

Incentive Contracts for Central Bankers under Uncertainty: Walsh-Svensson non-Equivalence Revisited

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Abstract

We look at the implications of uncertain monetary policy preferences for the targeting and contracting approach to monetary stability. It turns out that in presence of uncertain preferences a linear incentive contract in the sense of Walsh (1995) performs better in terms of social welfare than an explicit inflation target as proposed by Svensson (1997). The reason is that, although both approaches can get rid of the inflationary bias, the impact of uncertain preferences on the variance of inflation will be considerably higher with an inflation target. We also find that on top of an optimal linear contract or target, a quadratic contract, in the sense of Rogoff's (1985) "weight-conservative" central banker, improves the outcome. In the case of an inflation target, a more conservative banker is needed than with a Walsh contract.

Keywords: non-linearities, economic fluctuations, inflation targets, optimal contracts

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1 Introduction⁽²⁾

In the literature on reform of monetary institutions two ways have been advocated to reach low inflation. A survey of this literature can be found in Eijffinger and De Haan (1996).

The first is the *legislative* approach, i.e. to establish by law a independent central bank with an exclusive mandate for price stability. The major academic contribution in this area is Rogoff (1985). Rogoff develops a model in where monetary policy is delegated to a central banker (the *agent*) who is more inflation averse than society (the *principal*). The result is a lower inflation rate, but this is at the expense of a distorted response to output shocks. Thus, the Rogoff model features the famous *credibility-flexibility* trade-off.

The second is the *targeting* or *contracting* approach to monetary policy. The idea is to let the political principal of the central bank impose an explicit inflation target for monetary policy and make the central bank governor explicitly accountable for his success in meeting this target. Academic contributions in this area are Persson and Tabellini (1993), Walsh (1995) and Svensson (1997).

Walsh has shown that an optimal linear inflation contract can eliminate the inflationary bias without distorting stabilisation policy. Thus the credibility-flexibility trade-off is eliminated³ and makes inflation targeting superior to Rogoff's conservative central banker. Moreover, Svensson (1997) has shown that the linear contract can be mapped into an optimal *inflation target*. This means that these delegation arrangements are *equivalent*. They are both able to produce the pre-commitment outcome. However, both Walsh (1995) and Svensson (1997) on the one hand, and Rogoff (1985) on the other assume *symmetric information* in the principal-agent relationship. More specific, they assume that both the political principal and the private sector know the central banker's preferences.

This assumption was abandoned by Herrendorf and Lockwood (1997) and - most recently - by Beetsma and Jensen (1997).

Building on the contracting approach, Herrendorf and Lockwood (1997) demonstrated that if a monopolistic trade union has more information about productivity shocks than the principal, maximum social welfare can be achieved by having a conservative central banker with perverse preferences *on top of* the contract. Thus, - notwithstanding an optimal contract - Rogoff's conservative central banker is restored.

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³ However, McCallum (1995) argues that the Walsh contract merely shifts the credibility problem from the policymaker to the principal.

Beetsma and Jensen (1997), building on earlier work on preference uncertainty by Briault, Haldane and King (1996), Nolan and Schaling (1996) and Eijffinger, Hoeberichts and Schaling (1997), derive the very interesting result that - if the private sector and the political principal have imperfect information about the central banker's preferences - the equivalence between the linear Walsh contract and the Svensson inflation target breaks down. They show that the optimal linear inflation contract performs strictly better than the optimal inflation target when there is uncertainty about the central banker's preferences.

However, they model the central banker's preference uncertainty as 'pure' uncertainty. This implies that in their model there is no effect from preference uncertainty on the private sector's inflation expectations. Thus, inflation expectations are invariant to this kind of monetary policy uncertainty.

In this paper, building on our earlier work in this area⁴, we investigate the effects of relaxing this restriction. Using a model that is otherwise similar to theirs, we find results that are very different - and sometimes - exactly the opposite - of the Beetsma and Jensen (1997) model.

For instance, we find that it is optimal for the government to impose an inflation target on the central bank which depends on the degree of uncertainty about its preferences. This is in sharp contrast to Beetsma and Jensen (1997), who find that the optimal inflation target does *not* depend on the degree of preference uncertainty and is the same as in the Svensson (1997) model. Therefore here - contrary to BJ - certainty equivalence does *not* hold, and the optimal inflation target with uncertain central bank preferences does *not* correspond to the optimal target derived by Svensson (1997) in the absence of uncertainty about central bank preferences.

Further, for the case of the Walsh contract we find that it is optimal to offer a linear inflation contract to a central banker that does *not* depend on the degree of uncertainty about its preferences. Again, this is in sharp contrast to Beetsma and Jensen (1997) (hereafter BJ), who find that the optimal linear contract *does* depend on the degree of preference uncertainty. Here our result is the same as in Walsh (1995) for the case *without* preference uncertainty. Hence, certainty equivalence *does* hold and the optimal linear inflation contract with uncertain central bank preferences is *identical* to the optimal Walsh contract in the absence of uncertainty about central bank preferences.

Finally, we find that in case of uncertain central banker preferences the *optimal* delegation arrangement is a combination of a linear inflation contract and a *quadratic contract*. Here the quadratic contract is equivalent to a Rogoff (1985) conservative central banker. Again, this is different from Beetsma and Jensen (1997), who find that a combination of a linear inflation contract, an *inflation target* and a quadratic contract performs best.

Moreover, our result is in line with Herrendorf and Lockwood (1997), and hence suggests that their 'restoration' of Rogoff appears to be a very robust result indeed.

⁴ In particular Nolan and Schaling (1996).

The paper is organised into six remaining sections followed by four appendices. In Section 2 we present the model. Section 3 looks at the optimal inflation target. In Section 4 we examine the linear inflation contract. Section 5 compares the inflation target with the linear contract. Section 6 considers quadratic contracts. Our conclusions are given in Section 7. The appendices provides the derivation of inflation expectations in the presence of non-linearities, the optimal inflation target, the optimal linear contract and the characterisation of quadratic contracts.

