Transparency, Flexibility and Macroeconomic Stabilization*

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Abstract

Many central banks have become more transparent during the last decade, in particular about macroeconomic prospects. This paper shows that such economic transparency could give central banks greater flexibility to respond to macroeconomic shocks. In particular, it allows central banks to stabilize aggregate demand and supply shocks without affecting private sector inflation expectations. In contrast, opaque central banks limit their stabilization efforts to avoid disturbing inflation expectations. As a result, they mute their interest rate response and no longer fully offset anticipated demand shocks. This leads to macroeconomic volatility that is socially detrimental.

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1 Introduction

There has been a remarkable rise in the transparency of monetary policy during the last two decades. A majority of central banks throughout the world nowadays regularly publish their macroeconomic forecasts. This paper shows that such transparency gives the central bank greater flexibility to offset macroeconomic disturbances. In contrast, opacity forces the central bank to limit the stabilization of macroeconomic shocks to prevent upsetting private sector inflation expectations. Thus, an opaque central bank mutes its interest rate response and no longer fully offsets aggregate demand shocks it anticipates. As a result, greater transparency about macroeconomic forecasts leads to more effective stabilization and is welfare improving.

Intuitively, the policy rate set by the central bank reflects both its inflationary intentions and the stabilization of aggregate demand and supply shocks. Transparency about the macroeconomic shocks to which the central bank responds allows the private sector to infer the central bank's inflationary intentions from its policy actions. But when there is opacity, the private sector confuses the central bank's stabilization efforts with changes in policy intentions, thereby causing greater volatility in private sector inflation expectations. This makes opaque central banks more reluctant to use the policy rate to stabilize macroeconomic shocks.

This paper analyzes a two-period model of discretionary monetary policy in the tradition of Kydland and Prescott (1977) and Barro and Gordon (1983). The structure of the economy is described by an expectations-augmented Phillips equation and an aggregate demand equation, where the central bank sets the policy rate. The public is uncertain about the central bank's inflationary intentions and faces asymmetric information about the aggregate demand and supply shocks observed by the central bank. Thus, the model is similar to Geraats (2005), except that it features a central bank objective function that is quadratic in both inflation and output, does not exhibit an inflation bias and allows for intermediate degrees of transparency about macroeconomic shocks. Following Geraats (2002), the latter is referred to as 'economic transparency' and describes the extent to which the private sector faces no asymmetric information about the macroeconomic information used by the central bank for monetary policymaking.

Although Geraats (2005) shows that economic transparency is beneficial because it reduces the inflation bias, much of the rest of the literature has found it to be detrimental. For instance, Cukierman (2001) and Gersbach (2003) show that the release of aggregate supply shocks negatively affects private sector inflation expectations in a simple static model. Using a two-period model with a New Keynesian Phillips curve and uncertainty about the central bank's output gap target, Jensen (2000, 2002) finds that greater transparency hampers the stabilization of supply shocks. Walsh (2007*a*, 2007*b*, 2008), who analyzes announcements to a fraction of agents in the New Keynesian model, also finds that imperfect economic transparency is generally desirable. In contrast to these studies, the present paper shows that transparency about aggregate supply shocks could actually be beneficial and enhance the stabilization of macroeconomic shocks. Thus, it helps to explain why economic transparency has been embraced by so many central banks (Geraats 2009).

Regarding the remainder of the paper, the model is presented in section 2 and the solution in section 3. Section 4 examines the effects of greater macroeconomic transparency on the volatility the interest rate, inflation and output, and on expected social welfare. The discussion section 5 explains how robust the results are to extensions of the model, and section 6 concludes.

2 Model

The central bank has the objective function

$$W_t = -\frac{1}{2}\alpha\left(\pi_t - \tau\right)^2 - \frac{1}{2}\left(y_t - \bar{y}\right)^2 \qquad (1)$$

where π_t is the rate of inflation; y_t is the level of real output; τ is the central bank's inflation target, which is stochastic but time-invariant: $\tau \sim N\left(\bar{\tau}, \sigma_\tau^2\right)$ with $\sigma_\tau^2 > 0$; $\bar{y}$ equals the natural rate of output; α is the relative weight on inflation stabilization ($\alpha > 0$); and the subscript t denotes the time period, $t \in \{1, 2\}$. The central banker is in office for two periods and maximizes the expected valued of

$$U = W_1 + \delta W_2 \qquad (2)$$

where δ is the intertemporal discount factor($0 < \delta \leq 1$).

The structure of the economy is described as follows. The demand for output satisfies

$$y_t = \bar{y} - \gamma\left(i_t - \pi_t^e - \bar{r}\right) + d_t \qquad (3)$$

where i_t is the nominal interest rate; π_t^e denotes inflation expectations formed by the private sector; d_t is an aggregate demand shock: $d_t \sim N\left(0, \sigma_d^2\right)$ with $\sigma_d^2 > 0$; and $\bar{r}$ is the long-run, ex ante real interest rate. The supply of output satisfies the aggregate supply (or price adjustment) relation

$$\pi_t = \pi_t^e + \beta\left(y_t - \bar{y}\right) - s_t \qquad (4)$$

where s_t is a (beneficial) aggregate supply shock: $s_t \sim N(0, \sigma_s^2)$ with $\sigma_s^2 > 0$. It is assumed that τ, d_t and s_t are independent. The structure of the economy is kept simple to keep the algebra tractable and obtain analytical results, in contrast to much of the related literature, which depends on numerical findings.

The central bank is assumed to know the aggregate demand and supply shocks (d_t, s_t), either through direct observation or by means of perfect forecasting. Imperfect central bank forecasts could be introduced but would not affect the conclusions.

A crucial assumption is that the private sector does not have the same information as the central bank. There are two sources of asymmetric information. First, the private sector only observes a signal of the demand and supply shocks. More precisely, the economic shocks can be decomposed into an unbiased public signal (ξ_t^d, ξ_t^s) and an independent white noise shock (η_t^d, η_t^s) only observed by the central bank:

$$d_t = \xi_t^d + \eta_t^d \quad (5)$$

$$s_t = \xi_t^s + \eta_t^s \quad (6)$$

The public's forecast errors depend on the extent of the information asymmetry: $\eta_t^d \sim N(0, (1-\kappa_d)\sigma_d^2)$ and $\eta_t^s \sim N(0, (1-\kappa_s)\sigma_s^2)$, where $0 \leq \kappa_d \leq 1$, $0 \leq \kappa_s \leq 1$, and η_t^d and η_t^s are assumed to be independent of τ. The parameters κ_d and κ_s provide a measure of the degree of economic transparency. In the special case of $\kappa_d = \kappa_s = 0$, the public is completely ignorant about the economic disturbances ($\xi_t^d = \xi_t^s = 0$); for $\kappa_d = \kappa_s = 1$, perfect transparency about the macroeconomic shocks prevails ($\xi_t^d = d_t$, $\xi_t^s = s_t$). The assumption that the central bank may have access to superior economic information is consistent with empirical evidence provided by Peek, Rosengren and Tootell (1999) and Romer and Romer (2000). The model could be modified to allow for a private sector information advantage, in which case indeterminacies may arise if the central bank attempts to infer information from private sector inflation expectations (Bernanke and Woodford 1997). But if the central bank would refrain from such attempts, the conclusions of the present model would be the same because any information asymmetry regarding economic disturbances suffices.

The second source of asymmetric information is that the private sector faces some initial uncertainty about the inflation target τ that the central bank pursues. This could be the case even if there exists an explicit inflation target, as the latter is often formulated as a range and need not be perfectly credible. In addition, the central bank's preferences cannot be directly observed. So, the absence of complete certainty about preferences appears plausible and a tiny amount of ex ante uncertainty $\sigma_\tau^2 > 0$ already suffices to obtain the results in this paper. Although other forms of preference uncertainty may be more appealing, for instance about the relative weight on inflation stabilization, this would come at the loss of analytical tractability.

The timing of events as follows. Before the first period, the central bank's inflation target τ is drawn by nature but only observed by the central bank. In addition, private sector inflation expectations π_1^e are formed using its prior on τ. In the first period, the public signals ξ_1^d and ξ_1^s are revealed, and the central bank observes the economic disturbances d_1 and s_1, and sets the nominal interest rate i_1 accordingly. At the end of the first period, the private sector updates its prior on τ using the nominal interest rate i_1 and public signals (ξ_1^d, ξ_1^s). So, its first-period posterior of τ depends on the degree of economic transparency (κ_d, κ_s) and is incorporated into private sector inflation expectations π_2^e. At the beginning of the second period, the levels of inflation π_1 and output y_1 are observed. In addition, the public signals ξ_2^d and ξ_2^s are revealed, and the central bank observes the economic disturbances d_2 and s_2, and sets the nominal interest rate i_2. After this last period, inflation π_2 and output y_2 are known.

The assumption that information on inflation π_1 and output y_1 is not available when the private sector forms its inflation expectations π_2^e is due to lags in the effect of monetary policy decisions. Since the macroeconomic outcome of a previous decision is not yet known, the private sector uses the policy instrument and its information about economic disturbances to determine inflation expectations, which are relevant for the next policy decision. This captures the prevalent practice that the private sector pays close attention to the central bank's interest rate decisions to infer its intentions.

It is assumed that people have rational expectations. Formally, the information set available to the public when it forms its inflation expectations π_1^e and π_2^e equals $\Omega \equiv \{\bar{r}, \bar{y}, \alpha, \beta, \gamma, \delta, \kappa_d, \kappa_s, \bar{\tau}, \sigma_\tau^2, \sigma_d^2, \sigma_s^2\}$ and $\{i_1, \Omega_1\}$, respectively, where $\Omega_1 \equiv \left\{\xi_1^d, \xi_1^s, \Omega\right\}$. The next section provides the solution to the model.

3 Solution

The model is solved by backwards induction. In period two, the central bank maximizes W_2 with respect to i_2 subject to (4) and (3), and given π_2^e, d_2 and s_2. The first order condition implies

$$i_2 = \bar{r} + \pi_2^e - \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\left(\tau - \pi_2^e\right) + \frac{1}{\gamma}d_2 - \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}s_2 \tag{7}$$

Using (3) and (4) this yields

$$y_2 = \bar{y} + \frac{\alpha\beta}{1+\alpha\beta^2}\left(\tau - \pi_2^e\right) + \frac{\alpha\beta}{1+\alpha\beta^2} s_2 \tag{8}$$

$$\pi_2 = \pi_2^e + \frac{\alpha\beta^2}{1+\alpha\beta^2}\left(\tau - \pi_2^e\right) - \frac{1}{1+\alpha\beta^2} s_2 \tag{9}$$

An inflation target above the expected rate of inflation has an expansionary effect and reduces the interest rate and increases output and inflation. Demand shocks d are fully offset by an increase in the interest rate, whereas the effect of a (deflationary) supply shock s is partially neutralized by a decrease in the interest rate that raises output. A more conservative central bank (higher α) has a stronger interest rate response to supply shocks, which therefore have a larger effect on output but a smaller impact on inflation.

Substituting (8) and (9) into (1) and taking expectations conditional on τ and π_2^e gives

$$\mathrm{E}\left[W_2|\tau, \pi_2^e\right] = -\frac{1}{2}\frac{\alpha}{1+\alpha\beta^2}\left[\left(\pi_2^e - \tau\right)^2 + \sigma_s^2\right] \tag{10}$$

where moment operators with subscript t are conditional on the information set Ω_t. The expected payoff to the central bank in period two is maximized when the private sector perfectly anticipates the central bank's type: $\pi_2^e = \tau$. Thus, it is in the central bank's interest to reveal its type through its policy action i_1.

Facing imperfect information, the private sector uses the nominal interest rate i_1 and the public signals ξ_1^d and ξ_1^s to update its prior on τ and form its inflation expectations π_2^e. Suppose that the private sector uses the following updating equation:

$$\pi_2^e = u_0 + u_i i_1 + u_d \xi_1^d + u_s \xi_1^s \tag{11}$$

Below it is shown that this is consistent with a rational expectations equilibrium.[1] The simple linear structure follows from the normality assumptions on τ, η_1^d and η_1^s.

