Learning and the Welfare Implications of Changing Inflation Targets

Kevin Moran

Introduction

A number of central banks throughout the world now follow inflation-targeting policies. Overall, these policies have been accompanied by good economic outcomes, and inflation targeting is generally deemed to be a success.[1]

Good governance dictates, however, that even successful policies ought to be revisited periodically and the pertinence of modifying them analyzed. In that context, revising the numerical target for the inflation rate is perhaps the most natural change that could be considered for an inflation-targeting policy.

This paper provides a welfare analysis of such a change. Specifically, it computes the welfare implications, for a representative agent, of lowering the monetary authority's inflation target from 2 per cent per annum to zero. The computations are performed using a standard monetary business cycle model, under two scenarios regarding the information publicly available during the transition that follows the adoption of the new target. In particular, one of these scenarios assesses how much the welfare computations are affected by assuming that economic agents do not observe the target shift directly and learn about it using Bayesian updating.

The paper's findings are as follows. When measured by comparing steady states, the welfare benefits of reducing the inflation target from 2 per cent to

1. See Ragan (this volume) for a positive assessment of the Canadian experience with inflation targeting.

zero appear to be significant. In our benchmark model, these benefits represent a utility windfall equivalent of 0.26 per cent of steady-state consumption, and up to 0.5 per cent of consumption in some of the model extensions examined. However, accounting for the transition towards the new, low-inflation steady state significantly reduces these computed welfare benefits, by at least one-half, and by up to 85 per cent. The key message of the paper is thus the following: The welfare benefits of lowering inflation from 2 per cent to zero might be very modest once the transition towards the new steady state is carefully modelled, particularly if this transition is characterized by incomplete information and Bayesian learning.

These results are arrived at by simulating a cash-in-advance, representative agent, complete markets, and monopolistic-competition economy, similar to that of Yun (1996).[2] In such an economy, sustained inflation has important allocative effects. Specifically, inflation represents a tax on the consumption of goods—more generally on participating in market activities—that are subject to the cash-in-advance constraint. Optimizing agents avoid the tax by reducing consumption of these goods. Lowering steady-state inflation reduces these distortions and has the potential to significantly increase capital formation and welfare.

Accounting for the transition towards the low-inflation steady state reduces the computed welfare benefits, for two reasons. First, the accumulation of additional capital is costly, resulting in foregone consumption or leisure along the transition paths towards the new steady state. Second, incomplete information about the shift may lead economic agents to incorrectly identify as transitory monetary tightenings the high interest rates prevailing immediately after the shift. In such a case, the initial responses of the economy to the shift, i.e., its consumption, employment, and output paths, may be different from those occurring under complete information. Eventually, as agents' learning helps ascertain the true nature of the monetary policy shift, these responses are adjusted and the early mistakes corrected. Nevertheless, these early "incorrect" responses affect the welfare computations, further reducing the welfare benefits of the new, low-inflation policy.

2. Apart from the cash-in-advance constraint, this environment is a standard representative of those in the New Keynesian literature. Other papers in this rapidly expanding literature include Ireland (1997, 2001); Dib (2003, 2006); Erceg, Henderson, and Levin (2000); Smets and Wouters (2003); Ambler, Guay, and Phaneuf (2003); and Christiano, Eichenbaum, and Evans (2005). A detailed introduction to the mechanics of this model can be found in King (2000).

Quantitative analysis of the welfare costs of inflation originates in Bailey (1956),[3] which computes the deadweight loss under an estimated money demand for different inflation rates and identifies the welfare benefits of reducing inflation by the differences of these losses for high and low inflation. In contrast, recent papers studying the costs of inflation—Cooley and Hansen (1989, 1991), Gomme (1993), Dotsey and Ireland (1996), Wu and Zhang (1998, 2000), and Andolfatto and Gomme (2003)—use a quantitative, monetary general-equilibrium model that is explicit about the effects of inflation on the economy. These authors compute the welfare benefits of lowering inflation by directly comparing the lifetime utility of the representative agent under high and low inflation.[4] They show that a general-equilibrium approach can affect the computations significantly, by identifying margins along which lower inflation affects economic decisions that are potentially missing when using the Bailey approach.[5]

This paper extends the latter studies by using a model from the New Keynesian literature, the now-standard tool of applied monetary analysis. This ensures that results arrived at in the early literature also obtain within this class of model. More importantly, the paper also contributes to the set of available results by arguing that incomplete information may impair the transition towards the new steady state, and by assessing quantitatively the welfare impact of these impairments.[6] To do so, the paper appeals to a literature that examines the business cycle effects of incomplete information about the monetary authority's actions and objectives.[7]

The rest of the paper is organized as follows. Section 1 presents the model, and the following section discusses its calibration and solution and illustrates the learning behaviour of private agents after the shift in the inflation target. Section 3 contains the welfare results for our benchmark

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3. See Fischer (1981) and Lucas (1981) for more recent quantitative estimates of the welfare benefits of low inflation using this approach.
4. The present paper does not consider the possibility that inflation affects economic agents differently. Wu and Zhang (2000) study the welfare consequence of such heterogeneous impacts.
5. Lucas (2000) shows that a correspondence can exist between the two approaches and their welfare results, provided that the general-equilibrium model is simple. Benabou (1991) identifies the presence of capital (and the fact that lower inflation encourages capital accumulation) as the key factor leading the two approaches to exhibit different results.
6. Andolfatto and Gomme (2003) also assess the importance of incomplete information when computing the welfare benefits of lower inflation. As their analysis is conducted using a different modelling technology, our results complement theirs.
7. For example, these learning effects are often used to explain the persistent responses of real variables following monetary policy shocks. See Andolfatto and Gomme (2003); Andolfatto, Hendry, and Moran (2002); Erceg and Levin (2003); and Schorfheide (2005). An earlier contribution can be found in Brunner, Cukierman, and Meltzer (1980).

model, as well as a sensitivity analysis of these results to model specification. The final section discusses the results and concludes.

1 Model

This section presents the model used to perform our welfare computations. We describe the optimization problem of households and firms, as well as the policy rule followed by the monetary authority. In addition, we describe the shift in the inflation target of monetary authorities we consider, as well as the mechanism by which private agents learn about this shift.

The model belongs to the New Keynesian class, the standard methodological tool for applied monetary analysis. Time is discrete and one model period represents one quarter. There are two sectors of production. The first sector, producing final goods, is competitive: firms take input prices as given and produce a homogeneous good that they sell at flexible prices. Final good production is divided between consumption and investment. The firms in the second sector, which produces intermediate goods, operate under monopolistic competition. Each firm produces a distinct good for which it chooses the market price. Changes to the price of these goods are restricted, following Calvo (1983), so that the prices are "sticky." Intermediate goods production requires capital and labour services, inputs for which the firms act as price-takers. Finally, the monetary authority's policy rule manages movements in the short-term nominal interest rate to respond to inflation deviations from its target and deviations of output from its trend.

1.1 Household sector

There exists a continuum of identical, infinitely lived households with preferences given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_{1t}, c_{2t}, n_t), \tag{1}$$

where c_{1t} denotes consumption of the "cash" good, c_{2t} is the consumption of the "credit" good, n_t denotes employment, and $0 < \beta < 1$ is the households' subjective discount factor.[8]

8. Lucas and Stockey (1987) analyze the existence of recursive equilibria in economies such as the one in this paper, where consumption is separated between those goods for which a cash-in-advance constraint applies (the "cash" goods) and those for which it does not (the "credit" goods).

At the start of period t, a household holds M_t dollars of financial wealth (cash). It then receives a beginning-of-period cash transfer X_t from the monetary authority. This transfer is related to the authority's management of the short-term interest rate through its policy rule (described below). The household also receives a cash payment of $R_{t-1}B_t$, where B_t denotes detention of one-period, non-contingent bonds and R_{t-1} is the (gross) interest rate on these bonds. These sources of financial income must be sufficient to cover the household's planned expenditure on the cash good c_{1t} and on purchases of new bonds B_{t+1}, i.e., assume the following cash-in-advance constraint:

$$c_{1t} + \frac{B_{t+1}}{P_t} \le \frac{M_t^c + X_t + R_{t-1}B_t}{P_t}, \tag{2}$$

where P_t is the dollar price of the cash good.

