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Learning and the Welfare Implications of Changing Inflation Targets

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Abstract:

This paper computes the welfare consequences, for a representative agent, of a shift in the inflation target of monetary authorities. The welfare computations are conducted first by comparing the two steady states that the different inflation targets entail, and next by accounting for the transition from one steady-state to the next. Further, the paper allows this transition to be characterized by incomplete information, under which private agents learn about the inflation target shift using Bayesian updating. The analysis is repeated in a variety of model parameterizations, to test the robustness of the results.

We find that the welfare benefits of reducing the target rate of inflation from 2% initially to 0% may at first appear to be significant. When measured by comparing steady states, these benefits are worth up to 0.5% of steady-state consumption. However, accounting for the transition towards the new, low inflation steady state significantly reduces the computed benefits, by at least one half.

Keywords: Inflation targeting, welfare benefits of lower inflation, new keynesian model

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Learning and the Welfare Implications of Changing Inflation Targets [*]

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Abstract

This paper computes the welfare consequences, for a representative agent, of a shift in the inflation target of monetary authorities. The welfare computations are conducted first by comparing the two steady states that the different inflation targets entail, and next by accounting for the transition from one steady-state to the next. Further, the paper allows this transition to be characterized by incomplete information, under which private agents learn about the inflation target shift using Bayesian updating. The analysis is repeated in a variety of model parameterizations, to test the robustness of the results.

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1 Introduction

Several 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.

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

This paper provides such an analysis. 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 within a standard monetary business cycle model, under different scenarios regarding the transition following the implementation of the new target. In particular, we compute 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. We report that the welfare benefits of reducing the target from 2 per cent to zero may appear to be significant. When measured by comparing steady states, these benefits represent a utility windfall equivalent of 0.26% of steady-state consumption in our benchmark model, and up to 0.5% in some of the extensions we analyze. However, accounting for the transition towards the new low-inflation steady state significantly reduces these computed welfare benefits, by at least one half.

The economic environment examined is drawn from the cash-in-advance, representative agent, complete markets and monopolistic competition economy of Yun (1996).[1] In such an economy, positive inflation discourages market-related activities, distorting decision rules for consumption, work, and investment plans. Lowering average inflation reduces this distortion and therefore represents a welfare benefit for the economy.

Accounting for the transition towards the lower inflation steady state reduces the computed welfare benefits for two reasons. First, the reduced distortions do encourage and ultimately increase capital formation, but this additional capital must first be accumulated, at the cost of postponed consumption or leisure. Further, incomplete information may lead economic agents to incorrectly interpret the high interest rates that prevail immediately after the shift as temporary monetary tightenings; in such a case, the initial responses of consumption, employment and output may be different

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[1] 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, forthcoming), Erceg et al. (2000), Smets and Wouters (2003), Ambler et al. (2003), and Christiano et al. (2005). A detailed exposition of the model can be found in King (2000).

from their long-term ones. Eventually as agents' learning helps ascertain the true nature of the monetary policy shift, these responses are reversed; however, the early incorrect actions further reduce the welfare benefits of the new low-inflation policy.

Quantitative analysis of the welfare costs of inflation can be traced back to Bailey (1956)'s computations of the deadweight loss under the money demand curve for different levels of inflation. More recent studies that use similar logic include Fisher (1981) and Lucas (1981, 2000).

In contrast with the Bailey strategy, the present paper uses a fully-developed general equilibrium monetary model to perform the computations; this allows a more complete characterization of the effects of inflation on the economy and on the representative agent's welfare.[2] Further, solving for the path the economy follows in its transition towards the new low-inflation steady state is straightforward.[3]

Earlier papers (Cooley and Hansen, 1989, 1991; Dotsey and Ireland, 1996; Wu and Zhang, 1998, 2000) also compute the welfare benefits of lower inflation using a fully developed quantitative model as their measuring tool. The present paper extends this earlier work by using a model from the the *New Keynesian* literature, the standard in recent applied monetary analysis. It further contributes to the set of available results by considering that incomplete information may impair the transition towards the new low-inflation target and providing a quantitative assessment of the welfare impact of these impairments. To do so, the paper borrows from a literature that examines the impact of incomplete information about the monetary authority's actions and objectives.[4]

The rest of the paper is organized as follows. Section 2 presents the model, a representative of the New-Keynesian literature. Section 3 discusses the calibration of the model, while section 4 presents the welfare computations and discusses them. Section 5 assesses these results and concludes.

