\left[i \mid I_{p0}\right]\right] = a\left(i - E\left[i \mid I_{p0}\right]\right) \qquad (11)$$

where crucially the coefficient a is determined as the asymptotic ordinary least squares estimate of the coefficient in a regression of market surprises on expectation errors:[18]

$$a = \frac{E\left[i - E\left[i \mid I_{p0}\right], z - E\left[z \mid I_{p0}\right]\right]}{E\left[\left(i - E\left[i \mid I_{p0}\right]\right)^2\right]} \qquad (12)$$

Thus to derive the agents' expectations of the shock, note that according to the *law of iterated expectations*:

$$E\left[E\left[e \mid I_{p0}\right] \mid i - E\left[i \mid I_{p0}\right]\right] = E\left[e \mid I_{p0}\right] \qquad (13)$$

and

$$E\left[e \mid i - E\left[i \mid I_{p0}\right]\right] = E\left[e \mid I_p\right] \qquad (14)$$

Equations (**5**), (**6**) and (**10**) imply that $E\left[i \mid I_{p0}\right] = 0$. So the market surprise is simply given by market interest rates themselves and is written as

$$i - E\left[i \mid I_{p0}\right] = i = c_1 s + c_2 \tau + q \qquad (15)$$

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(17) See Sargent (1987, page 228) for example.
(18) We are assuming that agents know exactly how that shock is related to the interest rate surprise although they not observe the current value of the shocks. In other words, they know the distribution that determines $E\left[z - E\left[z \mid I_{p0}\right] \mid i - E\left[i \mid I_{p0}\right]\right]$ without ever knowing the current value of z. We do not model how agents acquired this information. That is the subject of a large literature on dynamic learning, reviewed in Evans and Honkapohja (1999). See also Sargent (1993). Note also that coefficient a can be thought of as the Kalman filter gain.

Substituting equations **(6)**, **(10)**, **(13)**, **(14)** and **(15)** into **(11)** and **(12)** gives an expression for the expectation of the shock as a function of the policy signal:

$$E\left[e \mid I_p\right] = \frac{c_1}{(g_i)^2} i \tag{16}$$

with

$$(g_i)^2 \equiv (c_1)^2 \left(1 + g_v\right) + (c_2)^2 g_\tau^2 + \left(g_q\right)^2 \tag{17}$$

i^P — the noise-free signal — is the part of the interest rate signal which is in the policymakers' information set:

$$i^P \equiv c_1 s + c_2 \tau$$

Its variance is $(g_{iP})^2 \sigma_e^2$ and is related to the coefficients by

$$(g_{iP})^2 = (c_1)^2 \left(1 + (g_v)^2\right) + (c_2)^2 (g_\tau)^2 \tag{18}$$

Agents' expectations of i^P are therefore given by

$$E\left[i^P \mid I_p\right] = \frac{(g_{iP})^2}{(g_i)^2} i \tag{19}$$

In order to be consistent policymakers also form expectations using the same learning rule, but conditional on their own information. For example their expectation of the shock will be simply given by

$$E\left[e \mid I_{mp}\right] = \frac{1}{1 + (g_v)^2} s \tag{20}$$

and their expectation of market rates will be

$$E\left[i \mid I_{mp}\right] = i^P \tag{21}$$

2.6 Market surprises

At this point it is worth clarifying how the variables in the model could relate to the empirical concept of a market surprise. The *market surprise* is defined as the revision in agents' predictions of the signal they receive:

$$i - E\left[i \mid I_{p0}\right] = i \tag{22}$$

The likelihood of the market surprise is given by the unconditional variance of these revisions:

$$
\begin{aligned}
E\left[\left(i - E\left[i \mid I_{p0}\right]\right)^2\right] &= E\left[(i)^2\right] \\
&= (g_i)^2 \sigma_e^2
\end{aligned}
\tag{23}
$$

where $E[z]$ denotes the unconditional expectation of z and should not be confused with agents' expectations which are conditional on a particular information set.

Equations (5), (16) and (23) take us towards expressions for the policymakers' expectations of agents' expectations of other variables, and so help explain how policymakers can internalise their beaconing. But they are incomplete characterisations in the sense that c_1 and $(g_q)^2$ are yet to be determined. In the following section, I solve for the optimal value of c_1 and $(g_q)^2$ and explicitly link them to the variance of interest rates.

3 Solving the model

The set-up and solution method are not completely unfamiliar, and therefore we should not expect the solution properties to differ much either from earlier findings. Pearlman (1992) and Svensson and Woodford (2003) showed that under evenly distributed partial information, the monetary policy problem in a forward-looking dynamic setting with a linear transmission mechanism and a quadratic loss function is characterised by two related properties: *partial certainty equivalence* and *the separation property*. *Partial certainty equivalence* means that the optimal policy is the same as if the state of the economy were fully observed except that one responds to an efficient estimate of the state rather than its actual value. According to *the separation property*, the problem of the determination of the optimal response coefficients to be applied by policymakers to their estimate of the state of the economy can be separated from the problem of estimating the true current state of the economy from noisy data. Svensson and Woodford (2004) went on to demonstrate that when information is asymmetrically distributed — as is the case in the model — then neither certainty equivalence nor separation holds. [19]

---

[19] In Svensson and Woodford (2004) agents have more information than policymakers on the effect of economic shocks on macroeconomic variables. In our model policymakers know more than agents about what those shocks mean for monetary policy setting.

