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Point versus Band Targets for Inflation*

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Abstract

Inflation targets come in different shapes and sizes. We explore the choice of a point or band target for inflation in a stylised economy in which agents learn about the inflation-generating process. We simulate under two conditions, namely *i)* a point inflation target and *ii)* a band inflation target from within which the central bank chooses its current specific target. In many parameterizations of the model, the preferred target type rests on the inflation-output stabilization preferences of the central bank. A band target tends to be associated with higher volatility of inflation and lower volatility of the output gap than a point target. As such, a very strong preference for output stabilisation speaks in favour of a band inflation target. With preferences for inflation stabilisation closer to those thought to prevail in practice, a point target almost always outperforms a band target.

JEL Classification: E52, E58

Keywords: Inflation targeting, Learning, Constant gain least squares

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1. Introduction

Inflation targeting has been widely adopted over the last thirty years but the formulation of inflation targets differs. Some inflation targets are cast as a point and others as a band, with different degrees of accompanying guidance about the horizon over which the goal will be fulfilled. The choice of target type is likely guided by beliefs about how inflation expectations are formed, by the central bank's stabilisation preferences and by political economy considerations such as evaluation and accountability of the central bank.

The point-versus-band question has received renewed focus in light of the decade of low inflation following the global financial crisis. Central banks have fought low inflation with an array of policy tools – low and negative policy-interest rates, asset purchases and direct funding of private sector borrowing – but inflation has been stubbornly below target in many economies.

Monetary-policy stimulus has supported the recovery in real economic activity but some commentators have questioned whether it has not also had downsides. Some have argued that loose policy has heightened financial stability risks by encouraging inappropriate allocation of investments by households, corporates and the financial sector.[1] Others have questioned the welfare distributional effects between borrowers and savers of low rates of return.[2] A proposed remedy has been to abandon point targets in favour of band targets, relieving the central bank of its obligation to stimulate inflation when trade-offs become unfavourable or risky.[3] For example, Warsh (2017) recently proposed that the Federal Reserve should replace its current target formulation with "*an inflation objective of around 1% to 2%, with a band of acceptable outcomes.*"[4]

In this paper we explore the choice of point or band inflation target from the perspective of a central bank with a preference for low volatility in inflation and output. Our goal is to better understand why target formulations differ and to illustrate the trade-offs in-

[1] See, for example, Andersson and Claussen (2017) for a recent overview.
[2] See, for example, Broadbent (2017) for a discussion and Bunn *et al.* (2018) for empirical analysis.
[3] Discussions of this issue are provided in, for exsample, Jansson (2015) and Apel and Claussen (2017).
[4] There has also been a wider debate regarding the Federal Reserve's inflation target. For example, Baker *et al.* (2017) suggested that the inflation target should be increased in order to have more room to stabilize the US economy in the future. Such an increase in the inflation target was recognized by chair Yellen as "…*one of the most important questions facing monetary policy around the world in the future*…" (Federal Open Market Committee, 2017, p. 14).

volved. The novelty and key contribution of our paper is to incorporate agents with imperfect knowledge who learn about the inflation target and inflation process, mirroring an important real-world aspect of monetary policy. As such, our approach differs from earlier analyses of point and band targets that assume rational expectations, such as Tetlow (2008) who relied on the large-scale model FRB-US.[5]

We simulate within a stylized macro-economy consisting of a private sector and a central bank, building on the model developed by Orphanides and Williams (2004). Neither the private sector nor the central bank enjoys full knowledge of the structure or parameterisation of the economy. Private sector agents form inflation expectations using an autoregressive model estimated on inflation outcomes with constant gain least squares. The central bank executes monetary policy with a rule-of-thumb policy reaction function.

Our key finding is that for many parameterizations of the economy, the preferred target type rests on the preferences of the central bank. Intuitively, when the central bank has a very high preference for output stability, it pays off to reduce the volatility of the output gap at the cost of greater inflation volatility. With such preferences, the flexibility afforded by a band target can be motivated. However, for inflation-stabilisation preferences closer to those thought to prevail in practice, a point target almost always outperforms a band target. The main channel through which this happens is that a point target promotes better anchoring of inflation expectations, in turn lowering the volatility of inflation.

By illustrating how target type interacts with expectations formation and the structure of the economy, the analysis in this paper makes a contribution to the literature on the anchoring of inflation expectations. Whereas Gürkaynak *et al*. (2010) and Beechey *et al*. (2011) addressed the merits of communicated versus implicit inflation targets, this paper takes this work one step further by considering the mechanisms underlying different formulations of explicit targets. Our results also echo the key result of the literature on central-bank communication – see, for example, Morris and Shin (2002), Svensson (2006), Sibert (2009) and Dale *et al*. (2011) – that in a world of imperfect knowledge, communication matters for economic outcomes.

[5] Our setup accordingly also differs from the adaptive expectations used by Orphanides and Wieland (2000) who analysed the closely related issue of target-zone preferences.

The paper is organised as follows. In Section 2, we define point and band targets more closely and relate them to concepts in inflation-targeting theory and practice. Section 3 outlines the model and Section 4 goes on to present results from model simulations; we start with a benchmark simulation and then vary key parameters to assess the robustness of our results. Section 5 concludes.

2. Inflation targets in theory and in practice

We begin with some terminology and definitions.[6] We define a *point target* as a single-value inflation target, communicated to the public and accompanied by guidance that the central bank seeks to achieve that value at some point in the future. We define a *band target* as an inflation target expressed as an interval that is communicated to the public. The central bank or its principal may set the target framework, but in the case of the band target, the central bank chooses from within the interval a point to which it aims to steer future inflation. The exact point that the central bank chooses as its current target is unknown to the public and might be time varying.[7] A point target that moves within a band can be envisioned in several ways. It may capture disagreement among the members of decision-making body (Tetlow, 2008), reflect evolving preferences of the decision-making body as its composition changes over time, or more strategic behaviour in which the central bank varies the target systematically in response to economic conditions.

A point target is the norm in the academic literature and is also more common in practice. Some central banks formulate their inflation target as a band, among them the Reserve Bank of Australia and the Reserve Bank of South Africa, and the Bank of England until 1997. Two main motivations for band targets are presented in the literature. First, a band target affords the central bank some freedom in choosing its inflation target in light of economic conditions, bringing more flexibility to the conduct of monetary policy. Second, a band target could strengthen the central bank's credibility because inflation outcomes will more often than not fall within the band target (see Castelnuovo *et al*., 2003).

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[6] Reviews of terminology and definitions can also be found in Dennis (1997), Sveriges Riksbank (2016) and Apel and Claussen (2017).

[7] The definition of a band target here differs subtly, yet meaningfully, from related concepts and designs in inflation-targeting theory and practice. For example, while our definition of a band target is similar to that used by Tetlow (2008), it differs from the formulation in Orphanides and Wieland (2000) in which the central bank conducts policy according to a point target but is indifferent about outcomes within an interval or "target zone". In our formulation the central bank is free to choose its current target from within the interval but the central bank's loss function penalizes deviations from the mean of the process.