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[2] The present paper does not consider the possibility that inflation affects economic agents differently. The work of Erosa and Ventura (2002) suggests that such heterogenous impacts might be important when considering changing the inflation target.

[3] We use the method of first-order approximation around the steady-state to compute this path, as implemented by King and Watson (2002).

[4] These learning effects are often used to explain the persistent responses of real variables following monetary policy shocks. See Andolfatto and Gomme (2003), Andolfatto et al. (2002), Erceg and Levin (2003), and Schorfheide (2005). An earlier contribution can be found in Brunner et al. (1980).

2 Model

This section presents the model used to perform our experiments. 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 inflation target shift we consider, as well as the mechanism by which private agents learn about this shift.

The model belongs to the new Keynesian class, the now standard methodological tool for applied monetary analysis. There are two sectors of production. The final good sector is competitive: firms in this sector take input prices as given, produce an homogenous good which they sell at perfectly flexible prices. The final good is divided between consumption and investment. By contrast, intermediate-good-producing firms operate under monopolistic competition. Each firm produces a distinct good for which it chooses the market price. However, nominal changes to the price these firms charge are restricted, following Calvo (1983), so that these prices are 'sticky'. Intermediate good production requires capital and labour services, for which the firms act as price takers. Finally, the monetary authority's policy rule manages the short-term nominal interest rate to respond to inflation deviations from its target, as well as to deviations of output from its trend.

2.1 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.

At the beginning of period t, a household possesses M_t dollars of financial wealth (cash). The household receives a beginning-of-period per-capita 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). Further, the households receives a cash payment of $R_{t-1}B_t$, where B_t denotes the household's 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:

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

where P_t is the dollar price of the cash good.

Households own the economy's capital stock k_t, which they rent to the intermediate-good producing firms at the real rental rate r_t. They also supply labour services to these firms, at nominal wage W_t. Further, let D_t denote nominal dividends the household earns through its ownership of the intermediate-good producing firms and Γ_t a (fiscal) lump-sump transfer from the government. These revenues, once any labour and capital income taxes are netted out and any cash left over is added, must be sufficient to cover the planned expenditures of the household. These include credit good purchases c_{2t} and investment in new capital i_t, as well as the financial wealth the household desires to hold at the beginning of the next period (M_{t+1}). Expressed in real terms, the following budget constraint applies:

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

The rate of income tax is denoted by τ_n whereas τ_k denotes the capital income tax. Observe that the term in the square brackets above will equal zero whenever the cash-in-advance constraint (2) binds.[5]

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 $S''(1) \equiv \kappa > 0$.[6]

The representative household chooses $c_{1t}, c_{2t}, n_t, B_{t+1}, M_{t+1}, i_t$ and k_{t+1} in order to maximize expected lifetime utility (1) subject to the cash-in-

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[5] The presence of the term $\delta\tau_k k_t$ in the budget constraint indicates that capital depreciation allowances are taken into account by the model.

[6] Specifying that capital adjustment costs depend on past and current levels of investment follows Christiano et al. (2005).

advance constraint (2), the budget constraint (3) and the capital accumulation equation (4). The first-order conditions for this problem are as follows:

$$
\begin{aligned}
u_1(c_{1t}, c_{2t}, n_t) &= \lambda_{1t} + \lambda_{2t}; && (5)\\
u_2(c_{1t}, c_{2t}, n_t) &= \lambda_{2t}; && (6)\\
u_3(c_{1t}, c_{2t}, n_t) &= (1-\tau_n)\frac{W_t}{P_t}\lambda_{2t}; && (7)\\
\lambda_{1t} + \lambda_{2t} &= \beta R_t E_t[\frac{\lambda_{1t+1} + \lambda_{2t+1}}{\pi_{t+1}}]; && (8)\\
\lambda_{2t} &= \beta E_t[\frac{\lambda_{1t+1} + \lambda_{2t+1}}{\pi_{t+1}}]; && (9)\\
\frac{\lambda_{2t}}{1 - S(\frac{i_t}{i_{t-1}}) - S'(\frac{i_t}{i_{t-1}})\frac{i_t}{i_{t-1}}} &= \beta E_t\{\lambda_{2t+1}[(1-\tau_k)r_{t+1} + \delta\tau_k \\
&\quad + \frac{(1-\delta)}{1 - S(\frac{i_{t+1}}{i_t}) - S'(\frac{i_{t+1}}{i_t})\frac{i_{t+1}}{i_t}}]\}; && (10)
\end{aligned}
$$

