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Central bank transparency with the cost channel

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Abstract: Using a New Keynesian model with the cost channel, characterized by distortions due to monopolistic competition and the firms' need to pre-finance their production, we show that central bank transparency affects the economy not only through the effects of inflation shocks but also of demand shocks. The economy is affected by opacity in the same way, but with smaller amplitude, in the case of demand shocks than in the case of inflation shocks except when the latter have a significantly lower variance. Generally, imperfect transparency could discipline the price-setting behavior of firms by reducing the average reaction of inflation to inflation and demand shocks and hence the volatility of inflation while increasing these of the output gap, and more so when these shocks are highly persistent. It could thus significantly improve social welfare if the society assigns a very low weight to output-gap stabilization. The presence of the cost channel reinforces significantly the effects of opacity on the responses of endogenous variables and their volatility to inflation shocks.

Key words: Cost channel, central bank transparency, distortions, disciplining effect of imperfect transparency.

JEL Classification: E52, E58.

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1. Introduction

In the past two decades, adopting high standards of transparency has become a common practice among a growing number of central banks. Improved transparency, which enhances the accountability and thus the public support for central bank independence, is perceived to reduce political influence over monetary policy. Besides the benefits of making central banks independent from the government, a significant amount of attention has been put on the effects of political, economic, procedural, policy and operational transparency in monetary policy decisions.[1]

On the basis of theoretical and empirical studies, most researchers share the view that central bank transparency is in general desirable because it lowers inflation expectations and inflation while making the central bank more credible and its policy more precisely anticipated by the private sector. Even though empirical evidence shows no obvious influence on output and output variability, one might expect that better economic decisions resulting from higher transparency leads to higher social welfare (Chortareas et al. 2002, Dincer and Eichengreen 2007, 2010).

Since the pioneer work undertaken by Cukierman and Meltzer (1986), issues of central bank transparency have been largely investigated across different types of models. However, existing studies do not account for the cost channel. The latter assigns banks a key role in the transmission of monetary policy, which stems from the idea that firms depend on credit to pre-finance production (Christiano and Eichenbaum 1992, Barth and Ramey 2001) so that their marginal cost and hence price decisions depend directly on the nominal rate of interest. In the presence of the cost channel, demand shocks will affect the equilibrium level of inflation and the output gap. Therefore, the central bank could not neutralize the effects of

[1] These five motives for central bank transparency are defined in Geraats (2002). The literature on central bank transparency is related to the broad literature on the issue of monetary uncertainty first emphasized by the seminal contribution of Brainard (1967). For some recent surveys, see Blinder et al. (2008), Crowe and Meade (2008), Geraats (2009), Eijffinger and van der Cruijsen (2010), and Ehrmann et al. (2012).

demand shocks by adopting an optimal interest rate policy and hence transparency will not only interact with inflation shocks but also with demand shocks.

This paper contributes to the literature on central bank transparency by examining the effects of opacity about the central bank's preferences, i.e. the uncertainty about the relative weight that the central bank assigns to output-gap stabilization, in a model with the cost channel based on Christiano et al. (2005) and Ravenna and Walsh (2006). A direct consequence of introducing such a channel is that a monetary contraction induces an upward pressure on prices by deteriorating credit conditions through higher interest rates besides the negative effect on inflation operating through the effect of the interest rate on the demand and hence the output (the interest rate channel). The presence of the cost channel implies that all shocks to the economy will generate a trade-off between stabilizing inflation and stabilizing the output gap, and thus could have important implications for central bank transparency.

Generally, it is quite common to see many central banks announcing their inflation target, communicating about their economic outlooks and publishing their minutes of decision. However, it has not been observed that a central bank has produced a public statement that specifies the weights assigned to its objectives. Imperfect transparency of this kind could not be justified in the Barro-Gordon framework since it has no significant effect on the average inflation and output gap but will increase inflation and output-gap variability (Geraats 2002, Demertzis and Hughes Hallet 2007).

In contrast, in the standard New Keynesian model (Clarida *et al.* 1999), imperfect disclosure about the central bank's preferences could be justified. In such a framework, imperfect transparency generally reduces the average reaction of inflation to inflation shocks and the volatility of inflation, but increases these of the output gap more so when inflation shocks are highly persistent, and could therefore improve the social welfare if the weight assigned to output-gap stabilization is low (Dai, 2012). In a New Keynesian framework, knowledge of the relative weight assigned to the output-gap target is essential for the private agents to evaluate how quickly the central bank plans to steer the economy back to the equilibrium following an inflation or demand shock. The higher is this weight, the longer time period is allowed by the central bank for the inflation to get back to its target following a shock, causing a larger volatility of inflation but a smaller volatility of output. These contradictory effects of an increase in opacity could improve social welfare or not, depending on the value of model parameters. Moreover, the cost channel could reinforce the effects of opacity, and more so when the degree of persistence is high.

Focusing on the effects of transparency through the cost channel, we find that imperfect transparency can similarly interact with demand shocks (including fiscal and productivity shocks) as with inflation (or supply) shocks. More precisely, imperfect transparency about central bank preferences could be welfare improving if, in average, the society assigns a low relative weight to output-gap stabilization. The effects of opacity associated with the cost channel could be substantial if the variance of demand shocks is significantly higher than that of inflation shocks. Moreover, the inclusion of the cost channel does modify quantitatively, but not qualitatively, the effects of imperfect transparency associated with inflation shocks.

The effects of opacity on social welfare could be potentially positive in a New-Keynesian framework with the cost channel. This does not suggest that the central bank should be intransparent about its preferences since these effects are model sensitive. In studies using the static Barro-Gordon framework (e.g., Nolan and Schaling 1998, Eijffinger et al. 2000, Faust and Svensson 2001, Beetsma and Jensen 2003, and Demertzis and Hughes Hallet 2007), it is shown that imperfect transparency about central bank preferences is detrimental to the social welfare when corrections are made for the effects due to arbitrary specifications of uncertainty about one or the other parameter attached to the central bank's objectives. The conclusions of our paper are to some extent similar to these obtained in models introducing distortions through the wage setting behavior of labor unions (e.g. Sørensen, 1991; Grüner, 2002), distortionary taxes (Hughes Hallett and Viegi, 2003; Ciccarone et al., 2007; Hefeker and Zimmer, 2011), or/and public investment (Dai and Sidiropoulos, 2011). In these models, central bank opacity could improve global welfare because it could discipline the private sector when setting wage or the government when setting the tax rate and public investment. In the New Keynesian model with the cost channel, characterized by two distortions, i.e. monopolistic competition with price rigidities and the effect of nominal interest rate on firms' marginal cost, imperfect transparency could discipline the price behaviors of firms.

Our results are about a special aspect of central bank transparency, i.e. political transparency. We do not attempt to capture the general effects of different aspects of transparency. Thus, our results are not in contradiction with empirical studies (Demertzis and Hughes Hallet, 2007; Geraats, 2009; Dincer and Eichengreen, 2007 and 2010; van der Cruijsen et al., 2010; Ehrmann et al. 2012) that generally show the positive effect of transparency on macroeconomic performance. Our study suggests that empirical studies should go further by separating the effects of uncertainty about the relative weight that central banks assign to output-gap stabilization from these of other transparency motives while taking into account the effects of monopolistic competition and the cost channel.

This paper is closely related to a number of recent studies that have explored various implications of the cost channel for the monetary policy by taking into account the matching technology in the labor market (Ravenna and Walsh 2008), the robust approach of monetary policy (Tillmann 2009), monopolistic competition in loan markets and fixation of loan rates in a staggered way (Hülsewig *et al*. 2009), interest rate smoothing (Kaufmann and Scharler

2009), and financial frictions arising from heterogeneity and asymmetric information in firms' productivity (Fiore and Tristani, 2012).[2]

The remainder of the paper is organized as follows. In Section 2, we present the basic model with the cost channel. In Section 3, we solve the model under monetary discretion. Section 4 analyzes the effects of opacity about central bank preferences on the level and volatility of macroeconomic variables and their dynamics. The last section concludes.

2. The model

Our framework is based on Christiano et al. (2005), and Ravenna and Walsh (2006) who introduce the cost channel into a standard New Keynesian model. The basic idea which distinguishes this kind of model from a standard New Keynesian model is that firms are assumed to pay their factors of production before receiving revenues from selling their products, and they need to borrow working capital from financial intermediaries. Therefore, a variation in the policy interest rate can affect not only the IS equation but also the Phillips curve, implying that the optimal monetary policy will not neutralize completely the effects of demand shock on inflation and the output gap.