2 The Model

We use a standard credibility model [Walsh (1995), Svensson (1997)]. In line with the credibility literature output is described by a standard reduced-form Lucas supply function:

$$y = (\pi - E\pi) + \varepsilon \quad (2.1)$$

where y is (the natural log of) output; inflation is denoted by π and nominal wage contracts signed at time $t-1$ are proxied by the private sector's expected inflation rate. ε is a supply shock with $E[\varepsilon] = 0$ and $E[\varepsilon^2] = \sigma_\varepsilon^2$. From these distributional characteristics it follows that the log of the natural rate of output is zero.

The welfare loss of the government (and of society) is given as

$$L^G = \frac{1}{2} E^G \left[(y - y^*)^2 + (\pi - \pi^*)^2 \right] \quad y^* > 0 \quad (2.2)$$

where the government's inflation target is π^* , and y^* denotes the government's preferred value for output. Given this specification it follows that the government's relative weight of inflation stabilisation relative to output stabilisation - by convenient normalisation - is unity. This simplifies the algebra without affecting the generality of results.

2.1 No Delegation of Monetary Policy

Now following Svensson (1997) and Beetsma and Jensen (1997), purely for illustrative purposes we first discuss the benchmark cases of pre-commitment and discretion and then delegation arrangements. This means that for the moment monetary policy is not delegated to an independent central bank, but set directly by the government.

Pre-commitment:

Monetary policy involves the choice of the inflation rate, which is assumed to be under the direct control of the authority who is in charge of monetary policy. The benchmark solution is obtained when the government is able to commit ex ante to some announced inflation rate. The optimal state-contingent monetary policy rule is found by minimising equation (2.2) subject to (2.1) and the restriction that inflation equals announced inflation on average. The solution is characterised by the following expressions for respectively, expected inflation, the variances of inflation and output, and the government's welfare loss

$$E^G[\pi] = \pi^*, \text{Var}\pi = \frac{1}{4}\sigma_\varepsilon^2, \text{Vary} = \text{Var}\pi$$

$$L^G = \frac{y^{*2}}{2} + \frac{1}{4}\sigma_\varepsilon^2 \quad (2.3)$$

Discretion:

As is well known, the policy rule that implies (2.3) is time-inconsistent and therefore not credible [Persson and Tabellini (1990)] if implemented by a government whose objective function is given by equation (2.1). Once nominal wages have been set, the government has the incentive to raise the inflation rate in order to stimulate output. To satisfy the incentive constraint, the equilibrium inflation rate must be optimal for the government when it takes wages and thus inflationary expectations as given. The discretionary equilibrium is found by minimising (2.2) subject to (2.1), taking inflation expectations as given. This yields⁵:

$$E^G[\pi] = \pi^* + y^*$$

$$L^G = y^{*2} + \frac{1}{4}\sigma_\varepsilon^2 \quad (2.4)$$

Expected inflation exceeds the optimal inflation rate by y^* because of the incentive to create surprise inflation in order to bring output closer to its target $y^* > 0$. Clearly, social welfare is higher under pre-

⁵ The variances of inflation and output are identical to those under pre-commitment.

commitment than under discretion. Hence, the government may try to improve its utility by delegating monetary policy to an independent central bank.

2.2 Delegation of Monetary Policy

For the remainder of the paper we assume that actual monetary policy is delegated to a central bank that has full *instrument* independence but uncertain preferences. More specifically, we assume that the central bank has the following loss function:

$$L^{CB} = \frac{1}{2} \left[(y - y^*)^2 + (1 - x)(\pi - \pi^*)^2 \right] \quad (2.5)$$

where x is a stochastic parameter unobserved by both the government and the private sector. Thus, the central bank's weight on inflation stabilisation is continuously hit by the preference disturbance term x , which is a random variable with $E[x] = 0$ and $E[x]^2 = \sigma_x^2$. Moreover, it is assumed that x is independent of ε , hence $E[\varepsilon x] = 0$, and that $x < 1$ with probability one.

This specification follows Briault, Haldane and King (1996) and Nolan and Schaling (1996), and differs from other authors who have stressed the role of imperfect information about the central bank's preferences⁶.

The timing of events is as follows. First monetary policy is delegated to the central banker. Then inflation expectations are formed. Next, the supply shock, ε , hits the economy and, finally, monetary policy is selected by setting the inflation rate.

3 The Optimal Inflation Target

We now consider the case of delegation with an *inflation target*. This means that the central bank no longer has *goal* independence. Rather the government imposes its own inflation target for the central bank to adhere to. This is similar to the situation in the UK where the Bank of England sets short-term interest rates independently, but where the inflation target (for this period 2.5%) is set by the government. Under the above arrangements the central bank's loss function becomes

⁶ For example, Beetsma and Jensen (1997) constrain the sum of the weights on $(y - y^*)^2$ and $(\pi - \pi^*)^2$ to be $(1 + x) + (1 - x) = 2$, as in society's loss function, but they assume the relative weights on output and inflation variances random. Using the notation of this paper, the BJ results are obtained by having

$$L^{CB} = \frac{1}{2} \left[(1 + x)(y - y^*)^2 + (1 - x)(\pi - \pi^*)^2 \right].$$
 Our specification has the implication that inflation expectations

for any given monetary regime depend on σ_x^2 . This allows us to derive results that are very different - and sometimes the opposite - of their model.

$$L^{CB} = \frac{1}{2} \left[(y - y^*)^2 + (1 - x)(\pi - \pi^b)^2 \right] \quad (3.1)$$

where π^b is the central bank's inflation target that is chosen by the government.

The central bank sets monetary policy, which involves the choice of the inflation rate. The central bank then sets inflation⁷ so as to minimise (3.1) subject to (2.1), having observed the supply shock and taking inflation expectations as given.

The first-order condition for a minimum implies the following reaction function

$$\pi = \pi^b + \frac{1}{2-x} (y^* - (\pi^b - \pi^e + \varepsilon)) \quad (3.2)$$

The term $(\pi^b - \pi^e + \varepsilon)$ is the output level consistent with the inflation target. It follows upon substituting π^b for π in (2.1). If y^* exceeds this level, the central bank has an incentive to set inflation above the inflation target.