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.

2.2 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 aggregation function is defined as

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

The final good-producing firms behave competitively, maximizing profits and taking the market price of the final good P_t as well as the intermediate-good prices $p_{jt}, j \in (0,1)$ 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 (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 good j as a function of its relative price and of the economy's total output of final good Y_t. The no profit condition in the sector implies that the final-good price index P_t satisfies

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

2.3 The intermediate good sector

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

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

Each intermediate good-producing firm sells its output under monopolistic competition; the economy-wide demand for the good produced by producer j is given by (12). Further, following Calvo (1983), we assume that each firm is only allowed to re-optimize 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 re-optimize and fix a completely new price. This implies that on average the firm will not re-optimize for $1/(1-\phi)$ periods.[7]

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

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

where D_{jt+k}/P_{t+k}, the real profit flow at time $t+k$, is

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

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[7] This particular specification of the Calvo mechanism follows Christiano et al. (2005). Alternatively, Yun (1996) assumes that when the re-optimization signal is not received, the price is indexed by the *average* inflation rate. Smets and Wouters (2003) implement a flexible specification that nests the two cases, and introduce an additional 'indexation' parameter.

where ϕ^k expresses the probability that $\widetilde{p}_{jt}$ remains in effect (including of indexation) at time $t+k$.

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

$$\begin{aligned} \frac{R_{kt}}{P_t} &= \alpha q_t \frac{y_{jt}}{k_{jt}}; && (16) \\ \frac{W_t}{P_t} &= (1-\alpha) q_t \frac{y_{jt}}{k_{jt}}; && (17) \\ \widetilde{p}_{jt} &= \frac{\theta}{\theta-1} \frac{E_t \sum_{k=0}^{\infty} (\beta\phi)^k (\prod_{s=0}^{k-1} \pi_{t+s}^{-\theta}) \lambda_{t+k} Y_{t+k} q_{t+k} P_{t+k}^{\theta}}{E_t \sum_{k=0}^{\infty} (\beta\phi)^k (\prod_{s=0}^{k-1} \pi_{t+s}^{1-\theta}) \lambda_{t+k} Y_{t+k} P_{t+k}^{\theta-1}}; && (18) \end{aligned}$$

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

Because of the symmetry in the demand they face for their good (12), all firms that are allowed to reoptimize choose the same price $\widetilde{p}_{jt}$, which we therefore denote $\widetilde{p}_t$. Considering the definition of the price index in (13) and the fact that at the economy's level, a fraction $1-\phi$ of intermediate-good producing firms reoptimize, the aggregate price index P_t evolves according to

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

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 us to derive the model's New Keynesian Phillips curve:

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

which relates the present period's deviation of the inflation rate from its average ($\widehat{\pi}_t$) to the expectation of future rates, past values of itself, as well as to the present period's marginal costs ($\widehat{q}_t$), an indicator of the strength of economic activity.[8]

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[8] Starting with Galí and Gertler (1999), a sizeable literature has employed single-equation econometric methods to estimate various specifications of the New Keynesian Philips Curve.