A stylized New Keynesian model with the cost channel is given by:

$$\pi_t = \beta \mathrm{E}_t \pi_{t+1} + \kappa(\sigma+\eta)x_t + \kappa\phi R_t + e_t \,, \tag{1}$$

$$x_t = \mathrm{E}_t x_{t+1} - \frac{1}{\sigma}(R_t - \mathrm{E}_t \pi_{t+1}) + u_t \,, \tag{2}$$

where π_t is the inflation rate, x_t the output gap, R_t the risk-free nominal interest rate controlled by the central bank and E_t the expectation operator. All variables are expressed in

[2] Empirical studies include, among others, Barth and Ramey (2001), Christiano et al. (2005), Tillmann (2008), Henzel et al. (2009), Gabriel and Martins (2010) and Castelnuovo (2012).

percentage log deviations around their respective steady-state values. The parameters β, σ and η denote discount factor, the coefficient of relative risk aversion, and the inverse Frisch elasticity of labor supply, respectively. The composite coefficient $\kappa \equiv (1-\omega)(1-\omega\beta)/\omega$, depends negatively on the degree of price stickiness, ω, which represents the fraction of firms that do not optimally adjust but simply update their previous price by the steady-state inflation rate. The parameter ϕ is a dummy variable. When $\phi = 1$, we are in the presence of the cost channel. Setting $\phi = 0$, we obtain the standard New Keynesian model.

Cost-push shock e_t and demand shock u_t, which captures productivity, taste and fiscal policy shocks, are serially correlated and follow AR(1) process:

$$e_t = \rho_e e_{t-1} + \upsilon_{et}, \qquad 0 \le \rho_e \le 1 \text{ and } \mathrm{E}_{t-1}\upsilon_{et} = 0 \ ; \tag{3}$$

$$u_t = \rho_u u_{t-1} + \upsilon_{ut}, \qquad 0 \le \rho_u \le 1 \text{ and } \mathrm{E}_{t-1}\upsilon_{ut} = 0 \ ; \tag{4}$$

where υ_{et} and υ_{ut} have zero mean and are serially uncorrelated, and ρ_e and ρ_u represent respectively the degree of persistence of inflation and demand shocks.

Following Sørensen (1991) and Kobayashi (2003), we specify that the central bank minimizes the following loss function:

$$L \equiv \frac{1}{2}\mathrm{E}_t \sum_{t=0}^{\infty} \beta^t \left[(1+\varepsilon)\pi_t^2 + (\lambda - \varepsilon)x_t^2\right], \tag{5}$$

where λ denotes the expected relative weight assigned by the central bank to the output-gap objective. The parameter $\varepsilon \in [-1, \lambda]$ is a stochastic variable, with zero mean and variance σ_ε^2, implying the weights associated with inflation and output-gap targets cannot be imperfectly predicted by the private sector. The latter represents the degree of opacity about central bank preferences. If $\sigma_\varepsilon^2 = 0$, the central bank is fully predictable and hence fully transparent. Given that ε takes values in a compact set and has an expectation equal to zero, Ciccarone *et al*. (2007) and Ciccarone and Marchetti (2009) have proved that σ_ε^2 has an upper bound so that

$\sigma_{\varepsilon}^{2} \in [0, \lambda]$. According to Beetsma and Jensen (2003), introducing uncertainty in the parameter associated with inflation or output-gap objective leads to very different results regarding the effects of transparency. The assumption that ε is associated with both objectives, adopted in this paper, avoids these arbitrary effects of central bank preference uncertainty.

3. Optimal monetary policy

The central bank is assumed to determine the optimal policy under discretion, i.e. it makes no pre-commitment about future policy and re-optimizes its objective function in each period taking inflation expectations as given. Under discretion, the decision problem of the central bank becomes the single period problem of choosing the values of inflation and the output gap that minimize the loss function subject to the inflation adjustment equation. The policy instrument is the interest rate which is set to implement the optimal time-consistent discretionary monetary policy.

3.1 The equilibrium

Under discretion, the central bank treats expected future inflation as given when minimizing the loss function (5) subject to constraints (1) and (2). The first-order condition is given by

$$(1+\varepsilon)\pi_t = -\frac{(\lambda - \varepsilon)}{[\kappa(\sigma + \eta) - \sigma\kappa\phi]} x_t \,. \qquad (6)$$

The system of equations (1), (2) and (6) has a unique non-explosive rational expectations solution. Known as the "minimal state variable" (MSV) solution, it can be obtained using the method of undetermined coefficients (McCallum, 1983). Given that cost-push shock e_t and demand shock u_t constitute the only state variables in this model, the solutions of endogenous variables are expressed as follows[3]

$$\mathrm{E}_t \pi_{t+1} = \frac{\rho_u \kappa\phi\sigma \mathrm{E}_t(\Theta) u_t}{1+\rho_u\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_u \mathrm{E}_t(\Theta)(\beta+\kappa\phi)} + \frac{\rho_e \mathrm{E}_t(\Theta) e_t}{1+\rho_e\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_e \mathrm{E}_t(\Theta)(\beta+\kappa\phi)}, \quad (7)$$

$$\mathrm{E}_t x_{t+1} = \frac{-\rho_u \kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) u_t}{1+\rho_u\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_u \mathrm{E}_t(\Theta)(\beta+\kappa\phi)} + \frac{-\rho_e \zeta \mathrm{E}_t(\Omega) e_t}{1+\rho_e\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_e \mathrm{E}_t(\Theta)(\beta+\kappa\phi)}, \quad (8)$$

$$\pi_t = \frac{\kappa\phi\sigma\Theta u_t}{1+\rho_u\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_u \mathrm{E}_t(\Theta)(\beta+\kappa\phi)} + \frac{\Theta e_t}{1+\rho_e\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_e \mathrm{E}_t(\Theta)(\beta+\kappa\phi)}, \quad (9)$$

$$x_t = -\frac{\kappa\phi\sigma\zeta\Omega u_t}{1+\rho_u\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_u \mathrm{E}_t(\Theta)(\beta+\kappa\phi)} - \frac{\zeta\Omega e_t}{1+\rho_e\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_e \mathrm{E}_t(\Theta)(\beta+\kappa\phi)}, \quad (10)$$

$$R_t = \frac{\sigma[1+\kappa\phi\sigma\zeta\Omega - \rho_u \mathrm{E}_t(\Theta)\beta] u_t}{1+\rho_u\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_u \mathrm{E}_t(\Theta)(\beta+\kappa\phi)} + \frac{[\sigma\zeta\Omega + \rho_e \mathrm{E}_t(\Theta) - \rho_e\sigma\zeta \mathrm{E}_t(\Omega)] e_t}{1+\rho_e\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_e \mathrm{E}_t(\Theta)(\beta+\kappa\phi)}, \quad (11)$$

where $\Omega \equiv \frac{1+\varepsilon}{\lambda-\varepsilon+\zeta^2(1+\varepsilon)}$ and $\Theta \equiv \frac{\lambda-\varepsilon}{\lambda-\varepsilon+\zeta^2(1+\varepsilon)}$ with $\zeta \equiv \kappa(\sigma+\eta)-\sigma\kappa\phi$. Their expected values are approximated using the second-order Taylor development as $\mathrm{E}_t(\Theta) \cong \frac{\lambda}{\lambda+\zeta^2} - \frac{\zeta^2(1+\lambda)(1-\zeta^2)}{(\lambda+\zeta^2)^3}\sigma_\varepsilon^2 < 1$ and $\mathrm{E}(\Omega) \cong \frac{1}{\lambda+\zeta^2} + \frac{(1+\lambda)(1-\zeta^2)}{(\lambda+\zeta^2)^3}\sigma_\varepsilon^2$. To ensure that a positive cost-push or demand shock always induces an increase in the expected inflation, we assume the denominators in (7)-(11) are positive.[4]

The variances of inflation and the output gap are calculated using (9) and (10) as:

$$\mathrm{var}(\pi_t) = \frac{\kappa^2\phi^2\sigma^2 \mathrm{E}_t(\Theta^2)}{[1+\rho_u\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_u \mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^2}\sigma_u^2 + \frac{\mathrm{E}_t(\Theta^2)}{[1+\rho_e\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_e \mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^2}\sigma_e^2 \quad (12)$$

$$\mathrm{var}(x_t) = \frac{\kappa^2\phi^2\sigma^2\zeta^2 \mathrm{E}_t(\Omega^2)}{[1+\rho_u\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_u \mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^2}\sigma_u^2 + \frac{\zeta^2 \mathrm{E}_t(\Omega^2)}{[1+\rho_e\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_e \mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^2}\sigma_e^2 \quad (13)$$

[3] The Appendix containing the details of solution is available upon request.

[4] Using parameter values in Ravenna and Walsh (2006), i.e., $\kappa = 0.0858$, $\sigma = 1.5$ and $\eta = 1$, $\beta = 0.99$, $\lambda = 0.25$ and $\zeta = 0.0858$, we have checked that the denominators in (7)-(11) are positive for $\phi = 1$, $\rho_e, \rho_e < 0.997$ and $\sigma_\varepsilon^2 = 0$.

where $\sigma_e^2 = \mathrm{var}(e_t)$ and $\sigma_u^2 = \mathrm{var}(u_t)$. $\mathrm{E}(\Omega^2)$ and $\mathrm{E}_t(\Theta^2)$ are respectively approached using the second-order Taylor development as $\mathrm{E}(\Omega^2) \cong \frac{1}{(\lambda+\zeta^2)^2} + \frac{(1+\lambda)(\lambda+3-2\zeta^2)}{(\lambda+\zeta^2)^4}\sigma_\varepsilon^2$ and $\mathrm{E}_t(\Theta^2) \cong \frac{\lambda^2}{(\lambda+\zeta^2)^2} + \frac{\zeta^2(1+\lambda)[\zeta^2+\lambda(3\zeta^2-2)]}{(\lambda+\zeta^2)^4}\sigma_\varepsilon^2$. Examining solutions (7)-(13), we notice that central bank opacity impacts $\mathrm{E}_t\pi_{t+1}$, $\mathrm{E}_t x_{t+1}$, R_t, $\mathrm{var}(\pi_t)$ and $\mathrm{var}(x_t)$ both through the numerator and the denominator while affecting π_t and x_t only via the denominator. The presence of the cost channel, i.e., $\phi = 1$, implies that opacity affects also the endogenous variables and their volatility through the demand shock. Their effects are not anymore neutralized as in the case of the standard New Keynesian model. Furthermore, the cost channel affects also the intensity of the effects of opacity on the levels and variances of inflation and the output gap through the inflation shock. Since the effects of opacity through the inflation shock in the standard New Keynesian model have been extensively studied in Dai (2012), we focus in this study on the effects of opacity through the demand shock and how the cost channel affects the effects of opacity when the economy is hit by inflation shocks.