Taking expectations conditional on the agents' information set of **(1)**, **(2)** and **(3)**, we have two equations in expected output:

$$E\left[y \mid I_p\right] = -\frac{E\left[e \mid I_p\right]}{\beta} \tag{24}$$

and

$$E\left[y \mid I_p\right] = y = -\alpha \left(E\left[i^P \mid I_p\right] - E\left[\Delta p \mid I_p\right]\right) \tag{25}$$

Equating equations **(24)** and **(25)** yields

$$-E\left[e \mid I_p\right] = -\alpha\beta \left(E\left[i^P \mid I_p\right] - E\left[\Delta p \mid I_p\right]\right) \tag{26}$$

which rearranges into an expression for expected inflation

$$E\left[\Delta p \mid I_p\right] = E\left[i^P \mid I_p\right] - \frac{1}{\alpha\beta}E\left[e \mid I_p\right] \tag{27}$$

Using equation **(16)** for $E\left[e \mid I_p\right]$ the solution for agents' inflation expectations is

$$
\begin{aligned}
E\left[\Delta p \mid I_p\right] &= \frac{(g_{iP})^2}{(g_i)^2}i - \frac{1}{\alpha\beta}\frac{c_1}{(g_i)^2}i \\
&= \frac{(g_{iP})^2 - \frac{c_1}{\alpha\beta}}{(g_i)^2}i
\end{aligned}
\tag{28}
$$

The real interest rate, inflation and output are given by

$$E\left[i^P \mid I_p\right] - E\left[\Delta p \mid I_p\right] = \frac{1}{\alpha\beta}\frac{c_1}{(g_i)^2}i \tag{29}$$

$$
\begin{aligned}
\Delta p &= \frac{(g_{iP})^2 - \frac{c_1}{\alpha\beta}}{(g_i)^2}i - \frac{c_1}{(g_i)^2}i + e \\
&= \frac{(g_{iP})^2 - c_1\frac{(1+\alpha\beta)}{\alpha\beta}}{(g_i)^2}i + e
\end{aligned}
\tag{30}
$$

and

$$y = -\frac{1}{\beta}\frac{c_1}{(g_i)^2}i \tag{31}$$

respectively.

I now solve for policymakers' expectations. Taking expectations conditional on the policymakers' information set of equation **(28)** and using equation **(21)** gives the policymakers' expectations of agents' inflation expectations and of the real market rate as

$$E\left[E\left[\Delta p \mid I_p\right] \mid I_{mp}\right] = \frac{(g_{iP})^2 - \frac{c_1}{\alpha\beta}}{(g_i)^2} i^P \tag{32}$$

and

$$E\left[r \mid I_{mp}\right] = \frac{1}{\alpha\beta} \frac{c_1}{(g_i)^2} i^P \tag{33}$$

Their expectations of output and inflation are then

$$\begin{aligned} & E\left[y \mid I_{mp}\right] \\ = \; & -\frac{1}{\beta} \frac{c_1}{(g_i)^2} i^P \end{aligned} \tag{34}$$

and

$$\begin{aligned} E\left[\Delta p \mid I_{mp}\right] & = \frac{(g_{iP})^2 - c_1 \frac{(1+\alpha\beta)}{\alpha\beta}}{(g_i)^2} i^P + E\left[e \mid I_{mp}\right] \\ & = \frac{(g_{iP})^2 - c_1 \frac{(1+\alpha\beta)}{\alpha\beta}}{(g_i)^2} i^P + \frac{1}{1 + (g_v)^2} s \end{aligned} \tag{35}$$

We can substitute from equations **(34)** and **(35)** into the loss function **(4)** to give

$$L = \frac{1}{2}\left(-\frac{1}{\beta}\frac{c_1}{(g_i)^2}i^P\right)^2 + \frac{1}{2}\gamma\left(\frac{(g_{iP})^2 - c_1\frac{(1+\alpha\beta)}{\alpha\beta}}{(g_i)^2}i^P + \frac{1}{1 + (g_v)^2}s - \tau\right)^2 \tag{36}$$

This is what policymakers will minimise when taking account of the endogeneity of agents' expectations. The solution to this problem ($\widehat{i^P}$) follows from the first-order condition:

$$\begin{aligned} 0 = \; & \left(\frac{1}{\beta}\frac{c_1}{(g_i)^2}\right)^2 \widehat{i^P} \\ & + \gamma\left(\frac{(g_{iP})^2 - c_1\frac{(1+\alpha\beta)}{\alpha\beta}}{(g_i)^2}\right)\left(\left(\frac{(g_{iP})^2 - c_1\frac{(1+\alpha\beta)}{\alpha\beta}}{(g_i)^2}\right)\widehat{i^P} + \frac{1}{1 + (g_v)^2}s - \tau\right) \end{aligned} \tag{37}$$