In the first period, the central bank maximizes the expected value of (2) with respect to i_1 subject to (4) and (3), given π_1^e, d_1 and s_1, and using (1), (10) and (11). The first order condition implies

$$\begin{aligned} i_1 = \frac{1}{\left(1+\alpha\beta^2\right)^2\gamma^2 + \delta\alpha u_i^2} \Big[& \left(1+\alpha\beta^2\right)^2 \gamma^2 \left(\bar{r} + \pi_1^e\right) - \alpha\beta\gamma\left(1+\alpha\beta^2\right)\left(\tau - \pi_1^e\right) + \delta\alpha u_i \left(\tau - u_0\right) \\ & - \delta\alpha u_i \left(u_d \xi_1^d + u_s \xi_1^s\right) + \left(1+\alpha\beta^2\right)^2 \gamma d_1 - \alpha\beta\gamma\left(1+\alpha\beta^2\right) s_1 \Big] \end{aligned} \tag{12}$$

[1] Although multiple rational expectations equilibria may exist, this specification precludes sunspots and satisfies McCallum's (1983) minimum-state-variable criterion.

The updating coefficients u_0, u_i, u_d and u_s can be found using the condition for rational expectations: $\pi_2^e = \mathrm{E}_1[\pi_2|i_1]$. Taking expectations and rearranging (9) gives $\pi_2^e = \mathrm{E}_1[\tau|i_1]$. Before tackling the general case, it is instructive to first consider the special case of perfect economic transparency.

3.1 Perfect Economic Transparency

In the case of perfect economic transparency, which is indicated by superscript T, $\kappa_d = \kappa_s = 1$, so that $d_t = \xi_t^d$ and $s_t = \xi_t^s$. In that case, (12) can be used to infer the central bank's inflation target τ from the interest rate i_1: $\mathrm{E}_1^T[\tau|i_1] = \tau$. Hence, $(\pi_2^e)^T = \mathrm{E}_1^T[\tau|i_1] = \tau$. Solving (12) for τ, matching coefficients with (11) and rearranging yields[2]

$$u_0^T = (\pi_1^e)^T + \frac{1+\alpha\beta^2}{\alpha\beta}\gamma\left[\bar{r} + (\pi_1^e)^T\right] \tag{13}$$

$$u_i^T = -\frac{1+\alpha\beta^2}{\alpha\beta}\gamma \tag{14}$$

$$u_d^T = \frac{1+\alpha\beta^2}{\alpha\beta} \tag{15}$$

$$u_s^T = -1 \tag{16}$$

Intuitively, a higher interest rate i_1 reduces inflation expectations ($u_i^T < 0$) as it is (correctly) attributed to a lower inflation target τ. In addition, a higher (perceived) demand shock ξ_1^d leads to higher inflation expectations π_2^e for a given interest rate i_1 ($u_d^T > 0$) as the inflation target τ implied by i_1 rises. Similarly, a higher (perceived) supply shock ξ_1^s lowers inflation expectations π_2^e given i_1 ($u_s^T < 0$) as the implied inflation target τ declines.

Substituting these updating equations into (12), using $\xi_t^d = d_t$ and $\xi_t^s = s_t$, and simplifying produces the nominal interest rate under perfect economic transparency:

$$i_1^T = \bar{r} + (\pi_1^e)^T - \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\left[\tau - (\pi_1^e)^T\right] + \frac{1}{\gamma}d_1 - \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}s_1 \tag{17}$$

Substituting (17) into (3) and (4), and imposing rational expectations (so that $(\pi_1^e)^T = \bar{\tau}$) gives

$$y_1^T = \bar{y} + \frac{\alpha\beta}{1+\alpha\beta^2}(\tau - \bar{\tau}) + \frac{\alpha\beta}{1+\alpha\beta^2}s_1 \tag{18}$$

$$\pi_1^T = \bar{\tau} + \frac{\alpha\beta^2}{1+\alpha\beta^2}(\tau - \bar{\tau}) - \frac{1}{1+\alpha\beta^2}s_1 \tag{19}$$

[2]The derivation is available in appendix A.1.

These expressions are similar to the ones for the second period. Demand shocks are again completely offset by monetary policy.

Finally, the expected payoff to the central bank under perfect economic transparency can be found using (2) after substituting (18) and (19) into (1) and $(\pi_2^e)^T = \tau$ into (10):

$$\mathrm{E}\left[U^T|\tau\right] = -\frac{1}{2}\frac{\alpha}{1+\alpha\beta^2}\left(\tau-\bar{\tau}\right)^2 - \frac{1}{2}\frac{\alpha}{1+\alpha\beta^2}\left(1+\delta\right)\sigma_s^2. \tag{20}$$

This shows that the expected payoff to the central bank is decreasing in the difference between the inflation target τ and the public's prior of it $\bar{\tau}$, and in the variance of supply shocks σ_s^2. The variance of demand shocks σ_d^2 is immaterial as they are fully offset under economic transparency.

3.2 General Case

Except for the special case of perfect economic transparency, the nominal interest rate i_1 and the public signals ξ_1^d and ξ_1^s generally do not suffice to infer the central bank's inflation target τ. To find the updating coefficients, use the fact that (12) implies that i_1 and τ have a jointly normal distribution, so that

$$\pi_2^e = \mathrm{E}_1\left[\tau|i_1\right] = \mathrm{E}_1\left[\tau\right] + \frac{\mathrm{Cov}_1\left\{i_1,\tau\right\}}{\mathrm{Var}_1\left[i_1\right]}\left(i_1 - \mathrm{E}_1\left[i_1\right]\right) \tag{21}$$

where a moment operator with subscript 1 indicates it is conditional on Ω_1. Using (12), (5) and (6), and matching coefficients between (21) and (11), and rearranging gives the following expression for u_i:[3]

$$\begin{aligned}
&-\alpha^2\beta\gamma\delta\sigma_\tau^2 u_i^2 \\
&+\left(1+\alpha\beta^2\right)\left[\alpha\left(\alpha\beta^2-\delta\right)\gamma^2\sigma_\tau^2 + \left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2 + \left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2\right]u_i \\
&\qquad + \alpha\beta\gamma^3\left(1+\alpha\beta^2\right)^2\sigma_\tau^2 = 0.
\end{aligned}$$

This equation has two real roots, $u_i^- < 0$ and $u_i^+ > 0$. However, the positive root u_i^+ can be excluded based on an argument by McCallum (1983). The reason is that u_i^+ is not valid for all admissible parameter values, because $\lim_{\kappa_d,\kappa_s\to 1} u_i^+ \neq u_i^T$. The remaining negative root can be written as

$$\begin{aligned}
u_i = \frac{1+\alpha\beta^2}{2\alpha^2\beta\gamma\delta\sigma_\tau^2}\Bigg\{&\alpha\left(\alpha\beta^2-\delta\right)\gamma^2\sigma_\tau^2 + \left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2 + \left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2 \\
&-\sqrt{\begin{array}{c}\left[\alpha\left(\alpha\beta^2+\delta\right)\gamma^2\sigma_\tau^2 + \left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2 + \left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2\right]^2 \\ -4\alpha\gamma^2\delta\left[\left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2 + \left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2\right]\sigma_\tau^2\end{array}}\Bigg\}
\end{aligned} \tag{22}$$

[3] The derivations for this section are in Appendix A.2.

From this it follows that $u_i \geq -\left(1+\alpha\beta^2\right)\gamma/\alpha\beta$, with a strict inequality if $\kappa_d \neq 1$ and/or $\kappa_s \neq 1$. Hence, $|u_i| \leq \left|u_i^T\right|$; the magnitude of the effect of the interest rate on inflation expectations is smaller under opacity because it is a noisier signal of the inflation target. Concerning intermediate degrees of transparency, $du_i/d\kappa_m \leq 0$ with a strict inequality if $\sigma_m^2 > 0$, where $m \in \{d, s\}$ denotes the macroeconomic shock. So, the magnitude of the sensitivity u_i of private sector inflation expectations π_2^e to the policy rate i_1 is increasing in the degree of economic transparency κ_m as the policy rate becomes a more accurate signal of the inflation target.

Regarding the other updating coefficients, matching coefficients and rearranging gives

$$u_0 = \bar{\tau} + u_i \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\left(\bar{\tau} - \pi_1^e\right) - u_i\left(\bar{r} + \pi_1^e\right) \tag{23}$$

$$u_d = -\frac{1}{\gamma}u_i \tag{24}$$

$$u_s = \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i \tag{25}$$

Intuitively, a higher interest rate i_1 reduces inflation expectations ($u_i < 0$) as it is partly attributed to a lower inflation target τ. In addition, a higher perceived demand [supply] shock ξ_1^d [ξ_1^s] leads to higher [lower] inflation expectations π_2^e for a given interest rate i_1 ($u_d > 0$, $u_s < 0$) as the inflation target τ implied by i_1 rises [falls]. Compared to perfect economic transparency, these effects are qualitatively the same, but they are more muted since the private sector faces greater uncertainty about these signals.

Substituting these updating coefficients into (12), using (5) and (6), and simplifying gives the nominal interest rate:

$$\begin{aligned} i_1 = {} & \bar{r} + \pi_1^e - \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\left(\tau - \pi_1^e\right) + (1-\mu)\left(\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma} + \frac{1}{u_i}\right)(\tau - \bar{\tau}) \\ & + \frac{1}{\gamma}\left(\xi_1^d + \mu\eta_1^d\right) - \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\left(\xi_1^s + \mu\eta_1^s\right) \end{aligned} \tag{26}$$

where $\mu \equiv \frac{\left(1+\alpha\beta^2\right)^2\gamma^2}{\left(1+\alpha\beta^2\right)^2\gamma^2 + \delta\alpha u_i^2}$ ($0 < \mu < 1$). Note that in the special case of perfect economic transparency, $u_i = -\left(1+\alpha\beta^2\right)\gamma/\alpha\beta$, $d_1 = \xi_1^d$, $s_1 = \xi_1^s$ and $\eta_1^d = \eta_1^s = 0$, so that (26) reduces to (17). Demand and supply shocks that are publicly anticipated (ξ_1^d and ξ_1^s) have the same effect as under transparency. However, the responsiveness of the interest rate to economic disturbances that are not anticipated by the private sector (η_1^d and η_1^s) is smaller under opacity. The reason is that the central bank is concerned about affecting private sector inflation expectations. As a consequence, (publicly unanticipated) demand shocks are no longer completely offset.

Substitute (26) into (3) and (4), use (5) and (6), and impose rational expectations (which yields $\pi_1^e = \bar{\tau}$) to get output and inflation:

$$
\begin{aligned}
y_1 &= \bar{y} + \left[\frac{\alpha\beta}{1+\alpha\beta^2} - (1-\mu)\left(\frac{1}{u_i} + \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\right)\gamma\right](\tau - \bar{\tau}) \\
&\quad + (1-\mu)\,\eta_1^d + \frac{\alpha\beta}{1+\alpha\beta^2}\left(\xi_1^s + \mu\eta_1^s\right) \qquad (27) \\
\pi_1 &= \bar{\tau} + \left[\frac{\alpha\beta^2}{1+\alpha\beta^2} - (1-\mu)\left(\frac{1}{u_i} + \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\right)\beta\gamma\right](\tau - \bar{\tau}) \\
&\quad + \beta(1-\mu)\,\eta_1^d - \frac{1}{1+\alpha\beta^2}\left(\xi_1^s + \left[1 + (1-\mu)\,\alpha\beta^2\right]\eta_1^s\right) \qquad (28)
\end{aligned}
$$

Although demand shocks anticipated by the public (ξ_1^d) are perfectly offset, the central bank reduces its response to publicly unanticipated demand shocks (η_1^d), which therefore affect both output and inflation. A publicly anticipated (deflationary) supply shock (ξ_1^s) leads to more expansionary monetary policy, which raises output and partly offsets the effect of the shock on inflation. For publicly unanticipated supply shocks (η_1^s), the central bank responds less so that the effect on output is smaller and the impact on inflation is larger. Note that $u_i < 0$ and $0 < \mu < 1$ imply that the coefficient of $(\tau - \bar{\tau})$ is positive. Intuitively, if the inflation target τ is higher than the public's prior $\bar{\tau}$, the central bank implements more expansionary policy than anticipated, which increases both output and inflation. In the special case of perfect economic transparency, $u_i = -\left(1+\alpha\beta^2\right)\gamma/\alpha\beta$, $d_1 = \xi_1^d$, $s_1 = \xi_1^s$ and $\eta_1^d = \eta_1^s = 0$, so that (27) and (28) reduce to (18) and (19), respectively.

