Central-bank information and interest-rate smoothing in a forward-looking model

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Abstract

At first glance it appears that transparency about shocks affecting inflation is inefficient for a central bank with a motive for interest-rate smoothing. In particular, with forward-looking behaviour of price setters the central bank's reluctance to significantly change the interest rate should constitute an incentive for the central bank to keep its private information secret. A New-Keynesian model with forward-looking price setters is presented to clarify this issue. In contrast to the reasoning above, we find that a general cost of transparency under interest-rate smoothing can only be established if forward-looking behaviour of price setters is absent. With forward-looking price setters transparency can well be efficient provided that the central bank's preferences are sufficiently close to strict inflation targeting.

Keywords: Transparency, monetary policy, interest-rate smoothing

JEL: E42, E52, E58

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I. Introduction

The paper deals with the central bank's information advantage about shocks and the suitable use of this information in communicating with the public. In this respect the issue belongs to the now extended literature discussing transparency in monetary policy, particularly the branch analysing potential costs of full transparency in the conduct of monetary policy.[1]

The focus of most of these papers is the role of transparency in dealing with the time-consistency problem of monetary policy. In particular, the question of possible trade-offs between transparency and efficiency in monetary policy is analysed, as is the case in Faust and Svensson (2001), Geraats (2001a) and Jensen (2001). The common feature of this literature is the assumption of an information advantage on the side of the central bank on critical parameters describing its preferences.[2]

In contrast to these papers we address the above mentioned information advantage concerning the state of the economy.[3] Suppose that a central bank has information about a cost-push shock which is not yet available to the public. Releasing the information to the public may turn out to put the central bank at a disadvantage, if the information gives rise to inflation expectations which in standard models with forward-

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1 For a broad discussion of the issue of transparency in monetary policy see Winkler (2000).

2 The typical assumption in this literature is that the presence of an inflation control error prevents the public from correctly inferring the central bank's true intentions. The extent of transparency then refers to the fraction of the control error revealed to the public ex post. An early application of this framework is Cukierman and Meltzer (1986).

3 Romer and Romer (2000) provide evidence that Federal Reserve forecasts of inflation are superior to those of commercial forecasters. Cukierman (2001) stresses that at least the public's information about some upcoming shocks would not have been known without publication of the central bank (Cukierman (2001), p. 18). Another application of the assumption of superior central bank information about shocks is Geraats (2001b and 2001c), focussing on the time-consistency problem and the role of the institutional framework of monetary policy for the assessment of transparency.

looking features have immediate consequences for current variables affecting the central bank's loss function. While this example suggests that transparency about current shocks might complicate monetary policy, it does in no way proof that transparency in fact increases expected losses for a central bank. As recently emphasised in Cukierman (2001), there is, however, a specific feature of central-bank behaviour that might make this conclusion inevitable. Rising inflation expectations due to the announcement of shocks afford a more determined reaction of the central bank which might be a problem if the central bank has a motive for interest-rate smoothing. Moreover, in this case the central bank's reluctance to react strongly enters the formation of expectations in the public. Thus it appears that the specific constellation of weights in the central bank's loss function is critical for the judgement of transparency about shocks. The aim of this paper is to clarify this issue, which turns out to depend on a number of further critical specification aspects.

This paper's results are derived from versions of the log-linearised stylised New-Keynesian model with microfoundations analysed in Clarida, Gali, and Gertler (1999, 2000), Rotemberg and Woodford (1997, 1999), McCallum (2001), and elsewhere. We consider equilibria with rational expectations under discretion abstracting from issues leading to an inflation bias, since the central bank cares only about stabilising the output gap without having a target to set output above potential output. We also ignore any strategic aspects regarding the central bank's information but focus on the comparison of different regimes based on different information sets of the public when forming inflation expectations.

Section II presents the model and derives the results when no forward-looking behaviour in price setting is present. Interest-rate smoothing is interpreted in the usual way, namely as a motive to reduce deviations of the interest rate from its value in the preceding period. The results show a general trade off between transparency and efficiency of monetary policy in case of interest-rate smoothing. Section III then considers the case that inflation expectations enter the decisions of price setters leading to important qualifications of the results without forward-looking behaviour. Section IV summarises and concludes.

II. Model and results without forward looking price setters

2.1. The model

The stylised New Keynesian model comprises two equations, which in a slightly generalised version can be represented as shown below (see Leeper and Zha, 2001). The macroeconomic relationships can be derived explicitly from optimisation by households and firms. The first equation is an "IS" curve that relates the output gap y inversely to the real interest rate:

$$y_t = -\left(\frac{1}{\sigma}\right)\left(i_t - E_t\left(p_{t+1} - p_t\right) - r\right) + \kappa\theta y_{t-1} + \kappa(1-\theta)E_t y_{t+1} + g_t\,. \tag{1}$$

The output gap y is the difference between actual and potential output with potential output as the level of output with perfectly flexible wages and prices. The inflation rate $\pi_{t+1} \equiv p_{t+1} - p_t$ is the percentage change in the price level from t to $t+1$ and r is the steady state real interest rate. κ is an indicator function equal to 0 or 1. The expected future output reflects consumption smoothing and the negative impact of the ex ante real interest rate $(i_t - E_t\pi_{t+1})$ stems from intertemporal substitution, with $(1/\sigma)$ being the intertemporal elasticity of substitution. The exogenous disturbance g represents expected changes in government purchases relative to expected changes in potential output. We assume $\sigma > 0$ and $0 \leq \theta \leq 1$.

The second equation is a Calvo (1983) type Phillips curve relating the inflation rate to the output gap and expected inflation:

$$\pi_t = \alpha_0 y_t + \alpha_1 y_{t-1} + \psi\pi_{t-1} + (1-\psi)\beta E_t\pi_{t+1} + v_t\ . \tag{2}$$

The equation reflects the setting of prices based on expectations of future marginal costs with v_t referring to a cost-push shock, i.e. deviations from the proportional relationship between the output gap and real marginal costs. ψ is an indicator function equal to 0 or 1 and $0 \leq \beta \leq 1$.

In order to obtain explicit analytical solutions we start with a simplified version of equations (1) and (2) focussing on the critical effects of inflation expectation, i.e. we set $\psi = \kappa = 0$. Furthermore, we assume that monetary policy can affect inflation only with a one-period lag by setting $\alpha_0 = 0$.

Given this, we can write equations (1), (2) as follows:

$$y_t = -\left(\frac{1}{\sigma}\right)(i_t - E_t\pi_{t+1}) + g_t \tag{3}$$

$$\pi_{t+1} = \alpha_1 y_t + \beta E_t \pi_{t+2} + v_{t+1} \tag{4}$$

$$\sigma > 0, \quad \alpha_1 > 0, \quad (1/\sigma)\alpha_1 < 1 \ .$$

The realisations g_t and v_{t+1} are elements of the central bank's information set in period t, whereas the public only observes them after having formed inflation expectations in period t. The timing of events is as shown in Figure 1. First the central bank observes the realisations of g_t and v_{t+1}, then the public forms inflation expectations and finally the central bank sets its instrument i_t, given inflation expectations.[4]

Output and inflation then are determined by equations (3) and (4) with the given interest rate and inflation expectations. The central bank's information advantage lasts one period, i.e. at the end of period t the public also know the realisations of g_t and v_{t+1}.

The informational asymmetry concerning the shocks leads us to compare two different regimes. In the regime called *transparency* (T) the central bank announces its information about the shocks before inflation expectations are formed, whereas in the regime called *secrecy* (S) inflation expectations are formed with knowledge only of equations (3) and (4) and previous shocks, i.e. $(v_t, v_{t-1}, \ldots)$ and $(g_{t-1}, g_{t-2}, \ldots)$.

The exogenous shocks obey

$$g_t = \rho g_{t-1} + \varepsilon_{g,t} \tag{5}$$

$$v_t = \rho v_{t-1} + \varepsilon_{v,t}$$

with $0 \le \rho \le 1$ and $\varepsilon_{g,t}$, $\varepsilon_{v,t}$ are *i.i.d.* random variables with zero means and variances $\sigma^2_{\varepsilon g}$ and $\sigma^2_{\varepsilon v}$, respectively.

The central bank minimises the intertemporal loss function

$$E_t \sum_{\tau=0}^{\infty} \delta^\tau L_{t+\tau} \ , \tag{6}$$

[4] This corresponds to the common specification in monetary policy games, according to which the private sector acts first. For a reversal of this assumption in a framework with asymmetric information about shocks see Geraats (2001c).

where E_t denotes expectations conditional upon information available in period t. The discount factor fulfils $0 < \delta < 1$ and the period loss function is

$$L_t = \frac{1}{2}\left(\pi_{t+1}^2 + \lambda_y y_t^2 + \lambda_i \left(i_t - i_{t-1}\right)^2\right) \tag{7}$$

where λ_y, λ_i are the weights on output-gap stabilisation and interest-rate smoothing respectively.[5]

Throughout the paper we consider the case of discretion: in each period policymakers set the current instrument and the contingent path of future instruments so as to minimise expected losses, taking the process of expectations formation as given.