Households own the economy's capital stock k_t and rent it to intermediate-goods-producing firms at the real rental rate r_t. They also supply labour services to these firms, at nominal wage W_t. Let D_t denote nominal dividends that the household earns through ownership of intermediate-goods-producing firms and Γ_t a (fiscal) lump-sum transfer from the government. These revenues, netted of labour and capital income taxes and supplemented by any remaining cash, must be sufficient to cover the planned expenditures of the household. These are the credit-good purchases c_{2t}, investment in new capital i_t, as well as financial wealth carried through the next period (M_{t+1}). Expressed in real terms, the following budget constraint obtains:

$$\begin{aligned}\frac{M_{t+1}}{P_t} + c_{2t} + i_t &\le (1-\tau_k)r_t k_t + (1-\tau_n)\frac{W_t}{P_t}n_t + D_t + \Gamma_t \\ &\quad + \delta\tau_k k_t + \left[\frac{M_t^c + X_t + R_{t-1}B_t - B_{t+1}}{P_t} - c_{1t}\right].\end{aligned} \tag{3}$$

The rate of income tax is denoted by τ_n, whereas τ_k denotes the capital income tax.[9] The term in the square brackets will equal zero whenever the cash-in-advance constraint (2) binds.

9. Adding back $\delta\tau_k k_t$ in the budget constraint reflects the presence of depreciation allowances in tax codes.

Investment i_t increases the capital stock over time according to

$$k_{t+1} = (1-\delta)k_t + i_t + [1 - S(i_t/i_{t-1})]i_t, \tag{4}$$

where $\delta \in (0, 1)$ is the constant capital depreciation rate and $[1 - S(i_t/i_{t-1})]i_t$ summarizes the process by which current and past levels of investment increase the available stock of capital. The function S is such that $S(1) = S'(1) = 0$ and $S''(1) \equiv \kappa > 0$.[10]

The representative household chooses c_{1t}, c_{2t}, n_t, B_{t+1}, M_{t+1}, i_t, and k_{t+1} to maximize expected lifetime utility (1) subject to the cash-in-advance constraint (2), the budget constraint (3), and the capital-accumulation equation (4). The first-order conditions for this problem are as follows:

$$u_1(c_{1t}, c_{2t}, n_t) = \lambda_{1t} + \lambda_{2t}, \tag{5}$$

$$u_2(c_{1t}, c_{2t}, n_t) = \lambda_{2t}, \tag{6}$$

$$u_3(c_{1t}, c_{2t}, n_t) = (1-\tau_n)\frac{W_t}{P_t}\lambda_{2t}, \tag{7}$$

$$\lambda_{1t} + \lambda_{2t} = \beta R_t E_t\left[\frac{\lambda_{1t+1} + \lambda_{2t+1}}{\pi_{t+1}}\right], \tag{8}$$

$$\lambda_{2t} = \beta E_t\left[\frac{\lambda_{1t+1} + \lambda_{2t+1}}{\pi_{t+1}}\right], \tag{9}$$

$$\frac{\lambda_{2t}}{1 - S\left(\frac{i_t}{i_{t-1}}\right) - S'\left(\frac{i_t}{i_{t-1}}\right)\frac{i_t}{i_{t-1}}} = \beta E_t\{\lambda_{2t+1}[(1-\tau_k)r_{t+1} + \delta\tau_k + \frac{(1-\delta)}{1 - S\left(\frac{i_{t+1}}{i_t}\right) - S'\left(\frac{i_{t+1}}{i_t}\right)\frac{i_{t+1}}{i_t}}]\}. \tag{10}$$

In these first-order conditions, $\pi_t \equiv P_t/P_{t-1}$ is the gross rate of aggregate price inflation, and λ_{1t}, λ_{2t}, and μ_t are the multipliers for the constraints (2), (3), and (4), respectively.

10. Specifying that capital-adjustment costs depend on past and current levels of investment follows Christiano, Eichenbaum, and Evans (2005).

1.2 The final-good sector

The final good, Y_t, is produced by assembling a continuum of intermediate goods y_{jt}, $j \in (0, 1)$ that are imperfect substitutes with a constant elasticity of substitution θ. The production function is defined as

$$Y_t \leq \left(\int_0^1 y_{jt}^{\frac{\theta - 1}{\theta}} \mathrm{d}_j \right)^{\frac{\theta}{\theta - 1}}, \qquad \theta > 1 . \tag{11}$$

Final-good-producing firms behave competitively, maximizing profits and taking the market price of the final good P_t as well as the price of each intermediate good p_{jt}, $j \in (0, 1)$ as given. The maximization problem of a representative, final-good-producing firm is therefore

$$\max_{\{y_{jt}\}_{j=0}^1} \left[P_t Y_t - \int_0^1 p_{jt} y_{jt} \mathrm{d}_j \right],$$

subject to equation (11). The resulting input demand function for the intermediate good *j* is

$$y_{jt} = \left(\frac{p_{jt}}{P_t} \right)^{-\theta} Y_t \tag{12}$$

and represents the economy-wide demand for intermediate good *j* as a function of its relative price and of the economy's total output of final good Y_t. The competitive nature of the final-good sector and constant-returns-to-scale production implies that firms make zero profits. Imposing this zero-profit condition leads to the following description of the final-good price index P_t:

$$P_t = \left(\int_0^1 p_{jt}^{\,1 - \theta} \mathrm{d}_j \right)^{\frac{1}{1 - \theta}} . \tag{13}$$

1.3 The intermediate-goods sector

The intermediate-good-producing firm *j* uses capital and labour services k_{jt} and h_{jt} to produce y_{jt} units of its differentiated good, according to the following constant-returns-to-scale technology:

$$y_{jt} \leq k_{jt}^{\alpha} h_{jt}^{1 - \alpha}, \qquad \alpha \in (0, 1) . \tag{14}$$

Notice that as written, there is no secular growth in the model.[11]

Recall that each intermediate-good-producing firm operates under monopolistic competition with the economy-wide demand for producer *j*'s good given by equation (12). Following Calvo (1983), assume that each firm is only allowed to reoptimize its output price at specific moments. Specifically, with probability ϕ, the firm must charge the price that was in effect in the preceding period, indexed by that period's rate of aggregate price inflation; with probability $1-\phi$, the firm is free to reoptimize and fix a completely new price. This implies that on average the firm will not reoptimize for $1/(1-\phi)$ periods.[12]

At time *t*, if firm *j* receives the signal to reoptimize, it chooses a price $\tilde{p}_{jt}$, as well as contingency plans for h_{jt+k}, k_{jt+k} $(k \geq 0)$ that maximize its discounted, expected (real) profit flows for the period where it will not be able to reoptimize again. The profit-maximization problem is the following:

$$\max_{\{k_{jt}, h_{jt}, \tilde{p}_{jt}\}} E_0\left[\sum_{k=0}^{\infty}(\beta\phi)^k \lambda_{t+k} D_{jt+k}/P_{t+k}\right],$$

with D_{jt+k}/P_{t+k} the real profit flow at time $t+k$ and

$$D_{jt+k} = \left(\tilde{p}_{jt}\prod_{s=0}^{k-1}\pi_{t+s}\right)y_{jt+k} - R_{kt+k}k_{jt+k} - W_{t+k}h_{jt+k}, \tag{15}$$

where ϕ^k expresses the probability that $\tilde{p}_{jt}$ remains in effect (including indexation) at time $t+k$, and $k-1_{s=0}\phi_{t+s}$ is the cumulated indexation factor.

Profit maximization is undertaken subject to the demand for good *j* (equation 12) and to the production function (14) (with which the Lagrange multiplier $\xi_t > 0$ is associated). The first-order conditions for this problem for k_{jt}, h_{jt}, and $\tilde{p}_{jt}$ are:

$$\frac{R_{kt}}{P_t} = \alpha q_t \frac{y_{jt}}{k_{jt}}, \tag{16}$$

11. Introducing trend growth in the production function (14) and repeating our welfare computations does not modify our welfare assessment of the inflation-target shift.