2.4 Fiscal Policy

The government rebates all its taxation revenues back to households in a lump-sum fashion. We thus have the following equilibrium condition:

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

2.5 Monetary Policy

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

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

where r^{ss} denotes the steady-state real rate of interest rate (on a net basis), π_t^T denotes the (net) inflation target of the monetary authority at time t, $\widehat{y}_t$ 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 $0 \leq \rho < 1$ indexes the degree to which the monetary authority wishes to smooth out interest rate movements; this parameter thus measures how fast the desired rate will be achieved. 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).[9] We view these shocks as possessing little persistence and accordingly, we assume that their evolution follows the distribution

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

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

2.6 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

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[9] Considering that control of i_t is achieved by manipulating the aggregate money supply, these shocks could alternatively be caused by imperfect control of the monetary authority over the growth rate of money supply.

monetary policy ($\rho, \lambda_\pi, \lambda_y, \rho_u$, 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 concerning future monetary policy.

The assumption of complete 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 a new central bank head may make a strong aversion for inflation known in public announcements, the lack of precision of these announcements may leave private agents uncertain as what they imply quantitatively for the inflation target. Agents might, as a result, modify their beliefs about the inflation target of monetary authorities only once several periods of lower inflation have been observed. More 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. To illustrate the signal extraction problem this 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:

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

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:

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

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

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

Comparing (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 transitory shock u_t. Specifically, 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 correct mean of u^*.

When complete information is assumed, private agents know the correct mean of the shocks 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^*.[10]

The information friction we assume is slightly different than in Andolfatto and Gomme (2003) and Schorfheide (2005), where the unobserved inflation target has only two possible values. Such a restriction simplifies the learning problem of economic agents and can imply a quick transition of the 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, p. 165).

2.7 Learning

Note that the correct specification for observed policy shocks u_t^* in (27) can be written 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 further that at time t, private agents have initial beliefs over $\mathbf{m}$ 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 over m. Bayesian updating on the sequence of observed shocks to monetary policy u_t^* will lead to the following sequence of posterior distribution of the beliefs:[11]

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

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[10] 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 the realized interest rate. Some empirical estimates of monetary policy rules (Clarida et al., 2000) suggest that such parameter shifts have occurred over the last few decades.

[11] see Hamilton (1994), chapter 12.

where $\mathbf{X}$ is the matrix form of the observations vectors $\mathbf{x}_t$ and $\mathbf{Y}$ denotes the stacked observations over u_t^*. Note that as the confidence over the priors decreases ($\mathbf{M}^{-1}$ decreases), $\mathbf{m}_{t+k}$ simply consists of the *OLS* estimator applied to observed monetary policy shocks.

2.8 Symmetric Competitive Equilibrium

In a symmetric equilibrium, all intermediate goods-producing firms make identical decisions. The 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 good-producing firms optimize, (ii) the monetary policy rule (22) is followed, and (iii) the following market-clearing conditions are satisfied:

$$
\begin{aligned}
k_t &= \int_0^1 k_{jt}\,\mathrm{d}j; && (31)\\
n_t &= \int_0^1 h_{jt}\,\mathrm{d}j; && (32)\\
M_t &= \overline{M_t}; && (33)\\
B_t &= 0; && (34)\\
Y_t &= c_{1t} + c_{2t} + i_t. && (35)
\end{aligned}
$$

3 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, following the method described in King and Watson (2002).[12] Nominal variables such as the price level and the wage rate are transformed so that they become stationary. Numerical values for the model's parameters are set by appealing to direct evidence or in order that the computed steady state replicates features of actual economies.

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

3.1 Preferences and Technology

The model is calibrated to a quarterly frequency. Following Cooley and Hansen (1995), the utility function takes the following form:

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

This formulation of utility incorporates the assumption that labour is indivisible, as featured by Hansen (1985). As shown by Cooley and Hansen (1995), combining (5)-(6), (8)-(9) and (2) 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 0.20, the value used by Cooley and Hansen (1995).

The rate of labour income taxation τ_n is set to 0.2 while that on capital income taxation, τ_k, is 0.4. This follows Cooley and Hansen (1991) and Lucas (1990).

The parameter θ, the price elasticity of demand for each intermediate good, is set to 6. This value, standard in the literature, ensures that the steady-state markup of price over marginal costs is 20 percent. The parameter ϕ, expressing the probability that the nominal price of an intermediate-good producer is not reoptimized, 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. The parameter κ, governing the severity of the adjustment costs in capital accumulation, is set to 2. This value is close to the average estimate from Christiano et al. (2005).