From the latter perspective, a band target has similarities to so-called tolerance intervals which are employed by a number of central banks, including Brazil, Canada, Chile and New Zealand. However, a tolerance interval differs critically from a band target. A tolerance interval generally accompanies a point target and is intended as a communication tool to illustrate that inflation outcomes cannot be controlled perfectly and that deviations from target are to be expected.[8] Some central banks are held formally accountable if outcomes fall outside their tolerance interval. A tolerance interval can also serve as a guide to longer-run evaluations of monetary policy.

Band targets have been subject to criticism. Mishkin (2008) argues that band targets can confuse communication of the central bank's objective – both within the central bank and to the general public – undermining the anchoring of inflation expectations and risking poorer economic outcomes. And while inflation outcomes will more often fall within a band target than hit a point target, this also comes at a cost. Bernanke *et al.* (1999) suggests that missing a target range could do more damage to credibility than missing a point target. Like Mishkin, Svensson (2001) argues that a band target is a less precise anchor for inflation expectations than a point target. However, Svensson (2011) is more sanguine about the choice, stating that the central bank's goal formulation "*… does not seem to matter in practice. A central bank with a target range seems to aim for the middle of the range*."

Other target formulations also exist, such as the ECB:s aim to maintain *"… inflation rates below, but close to, 2% over the medium term*" which can be seen as a hybrid between a point target and an asymmetric band target.

In sum, there is no consensus in the academic literature as to whether a point or a band target for inflation is the best monetary policy framework. This is reflected in central banks' practice where point targets, albeit often accompanied by tolerance intervals, are more common than band targets.[9] We turn now to the model economy to explore the mechanisms behind the choice and consequences of the two types of targets.

[8] The "variation band" that Sveriges Riksbank introduced in September 2017 fills a similar communicative role as a tolerance interval despite the differing terminology; see Sveriges Riksbank (2017).

[9] See Apel and Claussen (2017, p. 99) for a recent overview of the choices made by various central banks.

3. The model

We rely on a highly stylised macroeconomic model which takes its starting point in the work of Orphanides and Williams (2004). In the model, the private sector learns about the inflation process by observing outcomes and weighting newer outcomes more heavily. Private sector inflation forecasts are based on an autoregressive econometric model which is re-estimated each time period using constant gain least squares (CGLS). In choosing this setup, we depart from the twin assumptions of rational expectations and full information, an increasingly common departure in the macroeconomic literature in recent years.[10]

Turning to the details of the model, inflation is given by a modified Lucas supply function as

$$\pi_t = \phi\pi^e_{t|t-1} + (1-\phi)\pi_{t-1} + \alpha x_t + e_t \qquad (1)$$

where π_t is inflation and $\pi^e_{t|t-1}$ is the private sector expectation of time *t* inflation formed at *t*-1; x_t is the output gap and e_t is a disturbance with standard properties, $e_t \sim nid(0, \sigma_e^2)$. The central bank determines the output gap for period *t* according to its reaction function as

$$x_t = -\theta(\pi_{t-1} - \pi^*_{t-1}) \qquad (2)$$

where π^*_{t-1} is the inflation target of the central bank; the time subscript denotes that it may be time-varying. The central bank's loss function is given by

$$L = \omega var(\pi_t) + (1-\omega) var(x_t) \qquad (3)$$

that is, it places some weight on the variance of both inflation and the output gap and $\omega \in [0,1]$.

The evolution of the inflation target is important in our setup and is given by

[10] See, for example, Evans and Honkapohja (1999), Sargent (1999), Bullard and Mitra (2002), Gaspar *et al*. (2006) and Dale *et al*. (2011).

$$\pi_t^* = \pi_{t-1}^* + \nu_t \quad (4)$$

where ν_t is a disturbance with properties $\nu_t \sim nid(0, \sigma_\nu^2)$. We make two different assumptions about the evolution of equation (4) to compare a point target to a band target.

i. Point inflation target. $\pi_t^* = \bar{\pi}^* \; \forall t$, where $\bar{\pi}^*$ is the fixed point inflation target and $\sigma_\nu^2 = 0$.

ii. Band inflation target. We assume that the upper and lower values of the band inflation target, respectively π_{upper}^* and π_{lower}^*, are fixed over time. The current point target, π_t^*, moves around as a bounded random walk with $\sigma_\nu^2 > 0$ but cannot take on values larger than π_{upper}^* or lower than π_{lower}^*.[11]

We permit e_t and ν_t to co-vary when the central bank has a band target. One intuition for a positive covariance between the two is if the central bank systematically accommodates positive output shocks by increasing its inflation target. This reasoning is similar to that in Ireland (2007) where the central bank could systematically adjust its inflation target in response to either or both of the two supply shocks of the model.

Regardless of whether the central bank is conducting policy with a point or band target, the private sector models the inflation process and generates inflation forecasts using the AR(1) model

$$\pi_t = c_{0,t} + c_{1,t}\pi_{t-1} + \psi_t \quad (5)$$

The AR(1) form for modelling inflation coincides with the reduced form for inflation in this model under full information, rational expectations and a fixed point target.[12] Moreover, AR(1) models are often used as the standard reference tool in empirical forecasting in macroeconomics; see, for example, Pesaran *et al*. (2009).

[11] Other studies in which moving inflation targets are described as random walks include Cogley and Sbordone (2008) and Tetlow (2008).

[12] See Orphanides and Williams (2004) for details. If private agents were aware that the central bank conducted monetary policy strictly according to constant inflation target, the ensuing lack of time variation in the structure of the economy would mean that CGLS is not the optimal learning method for private agents. A method which uses all available information – such as OLS on an expanding sample – should be preferred. However, we model learning as CGLS in both cases, partly for consistency in our assumption about imperfect knowledge across target types and partly because agents may prefer CGLS out of more general concern for structural change in the economy. Evidence of changing inflation dynamics if plentiful in the literature; see, for example, Cogley and Sargent (2005), Beechey and Österholm (2012) and Akram and Mumtaz (2017).

Equation (5) is estimated using CGLS. The parameters are hence updated according to equations (6) and (7) below

$$\hat{c}_t = \hat{c}_{t-1} + \kappa R_t^{-1} X_t (\pi_t - X_t' \hat{c}_{t-1}) \qquad (6)$$

$$R_t = R_{t-1} + \kappa (X_t X_t' - R_{t-1}) \qquad (7)$$

where κ is the gain and $X_t = (1, \pi_{t-1})'$. The forecast is given by

$$\pi_{t+1|t}^e = \hat{c}_{0,t} + \hat{c}_{1,t} \pi_t \qquad (8)$$

Having given the basic structure of the model, we next turn to the specific calibrations used.