4. The equilibrium effects of central bank opacity

Central bank opacity indirectly exercises its effects on inflation, the output gap and the nominal interest rate through the inflation expectations (or indirect) channel. Imperfect transparency affects the volatility of inflation and the output gap through both the indirect channel and the policy rule (or direct) channel. The latter corresponds to the fact that uncertainty about central bank preferences modifies the average slope of the monetary policy rule (6), and hence the responses of inflation and the output gap to inflation and demand shocks and their respective volatilities.

Distinguishing these two channels, we examine the effects of opacity by considering first uncorrelated and then correlated inflation and demand shocks.

Serially uncorrelated inflation and demand shocks

In this case, we have $\rho_e = \rho_u = 0$, implying that $\mathrm{E}_t(e_t) = 0$ and $\mathrm{E}_t(u_t) = 0$, and hence $\mathrm{E}_t \pi_{t+1} = 0$. Given that $\mathrm{E}_t \pi_{t+1} = 0$, the effects of opacity on the average level and volatility of inflation and the output gap are transmitted through the policy rule channel, with their importance and sense depending on the value of structural parameters.

Studying the responses of π_t, x_t, $\mathrm{E}_t(\frac{\partial \pi_t}{\partial e_t})$, $\mathrm{E}_t(\frac{\partial \pi_t}{\partial u_t})$, $\mathrm{E}_t(\frac{\partial x_t}{\partial e_t})$, $\mathrm{E}_t(\frac{\partial x_t}{\partial u_t})$, $\mathrm{var}(\pi_t)$ and $\mathrm{var}(x_t)$ to an increase in imperfect transparency leads to following propositions.

Proposition 1a. *When inflation and demand shocks are serially uncorrelated, the level of inflation and the output gap are not affected by changes in degree of transparency for a given preference shock. In the presence of the cost channel, a lower degree of transparency reduces (increases) the average reaction of inflation (the output gap) to inflation and demand shocks if* $\kappa(\sigma + \eta) - \sigma\kappa\phi < 1$.

Proof. Deriving (9) and (10) with respect to e_t (or u_t) and σ_ε^2 for $\rho_e = 0$ (or $\rho_u = 0$) leads to the results reported in the first part of Proposition 1a. Calculating $\mathrm{E}_t(\frac{\partial \pi_t}{\partial e_t})$, $\mathrm{E}_t(\frac{\partial \pi_t}{\partial u_t})$, $\mathrm{E}_t(\frac{\partial x_t}{\partial e_t})$ and $\mathrm{E}_t(\frac{\partial x_t}{\partial u_t})$ using (9) and (10), and deriving the results with respect to σ_ε^2 for $\rho_e = 0$, $\rho_u = 0$ and $\zeta < 1$ leads to the results reported in the second part of Proposition 1a. ■

Proposition 1b. *Imperfect transparency reduces the volatility of inflation if* $\kappa(\sigma + \eta) - \sigma\kappa\phi < \sqrt{\frac{2\lambda}{1+3\lambda}}$ *and vice versa. It increases the volatility of the output gap if*

$\kappa(\sigma+\eta)-\sigma\kappa\phi<\sqrt{\frac{\lambda+3}{2}}$ *and vice versa. Without the cost channel, the effect of opacity is only associated with inflation shocks and the previous conditions become* $\kappa(\sigma+\eta)<1$, $\kappa(\sigma+\eta)<\sqrt{\frac{2\lambda}{1+3\lambda}}$ *and* $\kappa(\sigma+\eta)<\sqrt{\frac{\lambda+3}{2}}$.

Proof. Deriving $\operatorname{var}(\pi_t)$ and $\operatorname{var}(x_t)$ given by (12) and (13) with respect to σ_e^2 and σ_ε^2 for $\rho_e=0$ leads to

$$\frac{\partial^2 \operatorname{var}(\pi_t)}{\partial\sigma_e^2\partial\sigma_\varepsilon^2}=\frac{\partial \mathrm{E}_t(\Theta^2)}{\partial\sigma_\varepsilon^2}=\frac{\zeta^2(1+\lambda)[\zeta^2+\lambda(3\zeta^2-2)]}{(\lambda+\zeta^2)^4}<0\text{, if } \zeta<\sqrt{\frac{2\lambda}{1+3\lambda}}\,, \tag{14}$$

$$\frac{\partial^2 \operatorname{var}(x_t)}{\partial\sigma_e^2\partial\sigma_\varepsilon^2}=\frac{\partial \mathrm{E}_t(\Omega^2)}{\partial\sigma_\varepsilon^2}=\frac{\zeta^2(1+\lambda)(\lambda+3-2\zeta^2)}{(\lambda+\zeta^2)^4}>0,\text{ if } \zeta<\sqrt{\frac{\lambda+3}{2}}\,, \tag{15}$$

Similar results could be obtained for $\frac{\partial^2 \operatorname{var}(\pi_t)}{\partial\sigma_u^2\partial\sigma_\varepsilon^2}$ and $\frac{\partial^2 \operatorname{var}(x_t)}{\partial\sigma_u^2\partial\sigma_\varepsilon^2}$ for $\rho_u=0$. ■

The results presented in Propositions 1a and 1b reflect the absence of the inflation expectations channel in the transmission of the effects of opacity on inflation and the output gap. In effect, when inflation and demand shocks are serially uncorrelated, the expected inflation rate is always equal to zero. Thus, it is through the policy rule channel that the average reaction and the volatility of inflation and the output gap are affected by opacity.

For $\phi=0$, the cost channel is removed from the model. Thus, we fall back to the canonical New Keynesian framework where the effects of imperfect transparency are only related to inflation shocks, given that demand shocks are fully neutralized by the optimal monetary policy and do not affect inflation and the output gap. In the absence of the cost channel, the conditions in Propositions 1a and 1b become more restrictive.

In the presence of the cost channel, i.e. $\phi=1$, changes in the short-term interest rate shift the Phillips curve, implying that the optimal monetary policy will no longer be able to neutralize the effects of demand shocks on inflation and the output gap. Thus, imperfect transparency affects the level and volatility of these variables in their responses to both inflation and demand shocks. As for the effects of opacity in the case of inflation shocks, the cost channel modifies the conditions given in Propositions 1a and 1b. Using the standard parameter values ($\kappa = 0.0858$ and $\sigma = 1.5$) into equations (9), (10), (12) and (13), we find that the effects of imperfect transparency in the case of demand shocks represents a fraction of these in the case of inflation shocks if these two types of shocks have the same variance. If demand shocks have a variance significantly higher than inflation shocks, the effects of opacity associated with demand shocks could still be substantial.

The results in Propositions 1a and 1b depend crucially on the condition $\kappa(\sigma + \eta) - \sigma\kappa\phi < 1$, which is verified for the stand parameters values in Ravenna and Walsh (2006) with $\phi = 0$ or $\phi = 1$.

Serially correlated inflation shocks

Consider now that inflation and demand shocks are persistent, i.e. $0 < \rho_e < 1$ and $0 < \rho_u < 1$. As we have observed in the above, the numerical values set for parameters are such that $\kappa(\sigma + \eta) - \sigma\kappa\phi$ is generally very small. Thus, we only consider the case $\kappa(\sigma + \eta) - \sigma\kappa\phi < 1$ when examining the effect of imperfect transparency on the level and volatility of inflation and the output gap.