The remaining parameters, β, δ, B, and α are set to that the computed steady state matches the following: a real interest equal to 4 percent per annum, and investment to output ratio of 0.17, labour effort equal to 0.3 of total available hours, and a labour income share in GDP equal to 60 percent. These restrictions imply the following parameter values: $\beta = 0.9854$, $\delta = 0.0212$, $B = 1.9198$, and $\alpha = 0.4$. Finally, note that as written, the model implies that the intermediate-good producers, who operate in a monopolistic competition environment, exhibit positive levels of steady-state profits. To satisfy the requirement that no positive economic profits are maintained in the steady state, we introduce fixed costs of production, in a manner that eliminates these profits in the stationary state.[13]

3.2 The Monetary Policy Rule

According to the rule in (22), the nominal interest rate reacts to the deviations of inflation from its current target (with a 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 sizeable literature that estimates monetary policy rules uses a variety of specifications that sometimes differ significantly from the one we have retained to express monetary policy.[14] Further, some values of the triple (λ_π, λ_y, ρ) 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.

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 the possibility of 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 (Erceg and Levin, 2003; English et al., 2003; Schorfheide, 2005).

The smoothing parameter ρ is 0.5, a value within the range of recent empirical estimates (Erceg and Levin, 2003; Kozicki and Tinsley, 2003; Schorfheide, 2005). Note these empirical exercises allow for the possibility of within-sample 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 (2003). Finally, we consider that true monetary policy shocks have no serial correlation and thus we fix ρ_u to 0. Note that in our sensitivity analysis, we explore the consequences of using different values for ρ, λ_y and λ_π.

3.3 Learning Mechanism

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

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[13] See Christiano et al. (2005) for an illustration.

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

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

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

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. To assign a value to v_1, we follow the strategy of Erceg and Levin (2003) and choose v_1 in order for the learning behaviour of private agents to match some observed features of recent disinflation episodes. Specifically, Erceg and Levin (2003) estimate that during the recent US episodes where inflation was trending down, half of the change in the (implicit) inflation target of the monetary authority appeared to be incorporated in agents' forecasts within one year. We thus set the parameter v_1 for our learning behaviour to roughly match this fact.

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 thus decide whether the observed spike in interest rates arose from a temporary tightening of monetary policy (a positive u_t shock) or rather whether it indicates that the inflation target of the monetary authority has been reduced.

Figure 1 illustrates the resulting evolution of private agents' beliefs over the inflation target. It shows that initially, a small weight is assigned to the possibility that the observed u_t^* resulted from a decrease in the target; agents' beliefs decrease but slightly. Over subsequent periods, repeated observations of positive values for u_t^* lead to additional revisions and the beliefs about the inflation target converge smoothly to the correct, new value of zero. As indicated above, it takes roughly four quarters for the beliefs to reach a half-way point, at which the inflation target is thought to be 1% per annum; it takes around 15 quarters to reach the three quarters mark, where the target rate implied by the beliefs is 0.5% per annum.

3.4 The Economy's Responses Following the Shift

Figure 2 presents the responses of the economy following the decrease in the inflation target. First, the dotted lines indicate the new steady-state values of the variables. As mentioned above, lowering average inflation reduces the distortion imposed on the market economy by the cash-in-advance constraint (or more generally by the requirement that money must be used for certain economic transactions). As a result, households increase their labour market participation and hours worked. This allows production, investment and thus consumption to be permanently higher in the new steady state. For their part, inflation and nominal interest rates are lower by two percentage points.

The full lines of Figure 2 illustrate the paths taken by the economic variables in their transition towards the new steady-state. The inflation target decrease means that initially, nominal interest rates must increase. This interest rate tightening sets in motion a period of reduced economic activity that lasts for about four quarters. For example, this is approximately the time it takes for output to reach back to its pre-shock level. From this point on, the benefits of reduced inflation take hold and labour effort, consumption, output and finally investment smoothly increase towards their new stationary states.[15]