4. Simulations and results

We begin with a benchmark simulation to illustrate some key differences between a point and band target. We then investigate the sensitivity of our results by varying key parameters in the model: The width of the target interval, the central banks reaction function, the correlation between supply shocks and the time-varying inflation target, as well as parameters describing the forward-lookingness and slope of the modified Lucas supply function. Lastly we compare with a scenario in which the point target is fully credible which simplifies agents' learning.

In all cases, we simulate the economy for 1 000 000 periods and throw away the first 500 000 observations so that initial conditions shall not have meaningful impact on our results. Each period can be envisioned as a quarter. We use five different values of the gain, namely $\kappa = (0.01 \quad 0.025 \quad 0.05 \quad 0.075 \quad 0.10)$, where a higher value indicates that agents discount old data more quickly and place greater emphasis on newer observations. These values are in line with those typically used in the theoretical literature and are also empirically relevant.[13]

[13] See, for example, Orphanides and Williams (2004), Branch and Evans (2006), Dale *et al*. (2011) and Antipin *et al*. (2014).

4.1 Benchmark simulations

We simulate the economy under two cases: *i)* a point target and *ii)* a band from within which the central bank selects its desired target. In neither case is the target credible – that is, economic agents make their inflation forecasts by learning about the inflation-generating process purely from inflation outcomes. Concerning the parameterisation of the models, we largely follow Dale *et al*. (2011) and set the parameters of the modified Lucas supply function to $\phi = 0.5$, $\alpha = 0.5$ and $\sigma_e^2 = 1$.[14] The responsiveness of the central bank is set to $\theta = 0.6$.[15] When employing a point target, we set $\bar{\pi}^* = 2$. The band target is set as two percentage points wide, centred on two percent, that is, we choose $\pi_{lower}^* = 1$ and $\pi_{upper}^* = 3$. We set the variance of the disturbance governing the inflation target to $\sigma_v^2 = 0.25$. Finally, we set $\rho = corr(e_t, v_t) = 0.5$ so that positive shocks to the Lucas supply function are associated with an increase in the inflation target. This incorporates the notion that the central bank strategically adjusts targeted inflation in the same direction as supply shocks.

The results from these benchmark simulations are given in Table 1 and Figure 1.[16] Several results are worth noting here. First, both inflation variance and output gap variance increase monotonically with respect to the learning gain, that is, as older outcomes are discounted more rapidly. This is the case regardless of whether the central bank operates a point or a band target, but the deterioration in inflation variance is more pronounced under a band target. Second, for all gains, the variance of the output gap is lower and the variance of inflation higher under a band target.

Table 1 also reports weighted losses for a range of preferences for inflation stabilization. When $\omega = 0.5$, which we denote as "balanced preferences", losses are smaller with a point target for all gains. Likewise, with "hawkish" preferences – that is, when ω is high – inflation volatility is penalised heavily and losses are lower under a point target for all gains.

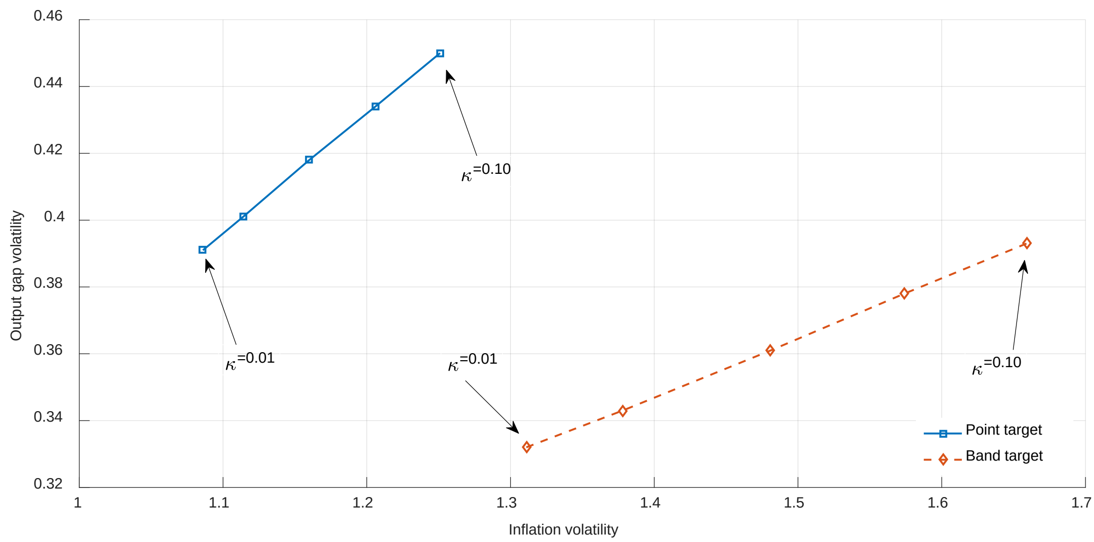
[14] As noted by Dale *et al*. (2011), these numbers are similar to Orphanides and Williams' (2007) estimates based on quarterly US data.
[15] Under full information and rational expectations, the central bank can set θ as to minimise the loss function. However, we prefer to choose a value of θ and view this as the central bank following a simple monetary policy rule which has not been optimised. A value of 0.6 would be close to optimal though under full information and rational expectations given the other parameters values just presented, a loss function as in equation (3) with $\omega = 0.5$ and a fixed inflation target; see, for example, Orphanides and Williams (2004).
[16] In order to give the reader an idea about the dynamics of the inflation target under the assumption of a band target, Figure A1 in Appendix A shows 50 observations of how inflation and the inflation target evolves in a simulation with this calibration of the model.

Table 1. Variances and losses under benchmark simulations.

	Gain				
	0.01	0.025	0.05	0.075	0.10
Point target					
Inflation variance	1.086	1.114	1.160	1.206	1.251
Output gap variance	0.391	0.401	0.418	0.434	0.450
Loss ($\omega = 0.1$)	0.461	0.472	0.492	0.511	0.530
Loss ($\omega = 0.5$)	0.739	0.758	0.789	0.820	0.850
Loss ($\omega = 0.9$)	1.017	1.043	1.086	1.129	1.171
Inflation expectation variance	0.089	0.145	0.240	0.334	0.426
Band target					
Inflation variance	1.311	1.378	1.481	1.574	1.659
Output gap variance	0.332	0.343	0.361	0.378	0.393
Loss ($\omega = 0.1$)	0.430	0.447	0.473	0.498	0.520
Loss ($\omega = 0.5$)	0.821	0.860	0.921	0.976	1.026
Loss ($\omega = 0.9$)	1.213	1.275	1.369	1.454	1.532
Inflation expectation variance	0.248	0.360	0.535	0.696	0.842

Note: Parameterization of the models is given by ϕ = 0.5, α = 0.5, $\sigma_e^2 = 1$, θ = 0.6, $\bar{\pi}^* = 2$, $\pi^*_{lower} = 1$, $\pi^*_{upper} = 3$, $\sigma_v^2 = 0.25$ and $\rho = corr(e_t, v_t) = 0.5$.