Rearranging equation **(37)**, we have

$$\left(\gamma \left(\frac{(g_{iP})^2 - c_1 \frac{(1+\alpha\beta)}{\alpha\beta}}{(g_i)^2} \right)^2 + \left(\frac{1}{\beta} \frac{c_1}{(g_i)^2} \right)^2 \right) \widehat{i}^P$$

$$= -\gamma \frac{(g_{iP})^2 - c_1 \frac{(1+\alpha\beta)}{\alpha\beta}}{(g_i)^2} \frac{1}{1+(g_v)^2} s + \gamma \frac{(g_{iP})^2 - c_1 \frac{(1+\alpha\beta)}{\alpha\beta}}{(g_i)^2} \tau$$

or in terms of the perceived interest rate,

$$\widehat{i} = -\gamma \frac{\frac{(g_{iP})^2 - c_1 \frac{(1+\alpha\beta)}{\alpha\beta}}{(g_i)^2}}{\left(\gamma \left(\frac{(g_{iP})^2 - c_1 \frac{(1+\alpha\beta)}{\alpha\beta}}{(g_i)^2} \right)^2 + \left(\frac{1}{\beta} \frac{c_1}{(g_i)^2} \right)^2 \right)} \frac{1}{1+(g_v)^2} s$$

$$+ \gamma \frac{\frac{(g_{iP})^2 - c_1 \frac{(1+\alpha\beta)}{\alpha\beta}}{(g_i)^2}}{\left(\gamma \left(\frac{(g_{iP})^2 - c_1 \frac{(1+\alpha\beta)}{\alpha\beta}}{(g_i)^2} \right)^2 + \left(\frac{1}{\beta} \frac{c_1}{(g_i)^2} \right)^2 \right)} \tau$$

$$+ q \tag{38}$$

Matching coefficients between equations **(38)** and **(5)** we have that

$$c_1 = -\gamma\,(g_i)^2 \frac{(g_{iP})^2 - c_1 \frac{(1+\alpha\beta)}{\alpha\beta}}{\left(\gamma \left((g_{iP})^2 - c_1 \frac{(1+\alpha\beta)}{\alpha\beta} \right)^2 + \left(\frac{1}{\beta}c_1 \right)^2 \right)} \frac{1}{1+(g_v)^2} \tag{39}$$

and

$$-\rho\,(1 - c_1) = \gamma\,(g_i)^2 \frac{(g_{iP})^2 - c_1 \frac{(1+\alpha\beta)}{\alpha\beta}}{\left(\gamma \left((g_{iP})^2 - c_1 \frac{(1+\alpha\beta)}{\alpha\beta} \right)^2 + \left(\frac{1}{\beta}c_1 \right)^2 \right)} \tag{40}$$

Hence we have an expression for the coefficient c_1:

$$c_1 = \frac{1}{1+(g_v)^2}\rho\,(1 - c_1)$$

$$\Rightarrow c_1 = \frac{\rho}{1+(g_v)^2 + \rho} \tag{41}$$

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Note that $\frac{dc_1}{d(g_v)^2} < 0$ with $\lim_{(g_v)^2 \to \infty} c_1 = 0$.

Proposition 1 The more ignorant the policymakers are about the shock, the less they will react to it. At the limit they will not react to shocks that they know very little about.

It is reassuring that the model allows for the realistic possibility that policymakers might not know much about the shock that is hitting the economy. In what follows we assume that the nature of the shock is at least imperfectly understood although possibly with a substantial degree of uncertainty.

Substituting from equation **(41)** into equation **(18)** gives us an expression for the variance of the noise-free signal:

$$
\begin{aligned}
(g_{iP})^2 &= (c_1)^2 \left(1 + (g_v)^2\right) + \rho^2 (1 - c_1)^2 (g_\tau)^2, \\
&= (c_1)^2 \left(1 + (g_v)^2\right) \left(1 + \left(1 + (g_v)^2\right)(g_\tau)^2\right), \\
&= \frac{\rho^2 \left(1 + (g_v)^2\right)\left(1 + \left(1 + (g_v)^2\right)(g_\tau)^2\right)}{\left(1 + (g_v)^2 + \rho\right)^2}
\end{aligned}
\tag{42}
$$

Define

$$
\omega_1 \equiv c_1 \left(1 + (g_v)^2\right)
\tag{43}
$$

$$
\omega_2 \equiv c_1 \frac{(1 + \alpha\beta)}{\alpha\beta}
\tag{44}
$$

and

$$
\omega_3 \equiv \frac{c_1}{\beta (\gamma)^{0.5}}
\tag{45}
$$

Using equations **(43)**, **(44)** and **(45)** we can rewrite equation **(39)** to derive expressions for the variance of the transparency noise surrounding the explanations and the likelihood of market surprises as

$$
\begin{aligned}
\omega_1 &= -\left((g_{iP})^2 + (g_q)^2\right) \frac{(g_{iP})^2 - \omega_2}{\left(\left((g_{iP})^2 - \omega_2\right)^2 + (\omega_3)^2\right)} \\
&\Rightarrow (g_q)^2 = \frac{\omega_1 \left(\left(\omega_2 - (g_{iP})^2\right)^2 + (\omega_3)^2\right)}{\omega_2 - (g_{iP})^2} - (g_{iP})^2
\end{aligned}
\tag{46}
$$