Given the specifications above, the model and the information assumptions are close to Cukierman (2001) who however ignores the expectations term in the Phillips curve and the intertemporal character of the central bank's optimisation problem. That means, in setting the current interest rate the central bank ignores the effect of this decision on expected future losses. Furthermore, the shocks in Cukierman (2001) are white noise.[6]

2.2. Solution

Inserting the IS curve (3) and the Phillips curve (4) into the loss function (7), we obtain the stochastic Euler equation for the central bank's minimisation problem. This equation implies

$$\lambda_i \sigma (1+\delta) i_t = \alpha_1 \pi_{t+1} + \lambda_y y_t + \lambda_i \sigma i_{t-1} + \delta \sigma \lambda_i E_t^C (i_{t+1}) \tag{8}$$

where the operator E_t^C denotes conditional expectations given the central bank's information set. For $\lambda_i = 0$ the equation implies the familiar relationship that inflation above target should be associated with a negative output gap. $\lambda_i > 0$ leads to the possibility that the interest rate is above its unconditional expectation even with $\pi_{t+1} = y_t = 0$. This will occur, if last period's interest rate was high or if the central bank expects to set a higher interest rate in the next period.

5 Note that target inflation is zero and the target for output is potential output.

6 Cukierman (2001) also presents an analysis for a simple Lucas-supply function model, where transparency is clearly disadvantageous even without any motive for interest-rate smoothing.

The IS curve (3), the Phillips curve (4), and the stochastic Euler equation (8) form a system of difference equations which can be solved using McCallum's method of undetermined coefficients.[7]

Under the regime *secrecy* the endogenous variables have solutions of the form

$$i_t = a_{i0} i_{t-1} + a_{i1} g_{t-1} + a_{i2} \varepsilon_{g,t} + a_{i3} v_t + a_{i4} \varepsilon_{v,t+1}$$

$$\pi_{t+1} = a_{\pi 0} i_{t-1} + a_{\pi 1} g_{t-1} + a_{\pi 2} \varepsilon_{g,t} + a_{\pi 3} v_t + a_{\pi 4} \varepsilon_{v,t+1} \qquad (9)$$

$$y_t = a_{y0} i_{t-1} + a_{y1} g_{t-1} + a_{y2} \varepsilon_{g,t} + a_{y3} v_t + a_{y4} \varepsilon_{v,t+1}$$

where the a-coefficients are to be determined. Note that under secrecy we need to treat the reaction to last period's state and current innovations separately, since the latter are only known by the central bank whereas the former are used by the public to form expectations. Given (9) and the shock processes in (5), the publics' inflation expectations are

$$E_t \pi_{t+1} = a_{\pi 0} i_{t-1} + a_{\pi 1} g_{t-1} + a_{\pi 3} v_t$$

$$E_t \pi_{t+2} = a_{\pi 0} E_t i_t + \rho a_{\pi 1} g_{t-1} + \rho a_{\pi 3} v_t \qquad (10)$$

with $$E_t i_t = a_{i0} i_{t-1} + a_{i1} g_{t-1} + a_{i3} v_t \; .$$

Furthermore we have

$$E_t^C i_{t+1} = a_{i0} i_t + a_{i1} g_t + a_{i3} v_{t+1} \; . \qquad (11)$$

The difference with *transparency* is that the public knows $\varepsilon_{g,t}$ and $\varepsilon_{v,t+1}$ when forming expectations. Thus we have[8]

$$E_t \pi_{t+1} = \pi_{t+1}$$

$$E_t \pi_{t+2} = a_{\pi 0} E_t i_t + a_{\pi 1} g_t + a_{\pi 3} v_{t+1} \qquad (10a)$$

with $$E_t i_t = i_t \; .$$

7 See McCallum (1983, 1986).

8 Note that with symmetric information it would be enough to have, i_{t-1}, g_t and v_t in the solutions in (9). But for better comparison of the regimes we use the extended form for transparency, too.

The solutions for the a-coefficients are obtained by replacing the variables in (3), (4), (8) with the expressions in (5), (9), (10), (11) and equating the coefficients of i_{t-1}, g_{t-1}, $\varepsilon_{g,t}$, v_t and $\varepsilon_{v,t+1}$ on both sides, which results in 15 equations for the 15 unknown coefficients, listed in appendix A, where we also proof the following proposition.

Proposition 1.

(i) *Given the parameter restrictions below equation (4) and a motive for interest rate smoothing* ($\lambda_i > 0$), *there exists a unique stable solution* $0 < a_{i0} < 1$ *which also satisfies* $k_1 \equiv -\alpha_1 + (1-\beta a_{i0})\sigma > 0$.

(ii) *Furthermore, we have* $a_{\pi 0} < 0$ *and* $a_{y0} < 0$. *The solutions for* a_{i0}, $a_{\pi 0}$ *and* a_{y0} *are the same for the regime of* transparency *and* secrecy.

(ii) *Persistence in the interest rate induced by interest-rate smoothing* (a_{i0}) *is the higher the higher the loss-function weight on interest-rate variability* (λ_i) *and the lower the weight on stabilisation of the output gap* λ_y.

Proof. See Appendix A

In order to compare the regimes of *secrecy* and *transparency* we use the expected loss

$$L^j = E\left(\pi_{t+1}^2 + \lambda_y y_t^2 + \lambda_i (i_t - i_{t-1})^2\right) \tag{12}$$

associated with each regime $j = T, S$, where T, S denote *transparency* and *secrecy* respectively. We start by considering the case $\beta = \delta = 0$, where the solution expressions are quite easy to analyse. From the equation system shown in the appendix it follows that

$a_{i0} = \lambda_i\sigma(-\alpha_1 + \sigma)/c_1$, $\quad a_{\pi 0} = -\lambda_i\alpha_1\sigma/c_1$, $\quad a_{y0} = -\lambda_i\sigma/c_1$,

$a_{i1} = \rho\sigma(\alpha_1^2 + \lambda_y)/c_1$, $\quad a_{\pi 1} = \rho\sigma^2\lambda_i\alpha_1/c_1$, $\quad a_{y1} = \rho\lambda_i\sigma^2/c_1$,

$a_{i3} = \rho(\alpha_1\sigma + \lambda_y)/c_1$, $\quad a_{\pi 3} = \rho(\sigma^2\lambda_i + \lambda_y)/c_1$, $\quad a_{y3} = \rho(-\alpha_1 + \lambda_i\sigma)/c_1$,

$$a_{i2}^T = \sigma(\alpha_1^2 + \lambda_y)/c_1, \qquad a_{i2}^S = \sigma(\alpha_1^2 + \lambda_y)/c_2,$$

$$a_{\pi 2}^T = \sigma^2 \lambda_i \alpha_1/c_1, \qquad a_{\pi 2}^S = \sigma^2 \lambda_i \alpha_1/c_2, \tag{13}$$

$$a_{y2}^T = \lambda_i \sigma^2/c_1, \qquad a_{y2}^S = \lambda_i \sigma^2/c_2,$$

$$a_{i4}^T = (\alpha_1 \sigma + \lambda_y)/c_1, \qquad a_{i4}^S = \alpha_1 \sigma/c_2,$$

$$a_{\pi 4}^T = (\sigma^2 \lambda_i + \lambda_y)/c_1, \qquad a_{\pi 4}^S = (\sigma^2 \lambda_i + \lambda_y)/c_2,$$

$$a_{y4}^T = (-\alpha_1 + \lambda_i \sigma)/c_1, \qquad a_{y4}^S = -\alpha_1/c_2$$

with $c_1 = \alpha_1^2 + \lambda_y - \lambda_i \alpha_1 \sigma + \lambda_i \sigma^2$, $\quad c_2 = \alpha_1^2 + \lambda_y + \lambda_i \sigma^2$.

Coefficients indexed by T, S refer to the regime of *transparency* and *secrecy*, respectively, while those coefficients without index are identical for both regimes. Note that only the instantaneous reactions to demand shocks and cost-push shocks differ by regime.

For demand shocks ($\varepsilon_g > 0$), the instantaneous reactions of the interest rate are positive under both transparency and secrecy, with $a_{i2}^T > a_{i2}^S$ for $\lambda_i > 0$. Despite the stronger reaction of the interest rate under transparency, output and inflation react more strongly to a demand shock under transparency for $\lambda_i > 0$. Regardless of the regime, for $\lambda_i = 0$ output and inflation would both be perfectly stabilised with equal interest-rate changes ($a_{i2}^T = a_{i2}^S = \sigma$). The intuition with $\lambda_i > 0$ is that the motive for interest-rate smoothing leads the central bank to compromise on inflation and output. Therefore, under transparency the announcement of a positive demand shock gives rise to inflation expectations, decreasing the ex ante real interest rate for a given nominal interest rate. This exerts additional pressure on the output-gap and, as a consequence, on inflation. A motive for interest-rate smoothing implies a trade off between the stability of the interest rate on the one side and output and inflation stability on the other side. And this trade off is worse under transparency than under secrecy.