Under persistent inflation shocks, expected future inflation rates will be different from zero independently of the presence or not of the cost channel. However, the latter is crucial for the expected future inflation to react to persistent demand shocks. This is explained by both the repercussions of current inflation (or demand) shocks on future inflations and the reactions of the central bank to these shocks. Equation (7) implies that

$$\frac{\partial^2 \mathrm{E}_t \pi_{t+1}}{\partial u_t \partial \sigma_\varepsilon^2} = \frac{-\rho_u \kappa\phi\sigma\zeta(1+\lambda)(1-\zeta^2)(\zeta+\rho_u\kappa\phi\sigma)}{(\lambda+\zeta^2)^3\left[1+\rho_u\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_u\mathrm{E}_t(\Theta)(\beta+\kappa\phi)\right]^2} < 0 \text{, if } \zeta < 1, \tag{16}$$

$$\frac{\partial^2 \mathrm{E}_t \pi_{t+1}}{\partial e_t \partial \sigma_\varepsilon^2} = \frac{-\rho_e \zeta(1+\lambda)(1-\zeta^2)(\zeta+\rho_e\kappa\phi\sigma)}{(\lambda+\zeta^2)^3\left[1+\rho_e\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_e\mathrm{E}_t(\Theta)(\beta+\kappa\phi)\right]^2} < 0 \text{, if } \zeta < 1. \tag{17}$$

Provided that $\frac{\partial \mathrm{E}_t \pi_{t+1}}{\partial e_t} > 0$ and $\frac{\partial \mathrm{E}_t \pi_{t+1}}{\partial u_t} > 0$, these second-order partial derivatives suggest that an decrease in central bank transparency will induce the private sector to moderate the adjustment of inflation expectations in response to current inflation and demand shocks. Thus, the central bank could reduce the responses of inflation (and hence the output gap) to inflation and demand shocks by being opaque. In the absence of the cost channel, $\phi = 0$, We have $\frac{\partial^2 \mathrm{E}_t \pi_{t+1}}{\partial e_t \partial \sigma_\varepsilon^2} = \frac{-\rho_e \zeta(1+\lambda)(1-\zeta^2)\zeta}{(\lambda+\zeta^2)^3\left[1-\rho_e\mathrm{E}_t(\Theta)\beta\right]^2} < 0$ if $\zeta < 1$ and $\frac{\partial^2 \mathrm{E}_t \pi_{t+1}}{\partial u_t \partial \sigma_\varepsilon^2} = 0$.

Proposition 2. *In the presence of the cost channel, an increase in opacity will reduce the sensitivity of inflation, inflation expectations and the output gap to a serially correlated inflation or demand shock, for* $\zeta < 1$. *Without the cost channel, the effect of opacity is only associated with inflation shocks and the previous condition becomes* $\kappa(\sigma+\eta) < 1$.

Proof. We derive (9) and (10) with respect to e_t (or u_t) and σ_ε^2. By inserting the approximated value of $\mathrm{E}_t(\Theta)$ and $\mathrm{E}_t(\Omega)$ into the resulting derivatives, it is straightforward to obtain the results about the effect of opacity on inflation and the output gap reported in Proposition 2. The effect of opacity on inflation expectations follows from (16) and (17). ■

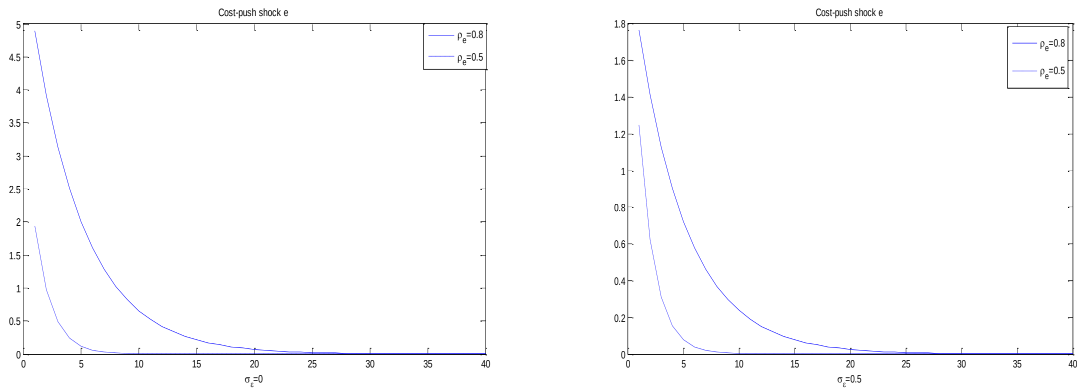

Figure 1a: The dynamic effects of opacity and persistence of shocks on the reaction of the expected inflation to cost-push shocks with the cost channel.

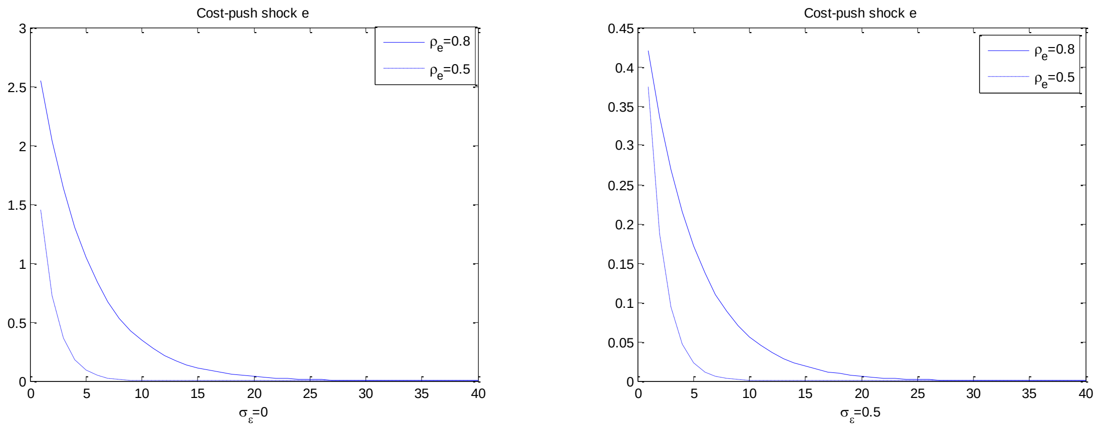

Figure 1b: The dynamic effects of opacity and persistence of shocks on the reaction of the expected inflation to cost-push shocks without the cost channel.

To grasp the relative importance of the effects of imperfect transparency on the expected inflation with and without the cost channel during the dynamic adjustment, we resort to numerical simulation where the parameters values are $\kappa = 0.0858$, $\sigma = 1.5$, $\beta = 0.99$, $\lambda = 0.25$ and $\eta = 1$. We consider one percent cost-push or demand shock with two degrees of persistence $\rho_e, \rho_u = 0.5$ and $\rho_e, \rho_u = 0.8$, and two values for initial degrees of opacity $\sigma_\varepsilon = 0$ and $\sigma_\varepsilon = 0.5$. Given these parameter values, we simulate the responses of the expected inflation to inflation shocks under the cost channel (Figure 1a) and without the cost channel (Figure 1b). Figures 1a and 1b show that the cost channel reinforces significantly the reaction of inflation expectations to cost-push shocks. Therefore, as shown the comparison of Figures 1a and 1b, it is clear that the cost channel could reinforce the moderating effect of opacity on inflation expectations in absolute terms but necessarily in relative terms. In all cases, an increase in the persistence of shocks reinforces the effect of opacity.

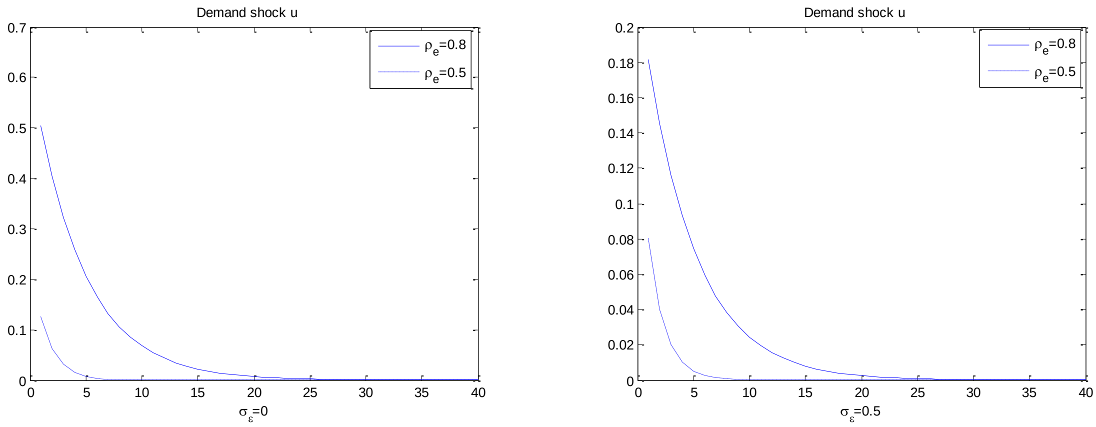

Figure 2: The dynamic effects of opacity and persistence of shocks on the reaction of the expected inflation to demand shocks with the cost channel.

Figure 2 illustrates the dynamic responses of the expected inflation to demand shocks and shows that a, increase in opacity σ_{ε} from 0 to 0.5 reduces more than half the effect of demand shocks on the expected inflation when $\rho_u = 0.8$. This attenuation effect is significantly smaller in relative terms than when $\rho_u = 0.5$.

Without the cost channel, the Phillips curve does not directly depend on variations in the policy interest rate, and thus, opacity will affect inflation and the output gap only when the inflation shock is persistent. In contrast, under the cost channel, an inflation shock affects the inflation dynamics not only through the direct channel and the inflation expectations channel but also through the funding cost when the central bank changes its policy interest rate. Thus, in the presence of the cost channel, the effects of imperfect transparency could play a greater role in stabilizing the economy. However, since other factors could also influence the equilibrium, the final impact of the cost channel on the effects of opacity associated with inflation shocks is not clear-cut.