Figure 1. Variances under benchmark simulations.



Note: Parameterization of the models is given by ϕ = 0.5, α = 0.5, $\sigma_e^2 = 1$, θ = 0.6, $\bar{\pi}^* = 2$, $\pi^*_{lower} = 1$, $\pi^*_{upper} = 3$, $\sigma_v^2 = 0.25$ and $\rho = corr(e_t, v_t) = 0.5$.

With “dovish” preferences – that is, when ω is low – output volatility is penalised heavily in the loss function whereas inflation volatility is better tolerated. As such, when ω = 0.1 the central bank’s overall loss is lower when operating a band target. When accommodating positive supply shocks in the inflation target, inflation volatility is high but is tolerated when the central bank has a relatively stronger preference for output gap stability.

The variance of inflation expectations – also shown in Table 1 – captures an important channel through which our results emerge. Inflation expectations are much more volatile when the central bank varies its current goal setting within a band target. For example, when $\kappa = 0.05$, the variance of inflation expectations under a band target is more than twice that as with a point target (0.240 under the point target and 0.535 under the band target). The de-anchoring of inflation expectations associated with the flexibility offered by a band target is accordingly costly.

In summary, it takes a high preference for output stability for a band target to be preferred by the central bank. In the next sections, we explore how the central bank’s behaviour and the parameterisation of the economy modify the results.

4.2 Varying the parameters of the model

The results of our benchmark simulations were contingent upon a single parameterisation of the economy, which allowed us to illustrate how central bank preferences over inflation-output stabilisation affect the point-versus-band target choice.

In the following sub-sections, we nuance our assessment by considering a span of central bank choices – the width of the target band, the reaction function, the degree of correlation between innovations – as well as the parameterisation of the economy, in particular the forward-lookingness of the supply function and elasticity of inflation to the output gap.

Lastly, we consider a regime in which the point target is credible and private agents’ long-run inflation expectations are fully anchored to the point target. In this setting they condition the target fully into their learning model but continue to learn about dynamics. By way of preview, the inflation-stabilisation rewards of a credible point inflation target are sufficiently strong that only extreme preferences for output-gap stability would induce the central bank to prefer a band target over a point target; for some calibrations, the point target generates better outcomes regardless of the preferences of the central bank.

4.2.1 VARYING THE WIDTH OF THE TARGET BAND

In practice, those central banks who have chosen to operate band targets have band widths of 1 or 2 percentage points. In our benchmark simulation we assumed that $\pi^*_{lower} = 1$ and $\pi^*_{upper} = 3$. In this section we allow the band to be as narrow as 0.6 percentage points and as wide as 6 percentage points, all the while centred on 2 percent. The other parameters of the model are set to the same values as for the benchmark simulations in Section 4.1, that is, $\phi = 0.5$, $\alpha = 0.5$, $\sigma_e^2 = 1$, $\theta = 0.6$, $\sigma_v^2 = 0.25$ and $\rho = corr(e_t, v_t) = 0.5$. The results are shown in Table 2 in Appendix B. The row entitled "Band target, [1.0, 3.0]" corresponds with the results shown for the band target in Table 1.

From Table 2 it can be seen that inflation variance is monotonically increasing with the width of the band and that all bands attract higher inflation variance than the point target. In contrast, the variance of the output gap with respect to the width of the band is u-shaped, with a width of one percentage point associated with the lowest output gap variance for all but the highest gain. For a band narrower than one percentage point, output gap variance rises and inflation variance declines, resembling the result under the point target. Moving in the other direction and making the band wider, the variance of both inflation and the output gap rise. Note that for extremely wide band target [-1.0, 5.0], output gap variance plateaus off when learning is rapid – that is, κ is large – but at the cost of substantially larger inflation variance.

While some bands reduce the degree of output gap volatility, the reduction is modest and needs to be weighed against the larger inflation volatility associated with a band. With balanced central bank preferences ($\omega = 0.5$), a point target typically delivers smaller losses than any of the bands presented. Exceptions can, however, be found; for the narrowest band target, [1.7, 2.3], the two smallest gains (slow discounting) are associated with a lower weighted loss under a band target than under a point target. Overall though, the conclusion from the benchmark simulation still stands: It takes a strong preference for output stability for a band target be the preferred choice.

4.2.2 VARYING THE STRENGTH OF CENTRAL BANK REACTION FUNCTION

In our benchmark simulation we assumed that the strength of the central bank's reaction to inflation deviations from target in equation (2) was $\theta = 0.6$. This parameterisation is close to optimal given the other benchmark parameters and a full-information, rational-expectations environment and a point inflation target. Needless to say, our model is far from that environment so we consider different reaction strengths. We consider $\theta = [0.2, 0.4, 0.6, 0.8, 1.0]$ where a larger value of θ means that the central bank reacts more aggressively to the deviation of inflation from target.

In a setting with full information, rational expectations and a point inflation target, optimal policy for a central bank with a stronger preference for inflation stability – that is, a larger ω – would correspond to a larger value of θ. However, we do not make this direct connection in this paper. As discussed in Section 4.1, we treat θ as separate from the loss function and rather as an *ad hoc* policy rule. For this exercise, the other parameters of the model are set to the same values as in the benchmark analysis in Section 4.1, that is, $\phi = 0.5$, $\alpha = 0.5$, $\sigma_e^2 = 1$, $\bar{\pi}^* = 2$, $\pi^*_{lower} = 1$, $\pi^*_{upper} = 3$, $\sigma_\nu^2 = 0.25$ and $\rho = corr(e_t, \nu_t) = 0.5$.

We present the results for the four additional values of θ in Table 3 in Appendix B. The rows in which $\theta = 0.6$ coincide with the benchmark results shown in Table 1. Intuitively, the variance of inflation is monotonically decreasing, and the variance of the output gap monotonically increasing, as θ increases. Moreover, inflation variance is lower under a point target than a band target, regardless of the value of θ and for all learning speeds; the opposite is true of output gap variance. In this situation – where the variance of one variable improves at the cost of deterioration in the other – the inflation-output stabilization preferences of the central bank matter for the choice of target. Echoing the benchmark results, only very strong preferences for output stability would lead the central bank to conclude that a band target is better.

4.2.3 VARYING THE CORRELATION BETWEEN THE ERROR TERMS

Our experiments so far have assumed that when operating a band target, the central bank systematically – and perhaps opportunistically – varies the current inflation target in the same direction as shocks to the supply curve. In this section we continue to explore positive correlations but from weak to strong, $\rho = corr(e_t, \nu_t) = [0.1, 0.3, 0.5, 0.7, 0.9]$. As the correlation between the error terms increases, the central bank accommodates supply shocks to a greater extent in the target, The other parameters of the model are set to the same values as in the benchmark simulations in Section 3.1, that is, $\phi = 0.5$, $\alpha = 0.5$, $\sigma_e^2 = 1$, $\theta = 0.6$, $\pi_{lower}^* = 1$, $\pi_{upper}^* = 3$ and $\sigma_v^2 = 0.25$.