An important property of (3.2) is that the effects of preference shocks on inflation are *asymmetric*. To see this consider the following example.

Setting $y^* - (\pi^b - \pi^e + \varepsilon) = 1$ and $\pi^b = 0$, if there is *no preference uncertainty*, implies that inflation is 0.50%. Now, if $x = +0.50$, inflation increases by 17 basispoints to 0.67%. However a negative preference shock of the same size decreases inflation by 10 basispoints to 0.40%. Hence, a positive preference shock has more *inflationary* impact than the *disinflationary* impact of a negative shock. The above example was constructed for a *given* level of expected inflation. To solve for private sector inflation expectations take the mathematical expectation (at time $t-1$) of equation (3.2).⁸ This yields

$$\pi^e = \pi^b + \Phi y^* \quad \text{where} \quad \Phi = \frac{4 + \sigma_x^2}{4 - \sigma_x^2} \quad (3.3)$$

⁷ Cukierman and meltzer (1986) examine the case where the authorities can set the control variable only imperfectly. That is, $\pi_t = \pi^p + \psi_t$, where $\psi \sim \mathcal{N}(0, \sigma_\psi^2)$ and p indicates a planned variable. We assume that there are no monetary control errors, that is $\sigma_\psi^2 = 0$.

⁸ The technical issue here, as we show in Appendix A, is that this involves taking expectations in the presence of non-linearities.

It is useful to consider the limiting value of π^e for the case without preference uncertainty

$$\lim_{\sigma_x^2 \rightarrow 0} \pi^e = \pi^b + y^* \quad (3.4)$$

Equations (3.3) and (3.4) indicate that inflation expectations are proportional to the output bias y^* and the inflation target imposed by the government, a familiar conclusion in the literature. However (3.3) differs in a significant way from (3.4), as a result of uncertainty regarding the central bank's preferences. It can be seen that with uncertainty about inflation stabilisation preferences expected inflation is higher than in the standard case. The reason is that *positive* shocks to x - more emphasis on output stabilisation - are *more inflationary* than negative shocks - more emphasis on inflation stabilisation - are *disinflationary*. With equal probabilities of positive and negative shocks to the central banker's preferences⁹, expected inflation will be adjusted upwards and the more so the higher the variance of the shocks hitting the central bank's preferences.

This can be restated in a more technical way by noting that the expectation of inflation involves the expectation of a *convex* function of the preference shock, which will always be *higher* than the value of this function at the (zero) expected value of the preference shock. Hence the channel through which the uncertainty affects expected inflation is the *Jensen's inequality effect*¹⁰.

Realised inflation under a given target follows upon inserting (3.3) back into (3.2)

$$\pi = \pi^e + \left(\frac{1 - \Phi(1-x)}{2-x} \right) y^* - \frac{1}{2-x} \varepsilon \quad (3.5)$$

It is important to realise that now monetary policy will on average *not* coincide with policy in the absence of uncertainty about the central banker's preferences. If we set the preference shock equal to zero in (3.5), monetary policy will still react to the degree of preference uncertainty (through the variance term in Φ). Thus, in this respect certainty equivalence does *not* hold. The reason is that the central banker optimises its policy taking inflation expectations as given. Since private sector inflation expectations depend on the second moment of the distribution of x (see equation (3.3)) so does the central bank's monetary policy stance.

⁹ However, results do not depend on the *symmetry* of this distribution.

¹⁰ I.e. $E\left(\frac{1}{2-x}\right)(\pi^e + y^*) + \pi^b E\left(\frac{1-x}{2-x}\right) > \pi^b + \frac{1}{2} E\left(y^* - (\pi^b - \pi^e + \varepsilon)\right)$. This effect is not present in the BJ model because they constrain the sum of the weights on output and inflation in the central banker's loss function to be the same as in society's loss function.

Combining (2.1) and (3.5) yields realised output as

$$y = \left(\frac{1 - \Phi(1-x)}{2-x} \right) y^* + \frac{1-x}{2-x} \varepsilon \quad (3.6)$$

From (3.5) and (3.6) it can be seen that inflation and output differ from their expected values when either x or ε differ from their (zero) expected values.

For the moment, assume that the supply shock is zero. Then the way the model works is extremely simple. Suppose there is a positive shock to the central banker's preferences ($\pi > \pi^e$). This implies that output will be above the natural rate. Conversely, if there is a negative realisation of x (more emphasis on inflation stabilisation) actual inflation will be lower than expected. Consequently, output will be below its natural level.

It is important to realise that the inflation surprise (be it positive or negative) is completely unaffected by the level of the imposed inflation target. Put differently, the delegation parameter π^b , has no effect on how the uncertainty about the central banker's preferences is transmitted to inflation and output. Here we show that their result continues to hold when private sector inflation expectations reflect the uncertainty about the central banker's preferences (through the term Φ).

To see this consider equation (3.3). A change in π^b changes inflation expectations one-for-one. Hence, the central banker's incentive to set inflation above the target is unaffected, because $(\pi^b - \pi^e + \varepsilon)$ in (3.2) is unaffected.

Put differently, the choice of inflation target has no implications for stabilisation policy. By inspecting (3.5) and (3.6), it can be seen that the term π^b does not affect the deviations of realised inflation from expectations $(\pi - \pi^e)$ or output from its (zero) trend. Thus, the variances of output and inflation are *independent* from the choice of inflation target.

For completeness these variances are

$$Var\pi = \left[\frac{(y^* + \Phi y^*)^2 + \sigma_\varepsilon^2}{4} \right] \frac{\sigma_x^2}{4} + \frac{\sigma_\varepsilon^2}{4} \left(1 + \frac{\sigma_x^2}{4} \right) \quad (3.7)$$

$$Vary = Var\pi + \sigma_\varepsilon^2 - \left(1 + \frac{\sigma_x^2}{4} \right) \sigma_\varepsilon^2 \quad (3.8)$$

To find the optimal inflation target, the government chooses the value of π^b that minimises L^G subject to (3.3), (3.5) and (3.6).