The above results show that inflation expectations are less responsive to current monetary policy actions characterized by imperfect transparency. This is consistent with the consensus in the literature on central bank transparency, which suggests that imperfect transparency deteriorates the private sector's understanding of the central bank's objectives and decisions. On the other hand, only unanticipated changes in monetary policy could affect the real economy, implying that imperfect transparency may increase the effectiveness of monetary policy by permitting the latter to surprise the public. Thus, intransparency enhances the central bank's ability to mitigate the effect of an inflation shock (and a demand shock under the cost channel) on the economy, thus reducing (increasing) the welfare costs of achieving a higher level of output gap (inflation). This explains that it helps to smooth the responses of inflation to shocks but amplify these of the output gap. Moreover, if the central bank has a greater preference for the output-gap stabilization, these effects could be reinforced due to an increased possibility of trade-off between stabilizing the output gap and stabilizing inflation.

The role of imperfect transparency in the monetary policy transmission mechanism depends on the persistence of inflation and demand shocks. Because an increase in the latter induces higher inflation expectations, it will reinforce the role of opacity and therefore amplify the attenuation effect of imperfect transparency on the expected inflation rate (see Figure 1).

Denote $\Gamma \equiv \frac{(\lambda+\zeta^2)^3+\rho_u(\lambda+\zeta^2)^2[(\beta+\kappa\phi)\lambda-\kappa\phi\sigma\zeta]}{\rho_u(1+\lambda)(1-\zeta^2)[\kappa\phi\sigma\zeta+(\beta+\kappa\phi)\zeta^2]}$. Examining the interactions between the effects of persistence and opacity on inflation and the output gap leads to the following proposition.

Proposition 3. *For $\zeta<1$, an increase in the persistence of inflation or demand shocks strengthens the effects of imperfect transparency on inflation expectations. It could reinforce the* *effects of imperfect transparency on inflation and the output gap if: a) $\lambda > \frac{\kappa\sigma\zeta}{\beta+\kappa}$ and $\sigma_\varepsilon^2 < \Gamma$ are simultaneously verified; b) $\lambda < \frac{\kappa\sigma\zeta}{\beta+\kappa}$, $\rho_u, \rho_e < \frac{\lambda+\zeta^2}{\kappa\sigma\zeta-\lambda(\beta+\kappa)}$ and $\sigma_\varepsilon^2 < \Gamma$ are simultaneously verified.*

Proof. Deriving (16) and (17) with respect to ρ_u and ρ_e, respectively leads

$$\frac{\partial^3 \mathrm{E}_t \pi_{t+1}}{\partial e_t \partial \sigma_\varepsilon^2 \partial \rho_e} = \frac{\zeta(1+\lambda)(1-\zeta^2)\overbrace{[\zeta+\rho_e\kappa\phi\sigma\zeta^2\mathrm{E}_t(\Omega)-\rho_e\zeta\mathrm{E}_t(\Theta)(\beta+\kappa\phi)-2(\zeta+\rho_e\kappa\phi\sigma)]}^{\Psi_e}}{(\lambda+\zeta^2)^3[1+\rho_e\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_e\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^3}.$$

$$\frac{\partial^3 \mathrm{E}_t \pi_{t+1}}{\partial u_t \partial \sigma_\varepsilon^2 \partial \rho_e} = \frac{\kappa\phi\sigma\zeta(1+\lambda)(1-\zeta^2)\overbrace{[\zeta+\rho_u\kappa\phi\sigma\zeta^2\mathrm{E}_t(\Omega)-\rho_u\zeta\mathrm{E}_t(\Theta)(\beta+\kappa\phi)-2(\zeta+\rho_u\kappa\phi\sigma)]}^{\Psi_u}}{(\lambda+\zeta^2)^3[1+\rho_u\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_u\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^3}$$

According to the definition of Ω, we have $\zeta^2\Omega \equiv \frac{\zeta^2(1+\varepsilon)}{\lambda-\varepsilon+\zeta^2(1+\varepsilon)} < 1$, implying that $\zeta^2\mathrm{E}_t(\Omega) < 1$. Therefore the numerator of the above derivatives is negative since

$$\Psi_j = -\rho_j\zeta(\beta+\kappa\phi)\mathrm{E}_t(\Theta) - (\zeta+\rho_j\kappa\phi\sigma) - \rho_j\kappa\phi\sigma[1-\zeta^2\mathrm{E}_t(\Omega)] < 0, \qquad \forall j = u, e.$$

This leads to $\frac{\partial^3 \mathrm{E}_t\pi_{t+1}}{\partial e_t \partial\sigma_\varepsilon^2 \partial\rho_e} < 0$ and $\frac{\partial^3 \mathrm{E}_t\pi_{t+1}}{\partial u_t \partial\sigma_\varepsilon^2 \partial\rho_e} < 0$ if $\zeta < 1$. Given that $\frac{\partial^2 \mathrm{E}_t\pi_{t+1}}{\partial u_t \partial\sigma_\varepsilon^2} < 0$ and $\frac{\partial^2 \mathrm{E}_t\pi_{t+1}}{\partial e_t \partial\sigma_\varepsilon^2} < 0$ according to (16) and (17), an increase in the persistence of inflation shocks reinforces the effect of opacity on inflation expectations.

Deriving (9) with respect to u_t, σ_ε^2 and ρ_u leads to

$$\frac{\partial^3 \pi_t}{\partial u_t \partial\sigma_\varepsilon^2 \partial\rho_u} = -\kappa\phi\sigma\Theta\left[\overbrace{\kappa\phi\sigma\zeta\frac{\partial \mathrm{E}_t(\Omega)}{\partial\sigma_\varepsilon^2} - (\beta+\kappa\phi)\frac{\partial\mathrm{E}_t(\Theta)}{\partial\sigma_\varepsilon^2}}^{>0}\right]\frac{\overbrace{1-\rho_u\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)+\rho_u\mathrm{E}_t(\Theta)(\beta+\kappa\phi)}^{\Xi}}{[1+\rho_u\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_u\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^3}$$

Substituting the approximated values of $\mathrm{E}_t(\Theta)$ and $\mathrm{E}(\Omega)$ into Ξ, we get

$$\Xi = 1 - \rho_u\frac{\kappa\phi\sigma\zeta - (\beta+\kappa\phi)\lambda}{\lambda+\zeta^2} - \frac{\kappa\phi\sigma\zeta + (\beta+\kappa\phi)\zeta^2}{(\lambda+\zeta^2)^3}\rho_u(1+\lambda)(1-\zeta^2)\sigma_\varepsilon^2.$$

For $\sigma_\varepsilon^2 > 0$, $\phi = 1$ and $\zeta < 1$, there are two cases where $\Xi > 0$. In the first case where $\lambda > \frac{\kappa\sigma\zeta}{\beta+\kappa}$, we have $\Xi > 0$ and hence $\frac{\partial^3 \pi_t}{\partial u_t \partial \sigma_\varepsilon^2 \partial \rho_u} < 0$ if $\sigma_\varepsilon^2 < \Gamma$. In the second case where $\lambda < \frac{\kappa\sigma\zeta}{\beta+\kappa}$, we have $\Xi > 0$ and $\frac{\partial^3 \pi_t}{\partial u_t \partial \sigma_\varepsilon^2 \partial \rho_u} < 0$, if $\rho_u < \frac{\lambda+\zeta^2}{\kappa\sigma\zeta-\lambda(\beta+\kappa)}$ and $\sigma_\varepsilon^2 < \Gamma$. Under these conditions, given that $\frac{\partial^2 \pi_t}{\partial u_t \partial \sigma_\varepsilon^2} < 0$, $\Xi > 0$ implies that under the cost channel an increase in persistence reinforces the effect of opacity on inflation when the economy is hit by demand shocks. If the above condition regarding the value of σ_ε^2 is not verified, i.e., $\sigma_\varepsilon^2 > \Gamma$, we have $\Xi < 0$ and $\frac{\partial^3 \pi_t}{\partial u_t \partial \sigma_\varepsilon^2 \partial \rho_u} > 0$.

Using the similarity between the expression of $\frac{\partial^3 \pi_t}{\partial u_t \partial \sigma_\varepsilon^2 \partial \rho_u}$ and these of other derivatives, i.e., $\frac{\partial^3 \pi_t}{\partial u_t \partial \sigma_\varepsilon^2 \partial \rho_e}$, $\frac{\partial^3 x_t}{\partial u_t \partial \sigma_\varepsilon^2 \partial \rho_u}$ and $\frac{\partial^3 x_t}{\partial u_t \partial \sigma_\varepsilon^2 \partial \rho_e}$, we obtain similar conditions under which an increase in persistence could reinforce or weaken the effects of opacity on inflation and the output gap.

■

Our previous propositions show that the serial correlation of inflation and demand shocks leads to, under opacity, a larger response of inflation expectations to both shocks if the output-gap elasticity of the inflation (i.e., $\zeta \equiv \kappa(\sigma+\eta) - \sigma\kappa\phi$ and $\zeta \equiv \kappa(\sigma+\eta)$ respectively in the presence or the absence of the cost channel) is lower than unity. In the absence of the cost channel, an increase in the persistence of inflation shocks will also amplify the effect of opacity on inflation and the output gap through the channel of inflation expectations. However, under the cost channel, an increase in the persistence of both shocks could also affect through the interactions between the cost channel and opacity the equilibrium solutions of inflation and the output gap in the opposite direction to the inflation expectation channel. Therefore, it could either amplify or attenuate the effect of opacity.