With respect to the efficiency loss associated with transparency we do not expect a large difference between the two regimes for plausible constellations of the parameters. The first-round effects under transparency relative to those under secrecy are determined by the factor $c_1/c_2 > 1$ for $\lambda_i > 0$. To be specific, suppose that a central bank cuts the first round response to a demand shock under secrecy from σ, which would apply for $\lambda_i = 0$, to $k\sigma$ with $(0 \le k \le 1)$. Using the expression for a_{i2}^S this implies $\lambda_i = (1-k)(\alpha_1^2 + \lambda_y)/(k\sigma^2)$. For this value of λ_i, the relation c_1/c_2 is

$$\frac{c_1}{c_2} = \frac{1}{1 - \frac{\alpha_1}{\sigma}(1-k)} \tag{14}$$

Thus, the first round effects in output, inflation and the interest rate under transparency will be close to those under secrecy if the intended reduction $(1-k)$ is small and α_1 is small compared to σ. For example, with a 25% reduction in the first-round step of interest rates under secrecy $(k = 0.75)$ and the parameter values $\alpha_1 = 0.1$, $\sigma = 1$ the relation c_1/c_2 would be 1.0256.[9]

As with demand shocks, in the case of positive cost-push shocks $(\varepsilon_v > 0)$ the interest rate will always be increased with a stronger reaction under transparency, i.e. $a_{i4}^T > a_{i4}^S$. This holds even for $\lambda_i = 0$, given $\lambda_y > 0$. This is due to the output inflation trade off in the case of cost-push shocks and a motive for stabilising output. Given $\lambda_y > 0$ the central bank will not perfectly stabilise inflation even with $\lambda_i = 0$ since this can be done only at the cost of output losses. Transparency thus generates inflation expectations with the disadvantageous consequences described above, leading to the result that $a_{\pi 4}^T > a_{\pi 4}^S$ for $\lambda_i > 0$. Inflation reacts stronger to cost-push shocks under transparency than under secrecy.

With a view on the solution for output it makes sense to assume $\lambda_i < \alpha_1/\sigma$. Since under transparency inflation equals inflation expectations, this condition ensures that in response to a cost-push shock both the nominal and the ex ante real interest rate rise under the regime of transparency. As a consequence, output will decrease under both regimes after a cost push shock, but less so with transparency.[10]

Despite the ambiguous effects for cost-push shocks we can proof the following proposition.

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9 The corresponding value for λ_i depends on λ_y. In the example above it is $\lambda_i = (0.01 + \lambda_y)/3$.

10 The condition is also sufficient for the ex ante real interest rate to rise after a demand shock under the regime of *transparency*. The condition can be viewed as guaranteeing the validity of the "Taylor principle", according to which the nominal interest rate should react stronger than one-to-one to expected inflation in a Taylor (1993) type policy-reaction function. For an extended discussion see McCallum (2001).

Proposition 2.

Given $\beta = \delta = 0$ *and a motive for interest-rate smoothing* ($\lambda_i > 0$)*, the expected loss defined in (12) will always be larger under* transparency *than under* secrecy*. This holds regardless of the relative variances of cost push and demand shocks.*

Proof. See Appendix B

Figure 2a and 2b give a graphical representation of the impulse responses to cost push and demand shocks using $\beta = 0$, $\delta = 0$, $\sigma = 1$, $\alpha_1 = 0.125$, $\lambda_y = 0.1$, $\lambda_i = 0.05$. The upper part a) has $\rho = 0.0$, the lower part b) has $\rho = 0.3$. As already discussed above, the differences between the regimes are quite moderate in the case of demand shocks, especially when the motive for stabilising interest rates is balanced by a motive to stabilise output. For cost-push shocks *transparency* implies a considerably stronger reaction of the interest rate compared to *secrecy*. The efficiency loss, however, is partly reversed by the smoother reaction of output due to the effect of inflation expectations on the ex ante real interest rate.

Figure 3 shows the percentage difference in the total loss between *transparency* and *secrecy* defined as $100((L^T/L^S)^{1/2} - 1)$, split into the contributions of demand and cost-push shocks, respectively. For demand shocks the difference increases with λ_i and decreases with λ_y. Assuming that λ_i is low in relation to λ_y, we hardly expect the difference in total losses to exceed 5%. A similar picture arises for cost-push shocks, except that an increasing weight for output stabilisation has less effect on the difference between the regimes.[11]

Summing up, for the case $\beta = \delta = 0$ we can establish a cost of transparency in terms of efficiency arising from a motive for interest-rate smoothing. The higher a central bank's weight on interest-rate smoothing, the higher is the efficiency loss arising from transparency.

Looking again at the response functions in Figure 2, a specific feature is worth to note. In particular for demand shocks, the central bank finds it optimal to destabilise output and inflation in the opposite direction in the following periods as a consequence of smoothly reducing the interest rate. We return to this aspect in the following section.

[11] Autocorrelation of shocks tends to decrease the percentage difference between regimes for $\beta = 0$, since the information advantage of the central bank lasts for only one period.

III. Forward-looking behaviour of price setters

In this section we turn to the case $\beta > 0$, $\delta > 0$. The discussion above suggests that the disadvantage of *transparency* increases if forward-looking behaviour in the Phillips curve is assumed. Since the announcement of demand and cost-push shocks generates inflation expectations, we expect a stronger disadvantage of transparency if these expectations enter the decisions of price setters. The impulse responses shown in Figure 2 however warn us that this conclusion might be false. The reason is that under certain parameter constellations interest-rate smoothing leads the central bank to accept second-round deviations of output and inflation in the opposite direction. If price setters take account of these effects, things might improve under *transparency*.

Is it possible that this effect reverses the result in Proposition 2, i.e. that transparency is more efficient than secrecy despite interest-rate smoothing? In general there is too much non-linearity to derive explicit conditions concerning the relative expected losses under the two regimes. The following proposition however states that the general efficiency advantage of secrecy is no longer present with forward-looking behaviour in the Phillips curve.

Proposition 3.

(i) With $\beta > 0$ there exist parameter constellations with $\lambda_i > 0$ for which the expected loss under transparency *is smaller than under* secrecy.

(ii) For $\rho = \lambda_y = 0$ the possibility of an efficiency disadvantage under secrecy *increases with β and decreases with λ_i. A necessary condition for* transparency *being superior is $\sigma\beta/\alpha_1 > 1 + \delta$.*

Proof. See Appendix C

Proposition 3 suggests that under plausible parameter constellations a central bank with preferences close to strict inflation targeting would choose transparency about shocks for mere efficiency considerations.[12] Figure 4 clarifies this by referring to

[12] Note that part (ii) of proposition 3 makes clear that ignoring the intertemporal character of the central bank's optimisation problem, i.e. assuming $\delta = 0$, can be quite misleading as regards the ranking of the regimes.

numerical solutions of the model for the case $\sigma = 1$, $\alpha = 0.125$, $\beta = 0.95$, $\delta = 0.95$ and $\rho = 0.1$. The figure shows the locus of combinations of λ_i and λ_y for which the expected losses are equal under *transparency* and *secrecy*. For combinations below the curves shown, transparency is superior. Starting from strict inflation targeting ($\lambda_i = \lambda_y = 0$) into the space of output stabilisation and interest-rate smoothing we first reach combinations for which transparency is associated with less expected losses than secrecy. It can be seen that in general the relative variances of cost-push and demand shocks have a critical influence on the ranking of the two regimes.

Figure 5 shows the impulse responses for the case $\lambda_i = \lambda_y = 0.005$ and contrasts them with the cases of strict inflation targeting ($\lambda_i = \lambda_y = 0$) and output stabilisation without interest-rate smoothing. In spite of the low weight on λ_i, the third column shows a significant reduction in the volatility of the interest rate compared to $\lambda_i = 0$. However, the expected loss is smaller under *transparency* for demand shocks and for cost-push shocks as well.

Considering that the superiority of transparency stems from the expectations effect in the Phillips curve, it is clear that with a rising autocorrelation of shocks the advantage of transparency eventually vanishes, regardless of the remaining parameters.

IV. Summary and conclusions

At first glance, transparency about shocks affecting inflation appears to be inefficient for an interest-rate smoothing central bank in a New-Keynesian setting. In fact, ignoring issues like shock correlation, forward-looking behaviour of price setters, and discounting on the side of the central bank, Cukierman (2001) showed that in a New-Keynesian framework transparency is associated with higher expected losses than secrecy, provided that the central bank has a motive for interest-rate smoothing, however small. This paper first clarifies that, ignoring forward-looking behaviour of price setters, secrecy is indeed more efficient than transparency with the advantage of secrecy rising with the central bank's weight on interest-rate smoothing. However, it can be argued that for plausible parameter values the relative difference in favour of secrecy can be expected to be small.