Using (26), $\pi_1^e = \bar{\tau}$ and the fact that $\operatorname{Var}[\eta_t^m] = (1-\kappa_m)\,\sigma_m^2$ and $\operatorname{Var}[\xi_t^m] = \kappa_m\sigma_m^2$, where $m \in \{d, s\}$ denotes the macroeconomic shock, the volatility of the interest rate i_1 (for a given inflation target τ) equals[4]

$$
\operatorname{Var}[i_1|\tau] = \frac{1}{\gamma^2}\left[1 - \left(1-\mu^2\right)(1-\kappa_d)\right]\sigma_d^2 + \frac{(\alpha\beta)^2}{\left(1+\alpha\beta^2\right)^2\gamma^2}\left[1 - \left(1-\mu^2\right)(1-\kappa_s)\right]\sigma_s^2 \qquad (29)
$$

In the case of perfect economic transparency ($\kappa_d = \kappa_s = 1$), this reduces to $\operatorname{Var}\left[i_1^T|\tau\right] = \frac{1}{\gamma^2}\sigma_d^2 + \frac{(\alpha\beta)^2}{\left(1+\alpha\beta^2\right)^2\gamma^2}\sigma_s^2$. Clearly, $\operatorname{Var}[i_1|\tau] \leq \operatorname{Var}\left[i_1^T|\tau\right]$, with a strict inequality in the case of some economic opacity ($\kappa_d \neq 1$ or $\kappa_s \neq 1$). Intuitively, the lack of economic transparency induces the central bank to limit its adjustment of the policy rate in response to macroeconomic shocks to avoid affecting private sector inflation expectations. As a result, economic opacity leads to a muted interest rate response.

[4]Note that $1 - \left(1-\mu^2\right)(1-\kappa_m) = \kappa_m + \mu^2(1-\kappa_m)$.

Regarding the volatility of output and inflation (given the inflation target τ), (27) and (28) imply that

$$\begin{aligned} \text{Var}\left[y_1|\tau\right] &= (1-\mu)^2(1-\kappa_d)\sigma_d^2 + \frac{(\alpha\beta)^2}{\left(1+\alpha\beta^2\right)^2}\left[1-\left(1-\mu^2\right)(1-\kappa_s)\right]\sigma_s^2 \quad (30) \\ \text{Var}\left[\pi_1|\tau\right] &= \beta^2(1-\mu)^2(1-\kappa_d)\sigma_d^2 \quad (31) \\ &\quad + \frac{1}{\left(1+\alpha\beta^2\right)^2}\left[\kappa_s + \left[1+(1-\mu)\alpha\beta^2\right]^2(1-\kappa_s)\right]\sigma_s^2 \end{aligned}$$

In the case of perfect economic transparency ($\kappa_d = \kappa_s = 1$), this reduces to $\text{Var}\left[y_1^T|\tau\right] = \frac{(\alpha\beta)^2}{\left(1+\alpha\beta^2\right)^2}\sigma_s^2$ and $\text{Var}\left[\pi_1^T|\tau\right] = \frac{1}{\left(1+\alpha\beta^2\right)^2}\sigma_s^2$. This shows that economic transparency reduces output volatility due to demand shocks, but increases it for supply shocks, so the net effect is ambiguous. The variance of inflation is unambiguously lower under economic transparency for both demand and supply shocks, so that $\text{Var}\left[\pi_1|\tau\right] \geq \text{Var}\left[\pi_1^T|\tau\right]$.[5] The intuition is that the enhanced flexibility under economic transparency allows the central bank to respond more vigorously to demand shocks, which decreases the variance of both output and inflation, and to supply shocks, which increases output volatility but reduces inflation variability.

The degree of opacity also affects macroeconomic volatility in the second period due to the noise it creates in private sector inflation expectations π_2^e. Substituting (23), (24), (25) and (26) into (11) produces

$$\pi_2^e = \tau - \mu\left(1 + \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)(\tau - \bar{\tau}) + \frac{1}{\gamma}u_i\mu\eta_1^d - \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\mu\eta_1^s \quad (32)$$

Intuitively, economic shocks η^d and η^s that are unanticipated by the public affect their inflation expectations because the corresponding interest rate response is partially attributed to the central bank's inflation target. In the case of perfect economic transparency, $u_i = -\left(1+\alpha\beta^2\right)\gamma/\alpha\beta$ and $\eta_1^d = \eta_1^s = 0$, yielding $\left(\pi_2^e\right)^T = \tau$, as in section 3.1. The volatility of private sector inflation expectations (for a given inflation target τ) are equal to

$$\text{Var}\left[\pi_2^e|\tau\right] = \frac{1}{\gamma^2}u_i^2\mu^2(1-\kappa_d)\sigma_d^2 + \frac{(\alpha\beta)^2}{\left(1+\alpha\beta^2\right)^2\gamma^2}u_i^2\mu^2(1-\kappa_s)\sigma_s^2 \quad (33)$$

Clearly, $\text{Var}\left[\pi_2^e|\tau\right] \geq \text{Var}\left[\left(\pi_2^e\right)^T|\tau\right] = 0$, with a strict inequality in the case of some economic opacity ($\kappa_d \neq 1$ or $\kappa_s \neq 1$).

[5] Note that $\kappa_s + \left[1+(1-\mu)\alpha\beta^2\right]^2(1-\kappa_s) = 1 + \left[2+(1-\mu)\alpha\beta^2\right](1-\mu)\alpha\beta^2(1-\kappa_s) \geq 1$.

Regarding the variability of the interest rate, output and inflation in the second period, (7), (8) and (9) yield

$$
\begin{aligned}
\operatorname{Var}[i_2|\tau] &= \left[1+\frac{\alpha\beta}{(1+\alpha\beta^2)\gamma}\right]^2 \operatorname{Var}[\pi_2^e|\tau] + \frac{1}{\gamma^2}\sigma_d^2 + \left[\frac{\alpha\beta}{(1+\alpha\beta^2)\gamma}\right]^2 \sigma_s^2 \\
\operatorname{Var}[y_2|\tau] &= \left(\frac{\alpha\beta}{1+\alpha\beta^2}\right)^2 \left\{\operatorname{Var}[\pi_2^e|\tau] + \sigma_s^2\right\} \\
\operatorname{Var}[\pi_2|\tau] &= \left(\frac{1}{1+\alpha\beta^2}\right)^2 \left\{\operatorname{Var}[\pi_2^e|\tau] + \sigma_s^2\right\}
\end{aligned}
$$

So, $\operatorname{Var}[i_2|\tau] \geq \operatorname{Var}\left[i_2^T|\tau\right]$, $\operatorname{Var}[y_2|\tau] \geq \operatorname{Var}\left[y_2^T|\tau\right]$ and $\operatorname{Var}[\pi_2|\tau] \geq \operatorname{Var}\left[\pi_2^T|\tau\right]$, with a strict inequality in the case of some economic opacity ($\kappa_m \neq 1$). As a result, the greater stability of private sector inflation expectations under economic transparency contributes to lower overall macroeconomic volatility in the second period.

4 Effects of Greater Macroeconomic Transparency

The previous section has derived how perfect transparency about macroeconomic shocks affects the interest rate, inflation (expectations) and output. This section examines intermediate degrees of transparency and shows the effect of greater macroeconomic transparency on the volatility of the interest rate, inflation (expectations) and output (in section 4.1) and on expected social welfare (in section 4.2).

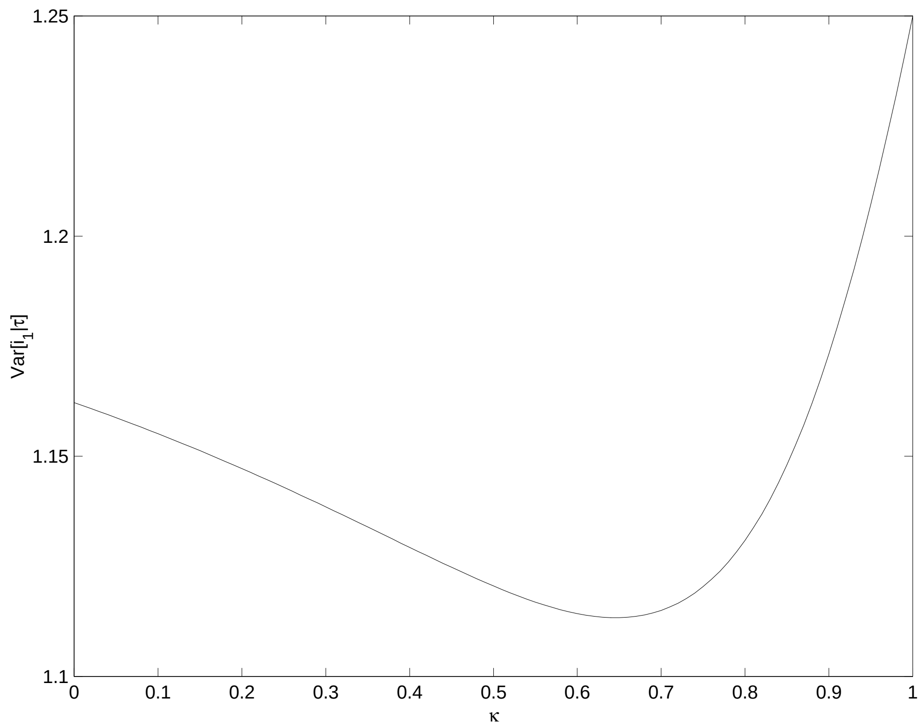
4.1 Macroeconomic Volatility

The analysis so far has shown that perfect economic transparency (i.e. $\kappa_d = \kappa_s = 1$) leads to greater interest rate variability ($\operatorname{Var}[i_1|\tau]$), but reduces the volatility of inflation and inflation expectations ($\operatorname{Var}[\pi_1|\tau]$ and $\operatorname{Var}[\pi_2^e|\tau]$), while the effect on output volatility ($\operatorname{Var}[y_1|\tau]$) is ambiguous. For intermediate degrees of transparency, (29), (30), (31) and (33) show that the effect of a change in κ_m depends on $d\mu/d\kappa_m$. Since $d\mu/du_i > 0$ and $du_i/d\kappa_m < 0$ it follows that $d\mu/d\kappa_m < 0$.[6] So, the effect of κ_m on macroeconomic volatility is in principle ambiguous.

To facilitate the analysis, assume that $\kappa_d = \kappa_s = \kappa$, i.e. the degree of economic transparency is the same for demand and supply shocks. Then it is straightforward to show that $\lim_{\kappa\to 1} d\operatorname{Var}[i_1|\tau]/d\kappa > 0$, $\lim_{\kappa\to 1} d\operatorname{Var}[\pi_1|\tau]/d\kappa < 0$ and $\lim_{\kappa\to 1} d\operatorname{Var}[\pi_2^e|\tau]/d\kappa <$

[6] Recall that $\mu \equiv (1+\alpha)^2 / \left[(1+\alpha)^2 + \delta\alpha u_i^2\right]$ and $u_i < 0$.

Figure 1: The effect of economic transparency on interest rate variability

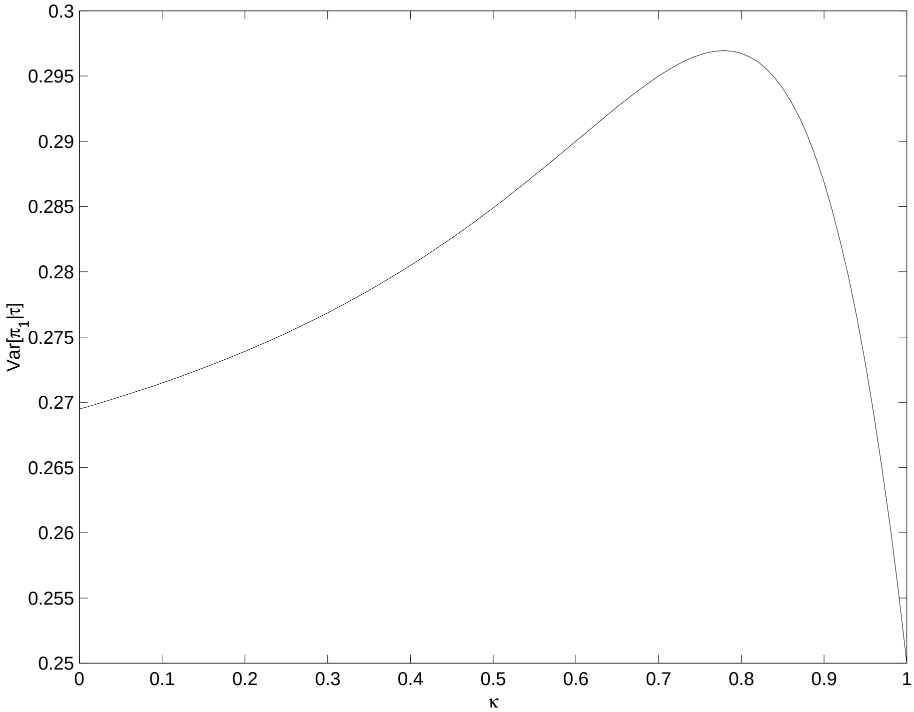


The effect of economic transparency κ for parameter values $\alpha = \beta = \gamma = \delta = 1$ and $\sigma_\tau^2 = \sigma_d^2 = \sigma_s^2 = 1$.