12. This particular specification of the Calvo mechanism follows Christiano, Eichenbaum, and Evans (2005). Alternatively, Yun (1996) assumes that when the reoptimization signal is not received, the price is indexed to *average* inflation. Smets and Wouters (2003) propose a flexible specification that nests the two cases.

$$\frac{W_t}{P_t} = (1-\alpha)q_t\frac{y_{jt}}{k_{jt}}, \tag{17}$$

$$\tilde{p}_{jt} = \frac{\theta}{\theta-1}\frac{E_t\sum_{k=0}^{\infty}(\beta\phi)^k\left(\prod_{s=0}^{k-1}\pi_{t+s}^{-\theta}\right)\lambda_{t+k}Y_{t+k}q_{t+k}P_{t+k}^{\theta}}{E_t\sum_{k=0}^{\infty}(\beta\phi)^k\left(\prod_{s=0}^{k-1}\pi_{t+s}^{1-\theta}\right)\lambda_{t+k}Y_{t+k}P_{t+k}^{\theta-1}}, \tag{18}$$

where $q_t = \xi_t/\lambda_t$ is the real marginal cost of the firm.

The symmetry in the demand for each intermediate good implies that all firms allowed to reoptimize choose the same price $\tilde{p}_{jt}$, which we denote $\tilde{p}_t$. Considering the definition of the price index in equation (13) and the fact that at the economy's level, a fraction $1-\phi$ of intermediate-goods-producing firms reoptimizes, the aggregate price index P_t evolves according to

$$P_t^{1-\theta} = \phi\pi_{t-1}^{1-\theta}p_{t-1}^{1-\theta} + (1-\phi)(\tilde{p}_t)^{1-\theta}. \tag{19}$$

Equations (16) and (17) state that firms choose their production inputs so that their costs equal their marginal product weighted by the real marginal cost. Equation (18) relates the optimal price to the expected future price of the final good and to the expected future real marginal costs. Taking a first-order approximation of conditions (18) and (19) and combining them leads to the model's New Keynesian Phillips curve:

$$\hat{\pi}_t = \frac{\beta}{1+\beta}\hat{\pi}_{t+1} + \frac{1}{(1+\beta)}\hat{\pi}_{t-1} + \frac{(1-\theta)(1-\beta\phi)}{\phi(1+\beta)}\hat{q}_t, \tag{20}$$

which relates $(\hat{\pi}_t)$, the deviation of aggregate price inflation from its average, to (the expectation of) future and past values of itself, as well as to the present period's marginal costs $(\hat{q}_t)$, an indicator of the strength of economic activity.[13]

1.4 Fiscal policy and tax distortions

We abstract from government purchases. Therefore, all tax revenues are rebated back to households in a lump-sum fashion. This focuses the analysis on the distortionary effects of taxation, while disregarding wealth effects associated with government consumption.

13. Starting with Galí and Gertler (1999), a sizable literature has used single-equation econometric methods to estimate similar specifications of the New Keynesian Phillips curve.

The government's budget constraint is thus:

$$\Gamma_t = \tau_n \frac{W_t}{P_t} n_t + \tau_k (r_t - \delta) k_t . \tag{21}$$

Distortionary taxation on labour and capital income introduces wedges between the marginal productivity of labour and the marginal utility of leisure, first, and between the rental rate of capital and its marginal product, second. Cooley and Hansen (1991) and Benabou (1991) show that the presence of these wedges can increase the welfare costs of inflation, and thus the benefits of lowering it, even though there is no direct interaction between the inflation tax and these other forms of taxation in the model.[14]

1.5 Monetary policy

The monetary authority sets the net nominal interest rate $i_t = R_t - 1$ according to the following Taylor-type rule:

$$i_t = (1-\rho)[r^{ss} + \pi_t^T + \lambda_\pi(\pi_t - \pi_t^T) + \lambda_y \hat{y}_t] + \rho i_{t-1} + u_t , \tag{22}$$

where r^{ss} denotes the steady-state real rate of interest (on a net basis), π_t^T denotes the (net) inflation target of the monetary authority at time t, $\hat{y}_t$ is the percentage deviation of output from trend (the output gap), and u_t denotes a monetary policy shock. The parameters λ_π and λ_y describe the extent to which the desired interest rate reacts to deviations of inflation from target and non-zero values of the output gap, respectively. In addition, the parameter $0 \le \rho < 1$ indexes the degree to which the monetary authority wishes to smooth interest rate movements. As mentioned above, the monetary authority achieves any particular i_t with an appropriate lump-sum injection/withdrawal of cash X_t to the household sector.

We interpret the monetary policy shock u_t as the reaction of monetary authorities to economic factors, such as financial stability concerns, not articulated by the rule (22).[15] We view these shocks as possessing little persistence and, accordingly, we assume that their evolution follows the distribution

14. Other authors explicitly study the direct interactions between inflation and other forms of taxation that originate in the non-indexation of many tax rates. See Bullard and Russell (2004) and Gavin, Kydland, and Pakko (2005).

15. Considering that control of i_t is achieved by manipulating the aggregate money supply, these shocks could alternatively be interpreted as arising from imperfect control of the monetary authority over the growth rate of money.

$$u_t = \rho_u u_{t-1} + e_t, \tag{23}$$

with $0 \le \rho_u \ll 1$ and $e_t \sim N(0, \sigma_u)$.

1.6 Information structure and shifts in the inflation target

We consider two information structures, distinguished by whether private agents can directly observe the inflation target π_t^T. First, *complete information* means that private agents know the complete parameterization of monetary policy, i.e., the parameters of the rule (ρ, λ_π, λ_y, ρ_u, and σ_u), as well as the inflation target π_t^T. As a result, they have sufficient information to compute the correct conditional expectations of future interest rates.

Full information supposes that the monetary authority is able and willing to clearly announce its inflation target, as well as any changes to it. However, such credible communication might be difficult to achieve in practice. For example, although new heads of central banks may make known a strong aversion for inflation in public announcements, the lack of precision of these announcements may leave private agents uncertain about what they imply quantitatively for the inflation target. Agents might, as a result, modify their beliefs about the inflation target of monetary authorities only after several periods of lower inflation have been observed. Explicit announcements of changes in the inflation target might also suffer, at least initially, from similar credibility problems.

To capture the spirit of this information problem, we define *incomplete information* as meaning that private agents cannot directly observe the inflation target π_t^T and instead must learn about it indirectly from observed interest rate outcomes. However, we continue to assume that agents know the parameters of the monetary policy rule.[16]

To illustrate the signal-extraction problem this information structure creates, consider the following turn of events. Initially, the inflation target is set to π^H, a relatively high rate. Accordingly, the rule followed by the monetary authority is:

$$i_t = (1-\rho)[r^{ss} + \pi^H + \lambda_\pi(\pi_t - \pi^H) + \lambda_y \hat{y}_t] + \rho i_{t-1} + u_t. \tag{24}$$

16. One could also assume that private agents have imperfect knowledge about the coefficients of the rule (λ_π, λ_y, and ρ) and learn about possible shifts to those parameters by repeated observations of realized interest rates. Some empirical estimates of monetary policy rules (e.g., Clarida, Galí, and Gertler 2000) suggest that such parameter shifts have occurred over the past few decades.

Next, assume that at time t, the monetary authority changes its inflation target to π^L, where $\pi^L < \pi^H$. The rule is now the following:

$$i_t = (1-\rho)[r^{ss} + \pi^L + \lambda_\pi(\pi_t - \pi^L) + \lambda_y \hat{y}_t] + \rho i_{t-1} + u_t. \tag{25}$$

Rewriting equation (25) by adding and subtracting π^H two times and then rearranging, gives:

$$\begin{aligned} i_t = {} & (1-\rho)[r^{ss} + \pi^H + \lambda_\pi(\pi_t - \pi^H) + \lambda_y \hat{y}_t] + \rho i_{t-1} \\ & \underbrace{+ (1-\rho)(1-\lambda_\pi)(\pi^L - \pi^H) + u_t}_{u_t^*}. \end{aligned} \tag{26}$$

Comparing equations (24) and (26) shows that from the perspective of a private agent whose initial belief about the inflation target of the monetary authority was π^H, the observed shock to the policy rule u_t^* is a combination of the shift in the inflation target $(1-\rho)(1-\lambda_\pi)(\pi^L - \pi^H)$ and of the real monetary policy shock u_t. Recalling equation (23), u_t^* can be expressed as:

$$u_t^* = (1-\rho_u)(1-\rho)(1-\lambda_\pi)(\pi^L - \pi^H) + \rho_u u_{t-1}^* + e_t, \tag{27}$$

where $m_1 \equiv (1-\rho)(1-\lambda_\pi)(\pi^L - \pi^H)$ is the mean of u^*.