22

and

$$
\begin{aligned}
(g_i)^2 &= (g_{iP})^2 + (g_q)^2, \\
&= \frac{\omega_1\left(\left(\omega_2 - (g_{iP})^2\right)^2 + (\omega_3)^2\right)}{\omega_2 - (g_{iP})^2}
\end{aligned}
\tag{47}
$$

respectively. Both of these are functions of the variance of the noise-free signal, $(g_{iP})^2$, which itself is monotonically related to the level of transparency surrounding the inflation objective, $(g_\tau)^2$, as in equation **(42)**. The extent of the policymakers' ignorance, $(g_v)^2$, also matters.

Looking at **(39)** we can see that all optimal solutions involve some degree of resistance to the inflation shock.[20] Indeed there are no solutions if there is too little transparency about the objectives of monetary policy:

$$
\begin{aligned}
c_1 &\geq 0 \\
&\Leftrightarrow (g_{iP})^2 \leq \omega_2 \\
&\Leftrightarrow (g_\tau)^2 \leq \frac{1}{\left(1 + (g_v)^2\right)}\left(\frac{\omega_2}{c_1\left(1 + (g_v)^2\right)} - 1\right)
\end{aligned}
\tag{48}
$$

Hence ω_2 defines a maximum value for $(g_{iP})^2 : (g_{iP})^2\,|_{\max} = \omega_2$. The minimum value is achieved when the inflation objective is fully transparent $((g_\tau)^2 = 0$ in equation **(42)**):
$(g_{iP})^2\,|_{\min} = (c_1)^2\left(1 + (g_v)^2\right)$.

We can differentiate expression **(47)** as

$$
\frac{d(g_i)^2}{d(g_{iP})^2} = \omega_1 \frac{(\omega_3)^2 - \left(\omega_2 - (g_{iP})^2\right)^2}{\left(\omega_2 - (g_{iP})^2\right)^2}
\tag{49}
$$

---

[20] In a dynamic model, the optimal policy in the absence of beaconing would not be to accommodate but to resist or lean against the wind. See Clarida, Gali and Gertler (1999) for example.

This slope will be positive when

$$
\begin{aligned}
& \omega_2 + \omega_3 \quad > \quad (g_{iP})^2 > \omega_2 - \omega_3 \\
\frac{\omega_2 + \omega_3}{(c_1)^2 \left(1 + (g_v)^2\right)^2} - \frac{1}{\left(1 + (g_v)^2\right)} \quad & > \quad (g_\tau)^2 > \frac{\omega_2 - \omega_3}{(c_1)^2 \left(1 + (g_v)^2\right)^2} - \frac{1}{\left(1 + (g_v)^2\right)} \\
& \Rightarrow \quad \frac{d\,(g_i)^2}{d\,(g_\tau)^2} = \frac{d\,(g_i)^2}{d\,(g_{iP})^2} \times \frac{d\,(g_{iP})^2}{d\,(g_\tau)^2} > 0
\end{aligned}
\tag{50}
$$

Differentiating expression **(46)** we have that

$$
\frac{d\,(g_q)^2}{d\,(g_{iP})^2} = \frac{\omega_1 (\omega_3)^2 - (\omega_1 + 1)\left(\omega_2 - (g_{iP})^2\right)^2}{\left(\omega_2 - (g_{iP})^2\right)^2}
\tag{51}
$$

and therefore

$$
\begin{aligned}
\omega_2 + \omega_3 \left(\frac{\omega_1}{1 + \omega_1}\right)^{0.5} \quad & > \quad (g_{iP})^2 > \omega_2 - \omega_3 \left(\frac{\omega_1}{1 + \omega_1}\right)^{0.5} \\
& \Rightarrow \quad \frac{\omega_2 + \omega_3 \left(\frac{\omega_1}{1 + \omega_1}\right)^{0.5}}{(c_1)^2 \left(1 + (g_v)^2\right)^2} - \frac{1}{\left(1 + (g_v)^2\right)} \\
& > \quad (g_\tau)^2 \\
& > \quad \frac{\omega_2 - \omega_3 \left(\frac{\omega_1}{1 + \omega_1}\right)^{0.5}}{(c_1)^2 \left(1 + (g_v)^2\right)^2} - \frac{1}{\left(1 + (g_v)^2\right)}
\end{aligned}
\tag{52}
$$