The optimal inflation target, denoted by π^{b*} is:¹¹

$$\pi^{b*} = \pi^* - \Phi y^* \quad (3.9)$$

As before it is useful to consider the limiting value of π^{b*} for the case without preference uncertainty

$$\lim_{\sigma_x^2 \rightarrow 0} \pi^{b*} = \pi^* - y^* \quad (3.10)$$

This is the Svensson (1997) result about the 'inflation target-conservative' central bank where the inflation target equals the socially best inflation rate less the inflation bias.

If $\sigma_x^2 > 0$, equation (3.9) reveals that it is optimal for the government to impose an inflation target on the central bank which depends on the degree of uncertainty about its preferences. This is in sharp contrast to Beetsma and Jensen (1997), who find that the optimal inflation target does *not* depend on the degree of preference uncertainty and is the same as in the Svensson (1997) model. Therefore here - contrary to BJ - certainty equivalence does *not* hold, and π^{b*} does not correspond to the optimal target derived by Svensson (1997) in the absence of uncertainty about central bank preferences.

The intuition behind our result is simple. First, from (3.7) and (3.8) we know that the choice of inflation target has no effect on the stochastic components of the government's loss function. Thus, the inflation target is chosen so as to equal *expected inflation* to the socially desirable inflation rate. Since, expected inflation depends on σ_x^2 (through Φ), the optimal inflation target also depends on σ_x^2 . Finally, comparing (3.9) with (3.10), it can be seen that with preference uncertainty the optimal inflation target is 'stricter' (lower) than the Svensson target. The reason is as follows. As is clear from (3.3), central banker uncertainty implies higher inflation expectations. To offset this additional inflation bias the degree of 'target conservativeness' has to increase as well.

¹¹ See Appendix B for the derivation.

4 The Optimal Linear Inflation Contract

Having characterised the optimal inflation target, we now turn to the case where delegation takes the form of a simple linear inflation contract. Walsh (1995) has shown that - in the absence of uncertainty about central bank preferences - such a contract can remove the inflation bias under discretion while still allowing the central bank to react optimally to supply shocks.

Thus, the trade-off between credibility and flexibility as emphasised by Rogoff (1985) and others is eliminated, and the pre-commitment outcome can be attained.

The contract adds a linear cost to the central bank's loss function. Let the added linear cost to inflation be $f_1(\pi - \pi^*)$, where f_1 is a constant.

Then the central bank is assigned the loss function

$$L^{CB} = \frac{1}{2} \left[(y - y^*)^2 + (1 - x)(\pi - \pi^*)^2 \right] + f_1(\pi - \pi^*) \quad (4.1)$$

The central bank chooses inflation so as to minimise (4.1) subject to (2.1) having observed the supply shock and taking inflation expectations as given.

From the first-order condition we obtain the following reaction function:

$$\pi = \pi^* + \frac{1}{2 - x} (y^* - (\pi^* - \pi^e + \varepsilon)) - \frac{f_1}{2 - x} \quad (4.2)$$

As before, the term $(\pi^* - \pi^e + \varepsilon)$ is the output level consistent with the socially optimal inflation rate π^* , i.e. the output level that follows upon substituting π^* for π in (2.1). If y^* exceeds this level, then the central bank has an incentive to set inflation above the social optimum.

Comparing (4.2) and (3.2) it can be seen that the central bank's reaction function under a linear inflation contract looks very similar to the reaction function under the optimal inflation target. In both cases the effects of preference shocks on inflation are *asymmetric*, with positive shocks increasing inflation by more than negative shocks decreasing it. There are two differences. The first is that in (4.2) the government imposed inflation target π^b is replaced by the socially optimal inflation rate. Secondly, under a linear contract inflation decreases with f_1 . The reason is that an increase in f_1 raises the central banker's marginal loss from higher inflation.

Taking expectations (at time $t - 1$) of the central bank's reaction function under a linear contract gives inflation expectations as

$$\pi^e = \pi^* + \Phi(y^* - f_1) \quad (4.3)$$

where the term Φ has the same meaning as in the private sector's forecasting rule under an optimal inflation target.¹²

Please note that, unlike Beetsma and Jensen (1997), uncertainty about the central banker's preferences increases inflation expectations. The intuition is similar to the case of the optimal inflation target. Positive preference shocks are more inflationary than negative shocks are disinflationary. Hence with equal probabilities of positive and negative shocks expected inflation will be adjusted upwards, and the more so the higher the variance term in Φ .

From expression (4.3) it is clear that inflation is expected to exceed its social optimum whenever $y^* > f_1$, in which case the marginal benefits of inflation are greater than the marginal costs, i.e. the incentive to inflate dominates the disciplining effect of the contract.

Inserting (4.3) back into (4.2) actual inflation is

$$\pi = \pi^e + \left(\frac{1 - \Phi(1-x)}{2-x} \right) (y^* - f_1) - \frac{\varepsilon}{2-x} \quad (4.4)$$

As in the case of the optimal inflation target, it is important to realise that monetary policy does not coincide with policy in the absence of uncertainty about the central banker's preferences. If we set the preference shock equal to zero in (4.4) monetary policy will still react to the variance term in Φ . Thus, in this respect certainty equivalence does *not* hold. The reason is that the central banker optimises its policy by taking inflation expectations as given. Since inflation expectations depend on the variance of the preference shocks (through Jensen's inequality; see expression (4.3)) so does the central bank's reaction function.

Combining (4.4) and (2.1) yields realised output:

$$y = \left(\frac{1 - \Phi(1-x)}{2-x} \right) (y^* - f_1) + \frac{1-x}{2-x} \varepsilon \quad (4.5)$$

As in the case of the optimal inflation target, inflation and output deviate from their expected values when either x or ε differ from their (zero) expected values. But compared with (3.5) and (3.6), the solutions for inflation and output differ in an important aspect: the delegation parameter f_1 , now affects how uncertainty about the central banker's preferences feed into inflation and output.