Table 4 in Appendix B summarises the results and shows the benchmark result for the point target for reference. Looking at the band target results, we see the intuitive result that as the correlation between the two error terms increases, inflation variance increases and output gap variance decreases. For low values of the correlation – when variation in the target is essentially only adding noise – the band target generates unambiguously worse variances for inflation and output gap than the point target. Only when the correlation is sufficiently large, $\rho \geq 0.5$, is output gap variance sufficiently moderate that it becomes ambiguous which target type is the best. As has been the case above though, it takes a high preference for output stability to prefer a band target.

That the band target is unambiguously worse for low values of the correlation is intuitive. Moving the current inflation target stochastically within the band adds noise to the economy and distracts agents from learning about inflation dynamics and the target. First when the inflation target is adjusted more systematically in response to other drivers of inflation in the economy (in this case the shock to the modified Lucas supply function) does the central bank exploit the inflation-output gap trade-off and earn some returns in terms of output stability. The cost is more volatile inflation expectations.

4.2.4 VARYING THE PARAMETERS OF THE SUPPLY FUNCTION

The structure of the economy – and specifically the dynamics of inflation determination – also play a role in the interaction between learning, inflation and target formulation. In all simulations presented so far, the parameters of the modified Lucas supply function have been set to $\phi = 0.5$ and $\alpha = 0.5$. Here we consider parameterisations of the economy with more forward-looking determination of inflation and less sensitivity of inflation to the output gap. We follow Orphanides and Williams (2004) and consider two specific cases: *i)* $\phi = 0.75$ and $\alpha = 0.25$ and *ii)* $\phi = 0.9$ and $\alpha = 0.1$.

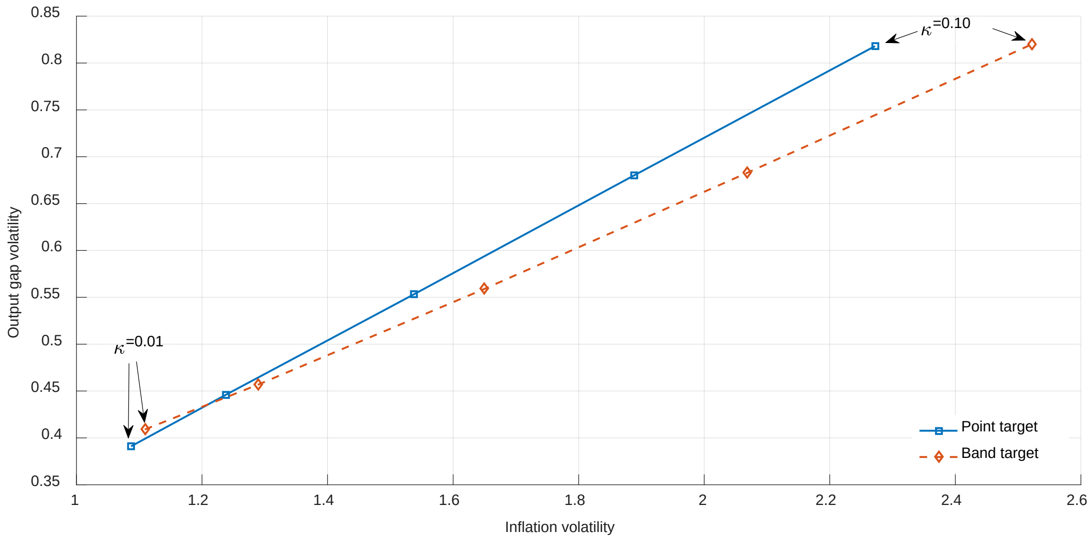
The other parameters are the same as in the benchmark simulation of Section 3.1, that is, $\sigma_e^2 = 1$, $\theta = 0.6$, $\bar{\pi}^* = 2$, $\pi_{lower}^* = 1$, $\pi_{upper}^* = 3$ and $\sigma_v^2 = 0.25$ and $\rho = corr(e_t, v_t) = 0.5$. Results are presented in Table 5 in Appendix B.

Overall, the results under more forward-looking specifications of the modified Lucas supply function are reasonable and fairly intuitive: when inflation is more forward looking and less responsive to the output gap, the inflation-anchoring benefits of a point target become stronger.

For the parameterisation $\phi = 0.75$ and $\alpha = 0.25$, a band target becomes less attractive and the output-stabilisation preferences of a central bank need to be very strong to achieve a lower level of losses with a band target than a point target. Specifically, for a gain of $\kappa = 0.05$, the weight on the variance of inflation now needs to be 0.12 (compared to 0.14 in the benchmark case).

When $\phi = 0.9$ and $\alpha = 0.1$, a point target is unambiguously better than a band target. Regardless of the gain, both the variance of inflation and the variance of the output gap are lower for a point target than a band target. This is illustrated in Figure 2. For any speed of learning, the variances with a point target are closer to the origin than those of the band target. When the Phillips curve is highly forward looking and flat, no conceivable central bank preferences over output and inflation stabilisation would motivate the choice of a band target, even when the target can accommodate supply shocks.

Figure 2. Variances when the parameters of the supply function are ϕ=0.9 and α=0.1.



Note: Parameterization of the model is given by ϕ = 0.75, α = 0.25, $\sigma_e^2 = 1$, θ = 0.6, $\bar{\pi}^* = 2$, $\pi^*_{lower} = 0$, $\pi^*_{upper} = 4$, $\sigma_v^2 = 0.25$ and $\rho = corr(e_t, v_t) = 0.5$.

4.3 Credibility: When a point target becomes potent

In the analysis conducted so far in this paper, the private sector has formed its inflation expectations by observing inflation outcomes and estimating an autoregressive econometric model, discounting older observations. They have done so regardless of which type of target the central bank operates. Learning from inflation outcomes rather than incorporating the target may be rational when agents doubt the central bank's commitment or ability to bring inflation to goal, or when the target is communicated diffusely.[17]

In this final sensitivity analysis, we follow Orphanides and Williams (2004) and Dale *et al*. (2011) and consider a regime in which the point target is sufficiently credible that private agents condition it fully into their learning model. The inflation target then becomes the focal point for agents' long-run inflation expectations.