0. So, greater macroeconomic transparency increases interest rate variability but decreases the volatility of inflation and inflation expectations for sufficiently high κ. For lower κ the effects tend to be reversed. This is illustrated in Figures 1, 2 and 4 for the parameter configuration $\alpha = \beta = \gamma = \delta = 1$ and $\sigma_\tau^2 = \sigma_d^2 = \sigma_s^2 = 1$.

Figure 1 shows that starting from complete opacity ($\kappa = 0$), higher macroeconomic transparency κ initially reduces and subsequently increases interest rate variability. Intuitively, for low levels of economic transparency, the interest rate i_1 is dominated by the central bank's response to publicly unanticipated shocks η_1^m. As the degree of economic transparency rises, the public rationally increases its reliance on the interest rate i_1 to update its inflation expectations π_2^e, so the central bank reduces its response to unanticipated shocks to prevent upsetting private sector expectations. Hence, the variability of the interest rate i_1 initially declines. But for a sufficiently high level of economic transparency, publicly anticipated shocks ξ_1^m start prevailing. Since the central bank need not mute its response to these shocks, the variance of the interest rate increases as anticipated shocks become more important at higher levels of economic transparency. As a result, there is a U-shaped effect on interest rate volatility.

Figure 2: The effect of economic transparency on inflation volatility



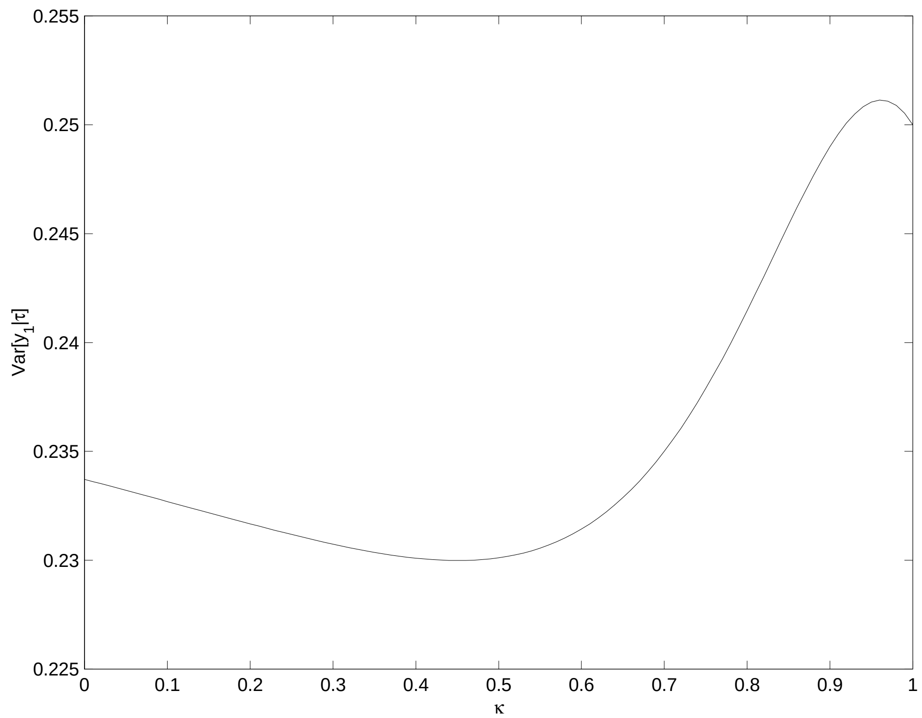
The effect of economic transparency κ for parameter values $\alpha = \beta = \gamma = \delta = 1$ and $\sigma_\tau^2 = \sigma_d^2 = \sigma_s^2 = 1$.

Figure 2 shows that more macroeconomic transparency κ initially raises and subsequently reduces inflation volatility in period one. As explained above, a rise in economic transparency causes the central bank to reduce its interest rate response to publicly unanticipated shocks, which therefore cause greater inflation volatility. But for higher levels of economic transparency, publicly anticipated shocks start becoming more important. These are adequately offset by the central bank, resulting in a reduction of the variability of inflation.

The effect of higher macroeconomic transparency κ on output volatility in period one exhibits a more peculiar pattern. For the baseline case of $\alpha = \beta = \gamma = \delta = 1$ and $\sigma_\tau^2 = \sigma_d^2 = \sigma_s^2 = 1$ shown in Figure 3, the variance of y_1 is initially decreasing, then increasing and finally decreasing again. However, this result is very sensitive to the parameter values. In particular, for higher values of α or σ_s^2, or lower values of σ_d^2 the response becomes U-shaped, whereas for higher values of σ_τ^2, the response becomes hump-shaped. Clearly, the effect of macroeconomic transparency on first period output volatility critically depends on the precise parameter configuration.

In the second period, greater macroeconomic transparency κ initially raises and sub-

Figure 3: The effect of economic transparency on output volatility

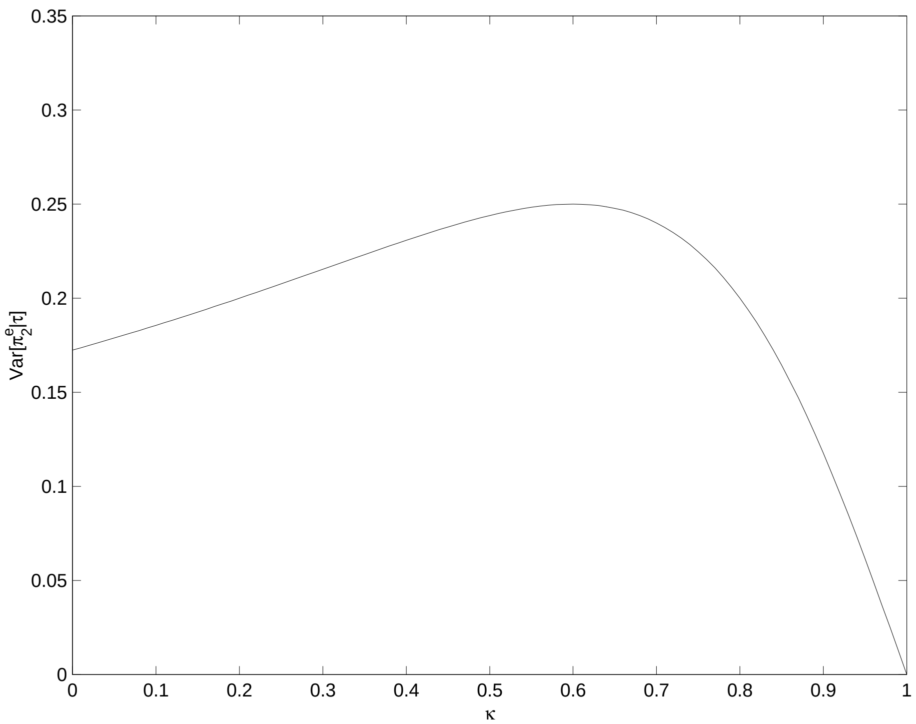


The effect of economic transparency κ for parameter values $\alpha = \beta = \gamma = \delta = 1$ and $\sigma_\tau^2 = \sigma_d^2 = \sigma_s^2 = 1$.

sequently reduces the volatility of private sector inflation expectations, as shown in Figure 4. The same holds for the volatility of the interest rate, output and inflation in period two. Intuitively, only macroeconomic shocks η_1^m that are not anticipated by the public affect its expectations. When the degree of economic transparency goes up, the public rationally relies more on the interest rate i_1 to update its inflation expectations π_2^e since it becomes a better signal of the central bank's intentions τ. This also raises the response of expectations to the noise caused by unanticipated shocks, which initially increases the volatility of inflation expectations. However, as the degree of economic transparency further rises, the unanticipated shocks start diminishing in importance and the variance of private sector inflation expectations declines.

The U-shaped effect of macroeconomic transparency κ on $\text{Var}\,[i_1|\tau]$ in Figure 1 and the hump-shaped effect for $\text{Var}\,[\pi_1|\tau]$ and $\text{Var}\,[\pi_2^e|\tau]$ in Figures 2 and 4 are fairly typical for reasonable parameter values, but they are by no means universal. Intuitively, the U-shaped and hump-shaped patterns arise from the differential effects of publicly unanticipated macroeconomic disturbances η_1^m, which dominate when economic transparency is low, and publicly anticipated shocks ξ_1^m, which prevail when economic transparency

Figure 4: The effect of economic transparency on the volatility of inflation expectations



The effect of economic transparency κ for parameter values $\alpha = \beta = \gamma = \delta = 1$ and $\sigma_\tau^2 = \sigma_d^2 = \sigma_s^2 = 1$.

is high. But the latter may already dominate straightaway, depending on the parameter values.

To assess the robustness of the results, a grid search was conducted for $\alpha \in \{0.1, 0.25 : 0.25 : 10\}$, $\delta \in [0.5 : 0.1 : 1]$, $\sigma_\tau^2 \in \{0.1, 0.25 : 0.25 : 10\}$, $\sigma_d^2 \in \{0.1, 0.25 : 0.25 : 10\}$ and $\sigma_s^2 \in \{0.1, 0.25 : 0.25 : 10\}$, covering 16,954,566 parameter configurations.[7] For this parameter space, the result of a U-shaped effect on the variability of the interest rate i_1 and/or the hump-shaped effect on the volatility of inflation π_1 and inflation expectations π_2^e does not hold for 14.99% of parameter values. Although the exceptions occur throughout the parameter space, there is a systematic deviation from the usual pattern when σ_τ^2 is large relative to σ_d^2 and/or σ_s^2. In particular, when macroeconomic volatility σ_m^2 is sufficiently small compared to preference uncertainty σ_τ^2, $\mathrm{Var}[i_1|\tau]$ is monotonically increasing in κ, and $\mathrm{Var}[\pi_1|\tau]$ and $\mathrm{Var}[\pi_2^e|\tau]$ are monotonically decreasing. More formally, for $\sigma_m^2 \to 0$, $du_i/d\kappa \to 0$ so $d\mu/d\kappa \to 0$.[8] Hence, (29), (31) and (33) yield $\lim_{\sigma_m^2 \to 0} d\,\mathrm{Var}[i_1|\tau]/d\kappa >$

[7]Values of α, σ_τ^2, σ_d^2 or σ_s^2 closer to zero are not used as they regularly give rise to numerical problems when computing (22).

[8]This follows from (43).

0, $\lim_{\sigma_m^2 \to 0} d \operatorname{Var}[\pi_1|\tau] / d\kappa < 0$ and $\lim_{\sigma_m^2 \to 0} d \operatorname{Var}[\pi_2^e|\tau] / d\kappa < 0$. In other words, relatively low macroeconomic volatility yields the same result as high macroeconomic transparency ($\kappa \to 1$), which is an intuitive finding.

4.2 Welfare Analysis

The analysis so far has shown that the effect of economic transparency on the volatility of inflation and output tends to be nonmonotonic. Even the effect of perfect economic transparency ($\kappa = 1$) appears ambiguous as the variance is lower for π_1, π_2 and y_2, but may be higher for y_1. Thus, it is essential to conduct a welfare analysis. Assume that the social welfare function is the same as the central bank's objective function: (1) and (2). This is a useful benchmark because it means that monetary policy is not affected by a principal-agent problem, but only by transparency issues.

Substituting (32) into (10) yields:

$$\mathrm{E}[W_2] = -\frac{1}{2}\frac{\alpha}{1+\alpha\beta^2}\left\{\mu^2\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)^2\sigma_\tau^2 + u_i^2\frac{\mu^2}{\gamma^2}\left(1-\kappa_d\right)\sigma_d^2 + \left[\frac{(\alpha\beta)^2}{\left(1+\alpha\beta^2\right)^2\gamma^2}u_i^2\mu^2\left(1-\kappa_s\right)+1\right]\sigma_s^2\right\} \quad (34)$$

Under perfect economic transparency, $u_i = -\left(1+\alpha\beta^2\right)\gamma/\alpha\beta$ and $\kappa_d = \kappa_s = 1$, so $\mathrm{E}\left[W_2^T\right] = -\frac{1}{2}\frac{\alpha}{1+\alpha\beta^2}\sigma_s^2 > \mathrm{E}[W_2]$. Not surprisingly, opacity is socially detrimental in period two as it makes private sector inflation expectations π_2^e more noisy and thereby increases the volatility of macroeconomic outcomes in the second period.