Here we show that their result still holds if private sector inflation expectations depend on the uncertainty about preferences.

¹² The derivation is similar to the case of an optimal inflation target, for more details see Appendix A.

For the moment, suppose that the supply shock is zero. From (4.2) it can be seen that the contract affects the inflation rate through two channels. The first channel operates *directly* by increasing the marginal loss of inflation. Consider a marginal increase in f_1 starting from $f_1 = 0$. The direct effect is then given by the term $-f_1 / 2 - x$. So this effect is *uncertain* and ultimately depends on the realisation of x . The second, *indirect* channel operates through inflation expectations. Here it is equal to $-\Phi f_1$ (see equation (4.3))¹³.

The combined direct and indirect effects of the contract imply that any deviation of x from its (zero) expected value will have *smaller* effects on actual inflation and output. Thus, with a contract in place, i.e. $f_1 > 0$, - contrary to the case of an optimal inflation target - the transmission of preference shocks to inflation and output is dampened.

Now, consider the effects of a supply shock. The transmission of this shock to inflation and output is affected by the preference shock. Consider a positive realisation of x . This means that there is more emphasis on output stabilisation which increases the willingness of the central bank to accommodate supply shocks. Hence, the higher x the more such shocks are dampened before they pass on to output. The flipside of the coin is that inflation volatility is less well cared for. Of course, if x is negative the reverse is true. Then, the central bank dampens the impact effect from the supply shock on inflation and output is allowed to fluctuate more.

Under a linear contract, i.e. if $f_1 > 0$, it is clear that the role of fluctuating preferences in the transmission of supply shocks to inflation and output is significantly reduced. Thus, there will be less scope for the central bank to impose its 'own' preferences on society and distort stabilisation policy by 'overstabilising' either inflation or output.

This can also be seen from the expressions for the variances of inflation and output

$$Var\pi = \left[\frac{(y^* - \pi^* + \pi^e - f_1)^2 + \sigma_\varepsilon^2}{4} \right] \frac{\sigma_x^2}{4} + \frac{\sigma_\varepsilon^2}{4} \left(1 + \frac{\sigma_x^2}{4} \right)^2 \quad (4.6)$$

$$Vary = Var\pi + \sigma_\varepsilon^2 - \left(1 + \frac{\sigma_x^2}{4} \right) \sigma_\varepsilon^2 \quad (4.7)$$

Through the first term on the right hand side of (4.6) the contract affects the variability of inflation and, through (4.7), of output.

¹³ In the BJ model the direct effect is *deterministic* and - using the notation of this paper - equal to $-f_1 / 2$. BJ have no effect from preference uncertainty on expected inflation so $\Phi \rightarrow 1$ and the indirect effect in their model is $-f_1$.

To find the *optimal* linear inflation contract, the government chooses f_1 so as to minimise L^G subject to (4.3), (4.4), and (4.5). Using the first-order condition, the optimal value of f_1 , denoted by f_1^* , is given by:¹⁴

$$f_1^* = y^* \tag{4.8}$$

This expression reveals that it is optimal to offer a linear inflation contract to a central banker that does *not* depend on the degree of uncertainty about its preferences. This is in sharp contrast to Beetsma and Jensen (1997), who find that the optimal linear contract *does* depend on the degree of preference uncertainty.

Please note that our result is the same as in Walsh (1995) for the case *without* preference uncertainty. Hence, contrary to BJ for the case of a linear contract, certainty equivalence *does* hold. The value f_1^* corresponds to the optimal Walsh contract in the absence of uncertainty about central bank preferences.

5 The Linear Walsh Contract versus the Svensson Inflation Target

In this section we compare the outcomes for inflation and output under a Walsh contract with the outcomes under a Svensson inflation target. In absence of uncertainty about the central banker's preferences, Svensson (1997) has shown that the linear Walsh contract is equivalent with the Svensson inflation target. Both achieve optimal stabilization without an inflationary bias. We will show that this equivalence no longer holds when disturbances to the central banker's preferences are introduced.

Optimal Linear Inflation Contract:

Under the optimal linear inflation contract the inflationary bias is eliminated so that expected inflation is equal to the inflation target (this can be seen from (4.3)). Thus the credibility problem is solved. To see how the linear contract performs with respect to *stabilisation policy* we need to look at the variances on inflation and output. By substituting $f_1 = y^*$ into (4.6) and (4.7) we get

$$\text{Var}\pi = \frac{\sigma_\varepsilon^2}{4} \left(1 + \frac{3\sigma_x^2}{4} + \frac{\sigma_x^4}{16} \right)$$

¹⁴ See Appendix C for the derivation.

$$\text{Vary} = \frac{\sigma_\varepsilon^2}{4} \left(1 - \frac{\sigma_x^2}{4} + \frac{\sigma_x^4}{16} \right) \quad (5.1)$$

Optimal Inflation Target:

The optimal Svensson inflation target also solves the credibility problem. So in this respect it is identical to the linear inflation contract. However, its stabilisation properties are different from the linear inflation contract.

The variances of inflation and output under an optimal inflation target can be found by substituting $\pi^b = \pi^* - \Phi y^*$ into (3.7) and (3.8). This yields

$$\begin{aligned} \text{Var}\pi &= \frac{\sigma_\varepsilon^2}{4} \left(1 + \frac{3\sigma_x^2}{4} + \frac{\sigma_x^4}{16} \right) + \frac{4\sigma_x^2 y^{*2}}{(4 - \sigma_x^2)^2} \\ \text{Vary} &= \frac{\sigma_\varepsilon^2}{4} \left(1 - \frac{\sigma_x^2}{4} + \frac{\sigma_x^4}{16} \right) + \frac{4\sigma_x^2 y^{*2}}{(4 - \sigma_x^2)^2} \end{aligned} \quad (5.2)$$

Comparing (5.1) and (5.2), it is clear that in the presence of uncertainty about the central banker's preferences the Walsh contract unambiguously yields a lower variance of inflation and a lower variance of output than the Svensson inflation target. This means that the optimal linear inflation contract yields a lower expected loss to the government and, therefore, is *strictly superior* to the optimal inflation target. This result is similar to BJ. However, in their model stabilisation policy under a linear inflation contract is at the cost of expected inflation being *below* the socially optimal inflation rate. This trade-off is not present in this paper.