We incorporate this feature into the model by modifying the private sector's AR(1) model, specifying it in terms of deviations from the mean of the process and conditioning

[17] Announcing an inflation target is no guarantee that private agents will align their long-run inflation expectations with the target. For example, long-run inflation expectations in Sweden did not approach the Riksbank's inflation target until 1998 even though the inflation targeting regime was announced in 1993. And during the more recent period in which inflation outcomes were persistently below target for several years, long-run inflation expectations in Sweden dipped below the central bank's target. The ECB:s target formulation "*… aims to maintain inflation rates below, but close to, 2% over the medium term*" is sufficiently ambiguous that some private-sector agents may want to estimate the unconditional mean of the inflation process rather than impose a certain value.

the mean as the point inflation target. As such, the level to which inflation forecasts converge in the long-run is the point inflation target. Specifically, we write the AR(1) model as

$$\pi_t - \bar{\pi}^* = c_{1,t}(\pi_{t-1} - \bar{\pi}^*) + \psi_t \tag{9}$$

where $\bar{\pi}^*$, as stated above, is the fixed inflation target. The parameters are updated according to equations (10) and (11) below.

$$\hat{c}_t = \hat{c}_{t-1} + \kappa R_t^{-1} X_t((\pi_t - \bar{\pi}^*) - X_t' \hat{c}_{t-1}) \tag{10}$$

$$R_t = R_{t-1} + \kappa(X_t X_t' - R_{t-1}) \tag{11}$$

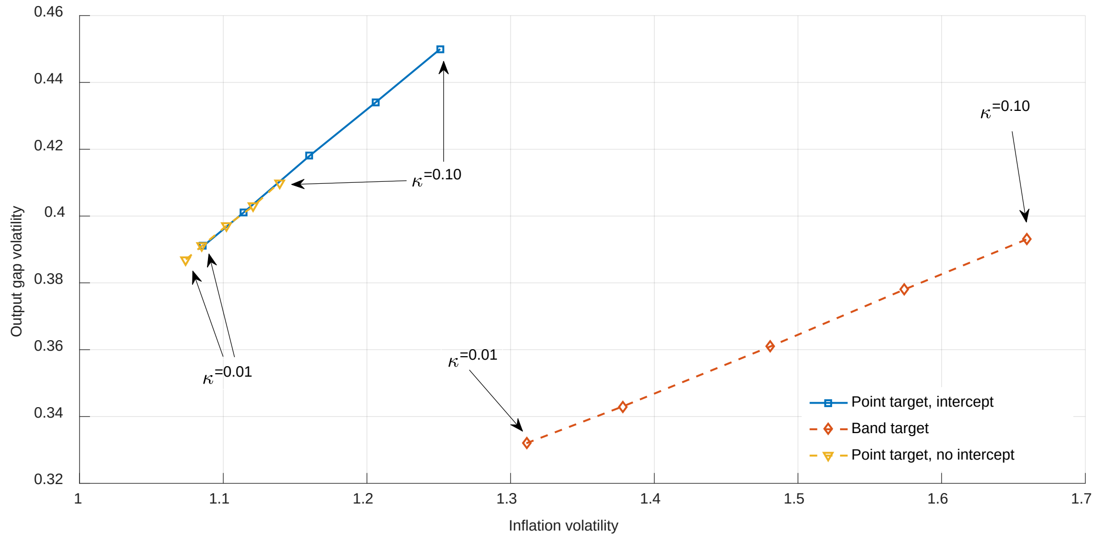
where κ, as before, is the gain and $X_t = \pi_{t-1} - \bar{\pi}^*$. Given the model in equation (9), the inflation forecasts are simply given as

$$\pi_{t+1|t}^e = \left(1 - \hat{c}_{1,t}\right)\bar{\pi}^* + \hat{c}_{1,t}\pi_t \tag{12}$$

Simulating the model under the assumption that the private sector forecasts are generated according to equation (12), we can assess the effect of this improved credibility. Tables 6 and 7 in Appendix B contain the results, including the sensitivity exercises for responsiveness of the reaction function to inflation deviations and the forward-lookingness of the supply function. The results which correspond to the benchmark simulation are “Point target, $\theta = 0.6$” in Table 6 and “Point target, $\phi = 0.5$, $\alpha = 0.5$” in Table 7. Figure 3 shows the results, alongside the benchmark simulations of Figure 2.

From Figure 3 we see that the inflation-output gap stabilisation trade-off improves when private agents incorporate the point target into their forecasting (yellow triangles) rather than learn about the intercept and dynamics of the inflation process (blue squares). The improvement is most noticeable for high gains. The results in Tables 6 and 7 confirm the improved variance trade-off in all calibrations of the model when private sector inflation expectations are formed from the AR(1) model without an intercept. This exercise illustrates the benefits of a clear and transparent point inflation target which is perceived as credible by society.

Figure 3. Variances with and without intercept in CGLS estimation under point target.



Note: Parameterization of the models is given by ϕ = 0.5, α = 0.5, $\sigma_e^2 = 1$, θ = 0.6, $\bar{\pi}^* = 2$, $\pi^*_{lower} = 0$, $\pi^*_{upper} = 4$, $\sigma_v^2 = 0.25$ and $\rho = corr(e_t, v_t) = 0.5$.

The band target (red diamonds) is associated with substantially greater inflation variance but lower output gap variance than a point target. But the improved variance trade-off that stems from a credible point target increases the span of parameterisations in which a point target is strictly preferred over a band target. We give some examples below:

- Wider band targets offer a strictly poorer trade-off between output and inflation variance, for all conceivable values of ω, than a credible point target. In the full AR(1) learning model, target bands as wide as four percentage points – while associated with very high levels of inflation variance – could still be preferred for extremely high preferences for output stability. Compared with a credible point target, only bandwidths of up to two percentage points remain in the zone of ambiguity.
- When the central bank reacts weakly to inflation deviations (θ is small), a credible inflation target has clearer advantages; for some gains a point target is now strictly preferred. When not credible, a point target always had ambiguous benefits over a band target, depending on the stabilization preferences of the central bank.
- Likewise, as the supply function becomes more forward looking and less sensitive to the output gap, the relative attractiveness of a band target diminishes. The band

target's benefits of lowering output gap variance are superceded by outcomes under the credible inflation target. Only for the marginal case of very slow discounting (gain of $\kappa = 0.01$) when $\phi = 0.75$ and $\alpha = 0.25$ does a two percentage point wide band target deliver output gap variance lower than that of the credible point target.

- As an exception, the de-meaned and anchored AR(1) yields similar conclusions to the full AR(1) learning model when considering correlations between innovations to the inflation target and the supply function. Namely, a point target is strictly preferred over a band target for $corr(e_t, \nu_t) = 0.1$ and 0.3 but not for larger values.

In summary, the stabilisation rewards of a credible point inflation target are such that only very strong preferences for output stabilisation can make a band target the preferred choice over a point target.

5. Conclusions

In this paper we have studied the relative merits of point and band targets of inflation from the perspective of a central bank concerned with inflation and output volatility. The key contribution of our paper is to introduce and explicitly model imperfect knowledge and learning about the inflation target and inflation process, a real-world challenge for monetary policy.