When complete information is assumed, private agents know the correct mean of u_t^* and thus the correct expectation about the path of the interest rate. By contrast, incomplete information is characterized by a situation where private agents have to learn and update their beliefs about the mean of u_t^*.

The information friction we assume is slightly different from that of Andolfatto and Gomme (2003) and Schorfheide (2005), where the unobserved inflation target has only two possible values. Such a restriction can simplify the learning problem of private agents and imply a rapid updating of beliefs following regime shifts. However, such a “two-point” learning problem may understate the severity of the information friction over monetary policy faced by real-world private agents (Kozicki and Tinsley, 2001, 165).

1.7 Learning

The evolution of the observed policy shocks u_t^* in equation (27) can be rewritten in the following regression form:

$$u_t^* = \mathbf{x_t}'\mathbf{m} + e_t, \tag{28}$$

where $\mathbf{x_t} = [1 \;\; u_{t-1}^*]'$ and $\mathbf{m} = [(1-\rho_u)(1-\rho)(1-\lambda_\pi)(\pi^L - \pi^H)\rho_u]'$.

Assume that at time t, private agents have initial beliefs over **m** represented by the following prior distribution:

$$\mathbf{m}_t \sim N(\mathbf{m}_0, \sigma_u^2\mathbf{M}), \tag{29}$$

where $\mathbf{M}^{-1}$ is interpreted as the confidence private agents put into their initial belief. After observing a sequence of k shocks $\hat{u}_{t+s}^*s = 0_{\hat{k}}$, Bayesian updating will result in a posterior distribution of agents' beliefs about **m** with the following mean:[17]

$$\mathbf{m}_{t+k} = (\mathbf{M}^{-1} + \mathbf{X}'\mathbf{X})^{-1}(\mathbf{M}^{-1}\mathbf{m}_0 + \mathbf{X}'\mathbf{Y}), \tag{30}$$

where $\mathbf{X}$ is the matrix formed by stacking the observation vectors $\mathbf{x}_t$, and $\mathbf{Y}$ denotes the shocks u_t^* in vector form. Note that as confidence over priors $\mathbf{M}^{-1}$ decreases towards zero, $\mathbf{m}_{t+k}$ comes to resemble the simple ordinary-least-squares estimator on equation (28). Since they know the parameters of the monetary policy rule, private agents can then back out their best estimate of the inflation target from the mean of beliefs $\mathbf{m}_{t+k}$.

1.8 Symmetric competitive equilibrium

The symmetric equilibrium of this economy consists in a sequence of allocations, $\{Y_t, c_{1t}, c_{2t}, n_t, i_t, k_t\}_{t=0}^{\infty}$, a sequence of prices and co-state variables, $\{W_t, r_t, R_t, \pi_t, \lambda_{1t}, \lambda_{2t}, q_t\}_{t=0}^{\infty}$, and the stochastic process for the monetary policy shock u_t. These allocations, prices, and shocks are such that (i) households, final-good-producing firms, and intermediate-goods-producing firms optimize in a manner that is consistent with the information publicly available about the inflation target, (ii) the monetary policy rule (22) is satisfied, and (iii) the following market-clearing conditions are satisfied:

$$k_t = \int_0^1 k_{jt} \mathrm{d}_j, \tag{31}$$

$$n_t = \int_0^1 h_{jt} \mathrm{d}_j, \tag{32}$$

$$M_t = \overline{M}_t, \tag{33}$$

17. See Hamilton (1994), chapter 12.

$$B_t = 0, \tag{34}$$

$$Y_t = c_{1t} + c_{2t} + i_t. \tag{35}$$

Note that in this equilibrium, all intermediate-goods-producing firms make identical decisions.

2 Calibration and Solution of the Model

To conduct our experiments, we compute a first-order approximation of the model's solution around the non-stochastic steady state, using the algorithm described in King and Watson (2002).[18] Nominal variables are expressed in real terms so that they become stationary. Numerical values for the model's parameters are set by appealing to direct evidence or so that the computed steady state replicates features of actual economies.

2.1 Preferences and technology

The model is calibrated to a quarterly frequency. Following Cooley and Hansen (1995), the utility function takes the following separable form with Hansen's (1985) indivisible labour:[19]

$$u(c_{1t}, c_{2t}, n_t) = \gamma log(c_{1t}) + (1-\gamma) log(c_{2t}) - Bn_t. \tag{36}$$

As shown by Cooley and Hansen (1995), combining equations (5)–(6), (8)–(9), and (2) in this context yields the following optimization-based money-demand equation:

$$\frac{c_t}{M_t/P_t} = \frac{1}{\gamma} + \frac{(1-\gamma)}{\gamma} i_t, \tag{37}$$

where $i_t = R_t - 1$ denotes the net nominal interest rate between t and $t+1$; $(1-\gamma)/\gamma$ can thus be interpreted as the interest rate elasticity of the velocity of money demand. We set γ to 0.84, so that this elasticity is around 0.20, similar to the value used by Cooley and Hansen (1995).

18. The policy change we consider—a reduction in the inflation target of the monetary authority—has first-order effects on the economy and it is those effects that our welfare computations are meant to take into account. Employing a first-order solution, rather than the recently developed second-order methods such as Schmitt-Grohé and Uribe (2004), should therefore not bias our welfare results.

19. Our welfare results remain essentially unchanged by repeating all experiments assuming a log-disutility of labour, so that $u(c_{1t}, c_{2t}, n_t) = \gamma log(c_{1t}) + (1-\gamma) log(c_{2t}) - Blog(1-n_t)$.

The rate of labour-income taxation τ_n is set to 0.2, while that on capital-income taxation, τ_k, is 0.4. These values are similar to those used by Cooley and Hansen (1991), Lucas (1990), and more recently by Gavin, Kydland, and Pakko (2005). They are drawn from empirical studies that estimate time series of effective rates of taxation.

The parameter θ, the price elasticity of demand for each intermediate good, is set to 5. This implies that the steady-state markup of price over marginal costs is 25 per cent, a standard value in the literature. The parameter ϕ, expressing the probability that a given intermediate-good producer does not reoptimize and choose a new price, is set to 0.6. This implies that, on average, prices are reoptimized every $1/(1-0.6) = 2.5$ quarters, or around eight months. This value is similar to those estimated in other studies, i.e., Ireland (2001), Dib (2003, 2006), and in the benchmark specification of the model in Christiano, Eichenbaum, and Evans (2005). The parameter κ, governing the severity of the adjustment costs in capital accumulation, is set to 1, the estimate arrived at in Christiano, Eichenbaum, and Evans (2005) in their model specification that is closest to the present one.

The remaining parameters, β, δ, B, and α, are set so that the computed steady state matches the following: the quarterly capital-output ratio is 8, the investment-output ratio is 0.17, labour effort is 0.3 of total available hours, and the labour-income share in GDP is equal to 60 per cent. These restrictions imply the following parameter values: $\beta = 0.9854$, $\delta = 0.0212$, $B = 1.9198$, and $\alpha = 0.4$.

Finally, the model as written implies that intermediate-goods producers enjoy sizable profits. To prevent this from occurring, fixed costs of production, in the form of fixed labour costs, are introduced.[20]

2.2 The monetary policy rule

According to the rule in equation (22), the nominal interest rate reacts to the deviations of inflation from its current target (the coefficient λ_π), to the deviations of output from its trend (λ_y), and to its own lagged value (ρ).

Calibrating these values is not straightforward, because the sizable literature that estimates monetary policy rules uses a variety of specifications that often differ significantly from the one we have retained to express monetary

20. This involves modifying the production function in equation (14) to $k_{jt}^{\alpha}(h_{jt}-H_0)^{1-\alpha}$ and setting the value of H_0 so that steady-state profits are zero. See Yun (1996) for details.

policy.[21] Furthermore, some values of the triple $(\lambda_\pi, \lambda_y, \rho)$ lead to non-uniqueness (or non-existence) of stable equilibria in the model. We therefore use this literature as a guide to select likely values for the parameters. In the next section, we show that, overall, our welfare results are not sensitive to the calibration of the monetary policy rule, provided that the parameters of the rule are drawn from the range suggested by the literature.