The effect of imperfect transparency on inflation and the output gap through the policy channel can only manifest itself when we examine the average reactions of these variables.

Proposition 4a. *An increase in opacity will attenuate the average reaction of inflation to serially correlated inflation and demand shocks if* $\zeta < 1$. *It will strengthen the average reaction of the output gap to these shocks only if* $\rho_u < \frac{1}{\beta+\kappa\phi}$ *and* $\zeta < 1$.

Proof. To evaluate the effects of imperfect transparency on the average reactions of inflation and the output gap to both shocks, we derive (9) and (10) first with respect to u_t and e_t, and then the expected values of resulting derivatives with respect to σ_ε^2 as follows:

$$\frac{\partial \mathrm{E}\left[\frac{\partial \pi_t}{\partial u_t}\right]}{\partial \sigma_\varepsilon^2} = \frac{-\kappa\phi\sigma\zeta(1+\lambda)(1-\zeta^2)(\zeta+\rho_u\kappa\phi\sigma)}{(\lambda+\zeta^2)^3\left[1+\rho_u\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_u\mathrm{E}_t(\Theta)(\beta+\kappa\phi)\right]^2} < 0, \text{ if } \zeta < 1, \tag{18}$$

$$\frac{\partial \mathrm{E}\left[\frac{\partial \pi_t}{\partial e_t}\right]}{\partial \sigma_\varepsilon^2} = \frac{-\zeta(1+\lambda)(1-\zeta^2)(\zeta+\rho_e\kappa\phi\sigma)}{(\lambda+\zeta^2)^3\left[1+\rho_e\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_e\mathrm{E}_t(\Theta)(\beta+\kappa\phi)\right]^2} < 0, \text{ if } \zeta < 1, \tag{19}$$

$$\frac{\partial \mathrm{E}\left[\frac{\partial x_t}{\partial u_t}\right]}{\partial \sigma_\varepsilon^2} = \frac{-\kappa\phi\sigma\zeta(1+\lambda)(1-\zeta^2)\left[1-\rho_u(\beta+\kappa\phi)\right]}{(\lambda+\zeta^2)^3\left[1+\rho_u\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_u\mathrm{E}_t(\Theta)(\beta+\kappa\phi)\right]^2} < 0 \text{ if } \rho_u < \frac{1}{\beta+\kappa\phi} \text{ and } \zeta < 1, \tag{20}$$

$$\frac{\partial \mathrm{E}\left[\frac{\partial x_t}{\partial e_t}\right]}{\partial \sigma_\varepsilon^2} = \frac{-\zeta(1+\lambda)(1-\zeta^2)\left[1-\rho_u(\beta+\kappa\phi)\right]}{(\lambda+\zeta^2)^3\left[1+\rho_e\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_e\mathrm{E}_t(\Theta)(\beta+\kappa\phi)\right]^2} < 0, \text{ if } \rho_u < \frac{1}{\beta+\kappa\phi} \text{ and } \zeta < 1. \tag{21}$$

Comparing the results given by (18)-(21) with the average reactions of inflation and the output gap to serially correlated inflation and demand shocks ($\mathrm{E}\left[\frac{\partial \pi_t}{\partial u_t}\right] > 0$, $\mathrm{E}\left[\frac{\partial \pi_t}{\partial e_t}\right] > 0$, $\mathrm{E}\left[\frac{\partial x_t}{\partial u_t}\right] < 0$ and $\mathrm{E}\left[\frac{\partial x_t}{\partial e_t}\right] < 0$), we obtain the results reported in Proposition 4a. ■

In the absence of the cost channel, given that the demand shock does not affect inflation and the output gap and therefore, the degree of opacity will have no impact on the average reactions of inflation and the output gap to serially correlated demand shocks. Furthermore, the condition $\rho_u < \frac{1}{\beta+\kappa\phi}$ will be redundant since in this case, i.e., $\phi = 0$, implying that $\frac{1}{\beta+\kappa\phi} > 1$.

The introduction of the cost channel implies that the effect of serially correlated demand shocks is not neutralized by the optimal monetary policy. The average reactions of inflation and the output gap to serially correlated inflation shocks are thus also affected by imperfect transparency with the amplitude of its effect depending on the initial degree of imperfect transparency. More, the sign of this effect on the output gap depends on the degree of persistence of shocks.

The denominator in (18)-(21), i.e. $[1+\rho_u\kappa\phi\sigma\zeta \mathrm{E}_t(\Omega) - \rho_u \mathrm{E}_t(\Theta)(\beta+\kappa\phi)]$ is increasing in σ_ε^2 given that $\mathrm{E}_t(\Omega)$ and $\mathrm{E}_t(\Theta)$ are respectively increasing and decreasing in σ_ε^2. Since the numerators in (18)-(21) are independent of σ_ε^2, the effects of opacity reported in Proposition 4a become less important following an increase in the initial degree of imperfect transparency.

However, with the cost channel, the relationship between the persistence of shocks and the effects of opacity on the average reaction of endogenous variables is ambiguous. In effect, an increase in the degree of persistence will induce a higher expected future inflation rate according to Proposition 3, implying that opacity will generally make a larger impact on inflation and the output gap on average because of its stronger negative effect on inflation expectations. On the other hand, a higher degree of persistence reinforces the effects of shocks on endogenous variables through the policy channel. Deriving $\mathrm{E}\left[\frac{\partial \pi_t}{\partial u_t}\right]$ and $\mathrm{E}\left[\frac{\partial x_t}{\partial u_t}\right]$ with respect to ρ_u, and $\mathrm{E}\left[\frac{\partial \pi_t}{\partial e_t}\right]$ and $\mathrm{E}\left[\frac{\partial x_t}{\partial e_t}\right]$ respect to ρ_u, and comparing the resulting second derivatives with these first-order derivatives lead to the following proposition.

Proposition 4b. *An increase in the degree of persistence of inflation and demand shocks reinforces the effect of opacity on the average inflation if* $\frac{\kappa\phi}{\beta+\kappa\phi} < \frac{\mathrm{E}_t(\Theta)}{\sigma\zeta\mathrm{E}_t(\Omega)}$ *but weakens its effect if* $\frac{\kappa\phi}{\beta+\kappa\phi} > \frac{\mathrm{E}_t(\Theta)}{\sigma\zeta\mathrm{E}_t(\Omega)}$ *and* $\rho_u, \rho_e > \frac{1}{\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\mathrm{E}_t(\Theta)(\beta+\kappa\phi)} - 2\zeta$ *for* $\zeta < 1$. *When the initial degree of persistence is relatively low, i.e.* $\rho_u, \rho_e < \frac{1}{\beta+\kappa\phi}$, *an increase in the persistence will weaken the effect of opacity on the average output gap if* $\frac{\kappa\phi}{\beta+\kappa\phi} < \frac{\mathrm{E}_t(\Theta)}{\sigma\zeta\mathrm{E}_t(\Omega)}$, *and vice versa.*

Proof. Deriving (18) and (20) with respect to ρ_u, and (19) and (21) with respect to ρ_e, we obtain

$$\frac{\partial^2 \mathrm{E}\left[\frac{\partial \pi_t}{\partial u_t}\right]}{\partial \sigma_\varepsilon^2 \partial \rho_u} = -\frac{\kappa\phi\sigma\zeta(1+\lambda)(1-\zeta^2)\{\kappa\phi\sigma-(\rho_u\kappa\phi\sigma+2\zeta)[\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]\}}{(\lambda+\zeta^2)^3[1+\rho_u\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_u\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^3}, \quad (22)$$

$$\frac{\partial^2 \mathrm{E}\left[\frac{\partial \pi_t}{\partial e_t}\right]}{\partial \sigma_\varepsilon^2 \partial \rho_e} = -\frac{\zeta(1+\lambda)(1-\zeta^2)\{\kappa\phi\sigma-(\rho_e\kappa\phi\sigma+2\zeta)[\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]\}}{(\lambda+\zeta^2)^3[1+\rho_e\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_e\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^3}, \quad (23)$$

$$\frac{\partial^2 \mathrm{E}\left[\frac{\partial x_t}{\partial u_t}\right]}{\partial \sigma_\varepsilon^2 \partial \rho_u} = \frac{\kappa\phi\sigma\zeta(1+\lambda)(1-\zeta^2)\{\beta+\kappa\phi+[2-(\beta+\kappa\phi)\rho_u][\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]\}}{(\lambda+\zeta^2)^3[1+\rho_u\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_u\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^3}, \quad (24)$$

$$\frac{\partial^2 \mathrm{E}\left[\frac{\partial x_t}{\partial e_t}\right]}{\partial \sigma_\varepsilon^2 \partial \rho_e} = \frac{\zeta(1+\lambda)(1-\zeta^2)\{\beta+\kappa\phi+[2-(\beta+\kappa\phi)\rho_e][\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]\}}{(\lambda+\zeta^2)^3[1+\rho_e\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_e\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^3}. \quad (25)$$

Determining the signs of (22)-(25) according to parameter values and comparing them with these of (18)-(21) respectively leads to the results reported in Proposition 4b. ■

In the absence of the cost channel, an increase in the persistence of inflation shocks generally reinforces the attenuation effects of central bank opacity on the average reaction of inflation to inflation shocks. It weakens the amplification effects of opacity on the average reaction of the output gap to inflation shocks. Since $\phi = 0$, the condition $\frac{\kappa\phi}{\beta+\kappa\phi} < \frac{E_t(\Theta)}{\sigma\zeta E_t(\Omega)}$ is always verified and the case where $\frac{\kappa\phi}{\beta+\kappa\phi} > \frac{E_t(\Theta)}{\sigma\zeta E_t(\Omega)}$ is excluded.