Conditions **(48)**, **(50)** and **(52)** will all be jointly satisfied when $(g_\tau)^2$ falls into the range

$$
\frac{\omega_2}{(c_1)^2 \left(1 + (g_v)^2\right)^2} - \frac{1}{\left(1 + (g_v)^2\right)} \geq (g_\tau)^2 > \frac{\omega_2 - \omega_3 \left(\frac{\omega_1}{1 + \omega_1}\right)^{0.5}}{(c_1)^2 \left(1 + (g_v)^2\right)^2} - \frac{1}{\left(1 + (g_v)^2\right)}
\tag{53}
$$

The upper and lower bounds of **(53)** depend on many parameters. But if β is less than one and α just greater than one, both bounds will tend to be satisfied for a range of values of g_τ from even very low values of credibility (values of $g_\tau < 1$) to all but the smallest values of $(g_\tau)^2$. That $\alpha\beta$, the reduced form coefficient of real interest rates on inflation, is close to one implies that ω_2 will be close to two. β being smaller than one implies that ω_3 will be large. This also depends on fairly reasonable assumptions about the parameter values: ρ is taken to be close to but greater than 1; γ, the weight on inflation in losses, is placed close to 1; and the level of ignorance about the shock

could vary from 0.5 to 1, indicating that the standard deviation of policymakers' errors in understanding the shock varies from 25% to 100% of the standard deviation of the shock. In what follows I assume that these parameter values hold.

Proposition 2 Given parameter values that satisfy **(53)**, the likelihood of market surprises will fall and transparency in explanations will improve as the transparency about objectives is improved, up to all but high levels of transparency.

Crucially, there are always decreasing returns to improvements in transparency, whether or not **(53)** holds. Differentiating **(46)** gives:

$$\frac{d^2\,(g_i)^2}{d\left((g_{iP})^2\right)^2} = \frac{2\,(\omega_3)^2}{\left(\omega_2 - (g_{iP})^2\right)^3} > 0 \Rightarrow \frac{d^2\,(g_i)^2}{d\left((g_\tau)^2\right)^2} > 0 \tag{54}$$

Proposition 3 As the transparency about the inflation objectives improve, the likelihood of market surprises will only improve at a decreasing rate. So smaller falls in the likelihood of market surprises will be observed when transparency is increased further from already high levels. At the extreme the likelihood of market surprises could even rise slightly.

Combining **(49)** and **(51)** yields the slope of the locus between the likelihood of market surprises and the variance of the transparency noise surrounding explanations:

$$\frac{d\,(g_i)^2}{d\,(g_q)^2} = \frac{(\omega_3)^2 - \frac{(\omega_1+1)}{\omega_1}\left(\omega_2 - (g_{iP})^2\right)^2}{(\omega_3)^2 - \left(\omega_2 - (g_{iP})^2\right)^2} \tag{55}$$

From proposition 2 , $\frac{d(g_i)^2}{d(g_q)^2}$ will be positive as long as condition **(53)** holds. $\frac{d(g_i)^2}{d(g_q)^2}$ could be negative at high levels of transparency, if

$$
\begin{aligned}
&\frac{\omega_2 - \omega_3\left(\frac{\omega_1}{1+\omega_1}\right)^{0.5}}{(c_1)^2\left(1 + (g_v)^2\right)^2} - \frac{1}{\left(1 + (g_v)^2\right)} \\
> \quad & (g_\tau)^2 \\
> \quad & \frac{\omega_2 - \omega_3}{(c_1)^2\left(1 + (g_v)^2\right)^2} - \frac{1}{\left(1 + (g_v)^2\right)} \\
\Rightarrow \quad & \frac{d\,(g_i)^2}{d\,(g_q)^2} < 0
\end{aligned}
\tag{56}
$$

Proposition 4 As the transparency of explanations improve, the likelihood of market surprises will, in general, improve also. But at high levels of transparency this relationship may be negative, depending on parameters, so that improvements in the transparency of explanations are associated with a greater likelihood of market surprises.

Propositions 3 and 4 require some intuition. Essentially the convexity with respect to improvements in transparency arises from the beaconing function of policy announcements. That is improved under very transparent regimes where objectives are clearly defined. The greater accuracy of the information they are given enhances the ability of agents to revise their opinions, and there is more active economic decision-making and risk-taking. More transparency raises the sensitivity of short-term inflation expectations and that extra sensitivity feeds back onto interest rate setting. This is a special case of a famous result of LeRoy and Porter (1981) concerning the effect of more information on expectational variables. See LeRoy and Porter (1981, Theorem 2) and Geraats (2002, page 3) for an explanation of why this matters for transparency.

Nevertheless, it is important to recognise that greater transparency is favourable in the sense that it always contributes to improving the ease with which agents can predict shocks. The variance of agents' prediction errors in inflation (and in the economic shocks) is given by

$$
\begin{aligned}
& E\left[\left(\Delta p - E\left[\Delta p \mid I_p\right]\right)^2\right] \\
= \ & E\left[\left(e - E\left[e \mid I_p\right]\right)^2\right], \\
= \ & E\left[\left(e - \frac{c_1}{(\widehat{g_i})^2} i\right)^2\right], \\
= \ & \left(1 + (c_1)^2 \frac{\left((\widehat{g_i})^2 - 1\right)}{(\widehat{g_i})^2}\right) \sigma_e^2
\end{aligned}
\tag{57}
$$

This is an increasing function of the likelihood of market surprises. Given proposition 2, we have the following result:

Proposition 5 In general, the predictability of inflation also improves with transparency surrounding the inflation objective.