In contrast to what might be expected, considering forward-looking behaviour of price setters does not strengthen the case for secrecy. Rather it is shown that the overall superiority of secrecy vanishes and that there exist plausible parameter constellations, where transparency is efficient for an interest-rate smoothing central bank. Thus we obtain a conclusion similar to that of the literature analysing the effect of informational asymmetries concerning central-bank preferences on the time-consistency problem of monetary policy: on mere efficiency grounds there is neither a clear case in favour of transparency, nor against it.[13]

Interest-rate smoothing in this paper is interpreted as a central bank's motive to reduce the variance of deviations of the interest rate from its pre-period level. This leads to a policy-reaction function including a lagged interest rate, a feature widely used in research on monetary policy.[14] The theoretical impulse responses shown in this paper indicate that such a motive may well cause oscillating behaviour of inflation and extended deviations of output from its potential level after a shock. This points to the supposition that a motive as described above should be rather weak in practise. As a consequence, the case for transparency is underlined for two reasons. First, the results in this paper indicate that the ranking of transparency versus secrecy is ambiguous for small weights on interest-rate smoothing and that the percentage difference in expected losses is small. Second, there arises the possibility that other interpretations of interest-smoothing dominate the central-bank's loss function.[15] A prime candidate would be the motive to reduce the unexpected component in changes of the interest rate. This case was not considered in this paper but it is quite plausible that such a motive may very well increase the efficiency advantage of transparency compared to secrecy.

13 There are further aspects to be considered in this context. Issing (1999) argues that frequent releases of central bank forecasts might undermine the credibility of a central bank, due to the potentially flawed nature of these assessments. Morris and Shin (2000) present a game theoretic analysis of the issue of varying degrees of precision in public and private forecasts, showing that greater precision in revealed public forecasts need not to be efficient from the view of the central bank, as long as there remains some noise in the public information.

14 See, for example, Svensson (2000).

15 See Goodhart (1999) for the various central-bank motives behind interest-rate smoothing.

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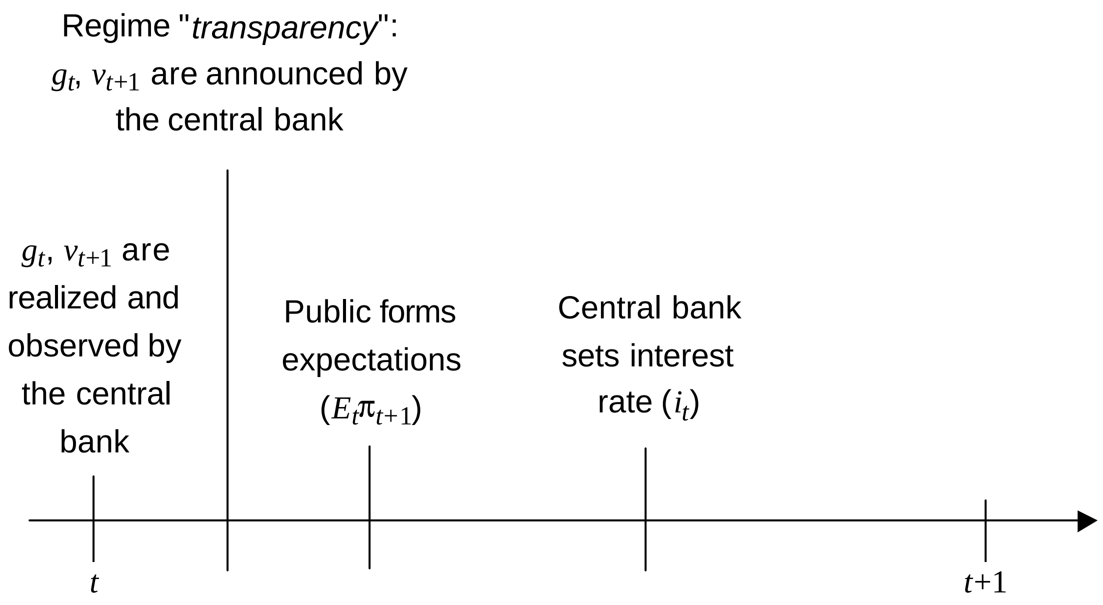
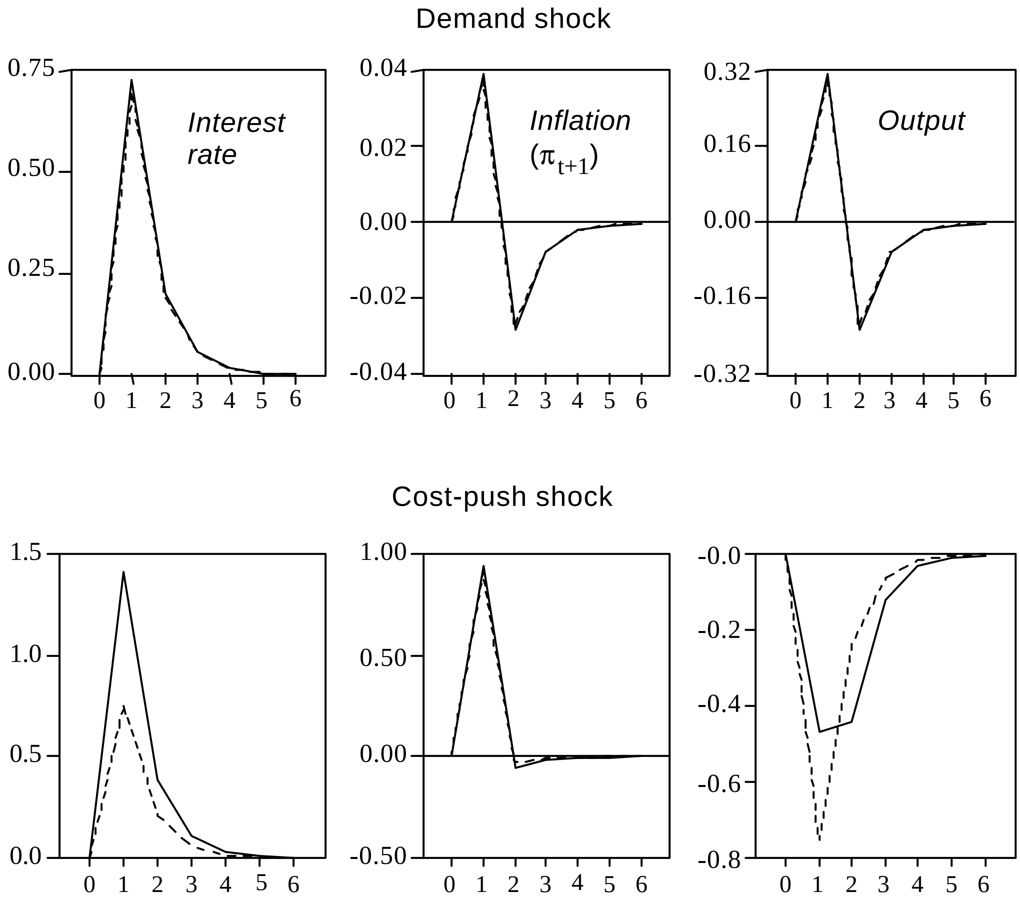
Figure 1



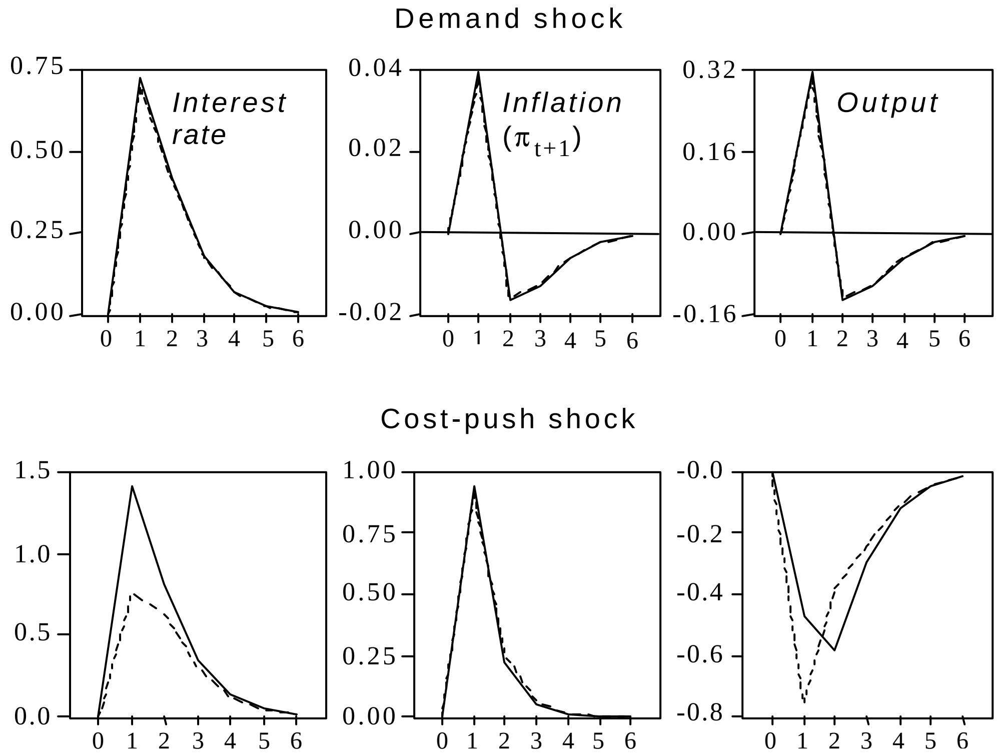
Regime "*transparency*": g_t, v_{t+1} are announced by the central bank
g_t, v_{t+1} are realized and observed by the central bank
Public forms expectations ($E_t\pi_{t+1}$)
Central bank sets interest rate (i_t)
t
t+1