Our key finding is that for many parameterizations of the economy, the preferred target type rests on the inflation-output stabilization preferences of the central bank. For balanced and "hawkish" preferences, a point target tends to be preferred to a band target. Only central banks with a very high preference for output stability would at a more general level find a band target more attractive than a point target. The decrease in output volatility that a band target can provide is more than offset by the increase in inflation volatility, primarily through greater variance of inflation expectations. This rhymes well with Mishkin's (2008) line of reasoning where he made the case for a point target "… *expressing an inflation objective in terms of a range makes it more difficult for a central bank to anchor inflation expectations, especially in the absence of any explicit emphasis on the midpoint.*"

Regarding the ongoing debate about whether the side effects of loose monetary policy can be mitigated by switching from point targets to band targets, our findings indicate that a central bank with a highly credible point target is likely to experience a non-negligible cost in terms of more volatile inflation if the point target is replaced with a band target. Whether this is a price worth paying will in practice depend on factors outside the modelling framework employed here. These considerations are also valuable for prospective inflation targeters considering their choices. Understanding the pros, cons and mechanisms of different target formulations and communication is valuable when deciding which target type to adopt and how to communicate it.

In the paper, a band is assumed to confer no additional benefit in and of itself other than allowing the central bank to adjust its target. It is possible, that a band target might foster credibility for the central bank's inflation-targeting policy strategy because inflation outcomes will tend to fall within the band target. Alternatively, it might weaken credibility for the monetary policy strategy, as misses, while relatively few, could be perceived as more serious. This type of credibility issue is not addressed in the model but adds an extra layer of consideration in the choice of target type.[18]

Accountability and evaluation considerations also play a role in choice of target. Different countries have devised different accountability mechanisms, such as regular reviews of inflation performance or the obligation to explain particularly large deviations to parliament. The specificity of a point target lends sharpness to the accountability and evaluation of the central bank in a way that a band target, particularly a wide one, does not. However, a point target can also invite an overly narrow evaluation of inflation performance. In the choice between point targets versus narrow bands, the central bank and its principal need to consider carefully their relative merits in holding the central bank transparent and accountable.[19] The target type which is socially optimal may not necessarily be the target type against which the central bank prefers to be evaluated.

[18] In addition, it has been pointed out by Lengwiler and Orphanides (2002) that with greater central bank credibility, there might be increased scope for discretion in policy.

[19] For a discussion concerning central bank communication, transparency and accountability, see Dincer and Eichengreen (2014).

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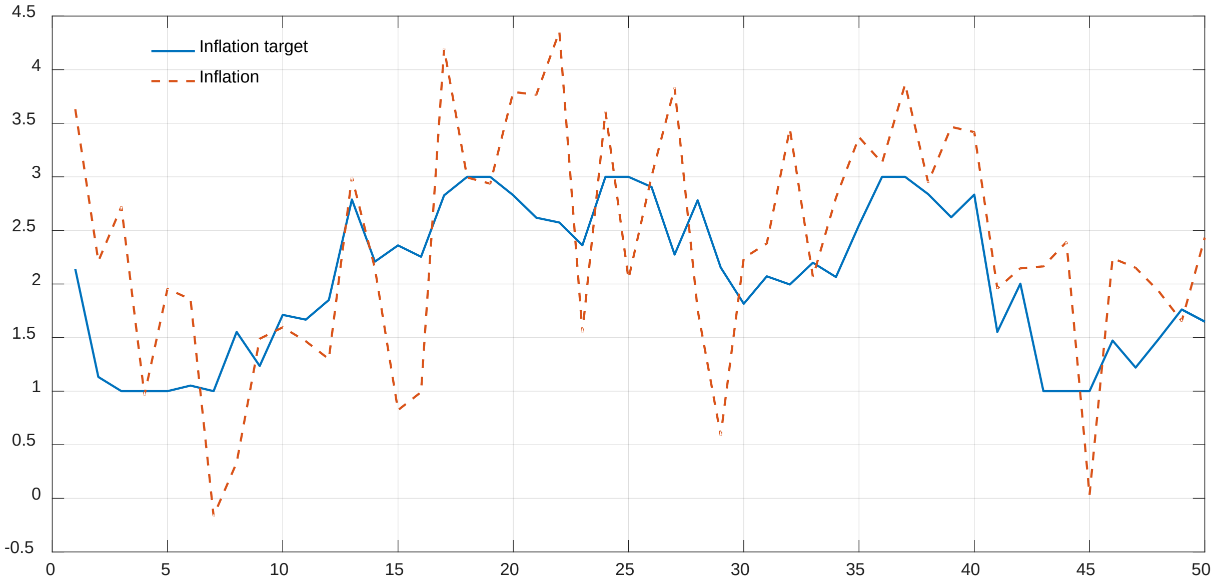
Appendix A

Figure A1. Evolution of inflation and the inflation target in a part of a standard simulation with a band target.



Note: Percent on the vertical axis. Parameterization of the model is given by ϕ = 0.5, α = 0.5, $\sigma_e^2 = 1$, θ = 0.6, $\pi^*_{lower} = 1$, $\pi^*_{upper} = 3$, $\sigma_v^2 = 0.25$ and $\rho = corr(e_t, v_t) = 0.5$.

Appendix B: Tables

Table 2. Variances when varying the width of the band target.

	Gain				
	0.01	0.025	0.05	0.075	0.10
Point target					
Inflation variance	1.086	1.114	1.160	1.206	1.251
Output gap variance	0.391	0.401	0.418	0.434	0.450
Band target, [1.7, 2,3]					
Inflation variance	1.128	1.162	1.216	1.269	1.321
Output gap variance	0.341	0.352	0.371	0.389	0.406
Band target, [1.5, 2,5]					
Inflation variance	1.168	1.207	1.271	1.332	1.390
Output gap variance	0.328	0.340	0.359	0.377	0.395
Band target, [1.0, 3.0]					
Inflation variance	1.311	1.378	1.481	1.574	1.659
Output gap variance	0.332	0.343	0.361	0.378	0.393
Band target, [0.0, 4.0]					
Inflation variance	1.949	2.143	2.392	2.580	2.727
Output gap variance	0.393	0.397	0.403	0.410	0.417
Band target, [-1.0, 5.0]					
Inflation variance	3.390	3.753	4.137	4.384	4.562
Output gap variance	0.446	0.442	0.435	0.432	0.432

Note: Parameterization of the models is given by $\phi = 0.5$, $\alpha = 0.5$, $\sigma_e^2 = 1$, $\theta = 0.6$, $\bar{\pi}^* = 2$, $\sigma_v^2 = 0.25$ and $\rho = corr(e_t, v_t) = 0.5$.

Table 3. Variances when varying the central bank reaction function.