Starting with Taylor (1993), the literature has argued that a relatively high response of interest rates to inflation (the coefficient λ_π) was necessary to avoid self-fulfilling expectations. In that context, we set $\lambda_\pi = 2.0$. This value is only slightly higher than the one advocated by Taylor and is in line with recent empirical estimates, as in Erceg and Levin (2003); English, Nelson, and Sack (2003); and Schorfheide (2005).

The smoothing parameter ρ is set to 0.5, a value also within the range of empirical estimates (see Erceg and Levin 2003, Kozicki and Tinsley 2003, and Schorfheide 2005). These empirical exercises allow for regime shifts in monetary policy and are therefore compatible with our environment. We also set λ_y to 0.25, a value similar to the one obtained by Erceg and Levin. Finally, we consider that true monetary policy shocks have no serial correlation and thus we set $\rho_u = 0$.

2.3 Learning mechanism

Consider a reduction of π^T, the inflation target of the monetary authority, from $\pi^H = 2.0$ per cent per annum to $\pi^L = 0$ per cent. Under the incomplete information structure, the mechanism (30) describes how private agents update their beliefs about the composite monetary policy shock u_t^* and ultimately their beliefs on the inflation target.

The prior belief $\mathbf{m}_0$ is set to $\begin{bmatrix} 0 & 0 \end{bmatrix}$. This indicates that at the time of the target shift, private agents consider the inflation target to be 2 per cent and correctly assign a zero serial correlation to the monetary policy shock u_t. The matrix $\mathbf{M}$ indexes the confidence that agents possess for these prior beliefs. We assume a diagonal form for $\mathbf{M}$ so that

21. Among other dimensions, the empirical estimates of rules differ on whether the estimated rule is forward looking, as in Clarida, Galí, and Gertler (2000) or reacting to current values of economic variables, as in Taylor (1993), and whether it is obtained from a single-equation estimation, as in Erceg and Levin (2003) and English, Nelson, and Sack (2003), or as part of a system-wide estimation, as in Schorfheide (2005) and Kozicki and Tinsley (2003).

$$\mathbf{M} = \begin{bmatrix} v_1 & 0 \\ 0 & v_2 \end{bmatrix}, \tag{38}$$

where v_1 and v_2 express the confidence in the beliefs over the mean and the serial correlation of u_t^*, respectively. We fix v_2 to a high value, which shuts down the learning about this parameter (recall that the confidence in the prior is expressed by the inverse of $\mathbf{M}$). To assign a value to v_1, we follow Erceg and Levin (2003) and choose v_1 so that the learning behaviour of private agents will match some observed features of recent disinflation episodes. Specifically, Erceg and Levin (2003) estimate that during a recent disinflation episode where US inflation was trending downward, one-half of the change in the inflation target of the monetary authority appeared to be incorporated in agents' forecasts within one year. We thus set the parameter $v_1 = 4$, which ensures that the learning behaviour of our model roughly matches this fact (see below).

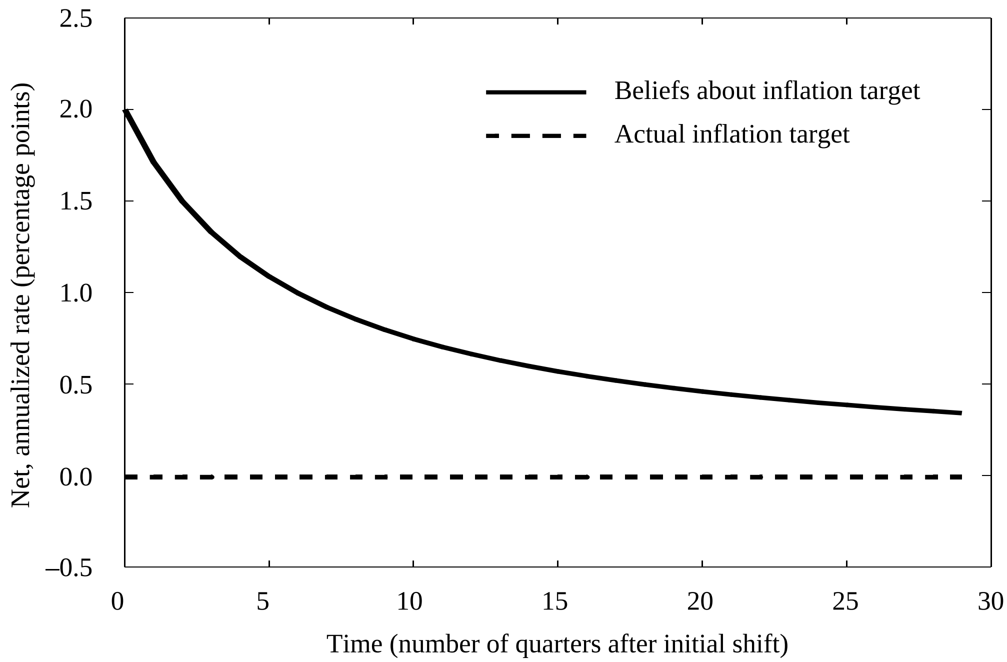
As a result of the shift, private agents observe a sudden increase in the nominal interest rate (recall the form of the composite monetary policy shock u_t^* and the fact that λ_π is greater than one). They must decide whether this spike in interest rates arose from a temporary tightening of monetary policy (a positive u_t shock) or whether it signals a decrease in the inflation target of the monetary authority.

Figure 1 illustrates the evolution of private agents' beliefs over the inflation target. It shows that, initially, only a small weight is assigned to the (correct) conjecture that the observed u_t^* resulted from a decrease in the inflation target; agents' beliefs decrease by a correspondingly small amount (solid lines). Over subsequent periods, repeated observations of positive values for u_t^* lead to additional updating, and the beliefs over the inflation target converge smoothly to the correct value of zero. As indicated above, it takes about four quarters for the beliefs to reach the halfway point, at which the inflation target is thought to be 1 per cent per annum; furthermore, it takes 15 quarters to reach the three-quarter mark, where the target rate implied by the beliefs is 0.5 per cent per annum.

2.4 The economy's responses following the shift

Figure 2 presents the responses of the economy following the decrease in the inflation target. First, the dashed lines depict the new steady-state values of the variables. As mentioned above, lowering trend inflation reduces the distortion imposed on the economy by the cash-in-advance constraint. As a result, households decrease their consumption of leisure, a commodity that is not affected by this constraint and was thus inefficiently high in the steady

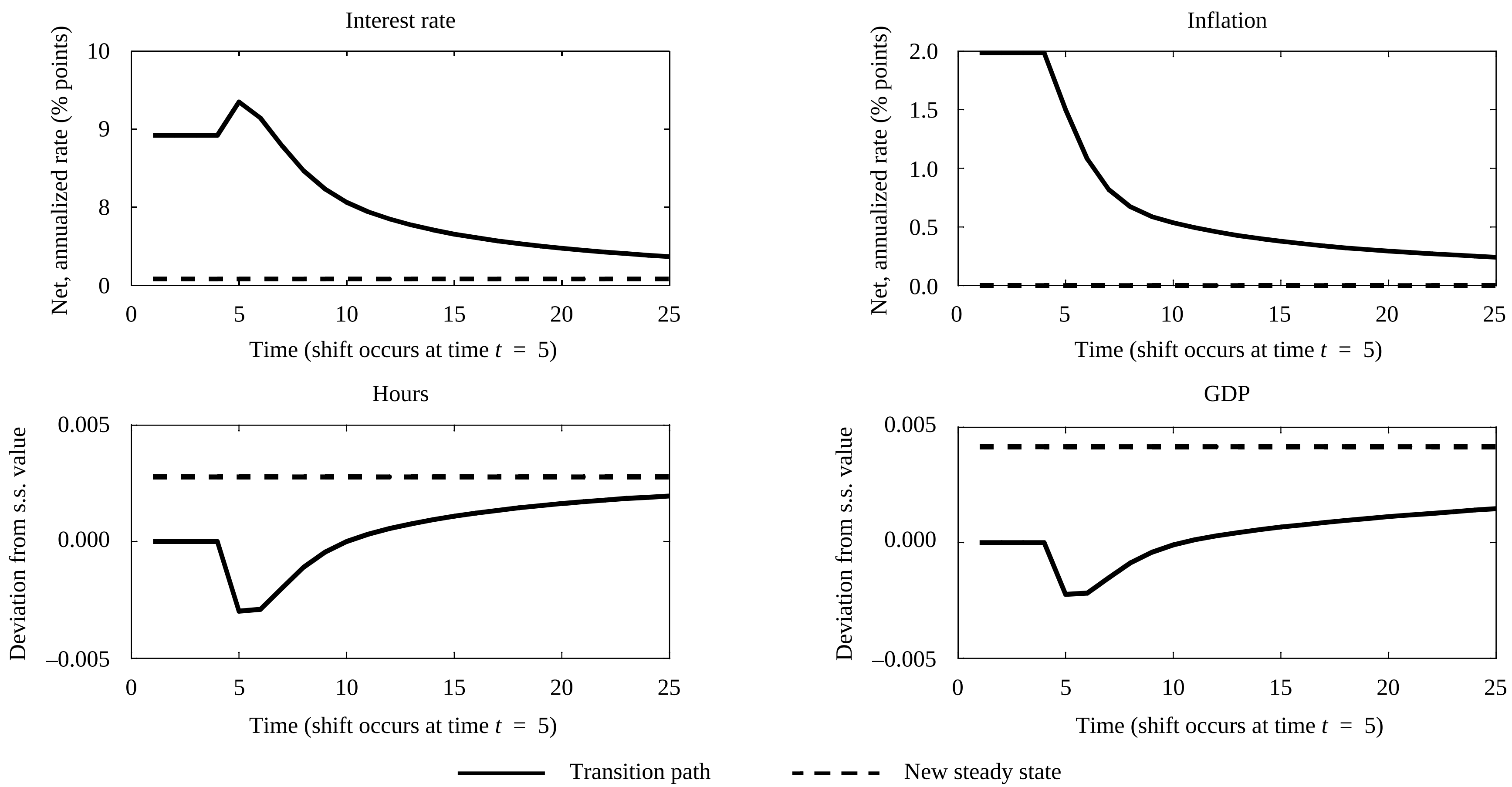
Figure 1
Learning about the inflation target