Figure 2. Impulse responses with $\beta = 0$.

a) $\rho = 0.0$



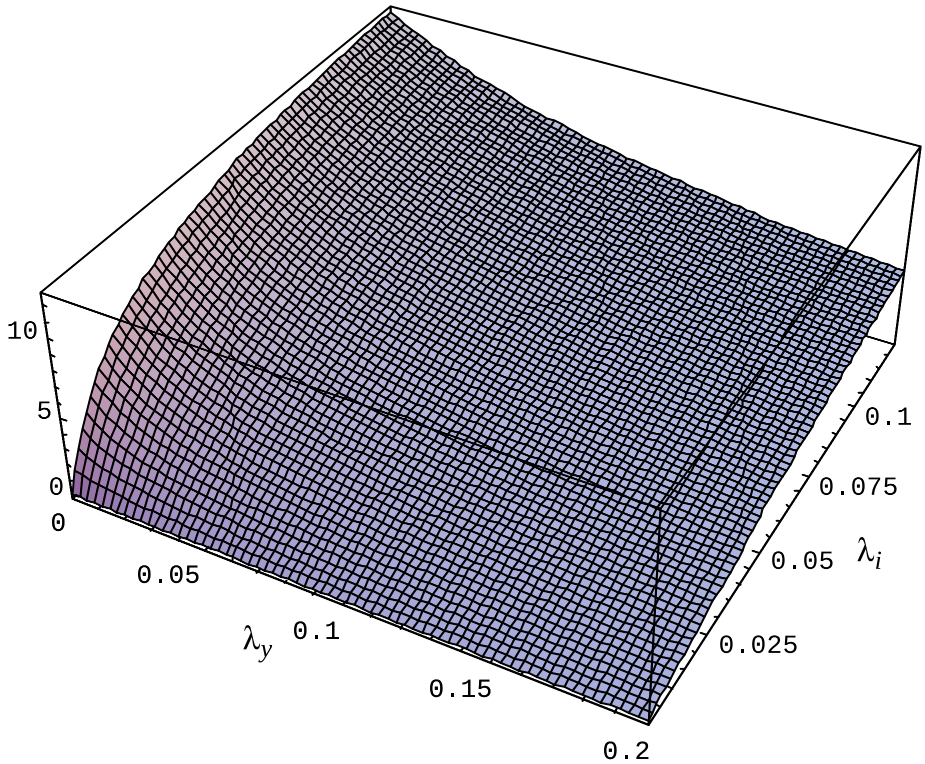
b) ρ = 0.3



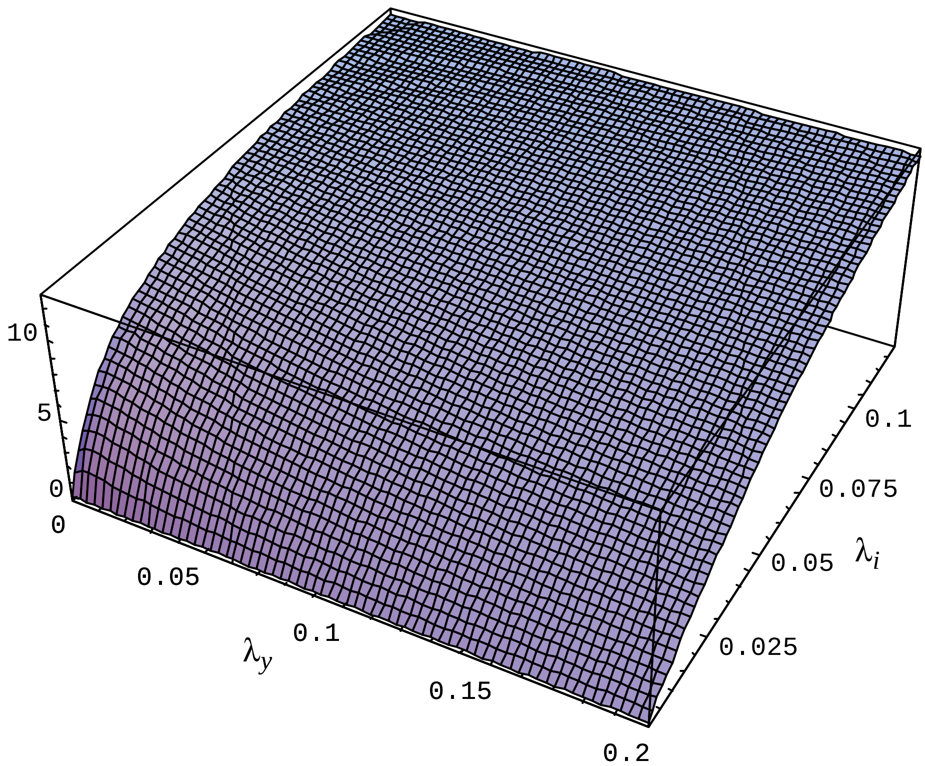
Note. The parameter values are $\alpha_1 = 0.125$, $\sigma = 1.0$, $\beta = 0$, $\delta = 0$, $\lambda_i = 0.05$; $\lambda_y = 0.1$. Dashed lines represent the regime *secrecy*, bold lines hold for *transparency*.

Figure 3

Percentage efficiency loss: demand shocks

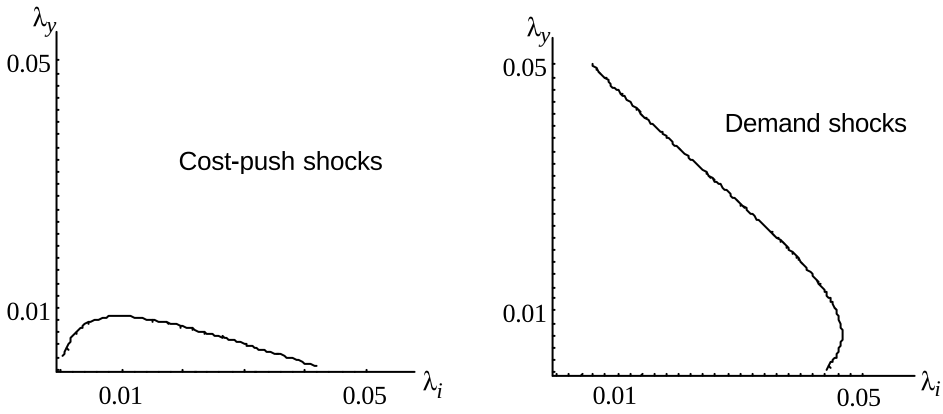


Percentage efficiency loss: cost-push shocks



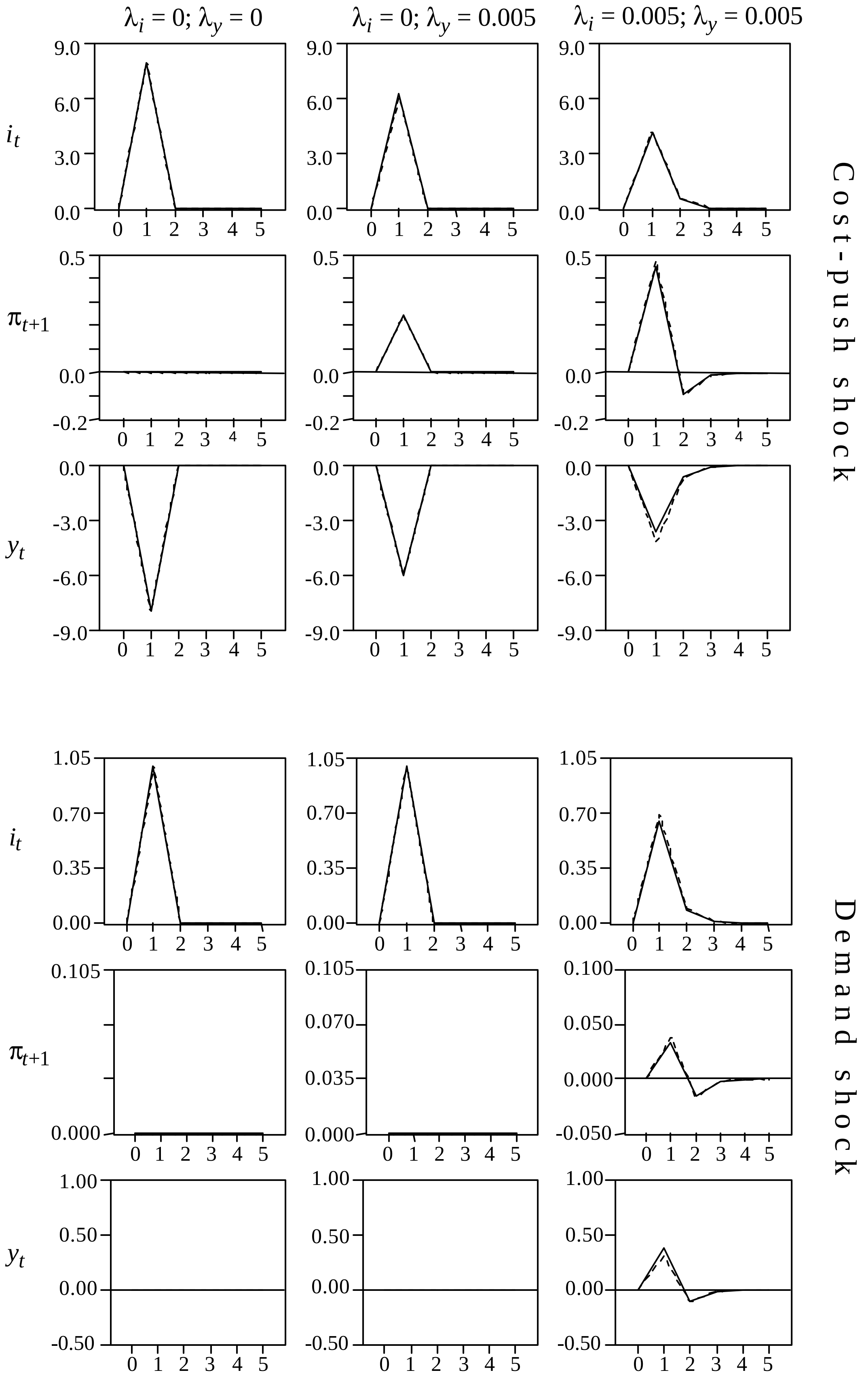
Note: the parameter values are $\rho = 0$, $\sigma = 1$, $\alpha_1 = 0.125$, $\beta = 0.95$, $\delta = 0.95$.