	Gain				
	0.01	0.025	0.05	0.075	0.10
Point target, θ=0.2					
Inflation variance	1.701	1.927	2.265	2.557	2.809
Output gap variance	0.068	0.077	0.091	0.102	0.112
Point target, θ=0.4					
Inflation variance	1.238	1.303	1.407	1.505	1.597
Output gap variance	0.198	0.208	0.225	0.241	0.256
Point target, θ=0.6					
Inflation variance	1.086	1.114	1.160	1.206	1.251
Output gap variance	0.391	0.401	0.418	0.434	0.450
Point target, θ=0.8					
Inflation variance	1.025	1.038	1.061	1.084	1.107
Output gap variance	0.656	0.664	0.679	0.694	0.708
Point target, θ=1.0					
Inflation variance	1.006	1.012	1.022	1.033	1.044
Output gap variance	1.006	1.012	1.022	1.033	1.044
Band target, θ=0.2					
Inflation variance	1.998	2.296	2.722	3.076	3.376
Output gap variance	0.060	0.070	0.085	0.097	0.107
Band target, θ=0.4					
Inflation variance	1.488	1.601	1.772	1.925	2.062
Output gap variance	0.170	0.182	0.200	0.216	0.231
Band target, θ=0.6					
Inflation variance	1.311	1.378	1.481	1.574	1.659
Output gap variance	0.332	0.343	0.361	0.378	0.393
Band target, θ=0.8					
Inflation variance	1.231	1.278	1.351	1.417	1.477
Output gap variance	0.552	0.561	0.575	0.590	0.604
Band target, θ=1.0					
Inflation variance	1.197	1.233	1.289	1.340	1.386
Output gap variance	0.841	0.846	0.856	0.866	0.876

Note: Parameterization of the models is given by ϕ = 0.5, α = 0.5, $\sigma_e^2 = 1$, $\bar{\pi}^* = 2$, $\pi_{lower}^* = 1$, $\pi_{upper}^* = 3$, $\sigma_v^2 = 0.25$ and $\rho = corr(e_t, v_t) = 0.5$.

Table 4. Variances when varying the correlation between the error terms.

	Gain				
	0.01	0.025	0.05	0.075	0.10
Point target					
Inflation variance	1.086	1.114	1.160	1.206	1.251
Output gap variance	0.391	0.401	0.418	0.434	0.450
Band target, ρ=0.1					
Inflation variance	1.218	1.267	1.346	1.419	1.486
Output gap variance	0.455	0.465	0.482	0.499	0.515
Band target ρ=0.3					
Inflation variance	1.262	1.320	1.411	1.495	1.571
Output gap variance	0.393	0.404	0.422	0.439	0.455
Band target, ρ=0.5					
Inflation variance	1.311	1.378	1.481	1.574	1.659
Output gap variance	0.332	0.343	0.361	0.378	0.393
Band target, ρ=0.7					
Inflation variance	1.364	1.439	1.553	1.656	1.748
Output gap variance	0.270	0.282	0.300	0.317	0.332
Band target, ρ=0.9					
Inflation variance	1.422	1.504	1.628	1.740	1.840
Output gap variance	0.208	0.220	0.239	0.256	0.271

Note: Parameterization of the models is given by α = 0.5, = ϕ = 0.5, $\sigma_e^2 = 1$, θ = 0.6, $\bar{\pi}^* = 2$, $\pi_{lower}^* = 1$, $\pi_{upper}^* = 3$ and $\sigma_v^2 = 0.25$.

Table 5. Variances when varying the parameters of the modified Lucas supply function.

					Gain
	0.01	**0.025**	**0.05**	**0.075**	**0.10**
Point target, ϕ=0.5, α=0.5					
Inflation variance	1.086	1.114	1.160	1.206	1.251
Output gap variance	0.391	0.401	0.418	0.434	0.450
Point target, ϕ=0.75, α=0.25					
Inflation variance	1.058	1.120	1.234	1.357	1.484
Output gap variance	0.381	0.403	0.444	0.488	0.534
Point target, ϕ=0.9, α=0.1					
Inflation variance	1.087	1.238	1.537	1.888	2.272
Output gap variance	0.391	0.446	0.553	0.680	0.818
Band target, ϕ=0.5, α=0.5					
Inflation variance	1.311	1.378	1.481	1.574	1.659
Output gap variance	0.332	0.343	0.361	0.378	0.393
Band target, ϕ=0.75, α=0.25					
Inflation variance	1.123	1.225	1.405	1.594	1.783
Output gap variance	0.362	0.381	0.420	0.462	0.506
Band target, ϕ=0.9, α=0.1					
Inflation variance	1.109	1.290	1.650	2.069	2.522
Output gap variance	0.409	0.457	0.559	0.683	0.820

Note: Parameterization of the models is given by $\sigma_e^2 = 1$, θ = 0.6, $\bar{\pi}^* = 2$, $\pi^*_{lower} = 1$, $\pi^*_{upper} = 3$, $\sigma_v^2 = 0.25$ and $\rho = corr(e_t, v_t) = 0.5$.

Table 6. Variances under fully credible point target – varying the responsiveness of the central bank.

	Gain				
	0.01	0.025	0.05	0.075	0.10
Point target, θ=0.2					
Inflation variance	1.605	1.696	1.846	1.987	2.117
Output gap variance	0.064	0.068	0.074	0.079	0.085
Point target, θ=0.4					
Inflation variance	1.211	1.235	1.277	1.318	1.359
Output gap variance	0.194	0.198	0.204	0.211	0.217
Point target, θ=0.6					
Inflation variance	1.074	1.085	1.102	1.121	1.139
Output gap variance	0.387	0.391	0.397	0.403	0.410
Point target, θ=0.8					
Inflation variance	1.019	1.024	1.032	1.041	1.050
Output gap variance	0.652	0.655	0.661	0.666	0.672
Point target, θ=1.0					
Inflation variance	1.004	1.006	1.009	1.013	1.018
Output gap variance	1.004	1.006	1.009	1.013	1.018

Note: Parameterization of the model is given by ϕ = 0.5, α = 0.5, $\bar{\pi}^* = 2$ and $\sigma_v^2 = 0$.

Table 7. Variances under fully credible point target – varying the parameters of the modified Lucas supply function.

	Gain				
	0.01	0.025	0.05	0.075	0.10
Point target, ϕ=0.5, α=0.5					
Inflation variance	1.074	1.085	1.102	1.121	1.139
Output gap variance	0.387	0.391	0.397	0.403	0.410
Point target, ϕ=0.75, α=0.25					
Inflation variance	1.028	1.040	1.066	1.098	1.134
Output gap variance	0.370	0.375	0.384	0.395	0.408
Point target, ϕ=0.9, α=0.1					
Inflation variance	1.011	1.023	1.050	1.092	1.152
Output gap variance	0.364	0.368	0.378	0.393	0.415

Note: Parameterization of the model is given by $\sigma_e^2 = 1$, θ = 0.6, $\bar{\pi}^* = 2$ and $\sigma_v^2 = 0$.