state with high inflation. Labour market participation and hours worked increase, which allows production, investment, and consumption to be permanently higher in the new steady state. As a result of the target shift and the Fisher equation, respectively, inflation and nominal interest rates are lower by two percentage points in the new steady state.

The solid lines of Figure 2 illustrate the transition paths of economic variables under the incomplete information structure. Initially, nominal interest rates increase and this tightening depresses economic activity with hours worked, output, and investment decreasing on impact. Subsequently, the economy experiences several periods of poor economic performance and high interest rates, instead of recovering rapidly. This occurs because of incomplete information. As discussed above, private agents are not yet convinced that target inflation has indeed been reduced, and they expect inflation to remain (relatively) high. Price-setters thus choose relatively high prices, which reduce aggregate demand and create downward pressure on output and no quick decreases in inflation. This period of below-average economic performance lasts approximately four quarters (for GDP). At that point, learning agents are becoming convinced that the target rate of inflation has diminished and the long-term, beneficial effects of this shift

Figure 2
Transition path following the inflation-target shift
(Shock occurs at $t = 5$)



(cont'd)

Figure 2 (cont'd)
Transition path following the inflation-target shift
(Shock occurs at $t = 5$)

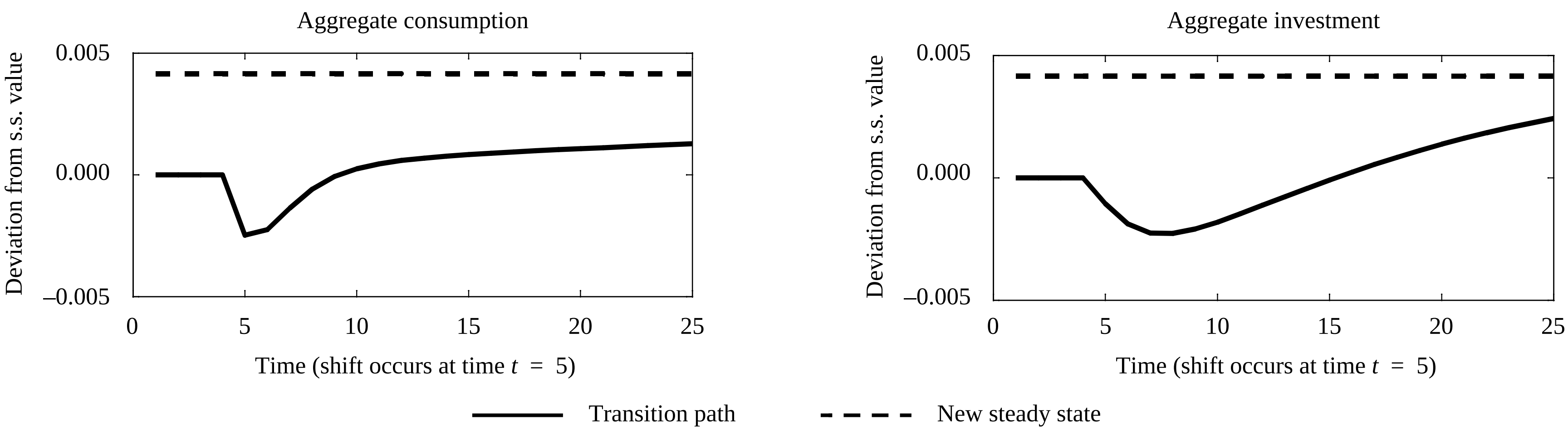
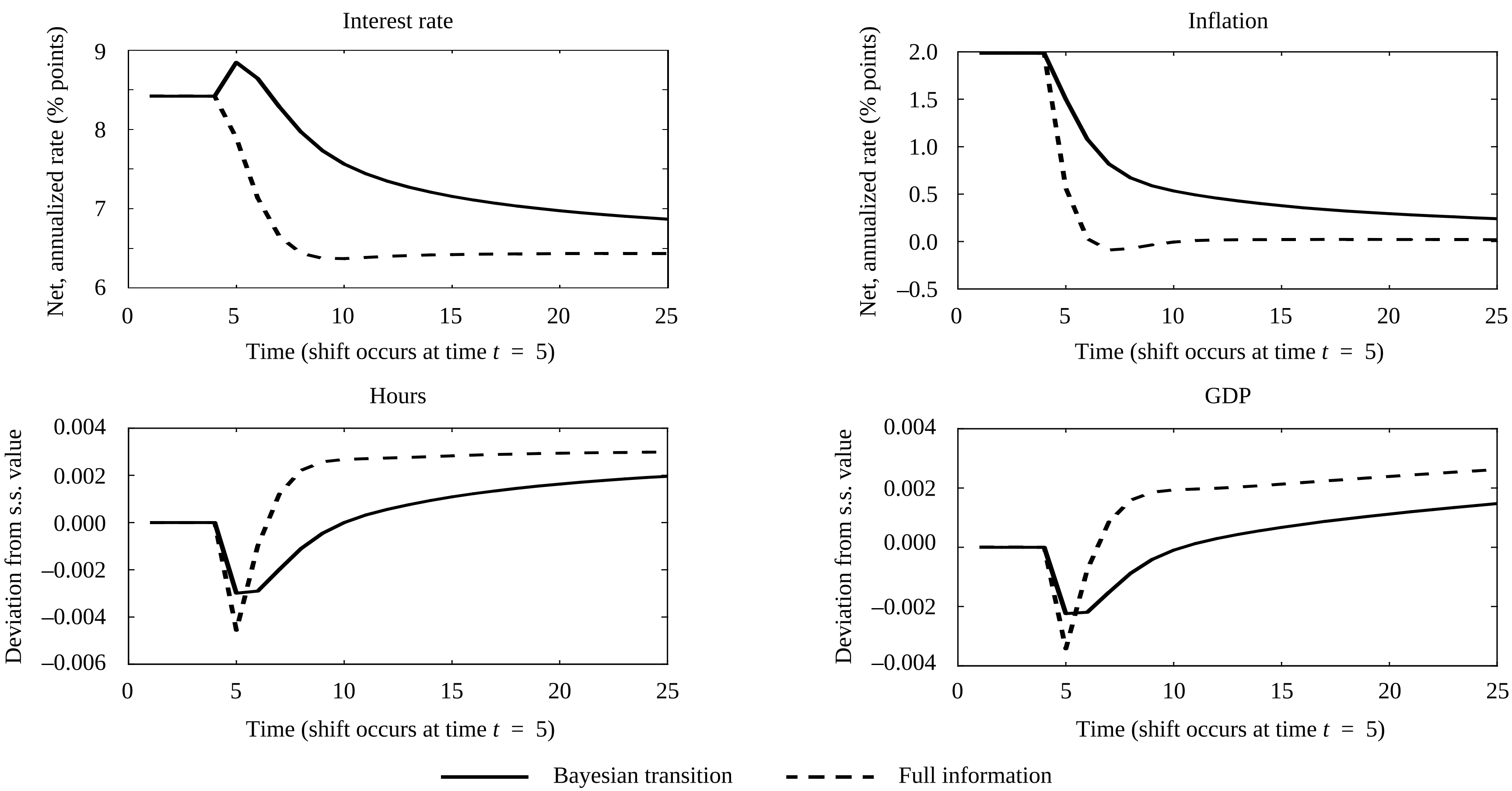