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4 Some numerical results

We can also examine the unconditional variances of inflation and output under different regimes, as this is what is usually assumed to only matter for welfare. The unconditional variance of output will be

$$
\begin{aligned}
E\left[(y)^2\right] &= \left(\frac{1}{\beta}\frac{c_1}{(g_i)^2}\right)^2 (g_i)^2\,\sigma_e^2, \\
&= \left(\frac{c_1}{\beta}\right)^2 \frac{(g_{iP})^2}{(g_{iP})^2 + (g_q)^2}\sigma_e^2
\end{aligned}
\tag{58}
$$

the unconditional variance of inflation will be

$$
\begin{aligned}
E\left[(\Delta p)^2\right] &= E\left[\left(\frac{(\widehat{g_{iP}})^2 - \frac{(1+\alpha\beta)}{\alpha\beta}c_1}{(\widehat{g_i})^2}i + e\right)^2\right], \\
&= E\left[\left(\frac{(\widehat{g_{iP}})^2 - \omega_2}{(\widehat{g_i})^2}i + e\right)^2\right], \\
&= \left(\frac{(\widehat{g_{iP}})^4}{(\widehat{g_i})^2}\left((\widehat{g_{iP}})^2 - \omega_2\right)^2 + \frac{c_1}{(\widehat{g_i})^2}\left((\widehat{g_{iP}})^2 - \omega_2\right) + 1\right)\sigma_e^2
\end{aligned}
\tag{59}
$$

and the unconditional variance of agent's inflation expectations will be

$$
E\left[(\Delta p \mid I_p)^2\right] = \frac{\left((g_{iP})^2 - \frac{c_1}{\alpha\beta}\right)^2}{(g_i)^2}
\tag{60}
$$

As these expressions are complex they need to be interpreted through calibrations. Most empirically fitted Phillips curves and IS curves have more dynamics and forward-looking terms and so is not straightforward to map empirical estimates of parameters from these models onto the simple static structure used here. For example Bean (1998) estimates a model of the form

$$
y_t = 1.119 * (1 - d) + 4.39 * (1 - d) * r_{t-1} - 0.466 * d * r_{t-1} + 0.729 * y_{t-1}
$$

and

$$
\Delta p_t = \Delta p_{t-1} + 0.492 * y_{t-1}
$$

on annual data for the United Kingdom (post-war until 1996). The dummy d takes the value of zero before 1972 and unity afterwards, and the variance of the error term in the Phillips curve is estimated to depend on the variance of predicted inflation.

At the cost of making some bold assumptions we can translate Bean's estimates into numerical values for our model. If we assume that α is captured by the static (long-run) effect of real interest rates on output in Bean's model; that empirically inflation expectations are captured by past inflation (Δp_{t-1} represents $E\left[\Delta p \mid \chi, i\right]$); and that the variance of inflation is constant, then we have some rough estimates of coefficients as follows: $\alpha = 0.466 * (1 - 0.729)^{-1} = 2.2$ and $\beta = 0.492$. The level of ignorance is placed at a standard deviation that is half that of the true standard deviation of the shock ($g_v = 0.5$) and the weight on inflation losses is set at $\gamma = 1$. The results are shown for different degrees of transparency about objectives ($g_\tau \in [0, 1]$, and different values of ρ ($\rho \in [0, 1.5]$). Constraints **(48)** and **(50)** will hold at these values.

Charts 1 and 2 plot the variances of market surprises and transparency in explanations as a function of transparency in objectives. These are scaled relative to a unit one standard deviation in the economic shock. We can see that as transparency about the inflation objectives improve ($(g_\tau)^2$ falls to zero), both variances fall. This is as in proposition 2. But they fall at a decreasing rate (proposition 3). Chart 3 shows the locus of the likelihood of market surprises against the variance of the noise surrounding explanations for $\rho = 1$, to show that the locus between the two is in general downward sloping, but might flatten at high levels of transparency (proposition 4).