Substituting (27) and (28) into (1) produces after some rearranging:[9]

$$\begin{aligned}\mathrm{E}[W_1] \;=\; & -\frac{1}{2}\frac{\alpha}{1+\alpha\beta^2}\left\{1+\alpha\beta^2\left(1-\mu\right)^2\left(\frac{\left(1+\alpha\beta^2\right)\gamma}{\alpha\beta u_i}+1\right)^2\right\}\sigma_\tau^2 \\ & -\frac{1}{2}\left(1+\alpha\beta^2\right)\left(1-\mu\right)^2\left(1-\kappa_d\right)\sigma_d^2 - \frac{1}{2}\frac{\alpha}{1+\alpha\beta^2}\left\{1+\alpha\beta^2\left(1-\mu\right)^2\left(1-\kappa_s\right)\right\}\sigma_s^2\end{aligned} \quad (35)$$

Under perfect economic transparency, $u_i = -\left(1+\alpha\beta^2\right)\gamma/\alpha\beta$ and $\kappa_d = \kappa_s = 1$, so $\mathrm{E}\left[W_1^T\right] = -\frac{1}{2}\frac{\alpha}{1+\alpha\beta^2}\sigma_\tau^2 - \frac{1}{2}\frac{\alpha}{1+\alpha\beta^2}\sigma_s^2 > \mathrm{E}[W_1]$. Intuitively, economic transparency reduces the variance of inflation and output due to demand shocks. Although there is greater output volatility due to supply shocks, this actually allows the central bank to achieve a

[9] The derivations for this section are in Appendix A.3.

more desirable trade-off between inflation and output volatility. Hence, perfect economic transparency is socially beneficial in period one.

Substituting (35) and (34) into (2) yields

$$\mathrm{E}\left[U\right] = -\frac{1}{2}A_{\tau}\sigma_{\tau}^{2} - \frac{1}{2}A_{d}\sigma_{d}^{2} - \frac{1}{2}A_{s}\sigma_{s}^{2} \tag{36}$$

where

$$A_{\tau} = \frac{\alpha}{1+\alpha\beta^{2}}\left\{1+\delta\mu\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^{2}\right)\gamma}u_{i}\right)^{2}\right\} \tag{37}$$

$$A_{d} = \left(1+\alpha\beta^{2}\right)\left(1-\mu\right)\left(1-\kappa_{d}\right) \tag{38}$$

$$A_{s} = \frac{\alpha}{1+\alpha\beta^{2}}\left\{1+\delta+\alpha\beta^{2}\left(1-\mu\right)\left(1-\kappa_{s}\right)\right\} \tag{39}$$

Note that $A_{\tau} > 0$, $A_{d} > 0$ and $A_{s} > 0$, so greater uncertainty about the inflation target τ and a higher volatility of demand and supply disturbances all increase social welfare losses. In the special case of perfect economic transparency, $u_{i} = -\left(1+\alpha\beta^{2}\right)\gamma/\alpha\beta$ and $\kappa_{d} = \kappa_{s} = 1$, so $A_{\tau}^{T} = \frac{\alpha}{1+\alpha\beta^{2}}$, $A_{d}^{T} = 0$ and $A_{s}^{T} = \frac{\alpha}{1+\alpha\beta^{2}}\left(1+\delta\right)$. Clearly, $A_{\tau}^{T} \leq A_{\tau}$, $A_{d}^{T} \leq A_{d}$ and $A_{s}^{T} \leq A_{s}$, with a strict inequality if $\kappa_{m} \neq 1$. So, perfect economic transparency is socially optimal, as could already have been inferred immediately from the welfare effects for period one and two.

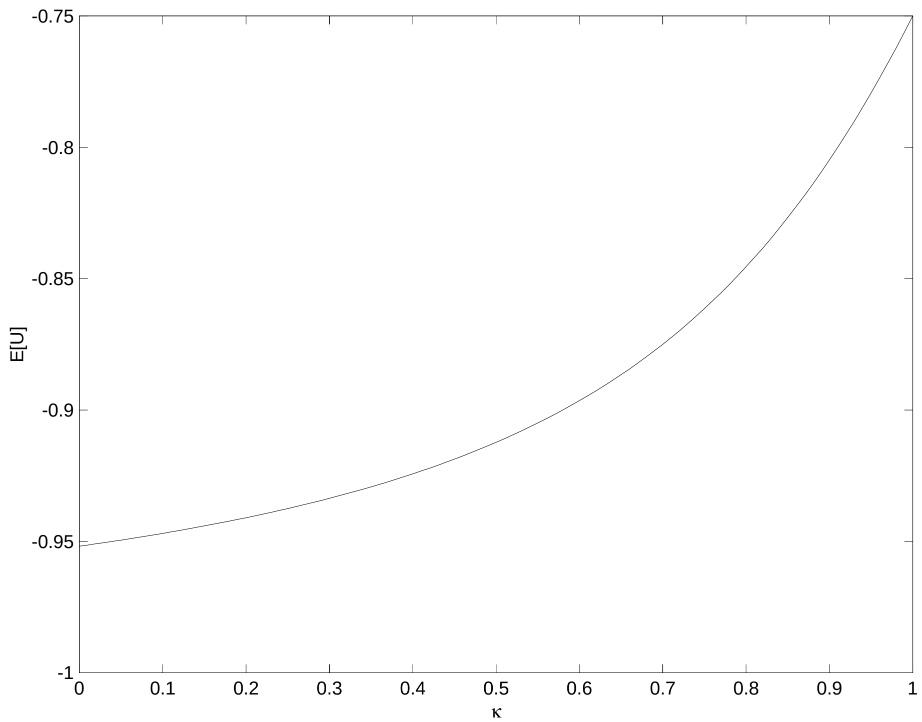
Concerning intermediate degrees of economic transparency, it is straightforward to show that $dA_{\tau}/d\kappa_{m} \leq 0$ using the fact that $d\mu/d\kappa_{m} < 0$ and $du_{i}/d\kappa_{m} < 0$. However, A_{d} and A_{s} are generally nonmonotonic in κ_{d} and κ_{s}, respectively. Assuming again that $\kappa_{d} = \kappa_{s} = \kappa$, Figure 5 shows that the net effect of κ on $\mathrm{E}\left[U\right]$ is unambiguously positive for the baseline parameter configuration with $\alpha = \beta = \gamma = \delta = 1$ and $\sigma_{\tau}^{2} = \sigma_{d}^{2} = \sigma_{s}^{2} = 1$. Moving from complete economic opacity ($\kappa = 0$) to full transparency ($\kappa = 1$) reduces expected social welfare losses stemming from macroeconomic volatility by over 20%.

The result that greater economic transparency is welfare improving holds more generally. In particular, it can be shown that $\mathrm{E}\left[U\right]$ is monotonically increasing in κ:

$$\frac{d\,\mathrm{E}\left[U\right]}{d\kappa} = \frac{1}{2}\frac{1-\mu}{1+\alpha\beta^{2}}\left[\left(1+\alpha\beta^{2}\right)^{2}\sigma_{d}^{2} + \alpha^{2}\beta^{2}\sigma_{s}^{2}\right] > 0 \tag{40}$$

As a result, the net effect of greater economic transparency on expected social welfare is always positive. Intuitively, it gives the central bank more flexibility to offset demand shocks without worrying about perturbing private sector inflation expectations. For the same reason, the central bank is able to achieve a more desirable trade-off between inflation and output volatility due to supply shocks.

Figure 5: The effect of economic transparency on expected social welfare



The effect of economic transparency κ for parameter values $\alpha = \beta = \gamma = \delta = 1$ and $\sigma_\tau^2 = \sigma_d^2 = \sigma_s^2 = 1$.

5 Discussion

The model shows how macroeconomic transparency gives the central bank greater flexibility to stabilize aggregate demand and supply shocks. In fact, central banks that are opaque about macroeconomic shocks optimally decide to mute their interest rate response to prevent undesired effects on private sector inflation expectations. As a result, opaque central banks effectively become less conservative in their reaction to supply shocks and no longer fully offset aggregate demand shocks they anticipate.

Nevertheless, more macroeconomic transparency could lead to greater volatility of inflation (expectations) and output, in particular when the degree of macroeconomic transparency is low and preference transparency is high. This finding is similar to Morris and Shin (2002), who show that greater transparency about economic fundamentals increases economic volatility when public signals are noisy compared to private signals (i.e. economic transparency is low). But their result relies on a coordination motive of private agents that induces them to put greater weight on the public signal, whereas this paper considers a signal extraction problem that is not distorted by other motives.

Although greater macroeconomic transparency could increase volatility, it is always welfare improving in the model. Of course, this result may be sensitive to the assumptions of the model. Since high levels of economic transparency make the interest rate more volatile, they may no longer be desirable if the central bank directly cares about interest rate volatility because of financial stability considerations. In addition, in an economy with capital formation, volatile interest rates are likely to negatively affect investment. Furthermore, if the central bank's objective does not coincide with social welfare due to the presence of a principal-agent problem, opacity may be beneficial because it leads to a level of inflation that is closer to the public's prior and slows down the updating of inflation expectations. So, economic opacity could be advantageous, similar to the finding by Geraats (2007), who considers a model in which political pressures make monetary mystique desirable.

The finding that greater transparency about macroeconomic shocks is beneficial is also in contrast to Jensen (2000, 2002) and Walsh (2007*a*, 2007*b*, 2008), who assume a New Keynesian Phillips curve rather than the plain expectations-augmented Phillips curve in the present paper. However, the latter is not driving the results, because one could substitute $\mathrm{E}_t [\pi_{t+1}]$ for π_t^e without affecting the key results (although auxiliary assumptions would then be needed to determine expectations in the final period). Instead, what matters more is the timing of the formation of expectations relative to the communication of macroeconomic shocks. This is also the reason why Cukierman (2001) and Gersbach (2003) find that transparency about aggregate supply shocks is detrimental in a simple static model. They assume that supply shocks s_t are observed before inflation expectations π_t^e are formed. However, long lags in the transmission of monetary policy mean that in practice, the effect of inflation expectations π_t^e on macroeconomic outcomes y_t and π_t is delayed and very little information is available about supply shocks so far in advance. In contrast, in the present paper the public signal ξ_t^m of macroeconomic shocks is only observed after inflation expectations π_t^e have been formed. Nevertheless, it helps the private sector to infer the central bank's intentions τ from its policy rate i_t, which makes private sector inflation expectations π_{t+1}^e less sensitive to the policy action i_t and gives the central bank greater flexibility to stabilize macroeconomic disturbances in period t.

Another issue is to what extent the results depend on the assumption of rational expectations. In particular, it may be unrealistic to presume that the public is able to perform the non-trivial computation of the rational updating coefficient u_i for its inflation expectations. De Grauwe (2010) abandons rational expectations by assuming that private sector agents have cognitive limitations and use simple rules for forecasting. In this spirit, assume that agents use the heuristic $u_i^H = -\kappa \left(1 + \alpha\beta^2\right) \gamma/\alpha\beta$ rather than (22). This simple yet reasonable rule has similar properties to (22), in particular, $0 \leq u_i^H \leq u_i^T$, $\lim_{\kappa \to 1} u_i^H = u_i^T$, and $du_i^H / d\kappa < 0$. So, inflation expectations π_2^e still respond negatively to the interest rate i_1 and the strength of the response is increasing in the degree of macroeconomic transparency κ as the interest rate becomes a more informative signal of the central bank's intentions.