Figure 3
Importance of the information structure



begin to set in. Consumption, output, and finally investment smoothly increase towards their new steady-state values.[22]

Figure 3 illustrates the importance of the information structure in shaping the responses of the economy following the shift. The solid lines again represent the incomplete-information responses, whereas the dashed lines present the responses obtained under full information, where private agents observe the inflation target directly and learning is unnecessary. The figure shows that the transition towards the new steady state is much more rapid under full information. Both inflation and output decrease significantly on impact, as price-setters have already factored in the consequences of lower trend inflation and accordingly set low prices. This allows the monetary authority to keep nominal rates low. The transition is rapid and while output decreases significantly on impact, no prolonged period of depressed economic activity occurs.

These differences between the responses of economic variables according to the information structure are also present in previous papers (Erceg and Levin 2003; Andolfatto and Gomme 2003; Schorfheide 2005). As in the present paper, these authors report that full information entails a quick transition following monetary policy regime shifts, while the transition under incomplete information and learning is quite protracted. Erceg and Levin report that, overall, the characterization of the transition under incomplete information accords better with available evidence about actual disinflationary episodes.

3 Welfare Computations

3.1 Benchmark model

The welfare benefits that arise from the decrease in trend inflation are computed by comparing the expected lifetime utility of a representative agent in the stationary state where inflation is $\pi^H = 2.0$ per cent with that of another representative agent in the economy where the shift to

22. The new steady state (dashed lines) is computed separately from the transition paths (full lines), which arise from the first-order approximation solution around the *initial* steady state. This provides a check on the quality of the approximate solution; in all of our computations and for all variables, the computed transition paths settle, at most, 1.5 per cent away from their new steady-state values.

Table 1
Welfare benefits from reducing inflation from 2 per cent to zero

	Steady-state comparison	Complete-information transition	Bayesian transition
Consumption equivalent μ	0.26%	0.13%	0.09%
◊ as a fraction of steady-state comparison	—	0.499	0.353

$\pi^L = 0$ per cent has been implemented.[23] We express the utility difference in consumption-equivalent terms. This requires finding the percentage increase in consumption that would make households indifferent about remaining in the high-inflation economy at the initial steady state, on the one hand, or living in the new, low-inflation economy. The consumption-equivalent μ thus solves the following equation:

$$E_0 \sum_{t=0}^{\infty} \beta^t u[(1+\mu)c_1^H, (1+\mu)c_2^H, n^H]$$

$$= E_0 \sum_{t=0}^{\infty} \beta^t u[c_{1t}^L, c_{2t}^L, n_t^L]. \tag{39}$$

The left-hand side of equation (39) is lifetime utility at the initial, high-inflation steady state, with consumption of both types of goods increased by the factor μ, whereas the right-hand side of the equation computes lifetime utility in the new, low-inflation economy.

This utility comparison can be implemented by comparing only the two steady states, in which case equation (39) reduces to the following:

$$u[(1+\mu)c_1^H, (1+\mu)c_2^H, n^H] = u[c_1^L, c_2^L, n^L]. \tag{40}$$

As mentioned in the introduction, this implicitly assumes that the transition to the new, low-inflation steady state has been immediate and costless.

23. In principle, the welfare computations could be repeated for any pair of inflation rates. Notably, a reduction of trend inflation from 2 per cent to that of the Friedman rule (deflation at the rate of time preference) could be examined. However, the structure of monetary transactions may be significantly modified when the economy passes between zero inflation and the Friedman rule. In such a case, the cash-in-advance constraint in equation (2) would likely change form.

In what follows, we report results arrived at by using both equations (39) and (40).

Table 1 presents our benchmark results. The first column reports the consumption equivalent μ when the comparison between steady states in equation (40) is used. The table shows that lowering inflation from 2 per cent to zero brings appreciable welfare gains, of the order of 0.26 per cent of steady-state consumption. The next two columns, however, using equation (39) and therefore taking into account the transition to the low-inflation steady state, show that the welfare benefits are decreased significantly. The benefits in the complete-information transition amount to only 0.13 per cent of steady-state consumption, which is just below 50 per cent of what they were in the steady-state comparisons. Furthermore, assuming that information is incomplete and that Bayesian learning characterizes the transition, further reduces the computed benefits, to 0.09 per cent of steady-state consumption, or 35 per cent of what they were in the steady-state comparison.

These results show that the two motivations to take the transition into account are important. Under complete information, the increased work effort and decreased consumption required to accumulate additional capital decrease computed benefits by one-half. Furthermore, Bayesian learning about the new target, a possible consequence of communication or credibility gaps, further reduces the computed benefits, to the point where they represent only about one-third of the figure obtained from the steady-state comparison. Working with a different modelling technology, Andolfatto and Gomme (2003) report welfare results that are broadly similar to these, which would suggest that such results are robust to modelling choices.

3.2 Sensitivity analysis

To explore the sensitivity of our results, we repeat the analysis above for several alternative calibrations of the model. The results are reported in Table 2. Each row describes a specific departure from the benchmark calibration under study. As in Table 1, the first column indicates the welfare benefits of the target shift when a comparison between steady states is employed. Meanwhile, the second and third columns report the computed benefit as a percentage of what was arrived at in the comparison between steady states. To facilitate comparisons, the benchmark results are repeated at the beginning of the table.

Panel A explores whether results are sensitive to the parameterization of the monetary policy rule. The table clearly shows that it is not the case. While

Table 2
Welfare benefits from reducing inflation from 2 per cent to zero: Sensitivity analysis
(Percentage)

Specification	**Steady-state comparison**[a]	**Complete-information transition**[b]	**Bayesian transition**[c]
Benchmark case	0.26	49.9	35.3
Panel A: Modifications to the monetary policy rule			
Higher response to inflation ($\lambda_\pi = 2.5$)	0.26	49.7	33.4
Lower response to inflation ($\lambda_\pi = 1.5$)	0.26	50.4	38.3
Higher interest rate smoothing ($\rho = 0.75$)	0.26	47.2	30.7
No interest rate smoothing ($\rho = 0.0$)	0.26	51.2	41.3
Higher response to output ($\lambda_y = 0.5$)	0.26	49.8	35.7
No response to output ($\lambda_y = 0$)	0.26	50.6	37.9
Higher confidence in prior ($v_1 = 8$)	0.26	49.9	27.2
Panel B: Alternative modelling choices[d]			
Investment and wage income in cash-in-advance constraint	0.54	33.2	23.5
Habit formation in consumption	0.47	21.3	17.7
Partial wage indexation	0.47	19.0	15.0

a. Measured as the consumption equivalent μ.
b. Measured as a fraction of number in comparison between steady states.
c. Measured as a fraction of number in comparison between steady states.
d. The modelling extensions are cumulative.

there are slight changes in the computed welfare benefits, neither the number arrived at in the steady-state comparisons, nor the amount by which accounting for the transition reduces this number, changes significantly. What slight changes there are accord well with expectations. For example, increasing interest rate smoothing (from $\rho = 0.5$ to $\rho = 0.75$) prolongs the transition and thus reduces benefits. Second, increasing the confidence in the prior belief (from $v_1 = 4$ to $v_1 = 8$) leads agents to downplay the importance of target shifts and thus to be slower to recognize one when it happens. This prolongs the transition and also reduces benefits. Modifying the response to output deviations (λ_y) has only marginal implications for welfare benefits. Finally, increasing the response to inflation (from $\lambda_\pi = 2.0$ to $\lambda_\pi = 2.5$) decreases only slightly the computed welfare benefits.