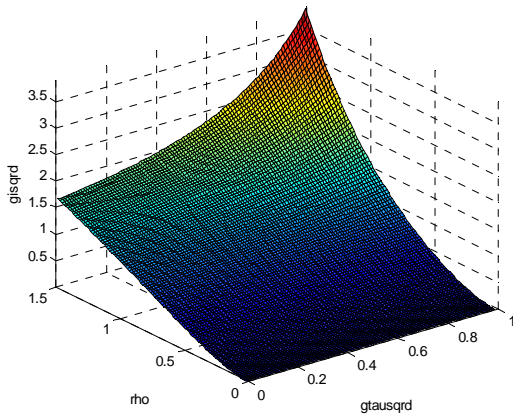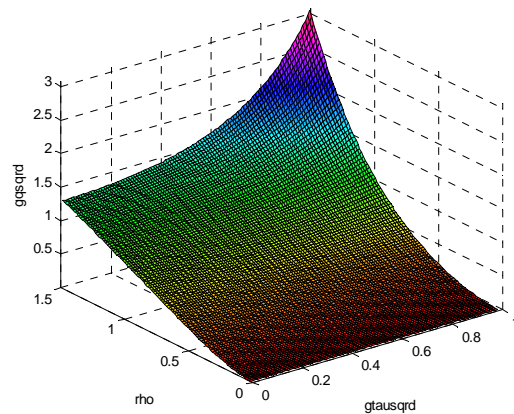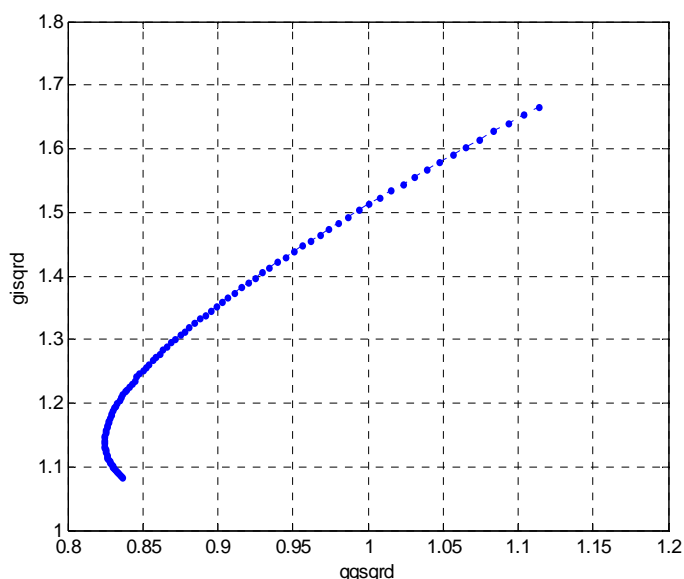**Chart 1: The volatility of market surprises**   **Chart 2: Transparency in explanations**

Chart 3: The locus of volatility of market surprises

against the volatility of transparency

noise in explanations for $\rho = 1$

Note that this is only true when ρ is positive: if the parameter ρ were zero then the likelihood of market surprises or the transparency of explanations would be relatively insensitive to the transparency surrounding objectives. It is the threat represented by a positive ρ that induces policymakers to be transparent with their explanations when given a more transparent objective.

Charts 4 and 5 plot the unconditional volatility of inflation and agents' inflation expectations. For any given value of ρ, these curves are downward sloping. As transparency about objectives is improved, the volatility of inflation and inflation expectations rise, reflecting the greater activity induced by the cleaner signal. However these slopes are fairly flat, indicating that these changes are relatively slight. And this does not mean that the agents' ability to predict worsens: Chart 6 plots the prediction errors in inflation, showing that a positive ρ, the likelihood of these errors recede with greater transparency.
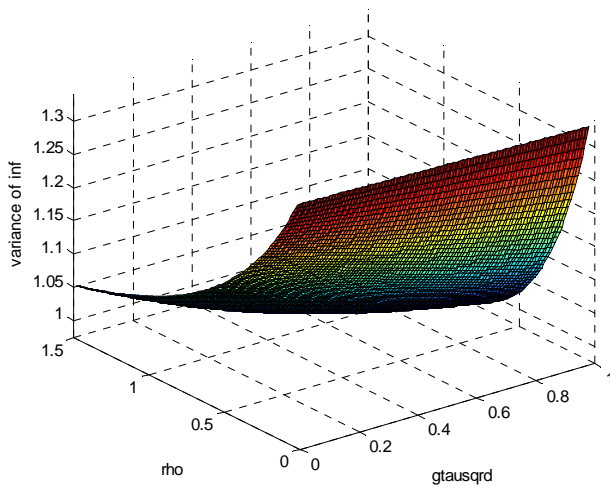
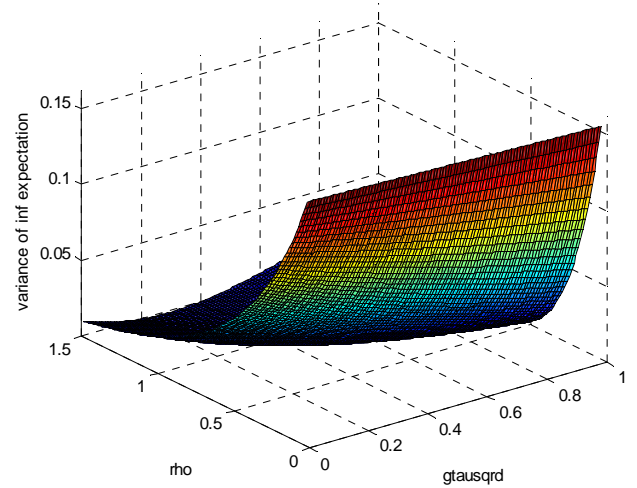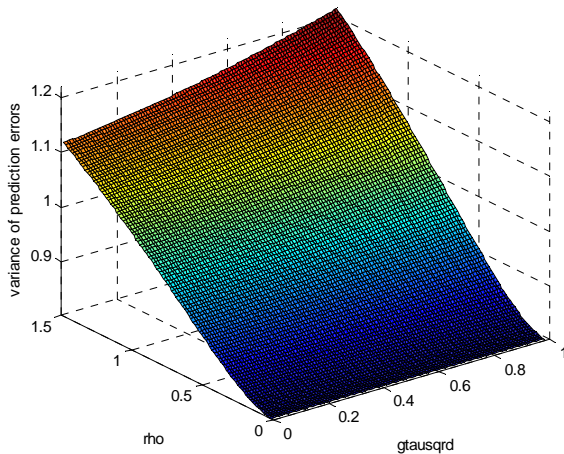**Chart 4: The volatility of inflation**   **Chart 5: The volatility of inflation expectations**