The intuition behind this result is simple. In Section 3 we showed that with an inflation target, the delegation parameter π^b , has no effect on how the uncertainty about the central banker's preferences is transmitted to inflation and output. Put differently, the choice of the inflation target has no implications for stabilisation policy. Thus, the variances of output and inflation are *independent* from the choice of inflation target.

From Section 4 we know that this is no longer true under a linear contract. With the optimal contract in place, i.e. $f_1^* = y^*$, - contrary to the case of an optimal inflation target - the transmission of preference shocks to inflation and output is dampened. Because the role of fluctuating preferences in the transmission of supply shocks to inflation and output is significantly reduced, the variances of inflation and output will be lower than in the case of an optimal inflation target.

The policy implications of this result are clear. It suggests that - in the presence of uncertainty about the central banker's preferences - the best institutional arrangement is to grant the central bank *instrument independence* and to make it *accountable* for its monetary policy performance by imposing a linear inflation contract. Moreover, this delegation arrangement has the appealing property that the optimal linear inflation contract is *independent* from the degree of preference uncertainty. So there is no need for the government (the principal) to make delegation arrangements conditional on this uncertainty. In other words, the legislator needs *less* information than in the case of the optimal inflation target (where the target *does* depend on σ_x^2) and still reaps the rewards of better stabilisation policy than in the case where policy is set by a central bank with an optimal inflation target.

6. Quadratic Contracts

Even though the optimal linear contract is superior to the optimal inflation target, it does not achieve the pre-commitment solution. The reason is that the interaction between the supply shocks and preference uncertainty generates excess macroeconomic variability.

We address this problem by expanding the set of admissible contracts to include quadratic contracts. A quadratic contract penalises quadratic (squared) deviations of inflation from some target.

Combination of a Linear and a Quadratic Contract

More specifically, to moderate the excess macroeconomic variability under the linear inflation contract we examine the combination of a linear and a quadratic contract. Let the added quadratic cost to inflation be $f_2(\pi - \pi^*)^2$, where f_2 is a constant. Then the central bank is assigned the loss function

$$L^{CB} = \frac{1-x}{2}(\pi - \pi^*)^2 + \frac{1}{2}(y - y^*)^2 + f_1(\pi - \pi^*) + \frac{f_2}{2}(\pi - \pi^*)^2 \quad (6.1)$$

From (6.1) it can be seen that - if $f_2 > 0$ - the quadratic contract is mathematically equivalent to Rogoff's (1985) conservative central banker. Of course, if this parameter is negative, we have a *liberal* central banker.

The optimal delegation arrangement is found in two steps. The first step is to solve for the optimal linear contract, taking f_2 as given. The second step is to solve for the optimal value of f_2 .

As was shown in the previous section, the variances of inflation and output do not depend on the parameters of the Walsh contract when the parameter f_1 is optimally chosen. Adding a quadratic penalty on inflation does not change the optimal Walsh contract. Therefore, in this section we have two independent instruments for two problems. We use the linear penalty term to eliminate the inflationary bias and we use the quadratic term to minimise the welfare loss to society caused by the variance of inflation and output. The quadratic term then brings a trade-off between the variance of inflation and the variance of output as is well-known from the Rogoff model. From Appendix D it follows that the optimal combination of a linear and a quadratic contract is

$$f_1^{**} = y,^* \quad 0 < f_2^* < \frac{9\sigma_x^2}{4 + 3\sigma_x^2} \quad (6.2)$$

Thus, in order to mitigate excess macroeconomic variability - due to the interaction between supply shocks and preference shocks - the linear Walsh contract needs to be augmented with a *conservative* central banker. This result was first found by Herrendorf and Lockwood (1997). Here we show that their result - which follows from information asymmetries between a monopolistic trade union and the political principal with respect to productivity shocks - continues to hold in our setting.¹⁵ The Walsh contract *cum* conservative central banker result is also found by Beetsma and Jensen (1997). Thus, the Herrendorf-Lockwood result appears to be very robust indeed.

Combination of an inflation target and a quadratic contract

As was shown in the previous section the optimal inflation target performs worse - in terms of social welfare - than the optimal linear contract. More specifically, because the inflation target has no effect on the transmission of uncertainty about the central banker's preferences to inflation and output, macroeconomic variability is higher than with an optimal linear contract. Thus, social welfare with an optimal inflation target will be even further away from the first-best pre-commitment outcome than in the case of a linear contract.

To mitigate this sub-optimal volatility, we now consider a combination of an optimal inflation target and a quadratic contract. Under this delegation scheme the central banker minimises

¹⁵ As can be seen in Appendix D, the combination of an optimal linear Walsh contract and a quadratic contract gives the Rogoff result that the variance of inflation decreases with f_2 whereas the variance of output increases with f_2 (for σ_x^2 sensibly small).

$$L^{CB} = \frac{1-x}{2}(\pi - \pi^b)^2 + \frac{1}{2}(y - y^*)^2 + \frac{f_2}{2}(\pi - \pi^*)^2 \quad (6.3)$$

As before, the optimal delegation arrangement is found in two steps. The first step is to solve for the optimal inflation target, taking f_2 as given. The second step is to solve for the optimal value of f_2 . As was shown in the previous section, the variances of inflation and output do not depend on the inflation target π^b . Thus, adding a quadratic penalty on inflation does not change the optimal inflation target. This means that, - as before - we now have two independent instruments for two problems. We use the inflation target to eliminate the inflationary bias, and we use the quadratic contract to minimize the welfare loss to society caused by the excess macroeconomic variability. From Appendix D it follows that the optimal combination of an inflation target and a quadratic contract is

$$\pi^{b**} = \pi^* - \Phi y^*, \quad f_2^{**} > f_2^* \quad (6.4)$$

From (6.4) it follows that the Svensson optimal inflation target (which already depends on the degree of preference uncertainty), also has to be augmented with a conservative central banker. Moreover, in Appendix D we show that now the central banker has to be even *more conservative*. The additional variance that the inflation target generates, compared to the Walsh result, can unambiguously be reduced by making the central banker more conservative. This explains why the central banker has to be even more conservative when he is assigned a Svensson target instead of a linear Walsh contract.