Under the cost channel, we could have either $\frac{\kappa}{\beta+\kappa} < \frac{E_t(\Theta)}{\sigma\zeta E_t(\Omega)}$ or $\frac{\kappa}{\beta+\kappa} > \frac{E_t(\Theta)}{\sigma\zeta E_t(\Omega)}$, where $\frac{\kappa}{\beta+\kappa}$ could be interpreted as representing the importance of the effect of inflation expectations through the cost channel κ (i.e. the interest rate in the Phillips curve) relative to the total effect of inflation expectations $\beta+\kappa$. An increase in the persistence of shocks could affect positively or negatively the effect of opacity on the average inflation and output gap through three channels: 1) the inflation expectation channel, 2) the policy rate, and 3) the cost channel. The importance of the effects through these channels crucially depend on the threshold conditions imposed on the degree of persistence as well as $\frac{\kappa}{\beta+\kappa} < \frac{E_t(\Theta)}{\sigma\zeta E_t(\Omega)}$ or $\frac{\kappa}{\beta+\kappa} > \frac{E_t(\Theta)}{\sigma\zeta E_t(\Omega)}$. The latter could be expressed in terms of threshold conditions imposed on the preference parameter for output-gap stabilization. Using $\zeta \equiv \kappa(\sigma+\eta) - \sigma\kappa = \kappa\eta$ and the approximated values of definition of $E_t(\Omega)$ and $E_t(\Theta)$, we can show that $\frac{\kappa}{\beta+\kappa} < \frac{E_t(\Theta)}{\sigma\zeta E_t(\Omega)}$ is equivalent to $\lambda > \frac{\sigma\eta\kappa^2}{\beta+\kappa} + \frac{(1+\lambda)(\lambda+\zeta^2)(1-\zeta^2)\sigma_\varepsilon^2}{(\lambda+\zeta^2)^2+(1+\lambda)(1-\zeta^2)\sigma_\varepsilon^2}$ and *vice versa*. When $\sigma_\varepsilon^2 = 0$, the last condition becomes $\lambda > \frac{\sigma\eta\kappa^2}{\beta+\kappa}$. Using the standard parameter values, we obtain $\lambda > \frac{\sigma\eta\kappa^2}{\beta+\kappa} = 0.01026$. Except when the central banker is an inflation nutter or practices strict inflation targeting, the previous condition is generally verified. However, given that the term $\frac{(1+\lambda)(\lambda+\zeta^2)(1-\zeta^2)\sigma_\varepsilon^2}{(\lambda+\zeta^2)^2+(1+\lambda)(1-\zeta^2)\sigma_\varepsilon^2}$ is increasing in σ_ε^2, the threshold condition on λ could be significantly relaxed when σ_ε^2 is large, making more likely the case where we have $\frac{\kappa}{\beta+\kappa} > \frac{E_t(\Theta)}{\sigma\zeta E_t(\Omega)}$ and hence an increase in the persistence of shocks weakens (reinforces) the effect of opacity on the average inflation (output gap).

As the interactions between monetary policy intransparency and persistence of shocks depend on the initial degrees of opacity and persistence, in the following, we only consider the case where the initial equilibrium is characterized by full transparency, i.e. $\sigma_\varepsilon^2 = 0$, to obtain some results with clear-cut conditions when examining the effects of opacity on macroeconomic volatility. These results show under what conditions the central bank has incentive to deviate from a situation characterized by full transparency.

Proposition 5a. *In the absence of the cost channel, departing from an initial equilibrium with full transparency, an increase in opacity will induce a lower inflation volatility induced by inflation shocks if* $\kappa(\sigma+\eta) < \sqrt{\frac{2\lambda}{1+3\lambda}}$, $\forall \rho \in [0,1]$ *or if* $\sqrt{\frac{2\lambda}{1+3\lambda}} < \kappa(\sigma+\eta) < 1$ *and* $\rho_e > \frac{(\lambda+\zeta^2)\{\kappa^2(\sigma+\eta)^2+\lambda[3\kappa^2(\sigma+\eta)^2-2)]\}}{(1+\lambda)\lambda\beta\kappa^2(\sigma+\eta)^2}$*; it will increase the volatility of the output gap induced by inflation shocks if* $\kappa(\sigma+\eta) < 1$, $\forall \rho \in [0,1]$.

Proof. Deriving the variances of inflation and the output gap σ_u^2 (and σ_e^2) and $\partial\sigma_\varepsilon^2$ using (12) and (13) yields

$$\frac{\partial^2\,\mathrm{var}(\pi_t)}{\partial\sigma_u^2\partial\sigma_\varepsilon^2} = \frac{-2\kappa^2\phi^2\sigma^2\mathrm{E}_t(\Theta^2)\left[\rho_u\kappa\phi\sigma\zeta\frac{\partial\mathrm{E}_t(\Omega)}{\partial\sigma_\varepsilon^2} - \rho_u(\beta+\kappa\phi)\frac{\partial\mathrm{E}_t(\Theta)}{\partial\sigma_\varepsilon^2}\right]}{[1+\rho_u\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_u\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^3} + \frac{\kappa^2\phi^2\sigma^2\frac{\partial\mathrm{E}_t(\Theta^2)}{\partial\sigma_\varepsilon^2}}{[1+\rho_u\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_u\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^2}, \tag{26}$$

$$\frac{\partial^2\,\mathrm{var}(x_t)}{\partial\sigma_u^2\partial\sigma_\varepsilon^2} = \frac{-2\kappa^2\phi^2\sigma^2\zeta^2\mathrm{E}_t(\Omega^2)\left[\rho_u\kappa\phi\sigma\zeta\frac{\partial\mathrm{E}_t(\Omega)}{\partial\sigma_\varepsilon^2} - \rho_u(\beta+\kappa\phi)\frac{\partial\mathrm{E}_t(\Theta)}{\partial\sigma_\varepsilon^2}\right]}{[1+\rho_u\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_u\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^3} + \frac{\kappa^2\phi^2\sigma^2\zeta^2\frac{\partial\mathrm{E}_t(\Omega^2)}{\partial\sigma_\varepsilon^2}}{[1+\rho_u\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_u\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^2}, \tag{27}$$

$$\frac{\partial^2\,\mathrm{var}(\pi_t)}{\partial\sigma_e^2\partial\sigma_\varepsilon^2} = \frac{2\mathrm{E}_t(\Theta^2)\left[\rho_e\kappa\phi\sigma\zeta\frac{\partial\mathrm{E}_t(\Omega)}{\partial\sigma_\varepsilon^2} - \rho_e(\beta+\kappa\phi)\frac{\partial\mathrm{E}_t(\Theta)}{\partial\sigma_\varepsilon^2}\right]}{[1+\rho_e\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_e\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^3} + \frac{\frac{\partial\mathrm{E}_t(\Theta^2)}{\partial\sigma_\varepsilon^2}}{[1+\rho_e\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_e\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^2}, \tag{28}$$

$$\frac{\partial^2\,\mathrm{var}(x_t)}{\partial\sigma_e^2\partial\sigma_\varepsilon^2} = \frac{-2\zeta^2\mathrm{E}_t(\Omega^2)\left[\rho_e\kappa\phi\sigma\zeta\frac{\partial\mathrm{E}_t(\Omega)}{\partial\sigma_\varepsilon^2} - \rho_e(\beta+\kappa\phi)\frac{\partial\mathrm{E}_t(\Theta)}{\partial\sigma_\varepsilon^2}\right]}{[1+\rho_e\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_e\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^3} + \frac{\zeta^2\frac{\partial\mathrm{E}_t(\Omega^2)}{\partial\sigma_\varepsilon^2}}{[1+\rho_e\kappa\phi\sigma\zeta\mathrm{E}_t(\Omega)-\rho_e\mathrm{E}_t(\Theta)(\beta+\kappa\phi)]^2}. \tag{29}$$

Using the approximated values of $\mathrm{E}_t(\Omega)$, $\mathrm{E}_t(\Omega^2)$, $\mathrm{E}_t(\Theta)$ and $\mathrm{E}_t(\Theta^2)$, substituting $\zeta \equiv \kappa(\sigma+\eta)-\sigma\kappa\phi$ and setting $\phi=0$ and $\sigma_\varepsilon^2=0$ in equations (26)-(29), and examining the resulting equations lead to the results reported in Proposition 5a. ■

The first and second terms on the right hand side of (26)-(29) represent the effect of imperfect transparency through the inflation expectations channel and the policy channel, respectively.