Panel B of Table 2 explores whether modifications to the other aspects of the model have an impact on the welfare results (model extensions are cumulative).

3.2.1 Wage rigidity

The first modelling change is to incorporate nominal-wage rigidity in the model. The literature often argues that this type of friction might be important to generate persistence in the responses of economic variables, particularly inflation, following monetary or technology shocks. Furthermore, the behaviour of nominal wages themselves may be better accounted for once wage rigidity is incorporated in modelling environments.

We thus follow Erceg, Henderson, and Levin (2000) and assume that households, like intermediate-goods-producing firms, are monopolistic suppliers of their labour services and that frictions prevent them from fully adjusting their nominal wage every period. This partial adjustment of wages implies a smoother adjustment of the marginal costs relevant to the intermediate-goods producers (one important component of this cost is the wage rate) that was the case in the benchmark model. Following the target shift, therefore, wages do not decline rapidly, which means that marginal costs also remain relatively high longer. In response, price-setters themselves keep price inflation fairly high relatively longer than in the benchmark model; recall the price-inflation equation in equation (20).[24]

Following this intuition, Table 2 reveals that the transition costs are more important once this model extension is accounted for, i.e., that the discrepancy between the welfare benefits with steady-state comparisons and those with the transition increases. The benefits with the incomplete-information environment now constitute only about one-third of those computed without transition.

3.2.2 The price-rigidity parameter

The parameter governing the severity of the price rigidity ϕ is set to a value of 0.6 in the benchmark model. This value is similar to those arrived at by authors who estimate New Keynesian models using maximum likelihood (Ireland 2001; Dib 2003, 2006). By contrast, in their model specification that most closely resembles ours, Christiano, Eichenbaum, and Evans (2005) estimate this value to be 0.8, using their method of matching theoretical and empirical vector-autoregression impulse responses.

We modify the model by increasing the value of this parameter from its benchmark value of 0.6 to a value of 0.8. This implies that price-setters

24. See Erceg, Henderson, and Levin (2000) for details concerning the implementation of this extension. A "Calvo" parameter, similar to the one in the optimization problem of the intermediate-goods producers above, should be calibrated: we follow Christiano, Eichenbaum, and Evans (2005) and fix it to 0.6.

reoptimize less often, and thus that the inflation-target shift is even less taken into account initially. Panel B of Table 2 reveals that, as a result, the welfare benefits of the monetary policy shift are further reduced, to the point where the full-information transition delivers benefits worth only 35 per cent of those computed using the steady-state comparison. The incomplete-information transition now sees benefits that are only around 17 per cent of that figure.

3.2.3 The cash-in-advance constraint

The next modelling extension follows Christiano and Gust (1999) and assumes that the cash-in-advance constraint is modified in two ways. First, current wage income is included, and second, investment is paid out of available liquid balances rather than on credit. This transforms the constraint in equation (2) to the following:

$$c_{1t} + i_t + \frac{B_{t+1}}{P_t} \leq \frac{M_t^c + X_t + R_{t-1}B_t}{P_t} + (1-\tau_n)\frac{W_t}{P_t}. \tag{41}$$

Although this modification removes the distortion that inflation imposes on labour market participation (as was the case in the benchmark model), it replaces it with one where inflation distorts the incentive to accumulate capital. This arises because capital accumulation must be financed with liquid balances.

Table 2 shows that this distortion is more costly to the economy, and that reducing it by decreasing the inflation target yields more important welfare benefits: these are now worth 0.54 per cent of steady-state consumption.[25] However, taking into account the transition towards the new steady state still reduces the welfare benefits significantly, so that these benefits are now worth only 30 per cent (full information) and 18 per cent (Bayesian transition) of the number arrived at in steady-state comparisons.

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25. In the benchmark model, reducing inflation increased consumption but also increased work participation, because the distortion on hours worked was reduced. This had a dampening effect on the welfare benefits, since these additional hours worked naturally brought disutility to households. Here, reducing inflation does not significantly modify work effort, but does markedly increase capital formation and thus, ultimately, consumption.

3.2.4 Habit formation

The next modification is to incorporate habit formation in the model. Following Christiano, Eichenbaum, and Evans (2005), this is done by modifying the utility function such that it becomes the following:

$$u(c_t, n_t) = log(c_t - bc_{t-1}) - Bn_t, \tag{42}$$

where $c_t = c_{1t}^{\alpha} c_{2t}^{1-\alpha}$. The coefficient b indexes the extent to which habit (last period's consumption) influences the valuation of consumption streams. Following the estimates of Christiano, Eichanbaum, and Evans (2005), we set $b = 0.6$.

Table 2 shows that this extension affects the benefits computed at the steady state and those that include the transition. In the steady-state comparison, the reduction in inflation is now worth 0.51 per cent of consumption, a number slightly lower than the preceding one. However, the reduction in benefits in the full-information transition are now more important: these benefits are now 27 per cent of the number computed in the comparison between steady states. Note also that, compared with the preceding case, this reduction is not shared by the incomplete-information (Bayesian) case, where the benefits are slightly higher, at 22 per cent of the steady-state comparison. This arises because the habit variable leads households to choose a much smoother path for consumption in the transition, one that exhibits a hump-shaped pattern, both in the complete- and incomplete-information cases.[26] Hence, as additional factors meant to impart smoothness in the responses of the economy are introduced in the model, the differences between the full-information and incomplete-information responses to the shift tend to be reduced.

Overall, Table 2 shows that our results are robust across model specifications. Both the welfare benefit arrived at in the steady-state comparisons, and the extent to which this number is reduced when the transition is taken into account, exhibit limited ranges across the parameterization or across the specification of the model. The key message of the paper—the actual welfare benefits of lower inflation are significantly lower than they might at first appear in comparisons between steady states—seems therefore likely to be robust to an even wider battery of model extensions.

26. This smooth, hump-shaped pattern of consumption is precisely the reason that habit formation has been incorporated into dynamic models such as that of Christiano, Eichenbaum, and Evans (2005).

Conclusion

This paper computes the welfare benefits of a reduction in the monetary authority's inflation target from 2 per cent per annum to zero. Although these benefits may appear significant when steady-state comparisons are employed, this paper shows that taking into account the transition towards the low-inflation steady state reduces the computed benefits significantly. This reduction is more important if the transition is characterized by incomplete information and learning over the inflation target shift.

The welfare computations are performed using a standard version of the New Keynesian model, the main tool of modern applied monetary analysis. The model contains several features of actual economies (e.g., income taxation, various nominal frictions, and adjustment costs) that increase the confidence that can be drawn from its welfare implications. A sensitivity analysis reports that (i) the welfare estimates are contained within a limited range and that (ii) the sharp discrepancy between the welfare benefits computed by comparing steady states and those arrived at when the transition is taken into account remains across model specifications.

Important extensions to this paper's analysis remain to be undertaken. First, the model should incorporate open economy features to quantify the influence of the exchange rate channel of monetary policy on the welfare computations. Second, the possibility that lowering trend inflation increases economic growth should be considered.[27] In addition, allowing for such features as downward nominal-wage rigidity or the zero lower bound for nominal interest rates, which could affect the transitions towards the new steady state but also the model's implications for this steady state, would further strengthen the confidence in our results. Finally, it is assumed throughout the analysis that the friction giving rise to money demand (the cash-in-advance constraint) is left unchanged by the inflation-target shift. Since the shift analyzed is modest, this assumption may not be unreasonable. Nevertheless, lowering inflation may affect the structure of monetary transactions, and these changes might be important.[28]

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27. Barro (1996) presents evidence supporting this conjecture. Gomme (1993), Dotsey and Ireland (1996), and Wu and Zhang (1998) model this link within general-equilibrium environments.

28. Lucas (2000) suggests that drastic changes to the structure of monetary transactions are most likely to occur at very low (or negative) rates of inflation, as the monetary authority implements the Friedman rule of deflating at the rate of time preference. A truly structural monetary model would therefore be necessary to conduct welfare experiments of this type. See Rocheteau and Wright (2004) for a welfare analysis (involving steady-state comparisons) within such a model.

Overall, however, our sensitivity analysis suggests that the key message of the analysis—that the benefits of lower inflation are probably significantly lower than they appear in steady-state comparisons—will be robust to model specifications.[29] This result could prove useful when larger and more complex models, where accounting for the transition is not straightforward, are used for analyzing choices for the appropriate inflation target.

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