**Chart 6: Inflation prediction errors**

Note also that in Charts 4 and 5, inflation and inflation expectations become more stable as ρ increases when $(g_\tau)^2$ is high. This is because higher values of the parameter ρ make accommodation costly and coerce less credible policymakers into resisting the shock. In this sense, this justifies imposing a positive ρ.

Finally Chart 7 plots the unconditional volatility in output. At moderate values of ρ the unconditional volatility of output falls with greater transparency. But at values of ρ close to one there is a hump shape. The improvements in transparency from low levels imply a more aggressive anti-inflationary stance when ρ is large, and this raises output volatility. Only once

transparency reaches a critical value can the benefit of more stable inflation expectations be felt on the stability of real rates, and so on output.

Chart 7: The volatility of output
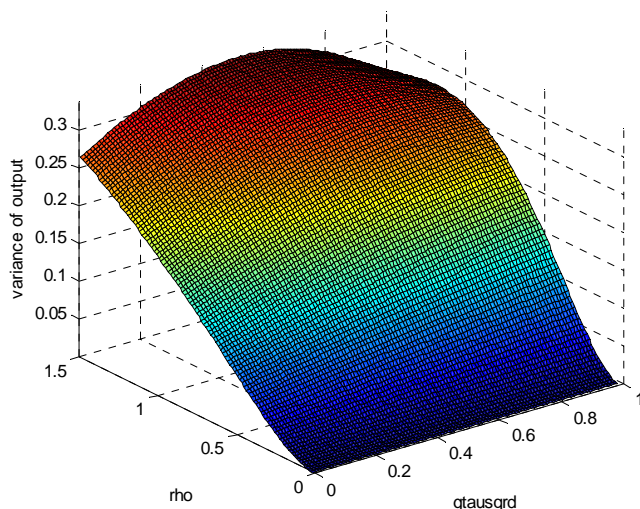
These calculations are at best suggestive: it would be better to derive numerical estimates of these transparency effects which are located in a fully specified dynamic model. But this exercise at least confirms that there are some parameter values which support the propositions and intuitions of the model.

5 Conclusions

This paper presents a model in which there is asymmetric information about policymakers' preferences and over their interpretation of shocks. Agents use policy announcements as a beacon: the policy announcement helps them understand how policymakers interpret shocks and what drives their objectives. In general, greater transparency about objectives promotes greater transparency about explanations and lowers the volatility of market interest rates. But this happens at a decreasing rate, at high levels of transparency, agents rely more on the cleaner signal, and that greater sensitivity of agents' expectations feeds back onto interest rates offsetting the effects of greater transparency.

The empirical evidence in the United Kingdom shows that surprises at closer horizons, in short and medium-term rates, have continued to occur despite falls in the underlying volatility of policy

interest rates. The theoretical findings in this paper suggest that this continued incidence of surprises — and their undiminished influence on near-horizon forecast revisions — should not be necessarily taken as evidence that transparency has deteriorated: they may even be indicative of greater transparency.

It is worth emphasising that greater transparency in general facilitates predictability in this model. Although it is common to see losses approximated by the unconditional volatilities of macroeconomic variables, when we are discussing the effects on improving transparency, predictability should matter too. The model would need to be extended to give a proper account of the separate effects of transparency on unconditional volatility and predictability of variables and also assess the welfare implications of greater accuracy, perhaps following Pearlman (1992) who found similar results in a model of partial but evenly distributed information or building on the insights of Woodford (2001, 2005).

There are other important features missing from this version which should feature in future work even though that will most likely come at the cost of no longer being able to derive analytical expressions. It will be better to work with a micro-founded welfare function that establishes how both the unconditional variances of inflation and output and their conditional values matter for policy setting. It also seems important to bring in more realism, for example to allow for a wider variety of shocks and to build in more backward and forward-looking dynamics into the model.[21]

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(21) Allowing for more shocks could matter. As Ellingsen and Söderström (2001) point out, when there is more than one shock, agents will not be able to directly observe the information of each shock separately from even a clean monetary policy signal.

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