In (26)-(29), the degrees of persistence and opacity interact, implying that the effect of an increase in opacity depends on the initial levels of ρ_u, ρ_e, σ_u^2 and σ_ε^2. The effects of opacity via the inflation expectations channel (indirect effect) on the volatility of inflation and the output gap are negative. Through the policy rule channel (direct effect), opacity has either negative or positive effect on the volatility of inflation but only positive effect on the volatility of the output gap. Therefore, the sign of the total effect of decreased transparency through these two channels is ambiguous.

In the absence of the cost channel, i.e. $\phi=0$, demand shocks have no effect on the macroeconomic volatility and hence will not interact with opacity. Applying $\phi=0$ to equations (28)-(29), it is straightforward to check that if $\zeta=\kappa(\sigma+\eta)<1$, the effects of opacity on the volatility of inflation and the output gap through the inflation expectations channel are both negative. The effect of opacity on the volatility of inflation via the policy rule channel could be negative if $\kappa(\sigma+\eta)<\sqrt{\frac{2\lambda}{1+3\lambda}}$ and *vice versa*. Therefore, the total effect of opacity on the variance of inflation is negative either when both direct and indirect effects of opacity are negative, i.e. if $\kappa(\sigma+\eta)<\sqrt{\frac{2\lambda}{1+3\lambda}}$, or when the indirect negative effect dominates the positive direct effect, i.e., if $\sqrt{\frac{2\lambda}{1+3\lambda}}<\kappa(\sigma+\eta)<1$ and

$\rho_e > \frac{(\lambda+\zeta^2)\{\kappa^2(\sigma+\eta)^2+\lambda[3\kappa^2(\sigma+\eta)^2-2)]\}}{(1+\lambda)\lambda\beta\kappa^2(\sigma+\eta)^2}$. For $\kappa(\sigma+\eta)<1$, the total effect of decreased transparency on the volatility of the output gap is positive given that the negative indirect effect is dominated by the positive direct effect whatever the degree of persistence of inflation shocks.

Proposition 5b. *In the presence of the cost channel, departing from an initial equilibrium with full transparency, an increase in opacity will reduce the volatility of inflation induced by inflation and demand shocks if* $\zeta < \sqrt{\frac{2\lambda}{1+3\lambda}}$, $\forall \rho_u, \rho_e \in [0,1]$ *or if* $\sqrt{\frac{2\lambda(1-\lambda)+\lambda\sqrt{4(1-\lambda)^2+8(1+3\lambda)}}{2(1+3\lambda)}} < \zeta < 1$, *and* $\rho_u, \rho_e > \frac{\zeta(\lambda+\zeta^2)[\zeta^2+\lambda(3\zeta^2-2)]}{\lambda(\beta+\kappa)\zeta^3(1+\lambda)-\kappa\sigma\{\zeta^2[\zeta^2+\lambda(3\zeta^2-2)]-2\lambda^2(1-\zeta^2)\}} > 0$*; it will increase the volatility of the output gap induced by inflation and demand shocks and* $\frac{\kappa}{\beta+\kappa} > \frac{\lambda(\lambda+3-2\zeta^2)+2\zeta^2(1-\zeta^2)}{\sigma\zeta(1+\lambda)}$, $\forall \rho \in [0,1]$ *or if* $\frac{\kappa}{\beta+\kappa} < \frac{\lambda(\lambda+3-2\zeta^2)+2\zeta^2(1-\zeta^2)}{\sigma\zeta(1+\lambda)}$ and $\rho_u, \rho_e < \frac{(\lambda+\zeta^2)(\lambda+3-2\zeta^2)}{(\beta+\kappa)[\lambda(\lambda+3-2\zeta^2)+2\zeta^2(1-\zeta^2)]-\kappa\sigma\zeta(1+\lambda)}$ for $\zeta < 1$.

Proof. Using the approximated values of $\mathrm{E}_t(\Omega)$, $\mathrm{E}_t(\Omega^2)$, $\mathrm{E}_t(\Theta)$ and $\mathrm{E}_t(\Theta^2)$, setting $\phi = 1$ and $\sigma_\varepsilon^2 = 0$ in equations (26)-(29) and examining the resulting equations lead to the results reported in Proposition 5b. ■

Notice that the condition $\frac{\zeta(\lambda+\zeta^2)[\zeta^2+\lambda(3\zeta^2-2)]}{\lambda(\beta+\kappa)\zeta^3(1+\lambda)-\kappa\sigma\{\zeta^2[\zeta^2+\lambda(3\zeta^2-2)]-2\lambda^2(1-\zeta^2)\}} > 0$ in Proposition 5b implies $\frac{\kappa}{\beta+\kappa} < \frac{\lambda\zeta^3(1+\lambda)}{\sigma\{\zeta^2[\zeta^2+\lambda(3\zeta^2-2)]-2\lambda^2(1-\zeta^2)\}}$. This implies that the lower bound for the degree of persistence ρ_u, ρ_e is positive only when the effect of inflation expectation through the cost channel relative to the total effect of inflation expectations is relatively small. Otherwise, this threshold constraint will no longer be useful.

Under the cost channel, i.e. $\phi = 1$, demand shocks affect the macroeconomic volatility and hence interact with central bank transparency. Furthermore, the cost channel modifies the interactions between the effects of opacity and the effects of inflation shocks on the macroeconomic volatility. These impacts of the cost channel are reflected in Proposition 5b by the fact that the equilibrium is similarly affected by imperfect transparency when there are demand and inflation shocks, and that the conditions presented in Proposition 5b are sensitively different from those reported in Proposition 5a.

Using equation (5), we define the social welfare function as follows:

$$W^s \equiv -\frac{1}{2}\mathrm{E}_t \sum_{t=0}^{\infty} \beta^t (\pi_t^2 + \lambda x_t^2) \tag{30}$$

The effects of imperfect transparency on social welfare could be appreciated by examining its effects on the economy through two channels. In the present model, greater opacity makes the expected inflation, and hence the level and volatility of inflation and the output gap less responsive to current monetary policy actions, with the size of moderating effect increasing with the presence of the cost channel. This is because imperfect transparency deteriorates the private sector's understanding of the central bank's objectives and decisions. The second channel corresponds to the effect of opacity on the consequences of unanticipated changes in monetary policy. In effect, imperfect transparency could increase the effectiveness of monetary policy by permitting the latter to surprise the public. Thus, imperfect disclosure about central bank preference makes easier for monetary policy to mitigate under the cost channel the effect of an inflation shock and a demand shock on inflation and the output gap. This explains that imperfect transparency may have contradictory effects on the volatility of inflation and the output gap.

More precisely, imperfect transparent monetary policy could help smooth the variations of inflation but amplify these of the output gap because it reduces (increases) the welfare costs of achieving a higher level of output-gap (inflation). These effects are stronger when the trade-off between inflation and the output gap is higher, due to higher persistence of inflation shocks and/or lower relative weight assigned to output-gap stabilization. Consequently, The effect of imperfect transparency on the social welfare will crucially depend on the relative weight that the society puts on the stabilization of the output gap. Generally, if this weight is low, imperfect transparency could improve social welfare.

5. Conclusions

This paper has examined the effects of political transparency under optimal monetary discretion in a forward-looking New Keynesian model with a role for the cost channel in the transmission of monetary policy, which stems from the observation that firms use bank credit to pre-finance production. This channel considerably modifies the effects of central bank transparency on the macroeconomic performance. The direct dependence of firms' marginal cost and hence price decisions on the nominal rate of interest implies that all shocks to the economy will generate a trade-off between stabilizing inflation and stabilizing the output gap, and thus central bank transparency could interact not only with inflation shocks but also with demand shocks.

We find that in the presence of inflation and demand shocks, imperfect transparency about the relative weight assigned by the central bank to output-gap stabilization affects the economy in the same direction but with different amplitude. The effects of imperfect transparency also vary according to their degree of persistence.

If inflation and demand shocks are serially uncorrelated, imperfect transparency does not modify inflation expectations and hence has no effect on the level of inflation and the output gap through this channel. Given that the equilibrium value of these variables are affected by shocks to central bank preferences, an increase in opacity will reduce the average reaction of inflation but increase that of the output gap to inflation and demand shocks for standard parameter values, implying a reduction in the volatility of inflation and an increase in the volatility of the output gap. The effects of opacity associated with the demand shock could be substantial, compared with these associated with the inflation shock, only if the first has a significantly higher volatility than the second.

Serial correlation of inflation and demand shocks reduces the sensitivity of inflation and the output gap to inflation or demand shocks in the New Keynesian model with the cost channel through the inflation expectations channel. However, through the policy rule channel, higher persistence of inflation shocks will reinforce (reduce) the attenuation (amplification) effect of opacity on the average reaction of inflation (the output gap) to inflation and demand shocks. In terms of macroeconomic performance, the volatility of inflation decreases with opacity while the volatility of the output gap increases with it, and both of them increase with shock persistence. The cost channel could increase the size of effects of opacity due to inflation shocks on the level of endogenous variables and the social welfare and could reinforce the effects of opacity associated with persistence. Generally, imperfect transparency could improve social welfare and more significantly so if the society is quite conservative in the sense of assigning a low weight to output-gap stabilization.

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