Figure 4. Combinations of λ_i, λ_y with equal losses under transparency and secrecy.



Note: the parameter values are $\rho = 0.1$, $\sigma = 1$, $\alpha_1 = 0.125$, $\beta = 0.95$, $\delta = 0.95$.

Figure 5



Note. The parameter values are $\alpha_1 = 0.125$, $\sigma = 1.0$, $\beta = \delta = 0.95$, $\rho = 0.0$. Dashed lines represent the regime *secrecy*, bold lines hold for *transparency*.

Figure A1

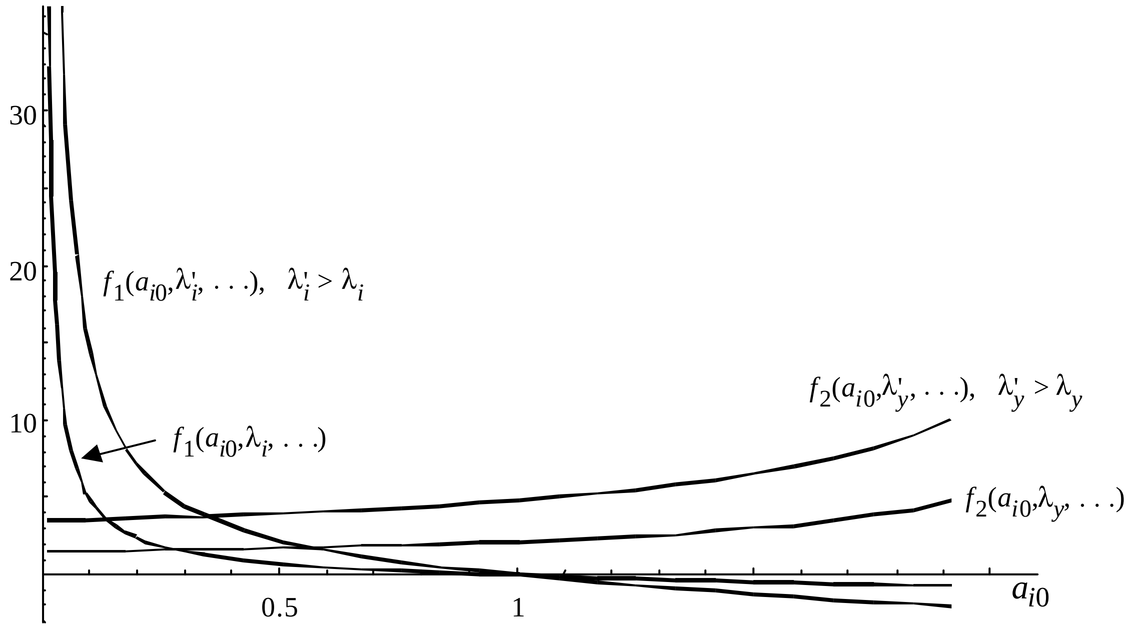
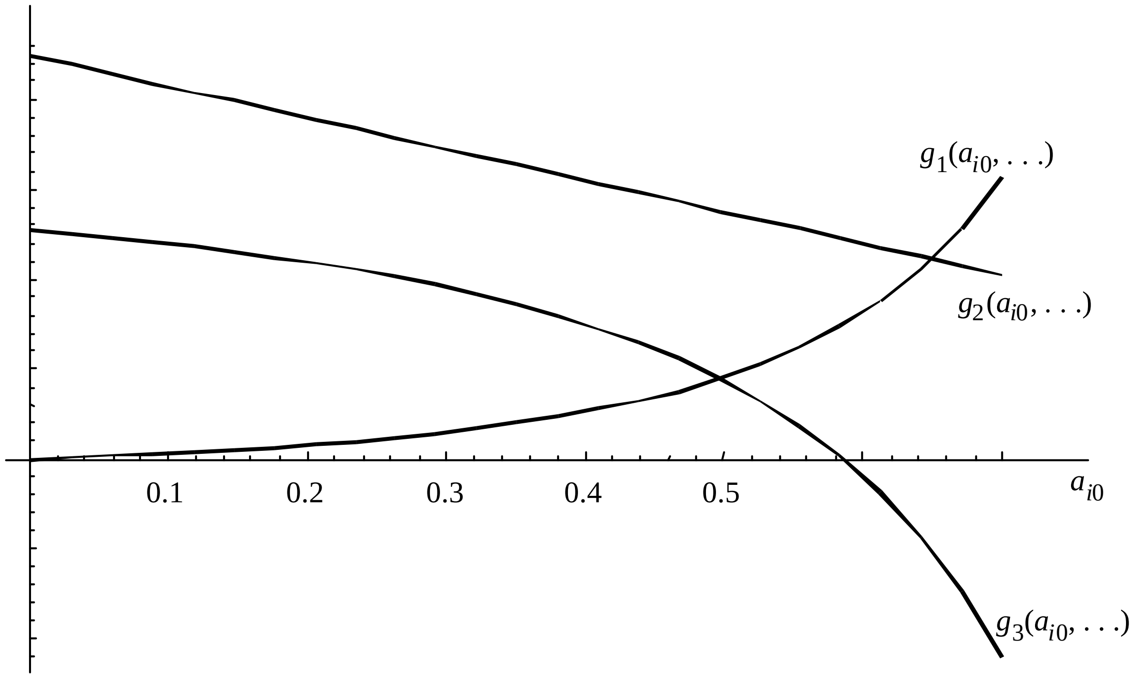

30
20
10
0.5
1
a_{i0}
$f_1(a_{i0},\lambda_i', \ldots), \quad \lambda_i' > \lambda_i$
$f_1(a_{i0},\lambda_i, \ldots)$
$f_2(a_{i0},\lambda_y', \ldots), \quad \lambda_y' > \lambda_y$
$f_2(a_{i0},\lambda_y, \ldots)$

Figure A2



Appendix A

Proceeding as described in the paragraph following equation (10a) in Section II leads to the following equations. The first 9 equations are identical for both regimes:

$$a_{y0} + a_{i0}/\sigma - a_{\pi0}/\sigma = 0 \tag{A1}$$

$$a_{\pi0} - \alpha_1 a_{y0} - \beta a_{i0} a_{\pi0} = 0 \tag{A2}$$

$$a_{i0} - (\alpha_1 a_{\pi0} + \lambda_y \mathrm{a}_{y0} + \delta\sigma\lambda_i a_{y0}^2 + \sigma\lambda_i)/(\sigma\lambda_i(1+\delta)) = 0 \tag{A3}$$

$$a_{y1} + a_{i1}/\sigma - a_{\pi1}/\sigma - \rho = 0 \tag{A4}$$

$$a_{\pi1} - \alpha_1 a_{y1} - \beta a_{i1} a_{\pi0} - \beta\rho a_{\pi1} = 0 \tag{A5}$$

$$a_{i1} - (\alpha_1 a_{\pi1} + \lambda_y a_{y1} + \delta\sigma\lambda_i a_{i1} a_{i0} + \rho\delta\sigma\lambda_i a_{i1})/(\sigma\lambda_i(1+\delta)) = 0 \tag{A6}$$

$$a_{y3} + a_{i3}/\sigma - a_{\pi3}/\sigma = 0 \tag{A7}$$

$$a_{\pi3} - \alpha_1 a_{y3} - \beta a_{i3} a_{\pi0} - \beta\rho a_{\pi3} - \rho = 0 \tag{A8}$$

$$a_{i3} - (\alpha_1 a_{\pi3} + \lambda_y a_{y3} + \delta\sigma\lambda_i a_{i3} a_{i0} + \rho\delta\sigma\lambda_i a_{i3})/(\sigma\lambda_i(1+\delta)) = 0 \tag{A9}$$