Using this heuristic, the algebraic expressions for the macroeconomic outcomes are still given by (26), (27), (28) and (32), and expected social welfare by (36), (37), (38) and (39), but with u_i replaced by u_i^H (also in μ). It is straightforward to show that perfect economic transparency ($\kappa = 1$) continues to be socially optimal in this case. To assess the robustness of the monotonicity of the welfare results, a grid search was conducted using the same parameter configurations as in section 4.1. Expected welfare $\mathrm{E}[U]$ continues to be monotonically increasing in κ when $\kappa > 0.65$ for all 16,954,566 parameter configurations, and even over the entire range of $\kappa \in [0, 1]$ for 63.42% of the parameter space. But for sufficiently small levels of macroeconomic transparency κ, $\mathrm{E}[U]$ is sometimes decreasing in κ. The range for κ over which $\mathrm{E}[U]$ is downward-sloping was on average 0.1569 over all parameter configurations. This provides some support for the argument by De Grauwe (2010) that cognitive limitations could affect the impact of central bank communications. More transparency could even be detrimental, but only in economies that are relatively opaque.

The result that economic opacity causes the central bank to mute its interest rate response to macroeconomic shocks, which continues to hold when using the heuristic u_i^H, could be interpreted as a form of interest rate 'smoothing'. But the latter is usually associated with monetary policy inertia, whereas in this paper the interest rate response is only attenuated but not delayed. This effect would be even stronger if the central bank were uncertain about the response u_i of private sector inflation expectations (in line with the uncertainty generated by the 'bottom-up' approach of De Grauwe (2010)). In particular, suppose that u_i is stochastic with $\mathrm{E}[u_i] = \bar{u}_i$ and $\mathrm{Var}[u_i] = \sigma_u^2$, then it is straightforward to show that this leads to multiplicative uncertainty for the central bank with $\mu = \frac{\left(1+\alpha\beta^2\right)^2\gamma^2}{\left(1+\alpha\beta^2\right)^2\gamma^2+\delta\alpha\left(\bar{u}_i^2+\sigma_u^2\right)}$. So, the central bank's policy response to macroeconomic shocks that are not anticipated by the public would be further reduced by the uncertainty σ_u^2 about the adjustment of private sector expectations.

A key feature of the model is that the central bank has private information that is reflected in the interest rate decision and relevant for future monetary policy. It implies that private sector expectations are affected by the policy rate decision and central bank communications (through the public signals ξ^d and ξ^s). There is ample empirical evidence for this (see Blinder, Ehrmann, Fratzscher, Haan and Jansen (2008) for a survey).

The model derives some interesting effects of transparency on macroeconomic volatility, which in principle would be testable. However, an assessment of the empirical implications of the model is greatly complicated by the predicted non-monotonic effects of transparency on the variability of the policy rate, output and inflation (expectations). So, the effects depend on the initial level of transparency. Although data on information disclosure practices by central banks could be used, such as the publication of central bank forecasts, this is hard to translate into the degree of economic transparency κ that is required to evaluate the testable implications. In addition, the critical points at which the effect of transparency on volatility reverses differ across the variables and are sensitive to the parameter values, including the degree of central bank conservativeness α, the initial preference uncertainty σ_τ^2, and the variance of aggregate demand and supply shocks σ_d^2 and σ_s^2. As a result, a rigorous empirical evaluation of the model appears practically infeasible.

More informally, there is some evidence in favor of the key result of the paper that greater economic transparency is welfare improving. There has been a world-wide trend towards greater information disclosure about monetary policymaking. As shown by Geraats (2009), some of the greatest advances have been in economic transparency. In particular, the publication of numerical macroeconomic forecasts has spread from 18% of central banks in 1998 to 57% in 2006, for a sample of 98 central banks. Since these increases in information disclosure tend to go far beyond formal accountability requirements, they could be interpreted as the revealed preference of central banks, which suggests that the rise in transparency has been beneficial.

6 Conclusion

Central banks have increasingly become transparent about macroeconomic prospects, often far beyond any formal disclosure requirements. This paper shows that such macroeconomic transparency may be beneficial to the central bank. The reason is that it allows the central bank to stabilize macroeconomic shocks without disturbing private sector inflation expectations. This makes it easier for the central bank to reach its macroeconomic objectives of inflation and output gap stabilization. But when there is opacity about the shocks to which the central bank responds, the policy rate becomes a noisier signal of the central bank's inflationary intentions, which induces greater volatility of private sector inflation expectations. To mitigate this problem, the central bank mutes the stabilization of macroeconomic shocks under opacity. In particular, an opaque central bank no longer fully offsets aggregate demand shocks it anticipates to avoid upsetting inflation expectations. As a result, opacity leads to undesirable macroeconomic volatility. The paper shows that expected social welfare is monotonically increasing in the degree of macroeconomic transparency. This helps to explain why so many central banks have become more transparent about the macroeconomic shocks they aim to stabilize.

A Appendix

This appendix derives (13), (14), (15) and (16) in section A.1, and (23), (22), (24) and (25) in section A.2.

A.1 Perfect Economic Transparency

In the special case of perfect economic transparency $\kappa_d = \kappa_s = 1$, so that $d_t = \xi_t^d$ and $s_t = \xi_t^s$. Use this to solve (12) for τ:

$$\begin{aligned}\tau = \frac{1}{\alpha\beta\gamma\left(1+\alpha\beta^2\right)-\delta\alpha u_i}\Big\{&-\left[\left(1+\alpha\beta^2\right)^2\gamma^2+\delta\alpha u_i^2\right]i_1+\left(1+\alpha\beta^2\right)^2\gamma^2\bar{r}\\&+\left[\left(1+\alpha\beta^2\right)^2\gamma^2+\alpha\beta\gamma\left(1+\alpha\beta^2\right)\right]\pi_1^e-\delta\alpha u_i u_0\\&+\left[-\delta\alpha u_i u_d+\left(1+\alpha\beta^2\right)^2\gamma\right]\xi_1^d-\left[\delta\alpha u_i u_s+\alpha\beta\gamma\left(1+\alpha\beta^2\right)\right]\xi_1^s\Big\}\end{aligned}$$

Then, use $\left(\pi_2^e\right)^T = \mathrm{E}_1^T\left[\tau|i_1\right] = \tau$ and match coefficients with (11):

$$\begin{aligned}u_0 &= \frac{1}{\alpha\beta\gamma\left(1+\alpha\beta^2\right)-\delta\alpha u_i}\left\{\left(1+\alpha\beta^2\right)^2\gamma^2\bar{r}+\left[\left(1+\alpha\beta^2\right)^2\gamma^2+\alpha\beta\gamma\left(1+\alpha\beta^2\right)\right]\pi_1^e-\delta\alpha u_i u_0\right\}\\u_i &= -\frac{\left(1+\alpha\beta^2\right)^2\gamma^2+\delta\alpha u_i^2}{\alpha\beta\gamma\left(1+\alpha\beta^2\right)-\delta\alpha u_i}\\u_d &= \frac{1}{\alpha\beta\gamma\left(1+\alpha\beta^2\right)-\delta\alpha u_i}\left[-\delta\alpha u_i u_d+\left(1+\alpha\beta^2\right)^2\gamma\right]\\u_s &= -\frac{1}{\alpha\beta\gamma\left(1+\alpha\beta^2\right)-\delta\alpha u_i}\left[\delta\alpha u_i u_s+\alpha\beta\gamma\left(1+\alpha\beta^2\right)\right]\end{aligned}$$

Solving these equations yields (13), (14), (15) and (16):

$$\begin{aligned}u_0^T &= \frac{1}{\alpha\beta\gamma\left(1+\alpha\beta^2\right)}\left\{\left(1+\alpha\beta^2\right)^2\gamma^2\bar{r}+\left[\left(1+\alpha\beta^2\right)^2\gamma^2+\alpha\beta\gamma\left(1+\alpha\beta^2\right)\right]\left(\pi_1^e\right)^T\right\}\\&= \left(\pi_1^e\right)^T+\frac{1+\alpha\beta^2}{\alpha\beta}\gamma\left(\bar{r}+\left(\pi_1^e\right)^T\right)\\u_i^T &= -\frac{1+\alpha\beta^2}{\alpha\beta}\gamma\\u_d^T &= \frac{1+\alpha\beta^2}{\alpha\beta}\\u_s &= -1\end{aligned}$$

A.2 General Case

To derive the updating coefficients for the general case, first substitute (5) and (6) into (12):

$$i_1 = \frac{1}{\left(1+\alpha\beta^2\right)^2\gamma^2+\delta\alpha u_i^2}\Big\{\left(1+\alpha\beta^2\right)^2\gamma^2\left(\bar{r}+\pi_1^e\right)-\alpha\beta\gamma\left(1+\alpha\beta^2\right)\left(\tau-\pi_1^e\right)+\delta\alpha u_i\left(\tau-u_0\right)$$
$$+\left[-\delta\alpha u_i u_d+\left(1+\alpha\beta^2\right)^2\gamma\right]\xi_1^d-\left[\delta\alpha u_i u_s+\alpha\beta\gamma\left(1+\alpha\beta^2\right)\right]\xi_1^s$$
$$+\left(1+\alpha\beta^2\right)^2\gamma\eta_t^d-\alpha\beta\gamma\left(1+\alpha\beta^2\right)\eta_t^s\Big\} \quad (41)$$

As a result,

$$\text{Cov}_1\{i_1,\tau\} = -\frac{1}{\left(1+\alpha\beta^2\right)^2\gamma^2+\delta\alpha u_i^2}\left[\alpha\beta\gamma\left(1+\alpha\beta^2\right)-\delta\alpha u_i\right]\sigma_\tau^2$$
$$\text{Var}_1[i_1] = \frac{1}{\left[\left(1+\alpha\beta^2\right)^2\gamma^2+\delta\alpha u_i^2\right]^2}\Big\{\left[\alpha\beta\gamma\left(1+\alpha\beta^2\right)-\delta\alpha u_i\right]^2\sigma_\tau^2$$
$$+\left(1+\alpha\beta^2\right)^4\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1+\alpha\beta^2\right)^2\left(1-\kappa_s\right)\sigma_s^2\Big\}$$

recalling that $\text{Var}\left[\eta_t^d\right]=\left(1-\kappa_d\right)\sigma_d^2$ and $\text{Var}\left[\eta_t^s\right]=\left(1-\kappa_s\right)\sigma_s^2$. So, matching coefficients between (21) and (11) yields

$$u_i = -\frac{\left[\left(1+\alpha\beta^2\right)^2\gamma^2+\delta\alpha u_i^2\right]\left[\alpha\beta\gamma\left(1+\alpha\beta^2\right)-\delta\alpha u_i\right]\sigma_\tau^2}{\left[\alpha\beta\gamma\left(1+\alpha\beta^2\right)-\delta\alpha u_i\right]^2\sigma_\tau^2+\left(1+\alpha\beta^2\right)^4\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1+\alpha\beta^2\right)^2\left(1-\kappa_s\right)\sigma_s^2}$$

Rearranging gives

$$\left[\alpha\beta\gamma\left(1+\alpha\beta^2\right)-\delta\alpha u_i\right]^2 u_i\sigma_\tau^2+\Big\{\left(1+\alpha\beta^2\right)^4\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1+\alpha\beta^2\right)^2\left(1-\kappa_s\right)\sigma_s^2\Big\}u_i =$$
$$-\left[\left(1+\alpha\beta^2\right)^2\gamma^2+\delta\alpha u_i^2\right]\alpha\beta\gamma\left(1+\alpha\beta^2\right)\sigma_\tau^2+\left[\left(1+\alpha\beta^2\right)^2\gamma^2+\delta\alpha u_i^2\right]\delta\alpha u_i\sigma_\tau^2$$

Note that $\delta^2\alpha^2u_i^3\sigma_\tau^2$ drops out from both sides, leaving the quadratic equation

$$-\alpha^2\beta\gamma\delta\sigma_\tau^2u_i^2$$
$$+\left(1+\alpha\beta^2\right)\left[\alpha\left(\alpha\beta^2-\delta\right)\gamma^2\sigma_\tau^2+\left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2\right]u_i$$
$$+\alpha\beta\gamma^3\left(1+\alpha\beta^2\right)^2\sigma_\tau^2=0 \quad (42)$$

This equation has two real roots, $u_i^+>0$ and $u_i^-<0$:

$$u_i = \frac{1+\alpha\beta^2}{2\alpha^2\beta\gamma\delta\sigma_\tau^2}\Bigg\{\alpha\left(\alpha\beta^2-\delta\right)\gamma^2\sigma_\tau^2+\left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2$$
$$\pm\sqrt{\begin{array}{c}\left[\alpha\left(\alpha\beta^2-\delta\right)\gamma^2\sigma_\tau^2+\left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2\right]^2\\+4\alpha^2\beta\gamma\delta\sigma_\tau^2\alpha\beta\gamma^3\sigma_\tau^2\end{array}}\Bigg\}$$