7 Concluding Remarks

In this paper we have investigated the effects of uncertain central bank preferences for the optimal institutional design of monetary policy. We have studied this in the context of a model that goes beyond 'pure' uncertainty. This means that we have relaxed the Beetsma and Jensen (1997) restriction that the central banker's preference uncertainty has no effect on private sector inflation expectations. As shown in the paper this implies that monetary policy will on average *not* coincide with policy in the absence of uncertainty. In this respect certainty equivalence does not hold. The reason is that the central bank optimises its policy, taking inflation expectations as given. Since private sector inflation expectations now depend on the degree of preference uncertainty (being the variance of the preference shock) so does monetary policy. Hence, through the expectations channel, preference

uncertainty now has *systematic* (as opposed to transitory) effects on policy. The implications of allowing the uncertainty to play a bigger role are substantial.

First, the optimal inflation target that has to be imposed on the central banker now depends on the degree of preference uncertainty, and has to be *stricter* (lower) the higher the uncertainty. The reason is that central banker uncertainty implies higher inflation expectations. To offset this additional inflation bias the degree of 'target conservativeness' has to increase as well.

This is in sharp contrast to Beetsma and Jensen (1997), who find that the optimal inflation target does *not* depend on the degree of preference uncertainty and is the same as in the Svensson (1997) model. Therefore in our model - contrary to BJ - certainty equivalence does *not* hold, and the optimal inflation target with uncertain central bank preferences does *not* correspond to the optimal target derived by Svensson (1997) in the absence of uncertainty about central bank preferences.

Further, for the case of the Walsh contract we find that it is optimal to offer a linear inflation contract to a central banker that does *not* depend on the degree of uncertainty about its preferences. Again, this is in sharp contrast to Beetsma and Jensen (1997), who find that the optimal linear contract *does* depend on the degree of preference uncertainty. Here our result is the same as in Walsh (1995) for the case *without* preference uncertainty. Hence, contrary to BJ for the case of a linear contract certainty equivalence *does* hold, and the optimal linear inflation contract with uncertain central bank preferences is *identical* to the optimal Walsh contract in the absence of uncertainty about central bank preferences.

Next, comparing the linear Walsh contract and the optimal inflation target, we find that the optimal linear inflation contract yields a lower expected loss to the government and therefore is *strictly superior* to the optimal inflation target. This result is similar to BJ. However, in their model stabilisation policy under a linear inflation contract is at the cost of expected inflation being *below* the socially optimal inflation rate. This trade-off is not present in this paper.

To conclude, we find that in case of uncertain central banker preferences the *optimal* delegation arrangement is a combination of a linear inflation contract and a *quadratic contract*. Here the quadratic contract is equivalent to a Rogoff (1985) conservative central banker. Again, this is different from Beetsma and Jensen (1997), who find that a combination of a linear inflation contract, an *inflation target* and a quadratic contract performs best.

The policy implications of this result are clear. It suggests that - in the presence of uncertainty about the central banker's preferences - the best institutional arrangement is to select a central banker that is more inflation averse than society, grant the central bank *instrument independence* and to make it *accountable* for its monetary policy performance by imposing a linear inflation contract. Moreover, this delegation arrangement has the appealing property that the optimal linear inflation contract is *independent* from the degree of preference uncertainty. Thus, there is no need for the government

(the principal) to make delegation arrangements conditional on this uncertainty. In other words the legislator needs *less* information than in the case of the optimal inflation target (where the target *does* depend on σ_x^2) and still reaps the rewards of better stabilisation policy than in the case where policy is set by a central bank with an optimal inflation target.

Appendix A Private Sector Inflation Expectations

Optimal Inflation Target

Taking expectations across expression (3.2):

$$E(\pi) = E\left(\frac{1}{2-x}\right)(\pi^e + y^*) + \pi^b E\left(\frac{1-x}{2-x}\right) \quad (\text{A.1})$$

This expression requires us to take the expected value of ratios of random variables. This can be achieved through a Taylor series expansion.

Our problem is to expand $\phi(z) = x/y$ about the respective means. Assuming that the first two moments of $E(x/y)$ exist we can write down the expression

$$E\left(\frac{X}{Y}\right) \approx \frac{\mu_x}{\mu_y} - \frac{1}{\mu_y^2} \text{cov}[X, Y] + \frac{\mu_x}{\mu_y^3} \text{var}[Y] \quad (\text{A.2})$$

This is the (second-order) approximation used in the paper, therefore we can write

$$E\left(\frac{1}{2-x}\right) \approx \frac{4 + \sigma_x^2}{8} \quad \text{and} \quad E\left(\frac{1-x}{2-x}\right) \approx \frac{4 - \sigma_x^2}{8} \quad (\text{A.3})$$

So substituting (A.3) in (A.1) and rearranging gives

$$\pi^e = \frac{4 + \sigma_x^2}{4 - \sigma_x^2} \cdot y^* + \pi^b \quad (\text{A.4})$$

which is expression (3.3) in the text. Again, it is clear that as $\sigma_x^2 \rightarrow 0$ the first part of the expression on the right hand side collapses to unity, and (A.4) is equivalent to (3.4).

Linear Inflation Contract

The derivation of private sector expectations for the case of a linear inflation contract is similar to the case of an optimal inflation target (see above).