4 Welfare Computations

4.1 Benchmark Model

The welfare benefits that arise from the policy change are computed by comparing the expected lifetime utility of a representative agent living in the stationary state where inflation is $\pi^H = 2.0\%$ with that of another representative agent living in the economy where the switch to $\pi^L = 0\%$ has been implemented. Because differences in indirect utility are difficult to interpret, we express the utility difference in consumption terms. This requires finding the numerical answer to the following question: what percentage increase in consumption would have made households indifferent between remaining in the high-inflation economy at the initial steady state, on the one hand, and living in the new, low-inflation economy, on the other? Mathematically, the goal is to find μ that solves the following equation:

$$E_0 \sum_{t=0}^{\infty} \beta^t u\left[(1+\mu)c_1^H, (1+\mu)c_2^H, n^H\right] = E_0 \sum_{t=0}^{\infty} \beta^t u[c_{1t}^L, c_{2t}^L, n_t^L]. \tag{39}$$

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[15] The new steady state (the dotted lines) is computed separately from the transition paths, which arises 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 never settles further away than a distance of 1% from the new steady state.

The left-hand side of (39) is lifetime utility at the initial, high-inflation steady state, where consumption of both types of goods has been 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 (39) reduces to the following

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

As mentioned in the introduction, this implicitly assumes that the transition to the new, low-inflation steady state has been immediate and costless. In what follows, we report results arrived at by using both (39) and (40).

Table 1 reports our benchmark results. The first column reports the consumption equivalent μ when the comparison between steady states in (40) is used. The table shows that lowering inflation from 2 percent to zero implies significant welfare gains, of the order of 0.26 percent of steady-state consumption. However, the next two columns, using (39) and therefore taking into account the transition from the initial steady state to the new, low-inflation one reduces these welfare benefits very significantly: the benefits when the transition features complete information now amount to only 0.13% of steady-state consumption, which is just below 50% of what they were in the steady-state comparisons; Further, assuming that information is incomplete and Bayesian learning characterizes the transition further reduces the computed benefits, to 0.09% of steady-state consumption, or 35% of what they were in the steady-state comparison.

These benchmark results show that the two reasons mentioned in the introduction for why the transition should be taken into account are important. Even under complete information, the increased work effort and decreased consumption required to accumulate the additional capital entailed by lower inflation cuts the computed benefits by one half. Further, accounting for learning about the new target, a potential result of a communication or credibility gap, further reduces the computed benefits, to the point where they only represent around one third of the figure obtained from the steady state comparison.

4.2 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. The rows of the table each describe the specific departure from the benchmark calibration under study. As in Table 1, the first column indicates the welfare benefits of the shift in inflation target, 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.

The first panel explores whether the results are sensitive to the parametrization of the monetary policy rule. The table clearly shows that it is not the case. While there are some 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 change significantly. Note that what slight changes there are accord well with our expectations. Specifically, 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 be slower to recognize one when it happens: this prolongs the incomplete information transition, thus also reducing 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 $\lambda_\pi = 2.5$) lower only very slight the computed welfare benefits.

The second panel of Table 2 explores whether more important changes to the model, over specific modeling choices, has an impact on the benchmark results (the extensions of the model are cumulative).

The cash-in-advance constraint

The first modeling change is to follow Christiano and Gust (1999) and assume 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 (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 inflation imposes on labour market participation (as was the case in the benchmark model), it replaces it by 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% of steady state consumption. Further, the table shows that the percentage by which these benefits are reduced when the transition is taken into account is even more significant. Notably, when information is incomplete, the computed benefits represent only 18% of the benefits arrived at in the steady state comparison.

Habit Formation

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

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

In this expression, the "credit good" c_2 has been eliminated and the coefficient b indexes the extent to which the habit (represented by last period's consumption) influences the valuation of consumption streams. Following the estimates of Christiano et al. (2005), we set $b = 0.6$.

Table 2 shows that this modeling choice affects both the benefits computed at the steady state and also those that include the transition. Indeed, in the steady state comparison, the reduction in the inflation target is now worth 0.47% in steady state consumption, a number slightly lower than the precedent. However, the reductions in benefits when the transition is taken into account are now greater; in particular an incomplete information transition now produces welfare benefits that are only 18% of those that were computed in the comparison between steady states. 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.[16]

Wage Rigidity

It is often argued in the literature that wage rigidity might be important to generate persistence in the responses of economic variables, particularly inflation, following monetary or technology shocks.