Note that these equations determine the a_{j0}, a_{j1} and a_{j3} parameters for $j = (i, \pi, y)$, which therefore are equal under *transparency* and *secrecy*. Next we have six equations depending on the regime. For *transparency* we have

$$a_{y2}^T + a_{i2}^T/\sigma - a_{\pi2}^T/\sigma - 1 = 0 \tag{A10}$$

$$a_{\pi2}^T - \alpha_1 a_{y2}^T - \beta a_{i2}^T a_{\pi0} - \beta a_{\pi1} = 0 \tag{A11}$$

$$a_{i2}^T - (\alpha_1 a_{\pi2}^T + \lambda_y a_{y2}^T + \delta\sigma\lambda_i a_{i2}^T a_{i0} + \delta\sigma\lambda_i a_{i1})/(\sigma\lambda_i(1+\delta)) = 0 \tag{A12}$$

$$a_{y4}^T + a_{i4}^T/\sigma - a_{\boldsymbol{P}4}^T/\sigma = 0 \tag{A13}$$

$$a_{\pi4}^T - \alpha_1 a_{y4}^T - \beta a_{i4}^T a_{\pi0} - \beta a_{\pi3} - 1 = 0 \tag{A14}$$

$$a_{i4}^T - (\alpha_1 a_{\pi4}^T + \lambda_y a_{y4}^T + \delta\sigma\lambda_i a_{i4}^T a_{i0} + \delta\sigma\lambda_i a_{i3})/(\sigma\lambda_i(1+\delta)) = 0 \tag{A15}$$

The respective equations for *secrecy* are

$$a_{y4}^S + a_{i4}^S/\sigma - 1 = 0 \tag{A10a}$$

$$a_{\pi 4}^S - \alpha_1 a_{y4}^S = 0 \tag{A11a}$$

$$a_{i4}^S - (\alpha_1 a_{\pi 4}^S + \lambda_y a_{y4}^S + \delta\sigma\lambda_i a_{i4}^S a_{i0} + \delta\sigma\lambda_i a_{i1})/(\sigma\lambda_i(1+\delta)) = 0 \tag{A12a}$$

$$a_{y4}^S + a_{i4}^S/\sigma = 0 \tag{A13a}$$

$$a_{\pi 4}^S - \alpha_1 a_{y4}^S - 1 = 0 \tag{A14a}$$

$$a_{i4}^S - (\alpha_1 a_{\pi 4}^S + \lambda_y a_{y4}^S + \delta\sigma\lambda_i a_{i4}^S a_{i0} + \delta\sigma\lambda_i a_{i3})/(\sigma\lambda_i(1+\delta)) = 0 \tag{A15a}$$

The reactions of i_t, y_t, and π_t to i_{t-1} are determined by equations (A1) - (A3). These can be reduced to

$$a_{y0} = -a_{i0}(1 - \beta a_{i0})/k_1; \qquad a_{\pi 0} = -\alpha_1 a_{i0}/k_1 \tag{A16}$$

$$f_1 \equiv \frac{(1 - a_{i0})(1 + \delta a_{i0})\sigma\lambda_i}{a_{i0}} = \frac{\alpha_1^2 + (1 - \beta a_{i0})\lambda_y}{-\alpha_1 + (1 - \beta a_{i0})\sigma} \equiv f_2 \tag{A17}$$

Proof of Proposition 1

Equation (A17) shows that the solutions for a_{i0} are the roots of a third degree polynomial in a_{i0}. First note that the assumption $(1/\sigma)\alpha_1 < 1$ rules out a stable solution with $-1 < a_{i0} < 0$. In this case f_1 would be negative requiring a negative denominator of f_2, violating the assumption. On the other hand suppose that $0 < a_{i0} < 1$ and that the denominator of f_2 is negative. This cannot be a solution since f_1 would be positive. Thus, a stable solution must lie in the range $0 < a_{i0} < 1$ and satisfy the condition

$$k_1 \equiv -\alpha_1 + (1 - \beta a_{i0})\sigma > 0. \tag{A18}$$

We now proof that there will always exist exactly one such root. We have $f_1 \to \infty$ for $a_{i0} \to +0$. In the range $0 < a_{i0} < 1$ the function f_1 decreases monotonically with a_{i0}, with $f_1(1) = 0$. This is shown in Figure A1.

f_2 is positive for $a_{i0} = 0$ and the derivative is positive, i.e. f_2 increases monotonically approaching ∞ for $a_{i0} \to (1 - \alpha_1/\sigma)/\beta$. The fact that $f_2(1) > 0$ whereas $f_1(1) = 0$ proofs that f_1 and f_2 cross exactly one time in the range $0 < a_{i0} < 1$. This proofs part (i).

A higher λ_y shifts f_2 upwards, leading to a smaller value for a_{i0}, whereas a higher λ_i shifts f_1 upwards implying a higher value for a_{i0}. This proofs part (iii).

Part (ii) immediately follows from (A16) and the fact that equations (A16), (A17) do not depend on the regime. Q.e.d.

Appendix B

In order to proof proposition 2 we need expressions for the variances of the variables appearing in the loss function. From the equations in (9) and (5) we obtain the following equation system, the form of which does not depend on the regime:

$$var(i) = 2a_{i0}(a_{i1}cov(g, i) + a_{i3}cov(v, i)) + a_{i2}^2\sigma_{\varepsilon g}^2 + a_{i4}^2\sigma_{\varepsilon v}^2 + a_{i1}^2 var(g) + a_{i0}^2 var(i) + a_{i3}^2 var(v)$$

$$var(\pi) = 2a_{\pi 0}(a_{\pi 1}cov(g, i) + a_{\pi 3}cov(v, i)) + a_{\pi 2}^2\sigma_{\varepsilon g}^2 + a_{\pi 4}^2\sigma_{\varepsilon v}^2 + a_{\pi 1}^2 var(g) + a_{\pi 0}^2 var(i) + a_{\pi 3}^2 var(v)$$

$$var(y) = 2a_{y0}(a_{y1}cov(g, i) + a_{y3}cov(v, i)) + a_{y2}^2\sigma_{\varepsilon g}^2 + a_{y4}^2\sigma_{\varepsilon v}^2 + a_{y1}^2 var(g) + a_{y0}^2 var(i) + a_{y3}^2 var(v)$$

$$var(\Delta i) = -2a_{i1}cov(g, i) + 2a_{i1}a_{i0}cov(g, i) - 2a_{i3}cov(v, i) + 2a_{i3}a_{i0}cov(v, i) + a_{i2}^2\sigma_{\varepsilon g}^2 + a_{i4}^2\sigma_{\varepsilon v}^2 + a_{i1}^2 var(g) + var(i) - 2a_{i0}var(i) + a_{i0}^2 var(i) + a_{i3}^2 var(v)$$

$$var(g) = \sigma_{\varepsilon g}^2 + \rho^2 var(g)$$

$$var(v) = \sigma_{\varepsilon v}^2 + \rho^2 var(v)$$

$$cov(g, i) = a_{i0}cov(g, i)\rho + a_{i2}\sigma_{\varepsilon g}^2 + a_{i1}\rho var(g)$$

$$cov(v, i) = a_{i0}cov(v, i)\rho + a_{i4}\sigma_{\varepsilon v}^2 + a_{i3}\rho var(v) \qquad \text{(B1)}$$

The solutions for the variances of output, inflation and interest-rate changes are:

$$var(\pi) = C_\pi + K_{\pi,g}\sigma_{\varepsilon g}^2 + K_{\pi,v}\sigma_{\varepsilon v}^2 \qquad \text{(B2)}$$

with $$K_{\pi,g} = a_{\pi 2}^2 + (a_{i2}^2 a_{\pi 0}^2)/(1 - a_{i0}^2) + (2a_{i2}a_{\pi 1}a_{\pi 0})/(1 - a_{i0}\rho) + (2a_{i2}a_{i1}a_{i0}a_{\pi 0}^2)/((1 - a_{i0}^2)(1 - a_{i0}\rho))$$

$$K_{\pi,v} = a_{\pi 4}^2 + (a_{i4}^2 a_{\pi 0}^2)/(1 - a_{i0}^2) + (2a_{i4}a_{\pi 3}a_{\pi 0})/(1 - a_{i0}\rho) + (2a_{i4}a_{i3}a_{i0}a_{\pi 0}^2)/((1 - a_{i0}^2)(1 - a_{i0}\rho))$$

$$var(y) = C_y + K_{y,g}\sigma_{\varepsilon g}^2 + K_{y,v}\sigma_{\varepsilon v}^2$$

with $$K_{y,g} = a_{y2}^2 + (a_{i2}^2 a_{y0}^2)/(1 - a_{i0}^2) + (2a_{i2}a_{y1}a_{y0})/(1 - a_{i0}\rho) + (2a_{i2}a_{i1}a_{i0}a_{y0}^2)/((1 - a_{i0}^2)(1 - a_{i0}\rho))$$

$$K_{y,v} = (a_{y4}^2 + (a_{i4}^2 a_{y0}^2)/(1 - a_{i0}^2) + (2a_{i4}a_{y3}a_{y0})/(1 - a_{i0}\rho) + (2a_{i4}a_{i3}a_{i0}a_{y0}^2)/((1 - a_{i0}^2)(1 - a_{i0}\rho)))$$

$$var(\Delta i) = C_i + K_{i,g}\sigma_{\varepsilon g}^2 + K_{i,v}\sigma_{\varepsilon v}^2$$

with $$K_{i,g} = 2a_{i2}(a_{i2} - a_{i1} + a_{i1}a_{i0} - a_{i2}a_{i0}\rho)/((1 + a_{i0})(1 - a_{i0}\rho))$$

$$K_{i,v} = 2a_{i4}(a_{i4} - a_{i3} + a_{i3}a_{i0} - a_{i4}a_{i0}\rho)/((1 + a_{i0})(1 - a_{i0}\rho))$$

The expressions C_π, C_y and C_i represent additive constants which do not depend on the regime observing that the coefficients a_{j0}, a_{j1} and a_{j3} $(j = y, i, \pi)$ do not depend on the regime.