The argument of the square root can be rearranged as follows:

$$\left[\alpha\left(\alpha\beta^2-\delta\right)\gamma^2\sigma_\tau^2+\left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2\right]^2+4\alpha^2\beta\gamma\delta\sigma_\tau^2\alpha\beta\gamma^3\sigma_\tau^2=$$
$$\left[\alpha\left(\alpha\beta^2+\delta\right)\gamma^2\sigma_\tau^2+\left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2\right]^2$$
$$-4\alpha\gamma^2\delta\left[\left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2\right]\sigma_\tau^2$$

Substitute this into u_i^- to obtain (22):

$$\begin{aligned}u_i &= \frac{1+\alpha\beta^2}{2\alpha^2\beta\gamma\delta\sigma_\tau^2}\left\{\alpha\left(\alpha\beta^2-\delta\right)\gamma^2\sigma_\tau^2+\left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2\right.\\ &\left.-\sqrt{\begin{array}{c}\left[\alpha\left(\alpha\beta^2+\delta\right)\gamma^2\sigma_\tau^2+\left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2\right]^2\\ -4\alpha\gamma^2\delta\left[\left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2\right]\sigma_\tau^2\end{array}}\right\}\end{aligned}$$

Note that

$$\begin{aligned}u_i &\geq \frac{1+\alpha\beta^2}{2\alpha^2\beta\gamma\delta\sigma_\tau^2}\left\{\alpha\left(\alpha\beta^2-\delta\right)\gamma^2\sigma_\tau^2+\left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2\right.\\ &\left.-\left[\alpha\left(\alpha\beta^2+\delta\right)\gamma^2\sigma_\tau^2+\left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2\right]\right\}\\ &= -\frac{1+\alpha\beta^2}{\alpha\beta}\gamma\end{aligned}$$

where the lower bound is reached if $\sigma_d^2 \to 0$ and $\sigma_s^2 \to 0$ or if $\kappa_d = \kappa_s = 1$. Hence, $-\frac{1+\alpha\beta^2}{\alpha\beta}\gamma = u_i^T \leq u_i < 0$.

Using (42) it follows from the implicit function theorem that

$$\begin{aligned}\frac{du_i}{d\kappa_d} &= \frac{\left(1+\alpha\beta^2\right)^3\gamma^2\sigma_d^2u_i}{-2\alpha^2\beta\gamma\delta\sigma_\tau^2u_i+c_u}\\ \frac{du_i}{d\kappa_s} &= \frac{\left(1+\alpha\beta^2\right)\left(\alpha\beta\gamma\right)^2\sigma_s^2u_i}{-2\alpha^2\beta\gamma\delta\sigma_\tau^2u_i+c_u}\end{aligned}$$

where

$$c_u \equiv \left(1+\alpha\beta^2\right)\left[\alpha\left(\alpha\beta^2-\delta\right)\gamma^2\sigma_\tau^2+\left(1+\alpha\beta^2\right)^2\gamma^2\left(1-\kappa_d\right)\sigma_d^2+\left(\alpha\beta\gamma\right)^2\left(1-\kappa_s\right)\sigma_s^2\right]$$

Substituting for c_u using (42) and simplifying yields

$$\begin{aligned}
\frac{du_i}{d\kappa_d} &= \frac{\left(1+\alpha\beta^2\right)^3 \gamma^2 \sigma_d^2 u_i^2}{-2\alpha^2\beta\gamma\delta\sigma_\tau^2 u_i^2 + \alpha^2\beta\gamma\delta\sigma_\tau^2 u_i^2 - \alpha\beta\gamma^3\left(1+\alpha\beta^2\right)^2\sigma_\tau^2} \\
&= -\frac{\left(1+\alpha\beta^2\right)^3 \gamma^2 \sigma_d^2 u_i^2}{\alpha^2\beta\gamma\delta\sigma_\tau^2 u_i^2 + \alpha\beta\gamma^3\left(1+\alpha\beta^2\right)^2\sigma_\tau^2} \\
\frac{du_i}{d\kappa_s} &= \frac{\left(1+\alpha\beta^2\right)\left(\alpha\beta\gamma\right)^2 \sigma_s^2 u_i^2}{-2\alpha^2\beta\gamma\delta\sigma_\tau^2 u_i^2 + \alpha^2\beta\gamma\delta\sigma_\tau^2 u_i^2 - \alpha\beta\gamma^3\left(1+\alpha\beta^2\right)^2\sigma_\tau^2} \\
&= -\frac{\left(1+\alpha\beta^2\right)\left(\alpha\beta\gamma\right)^2 \sigma_s^2 u_i^2}{\alpha^2\beta\gamma\delta\sigma_\tau^2 u_i^2 + \alpha\beta\gamma^3\left(1+\alpha\beta^2\right)^2\sigma_\tau^2}
\end{aligned}$$

Hence, $\frac{du_i}{d\kappa_d} < 0$ and $\frac{du_i}{d\kappa_s} < 0$. When the degree of economic transparency is the same for demand and supply shocks, i.e. $\kappa_d = \kappa_s = \kappa$, then

$$\begin{aligned}
\frac{du_i}{d\kappa} &= -\frac{\left(1+\alpha\beta^2\right)^2\sigma_d^2 + \left(\alpha\beta\right)^2\sigma_s^2}{\left[\alpha\delta u_i^2 + \gamma^2\left(1+\alpha\beta^2\right)^2\right]\alpha\beta\gamma\sigma_\tau^2}\left(1+\alpha\beta^2\right)\gamma^2 u_i^2 \\
&= -\frac{\left(1+\alpha\beta^2\right)^2\sigma_d^2 + \left(\alpha\beta\right)^2\sigma_s^2}{\left(1+\alpha\beta^2\right)\alpha\beta\gamma\sigma_\tau^2}\mu u_i^2 < 0 \qquad (43)
\end{aligned}$$

using the fact that $\mu \equiv \frac{\left(1+\alpha\beta^2\right)^2\gamma^2}{\left(1+\alpha\beta^2\right)^2\gamma^2 + \delta\alpha u_i^2} > 0$.

To derive the other updating coefficients, write (21) as $\pi_2^e = \bar{\tau} + u_i i_1 - u_i \mathrm{E}_1\left[i_1\right]$ and use (41) to substitute for $\mathrm{E}_1\left[i_1\right]$. Then, matching coefficients between (21) and (11) yields:

$$\begin{aligned}
u_0 &= \bar{\tau} - \frac{u_i}{\gamma^2\left(1+\alpha\beta^2\right)^2 + \delta\alpha u_i^2}\Big\{\left(1+\alpha\beta^2\right)^2\gamma^2\left(\bar{r}+\pi_1^e\right) - \alpha\beta\gamma\left(1+\alpha\beta^2\right)\left(\bar{\tau}-\pi_1^e\right) \\
&\qquad + \delta\alpha u_i\left(\bar{\tau}-u_0\right)\Big\} \\
u_d &= -\frac{u_i}{\gamma^2\left(1+\alpha\beta^2\right)^2 + \delta\alpha u_i^2}\left[-\delta\alpha u_i u_d + \left(1+\alpha\beta^2\right)^2\gamma\right] \\
u_s &= \frac{u_i}{\gamma^2\left(1+\alpha\beta^2\right)^2 + \delta\alpha u_i^2}\left[\delta\alpha u_i u_s + \alpha\beta\gamma\left(1+\alpha\beta^2\right)\right]
\end{aligned}$$

Rearranging each equation gives (23), (24) and (25):

$$
\begin{aligned}
u_0 &= \bar{\tau} + u_i \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\left(\bar{\tau}-\pi_1^e\right) - u_i\left(\bar{r}+\pi_1^e\right) \\
&= -\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma} u_i \pi_1^e + \left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma} u_i\right)\bar{\tau} - u_i\left(\bar{r}+\pi_1^e\right) \\
u_d &= -\frac{1}{\gamma} u_i \\
u_s &= \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma} u_i
\end{aligned}
$$

Substituting these updating coefficients into (12) and using (5) and (6) yields (26):

$$
\begin{aligned}
i_1 = {} & \frac{1}{\left(1+\alpha\beta^2\right)^2\gamma^2+\delta\alpha u_i^2}\Big\{\left(1+\alpha\beta^2\right)^2\gamma^2\left(\bar{r}+\pi_1^e\right) - \alpha\beta\gamma\left(1+\alpha\beta^2\right)\left(\tau-\pi_1^e\right) \\
& \quad + \delta\alpha u_i\left(\tau-\bar{\tau}-u_i\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\left(\bar{\tau}-\pi_1^e\right)+u_i\left(\bar{r}+\pi_1^e\right)\right) \\
& \quad + \delta\alpha u_i^2\frac{1}{\gamma}\xi_1^d - \delta\alpha u_i^2\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\xi_1^s + \left(1+\alpha\beta^2\right)^2\gamma d_1 - \alpha\beta\gamma\left(1+\alpha\beta^2\right)s_1\Big\} \\
= {} & \frac{\left(1+\alpha\beta^2\right)^2\gamma^2}{\left(1+\alpha\beta^2\right)^2\gamma^2+\delta\alpha u_i^2}\left\{\left[1+\frac{\delta\alpha u_i^2}{\left(1+\alpha\beta^2\right)^2\gamma^2}\right]\left(\bar{r}+\pi_1^e\right) - \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\left(\tau-\pi_1^e\right)\right. \\
& \quad \left. + \frac{\delta\alpha u_i}{\left(1+\alpha\beta^2\right)^2\gamma^2}\left[\left(1+u_i\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\right)\left(\tau-\bar{\tau}\right) - u_i\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\left(\tau-\pi_1^e\right)\right]\right\} \\
& \quad + (1-\mu)\left(\frac{1}{\gamma}\xi_1^d - \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\xi_1^s\right) + \mu\frac{1}{\gamma}d_1 - \mu\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}s_1 \\
= {} & \bar{r} + \pi_1^e - \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\left(\tau-\pi_1^e\right) + (1-\mu)\left(\frac{1}{u_i}+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\right)\left(\tau-\bar{\tau}\right) \\
& \quad + \frac{1}{\gamma}\left(\xi_1^d+\mu\eta_1^d\right) - \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\left(\xi_1^s+\mu\eta_1^s\right)
\end{aligned}
$$

where $\mu \equiv \frac{\left(1+\alpha\beta^2\right)^2\gamma^2}{\left(1+\alpha\beta^2\right)^2\gamma^2+\delta\alpha u_i^2}$ $(0<\mu<1)$.

Substituting (26) into (3) and (4), and using (24) and (25) produces

$$\begin{aligned} y_1 &= \bar{y} + \frac{\alpha\beta}{1+\alpha\beta^2}(\tau - \pi_1^e) - (1-\mu)\left(\frac{1}{u_i} + \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\right)\gamma(\tau - \bar{\tau}) \\ &\quad + (1-\mu)\eta_1^d + \frac{\alpha\beta}{1+\alpha\beta^2}\xi_1^s + \mu\frac{\alpha\beta}{1+\alpha\beta^2}\eta_1^s \\ \pi_1 &= \pi_1^e + \frac{\alpha\beta^2}{1+\alpha\beta^2}(\tau - \pi_1^e) - (1-\mu)\left(\frac{1}{u_i} + \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\right)\beta\gamma(\tau - \bar{\tau}) \\ &\quad + (1-\mu)\beta\eta_1^d - \frac{1}{1+\alpha\beta^2}\xi_1^s - \left(1 - \mu\frac{\alpha\beta^2}{1+\alpha\beta^2}\right)\eta_1^s \end{aligned}$$

Use the latter equation and impose rational expectations (i.e. $\pi_1^e = \mathrm{E}[\pi_1]$) to get $\pi_1^e = \bar{\tau}$. As a result, (27) and 28) follow:

$$\begin{aligned} y_1 &= \bar{y} + \left[\frac{\alpha\beta}{1+\alpha\beta^2} - (1-\mu)\left(\frac{1}{u_i} + \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\right)\gamma\right](\tau - \bar{\tau}) \\ &\quad + (1-\mu)\eta_1^d + \frac{\alpha\beta}{1+\alpha\beta^2}(\xi_1^s + \mu\eta_1^s) \\ \pi_1 &= \bar{\tau} + \left[\frac{\alpha\beta^2}{1+\alpha\beta^2} - (1-\mu)\left(\frac{1}{u_i} + \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\right)\beta\gamma\right](\tau - \bar{\tau}) \\ &\quad + (1-\mu)\beta\eta_1^d - \frac{1}{1+\alpha\beta^2}\left(\xi_1^s + \left[1 + (1-\mu)\alpha\beta^2\right]\eta_1^s\right) \end{aligned}$$

To find second period inflation expectations, substitute (23), (24) and (25) into (11) to get

$$\pi_2^e = \bar{\tau} + u_i\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}(\bar{\tau} - \pi_1^e) + u_i\left[i_1 - (\bar{r} + \pi_1^e)\right] - u_i\frac{1}{\gamma}\xi_1^d + \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\xi_1^s$$

Substituting (26) then yields (32):

$$\pi_2^e = \tau - \mu\left(1 + \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)(\tau - \bar{\tau}) + u_i\mu\frac{1}{\gamma}\eta_1^d - \frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\mu\eta_1^s$$

This reduces to $(\pi_2^e)^T = \tau$ in the case of perfect economic transparency as $u_i = -\left(1+\alpha\beta^2\right)\gamma/\alpha\beta$ and $\eta_1^d = \eta_1^s = 0$.