We thus follow Erceg et al. (2000) by assuming that households, like the firms producing intermediate goods, are monopolistic suppliers of their labour and that a similar friction prevents them from fully adjusting their nominal wage every period. This partial adjustment of wages implies a similarly smooth adjustment of the marginal cost relevant to the intermediate good producers following shocks (one important component of this marginal

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[16] This smooth, hump-shapes pattern of consumption is precisely the reason this feature has been traditionally incorporated into dynamic models. See Christiano et al. (2005) for a discussion.

cost is the wage rate) and thus imparts further smoothness to the economy's response.[17]

Following this intuition, Table 2 shows that the transition costs are more important, i.e. there is an increase in the discrepancy between the welfare benefits when steady state comparisons are used and those that arise when the transition is computed. The benefits with the incomplete information environment now constitute only 15% of those computed without transition. Note however that the difference between the full information and the incomplete information transition are reduced, as they were already in the model with habit formation. As we introduce in the model additional factors that are meant to impart smoothness to the responses of the economy to shocks, the full information responses to the target shift themselves become very smooth and thus the difference between full and incomplete information tends 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 fairly limited ranges across the parametrization or the specification of the model. This suggests that the key message of the paper, that the benefits of lower inflation are significantly lower than they might at first appear in comparisons between steady states, is likely to be robust to an even wider battery of model extensions.

5 Conclusion

This paper computes the welfare benefits of a reduction in the monetary authority's inflation target from two percent per annum to zero. Although these benefits may appear to be significant when steady-state comparisons are employed, the paper shows that taking into account the transition from the initial, higher-inflation state to the final, low inflation one reduces the computed benefits very significantly and at least by one half.

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 (income taxation, various nominal frictions and adjustment costs, etc.) that increase the confi-

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[17] See Erceg et al. (2000) for the details concerning the implementation of this extension. A 'Calvo' parameter, similar to the one in the optimization problem of the intermediate-good producers above, need to be calibrated: we follow Christiano et al. (2005) and fix it to 0.6.

dence that can be drawn from its welfare implications. A sensitivity analysis reports that the results are robust to model specification. Specifically, this analysis shows that the welfare estimates are contained within a limited range and that 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.

Some important extensions to the present paper's analysis should be conducted. First, the model should incorporate open-economy features, to verify that the influence of the exchange rate channel to monetary policy actions does not modify the results. Second, the possibility that lowering the inflation target of the monetary authority increases the economic growth should be considered.[18] Further, allowing for such features as downward nominal wage rigidity or the zero 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 one can attach to 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 unreasonable. Nevertheless, lowering inflation may affect the structure of monetary transactions and these changes might be important.[19]

Overall however, our sensitivity analysis suggests that the key message of the analysis –the benefits of lower inflation are probably significantly lower than they appear in steady state comparisons– will be robust to model specifications.[20] This result could be prove useful when larger and more complex models, for which accounting for the transition is not straightforward, are employed for analyzing choices over the proper inflation target.

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[18] Some evidence supporting the latter conjecture is contained in Barro (1996). Computational experiments within fully developed models that allow for this possibility can be found in Gomme (1993), Dotsey and Ireland (1996), and Wu and Zhang (1998).

[19] In a limited way, introducing money through a preference for real money balances in the utility function could allow the structure of monetary transactions to depend on average inflation. A more complete analysis of how inflation affects the structure of these transactions requires a complete model of monetary exchange; see Rocheteau and Wright (2004) for such an analysis that includes comparisons between the steady state implications of different values of average inflation.

[20] The welfare consequences of the transition only depend on the paths taken by consumption and hours worked while converging towards the new steady state, and any successful model is likely to exhibit similar paths for these variables to those featured in Figure 2.

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Table 1. Welfare Benefits from Reducing Inflation from Two Percent to Zero

	Steady-State Comparison	Complete Information Transition	Bayesian Transition
Consumption Equivalent μ	0.26%	0.13%	0.09%
$\diamond$ as a fraction of steady-state comparison	—	0.499	0.353

Table 2. Welfare Benefits from Reducing Inflation from Two Percent to Zero: Sensitivity Analysis

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 A: Alternative Modeling 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%

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[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 modeling extensions are cumulative.