Appendix B The Optimal Inflation Target

Since the choice of inflation target does not affect the stochastic components of the governments expected loss, its problem is

$$\text{Min}_{\pi^b} E^G \left[\frac{1}{2} (\pi^e - \pi^*)^2 \right] \quad (\text{B.1})$$

subject to

$$\pi^e = \pi^b + \Phi y^* \quad (\text{3.3})$$

The first-order condition (FOC) for minimising (B.1) with respect to π^b is

$$(\pi^e - \pi^*) \frac{\partial \pi^e}{\partial \pi^b} = (\pi^e - \pi^*) = 0 \quad (\text{B.2})$$

It follows that the FOC can be written as

$$\pi^e = \pi^* \quad (\text{B.3})$$

Substituting (3.3) for π^e yields

$$\pi^{b*} = \pi^* - \Phi y^* \quad (\text{B.4})$$

which is equation (3.9) in the main text.

Appendix C The Optimal Linear Contract

The governments problem is

$$\text{Min}_{f_1} E^G \left[\frac{1}{2} (\pi^e - \pi^*)^2 + \frac{1}{2} (\text{Var}\pi + \text{Var}y) \right] \quad (\text{C.1})$$

subject to (4.3), (4.7) and (4.8)

The first-order condition (FOC) for minimising (B.1) with respect to f_1 is

$$E^G (\pi^e - \pi^*) \frac{\partial \pi^e}{\partial f_1} + \frac{1}{2} \left[\frac{\partial \text{Var}\pi}{\partial f_1} + \frac{\partial \text{Var}y}{\partial f_1} \right] = 0 \quad (\text{C.2})$$

Substituting for π^e from (4.3) and using that $\partial \pi^e / \partial f_1 = -\Phi$ we get

$$E^G (-\Phi^2 (y^* - f_1)) + \frac{1}{2} \left[\frac{\partial \text{Var}\pi}{\partial f_1} + \frac{\partial \text{Var}y}{\partial f_1} \right] = 0 \quad (\text{C.3})$$

Then expanding $\frac{\partial \text{Var}y}{\partial f_1}$ as $\frac{\partial \text{Var}y}{\partial \text{Var}\pi} \frac{\partial \text{Var}\pi}{\partial f_1} = \frac{\partial \text{Var}y}{\partial f_1}$ and rearranging we get

$$-(\Phi^2 (y^* - f_1)) + \left[\frac{\partial \text{Var}\pi}{\partial f_1} \right] = 0 \quad (\text{C.4})$$

Finally, using that from (4.7) $\frac{\partial \text{Var}\pi}{\partial f_1} = \frac{-\sigma_x^2 (\Phi + 1) (y^* - f_1)}{4}$

the government's FOC can be written as

$$-\left[\frac{8\Phi^2 + 2(1 + \Phi)\sigma_x^2}{8} \right] (y^* - f_1) = 0 \quad (\text{C.5})$$

It can be easily seen that the optimal linear contract then is

$$f_1^* = y^* \quad (\text{C.6})$$

which is equation (4.8) in the main text.

Appendix D Quadratic Contracts

Optimal quadratic contract with optimal Walsh contract

$$\text{Var}\pi = \frac{\sigma_\epsilon^2}{(f_2 + 2)^2} \left(1 + \frac{3\sigma_x^2}{(f_2 + 2)^2} + \frac{\sigma_x^4}{(f_2 + 2)^4} \right) + \frac{y^{*2}\sigma_x^2(f_2 + 2)^2}{((f_2 + 1)(f_2 + 2)^2 - \sigma_x^2)^2} \quad (\text{D.1})$$

$$\text{Var}y = \frac{\sigma_\epsilon^2}{(f_2 + 2)^2} \left((f_2 + 1)^2 - \frac{(2f_2 + 1)\sigma_x^2}{(f_2 + 2)^2} + \frac{\sigma_x^4}{(f_2 + 2)^4} \right) \quad (\text{D.2})$$

The optimal value for f_2 is found at

$$f_2 = \frac{6\sigma_x^2}{(f_2 + 2)^2 + 3\sigma_x^2} + \frac{6\sigma_x^2}{(f_2 + 2)((f_2 + 2)^2 + 3\sigma_x^2)} \equiv G(f_2) \quad (\text{D.3})$$

Since, $G(0) = \frac{9\sigma_x^2}{4 + 3\sigma_x^2}$, $G(\infty) = 0$, and G is monotonically decreasing in f_2 , there is a unique solution to (D.3).

Optimal quadratic contract with optimal Svensson target

$$\text{Var}\pi = \frac{\sigma_\epsilon^2}{(f_2 + 2)^2} \left(1 + \frac{3\sigma_x^2}{(f_2 + 2)^2} + \frac{\sigma_x^4}{(f_2 + 2)^4} \right) + \frac{y^{*2}\sigma_x^2(f_2 + 2)^2}{((f_2 + 1)(f_2 + 2)^2 - \sigma_x^2)^2} \quad (\text{D.4})$$

$$\text{Var}y = \frac{\sigma_\epsilon^2}{(f_2 + 2)^2} \left((f_2 + 1)^2 - \frac{(2f_2 + 1)\sigma_x^2}{(f_2 + 2)^2} + \frac{\sigma_x^4}{(f_2 + 2)^4} \right) + \frac{y^{*2}\sigma_x^2(f_2 + 2)^2}{((f_2 + 1)(f_2 + 2)^2 - \sigma_x^2)^2} \quad (\text{D.5})$$

The optimal value for f_2 is found at

$$f_2 = G(f_2) + \frac{\sigma_x^2 y^{*2} (f_2 + 2)^6 ((2f_2 + 3)(f_2 + 2)^2 + \sigma_x^2)}{\sigma_\epsilon^2 ((f_2 + 1)(f_2 + 2)^2 - \sigma_x^2)^3 ((f_2 + 2)^2 + 3\sigma_x^2)} \quad (\text{D.6})$$

Comparing (D.6) to (D.3) it is clear that the solution to (D.6) is found at a higher value for f_2 . So we need a more conservative central bank under a Svensson inflation target than with a linear Walsh contract.

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