A.3 Welfare Analysis

Substituting (32) into (10) yields (34):

$$
\begin{aligned}
\mathrm{E}\left[W_2\right] &= -\frac{1}{2}\frac{\alpha}{1+\alpha\beta^2}\left\{\mu^2\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)^2\sigma_\tau^2\right. \\
&\qquad\left. +u_i^2\frac{\mu^2}{\gamma^2}\left(1-\kappa_d\right)\sigma_d^2+\left[\frac{(\alpha\beta)^2}{\left(1+\alpha\beta^2\right)^2\gamma^2}u_i^2\mu^2\left(1-\kappa_s\right)+1\right]\sigma_s^2\right\}
\end{aligned}
$$

Substituting (27) and (28) into (1) produces (35) after some rearranging:

$$
\begin{aligned}
\mathrm{E}\left[W_1\right] &= -\frac{1}{2}\alpha\left\{\left[\frac{1}{1+\alpha\beta^2}+(1-\mu)\left(\frac{1}{u_i}+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\right)\beta\gamma\right]^2\sigma_\tau^2\right. \\
&\qquad\left. +(1-\mu)^2\beta^2\left(1-\kappa_d\right)\sigma_d^2+\frac{1}{\left(1+\alpha\beta^2\right)^2}\left[\kappa_s+\left(1+(1-\mu)\alpha\beta^2\right)^2\left(1-\kappa_s\right)\right]\sigma_s^2\right\} \\
&\quad -\frac{1}{2}\left\{\left[\frac{\alpha\beta}{1+\alpha\beta^2}-(1-\mu)\left(\frac{1}{u_i}+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\right)\gamma\right]^2\sigma_\tau^2\right. \\
&\qquad\left. +(1-\mu)^2\left(1-\kappa_d\right)\sigma_d^2+\frac{(\alpha\beta)^2}{\left(1+\alpha\beta^2\right)^2}\left[\kappa_s+\mu^2\left(1-\kappa_s\right)\right]\sigma_s^2\right\} \\
&= -\frac{1}{2}\left\{\frac{\alpha}{1+\alpha\beta^2}+\left(\alpha\beta^2+1\right)\gamma^2(1-\mu)^2\left(\frac{1}{u_i}+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\right)^2\right\}\sigma_\tau^2 \\
&\quad -\frac{1}{2}\left(1+\alpha\beta^2\right)(1-\mu)^2\left(1-\kappa_d\right)\sigma_d^2 \\
&\quad -\frac{1}{2}\frac{\alpha}{\left(1+\alpha\beta^2\right)^2}\left\{\left(1+\alpha\beta^2\right)\kappa_s+\left[\left(1+\alpha\beta^2-\mu\alpha\beta^2\right)^2+\alpha\beta^2\mu^2\right]\left(1-\kappa_s\right)\right\}\sigma_s^2 \\
&= -\frac{1}{2}\frac{\alpha}{\alpha\beta^2+1}\left\{1+\alpha\beta^2(1-\mu)^2\left(\frac{\left(1+\alpha\beta^2\right)\gamma}{\alpha\beta u_i}+1\right)^2\right\}\sigma_\tau^2 \\
&\quad -\frac{1}{2}\left(1+\alpha\beta^2\right)(1-\mu)^2\left(1-\kappa_d\right)\sigma_d^2-\frac{1}{2}\frac{\alpha}{1+\alpha\beta^2}\left\{1+\alpha\beta^2(1-\mu)^2\left(1-\kappa_s\right)\right\}\sigma_s^2
\end{aligned}
$$

Substituting (35) and (34) into (2) yields

$$
\mathrm{E}\left[U\right] = -\frac{1}{2}A_\tau\sigma_\tau^2-\frac{1}{2}A_d\sigma_d^2-\frac{1}{2}A_s\sigma_s^2
$$

where

$$A_\tau = \frac{\alpha}{1+\alpha\beta^2}\left\{1+\left[(1-\mu)^2\frac{\left(1+\alpha\beta^2\right)^2\gamma^2}{\alpha u_i^2}+\delta\mu^2\right]\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)^2\right\}$$

$$A_d = \left(1+\alpha\beta^2\right)(1-\mu)^2(1-\kappa_d)+\frac{\delta\alpha u_i^2}{\left(1+\alpha\beta^2\right)\gamma^2}\mu^2(1-\kappa_d)$$

$$A_s = \frac{\alpha}{1+\alpha\beta^2}\left\{1+\alpha\beta^2(1-\mu)^2(1-\kappa_s)+\delta\left[\frac{\alpha^2\beta^2}{\left(1+\alpha\beta^2\right)^2\gamma^2}u_i^2\mu^2(1-\kappa_s)+1\right]\right\}$$

Using the fact that $\mu \equiv \frac{\left(1+\alpha\beta^2\right)^2\gamma^2}{\left(1+\alpha\beta^2\right)^2\gamma^2+\delta\alpha u_i^2}$ implies $\frac{\delta\alpha u_i^2}{\left(1+\alpha\beta^2\right)^2\gamma^2} = (1-\mu)/\mu$, rearranging gives (37), (38) and (39):

$$A_\tau = \frac{\alpha}{1+\alpha\beta^2}\left[1+\delta\mu\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)^2\right]$$

$$A_d = \left(1+\alpha\beta^2\right)(1-\mu)(1-\kappa_d)$$

$$A_s = \frac{\alpha}{1+\alpha\beta^2}\left[1+\delta+\alpha\beta^2(1-\mu)(1-\kappa_s)\right]$$

It is straightforward to show that

$$\frac{dA_\tau}{du_i} = \frac{\alpha}{1+\alpha\beta^2}\left[\delta\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)^2\frac{d\mu}{du_i}+2\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}\delta\mu\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)\right] \geq 0 \tag{44}$$

using $\frac{d\mu}{du_i} = -\mu^2\frac{2\delta\alpha u_i}{\left(1+\alpha\beta^2\right)^2\gamma^2} > 0$ and $u_i \geq -\frac{\left(1+\alpha\beta^2\right)\gamma}{\alpha\beta}$, with a strict inequality if $\kappa \neq 1$. Since $du_i/d\kappa_m < 0$ it follows that $dA_\tau/d\kappa_m \leq 0$, with a strict inequality if $\kappa_m \neq 1$. However, A_d and A_s are generally nonmonotonic in κ_d and κ_s, respectively. So, it is important to investigate the net effect of κ on $\mathrm{E}[U]$. Using (36), (37), (38) and (39) and substituting (43) gives

$$\frac{d\,\mathrm{E}\left[U\right]}{d\kappa} = -\frac{1}{2}\left\{\frac{\alpha\delta}{1+\alpha\beta^2}\left[\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)^2\frac{d\mu}{du_i}+\frac{2\alpha\beta\mu}{\left(1+\alpha\beta^2\right)\gamma}\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)\right]\frac{du_i}{d\kappa}\sigma_\tau^2\right.$$
$$\left.-\frac{1}{1+\alpha\beta^2}\left[\left(1-\kappa\right)\frac{d\mu}{d\kappa}+\left(1-\mu\right)\right]\left[\left(1+\alpha\beta^2\right)^2\sigma_d^2+\alpha^2\beta^2\sigma_s^2\right]\right\}$$
$$=\frac{1}{2}\frac{1}{1+\alpha\beta^2}\left\{\left[-\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)^2\frac{2\mu^2\delta\alpha u_i}{\left(1+\alpha\beta^2\right)^2\gamma^2}\right.\right.$$
$$\left.+\frac{2\alpha\beta\mu}{\left(1+\alpha\beta^2\right)\gamma}\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)\right]\frac{\delta\mu u_i^2}{\left(1+\alpha\beta^2\right)\beta\gamma}$$
$$\left.+\left[\left(1-\kappa\right)\mu^2\frac{2\delta\alpha u_i}{\left(1+\alpha\beta^2\right)^2\gamma^2}\frac{\left(1+\alpha\beta^2\right)^2\sigma_d^2+\left(\alpha\beta\right)^2\sigma_s^2}{\left(1+\alpha\beta^2\right)\alpha\beta\gamma\sigma_\tau^2}\mu u_i^2+\left(1-\mu\right)\right]\right\}$$
$$*\left[\left(1+\alpha\beta^2\right)^2\sigma_d^2+\alpha^2\beta^2\sigma_s^2\right]$$
$$=\frac{1}{2}\frac{1-\mu}{1+\alpha\beta^2}\left\{-\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)^2\frac{2\mu^2\delta u_i}{\left(1+\alpha\beta^2\right)\beta\gamma}+2\mu\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)\right.$$
$$\left.+\left(1-\kappa\right)\mu^2 2u_i\frac{\left(1+\alpha\beta^2\right)^2\sigma_d^2+\left(\alpha\beta\right)^2\sigma_s^2}{\left(1+\alpha\beta^2\right)\alpha\beta\gamma\sigma_\tau^2}+1\right\}\left[\left(1+\alpha\beta^2\right)^2\sigma_d^2+\alpha^2\beta^2\sigma_s^2\right]$$

where the last equality uses the fact that $\frac{\delta\alpha u_i^2}{\left(1+\alpha\beta^2\right)^2\gamma^2}=\frac{1-\mu}{\mu}$. Using the latter equality and the fact that (42) implies

$$\left(1-\kappa\right)\left[\left(1+\alpha\beta^2\right)^2\sigma_d^2+\left(\alpha\beta\right)^2\sigma_s^2\right]u_i=\frac{\alpha^2\beta\delta\sigma_\tau^2u_i^2}{\left(1+\alpha\beta^2\right)\gamma}-\alpha\beta\gamma\left(1+\alpha\beta^2\right)\sigma_\tau^2-\alpha\left(\alpha\beta^2-\delta\right)\sigma_\tau^2u_i$$

the term in curly brackets can be further simplified to

$$\left[-\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)\frac{2\mu^2\delta u_i}{\left(1+\alpha\beta^2\right)\beta\gamma}+2\mu\right]\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)$$
$$+2\mu^2\frac{\alpha\delta u_i^2}{\left(1+\alpha\beta^2\right)^2\gamma^2}-2\mu^2\left(1+\frac{\alpha\beta u_i}{\left(1+\alpha\beta^2\right)\gamma}\right)+2\mu^2\frac{\delta u_i}{\left(1+\alpha\beta^2\right)\beta\gamma}+1$$
$$=\left[-\frac{2\mu^2\delta u_i}{\left(1+\alpha\beta^2\right)\beta\gamma}-2\mu\left(1-\mu\right)+2\mu-2\mu^2\right]\left(1+\frac{\alpha\beta}{\left(1+\alpha\beta^2\right)\gamma}u_i\right)+2\mu\left(1-\mu\right)+\frac{2\mu^2\delta u_i}{\left(1+\alpha\beta^2\right)\beta\gamma}+1$$
$$=-\frac{2\mu^2\delta u_i}{\left(1+\alpha\beta^2\right)\beta\gamma}-2\mu\left(1-\mu\right)+2\mu\left(1-\mu\right)+\frac{2\mu^2\delta u_i}{\left(1+\alpha\beta^2\right)\beta\gamma}+1=1$$

Therefore, the effect of greater economic transparency on expected social welfare is unambiguously positive:

$$\frac{d\,\mathrm{E}\left[U\right]}{d\kappa} = \frac{1}{2}\frac{1-\mu}{1+\alpha\beta^2}\left[\left(1+\alpha\beta^2\right)^2\sigma_d^2 + \alpha^2\beta^2\sigma_s^2\right] > 0$$

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