Proof of Proposition 2

The expected losses under *transparency* (T)and *secrecy* (S) can be written as

$$L^T = (C_\pi + \lambda_y C_y + \lambda_i C_i) + (K_{\pi,g}^T + \lambda_y K_{y,g}^T + \lambda_i K_{i,g}^T)\sigma_{\varepsilon g}^2 + (K_{\pi,v}^T + \lambda_y K_{y,v}^T + \lambda_i K_{i,v}^T)\sigma_{\varepsilon v}^2$$

$$L^S = (C_\pi + \lambda_y C_y + \lambda_i C_i) + (K_{\pi,g}^S + \lambda_y K_{y,g}^S + \lambda_i K_{i,g}^S)\sigma_{\varepsilon g}^2 + (K_{\pi,v}^S + \lambda_y K_{y,v}^S + \lambda_i K_{i,v}^S)\sigma_{\varepsilon v}^2$$

where the terms indexed T and S are obtained by inserting the respective solutions from (13) for the a-coefficients in (B2).

Proposition 2 now follows from the fact that

$$K_{\pi,g}^T > K_{\pi,g}^S, \qquad K_{y,g}^T > K_{y,g}^S, \qquad K_{i,g}^T > K_{i,g}^S$$

$$K_{\pi,v}^T + \lambda_y K_{y,v}^T > K_{\pi,v}^S + \lambda_y K_{y,g}^S, \qquad K_{i,v}^T > K_{i,v}^S$$

This follows immediately by considering the following expressions obtained using the equations in (13) and (B2), which are all positive assuming $(1/\sigma)\alpha_1 < 1$:

$$K_{\pi,g}^T - K_{\pi,g}^D = 2\alpha_1^3\lambda_i^3\sigma^5((\alpha_1^2 + \lambda_y)(2-\rho) + \lambda_i(1-\rho)(2\sigma - \alpha_1)\sigma)/$$
$$((\alpha_1^2 + \lambda_y + \lambda_i\sigma^2)^2(\alpha_1^2 + \lambda_y - 2\alpha_1\lambda_i\sigma + 2\lambda_i\sigma^2)(\alpha_1^2 + \lambda_y + \lambda_i(1-\rho)\sigma(\sigma - \alpha_1)))$$

$$K_{y,g}^T - K_{y,g}^S = 2\alpha_1\lambda_i^3\sigma^5((\alpha_1^2 + \lambda_y)(2-\rho) + \lambda_i(1-\rho)(2\sigma - \alpha_1)\sigma)/$$
$$((\alpha_1^2 + \lambda_y + \lambda_i\sigma^2)^2(\alpha_1^2 + \lambda_y - 2\alpha_1\lambda_i\sigma + 2\lambda_i\sigma^2)(\alpha_1^2 + \lambda_y + \lambda_i(1-\rho)\sigma(\sigma - \alpha_1)))$$

$$K_{i,g}^T - K_{i,g}^S = 2\alpha_1\lambda_i\sigma^3(\alpha_1^2 + \lambda_y)^2((\alpha_1^2 + \lambda_y)(2-\rho) + \lambda_i(1-\rho)(2\sigma - \alpha_1)\sigma)/$$
$$((\alpha_1^2 + \lambda_y + \lambda_i\sigma^2)^2(\alpha_1^2 + \lambda_y - 2\alpha_1\lambda_i\sigma + 2\lambda_i\sigma^2)(\alpha_1^2 + \lambda_y + \lambda_i(1-\rho)\sigma(\sigma - \alpha_1)))$$

$$K_{i,v}^T - K_{i,v}^S = 2(\alpha_1^2 + \lambda_y)(\lambda_y + \lambda_i\sigma^2)(\lambda_y^2(1-\rho) + \alpha_1^3(2-\rho)\sigma + \lambda_i(1-\rho)\sigma^2(-\alpha_1^2 + \lambda_y + 2\alpha_1\sigma)$$
$$+ \alpha_1\lambda_y(\alpha_1 - \alpha_1\rho + 2\sigma - \rho\sigma))/$$
$$((\alpha_1^2 + \lambda_y + \lambda_i\sigma^2)^2(\alpha_1^2 + \lambda_y - 2\alpha_1\lambda_i\sigma + 2\lambda_i\sigma^2)(\alpha_1^2 + \lambda_y + \lambda_i(1-\rho)\sigma(\sigma - \alpha_1)))$$

$$K_{\pi,v}^T + \lambda_y K_{y,v}^T - (K_{\pi,v}^S + \lambda_y K_{y,v}^S) = 2\lambda_i^2\sigma^2(\lambda_y + \lambda_i\sigma^2)(\lambda_y^2(1-\rho) + \alpha_1^3(2-\rho)\sigma$$
$$+ \lambda_i(1-\rho)\sigma^2(-\alpha_1^2 + \lambda_y + 2\alpha_1\sigma) + \alpha_1\lambda_y(\alpha_1 - \alpha_1\rho + 2\sigma - \rho\sigma))/$$
$$((\alpha_1^2 + \lambda_y + \lambda_i\sigma^2)^2(\alpha_1^2 + \lambda_y - 2\alpha_1\lambda_i\sigma + 2\lambda_i\sigma^2)(\alpha_1^2 + \lambda_y + \lambda_i(1-\rho)\sigma(\sigma - \alpha_1)))$$

Q.e.d.

Appendix C

Proof of Proposition 3

Given $\lambda_y = \rho = 0$ and using the equation system (A1) - (A15) we see that the coefficients a_{j1} and a_{j3} for $j = (i, \pi, y)$ are zero. For the remaining parameters we obtain

$$a_{j2}^T / a_{j2}^S = a_{j4}^T / a_{j4}^S = \xi \quad \text{for} \quad j = (i, \pi, y) \tag{C1}$$

with $$\xi = k_1(\alpha_1^2 + \delta_1\lambda_i\sigma^2)/((\sigma - \alpha_1)(\alpha_1^2 + \delta_1 k_1\lambda_i\sigma))$$

$$\delta_1 = 1 + \delta(1 - a_{i0})$$

and $k_1 > 0$ defined in (A18).

From the expressions for the variances in (B2), equation (C1) and the fact that the coefficients in (C1) are positive for inflation and the interest rate under both regimes, it follows that $\xi < 1$ is sufficient and necessary for $L^T < L^S$.

Using (A17) to eliminate λ_i in the expression for ξ and with the definition of k_1, we obtain that

$$g_3 = \sigma\beta/\alpha_1 - (1 + \delta(1 - a_{i0}))/((1 - a_{i0})(1 - \delta a_{i0})) > 0 \tag{C2}$$

is a sufficient and necessary condition for $\xi < 1$, with a_{i0} being the solution to (see equation (A17)):

$$g_1 \equiv a_{i0}/((1 - a_{i0})(1 - \delta a_{i0})) = (-\alpha_1 + \sigma(1 - \beta a_{i0}))\sigma\lambda_i/\alpha_1^2 \equiv g_2.$$

For $\delta = 0$ condition (C2) reads

$$g_3 = \sigma\beta/\alpha_1 - 1/(1 - a_{i0}) > 0,$$

which for $\beta = 1$ implies $k_1 > 0$. In the proof of proposition 1 it has been shown that in a stable solution k_1 will always be larger than 0. This proofs part (i).

In general we have the picture shown in Figure A2. The intersection of g_1 and g_2 determines a_{i0}. In the case shown, g_3 is negative for that value of a_{i0} implying that transparency is inferior. Decreasing λ_i shifts g_2 downwards leading to smaller values of a_{i0} as shown in proposition 1, eventually implying $g_3 > 0$. Increasing β shifts g_3 upwards and makes g_2 steeper and thus can also lead to the situation $g_3 > 0$. Further note that g_3 is a decreasing function of a_{i0}. Thus a necessary condition for transparency to be superior is that $g_3 > 0$ for $a_{i0} = 0$. This leads to the condition shown in part (ii). Q.e.d.