Figure 1: Learning About The Inflation Target

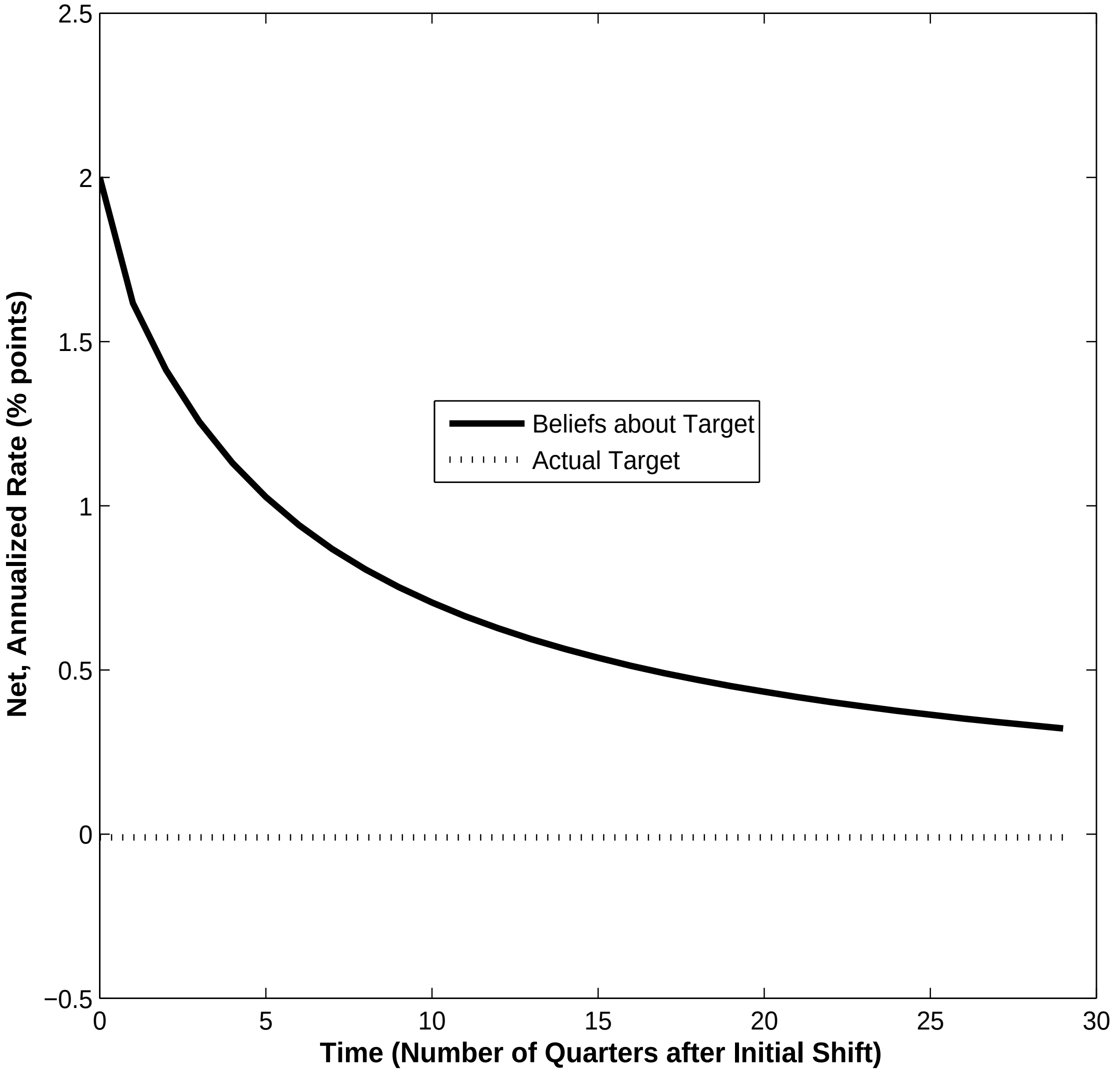

Figure 2: Transition Path Following the Inflation Target Shift

(Shock occurs at $t = 5$)