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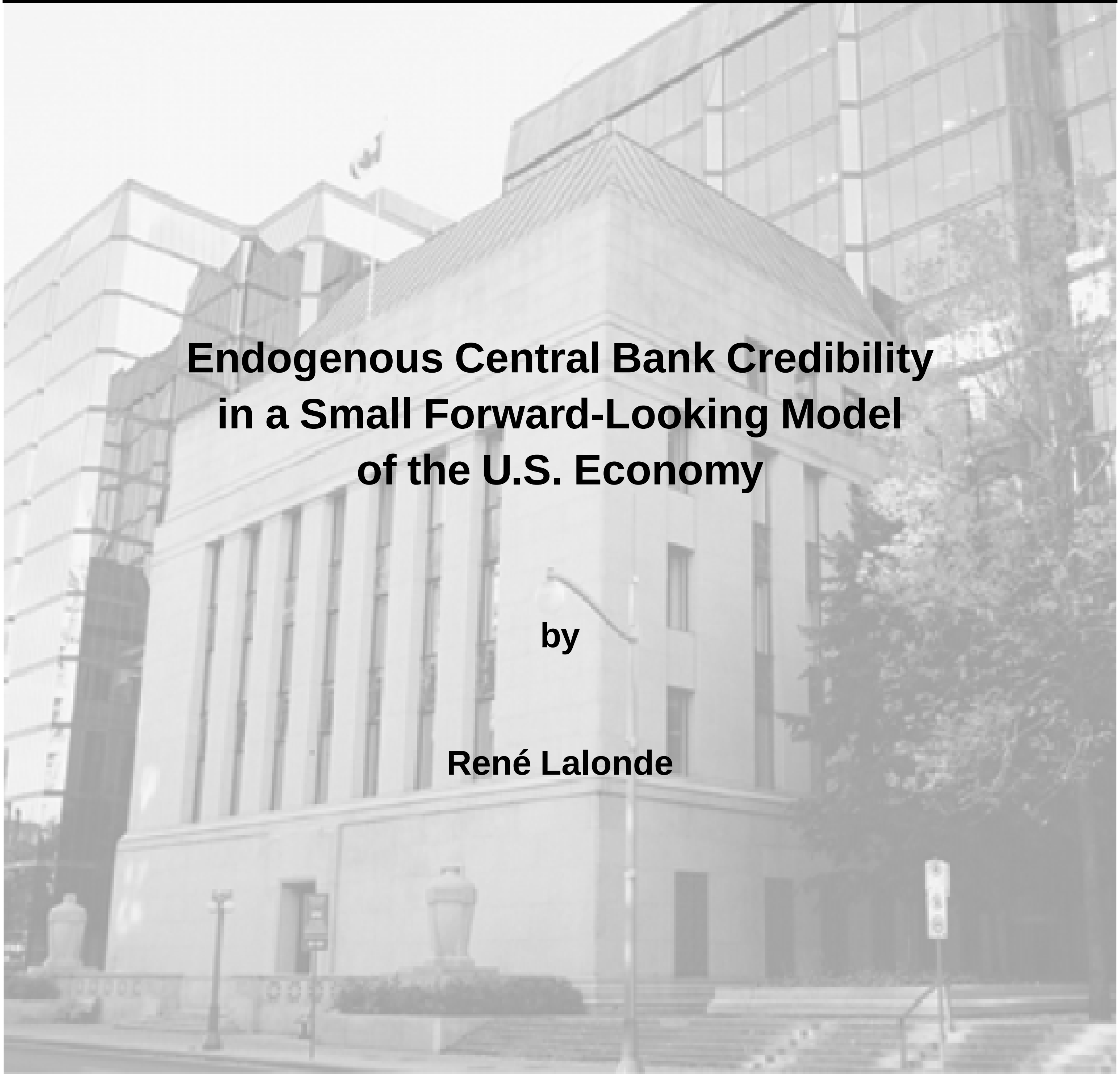

Endogenous Central Bank Credibility in a Small Forward-Looking Model of the U.S. Economy

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The views expressed in this paper are those of the author.
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Abstract

The linkages between inflation and the economy's cyclical position are thought to be strongly affected by the credibility of monetary authorities. The author complements existing research by estimating a small forward-looking model of the U.S. economy with endogenous central bank credibility. His work differs from the existing literature in several ways. First, he endogenizes and estimates credibility parameters, allowing inflation expectations to be a mix of backward- and forward-looking agents. Second, his models include both outcome- and action-based credibility. Third, he estimates a non-linear relation between policy credibility and divergences of inflation from target, which is also assumed to change over history. Finally, the author's non-linear time-varying credibility indexes do not rely on a two-regime definition, but on a continuum of credibility regimes. The author finds strong, stable, and statistically significant outcome- and action-credibility effects that generate important inflation inertia. According to his results, the value of the endogenous credibility indexes has risen steadily across the different monetary policy regimes.

JEL classification: E52, C32
Bank classification: Transmission of monetary policy; Econometric and statistical methods; Inflation and prices

Résumé

Le crédit dont jouissent les autorités monétaires influerait fortement sur la relation entre l'inflation et la position de l'économie dans le cycle. En complément des recherches existantes, l'auteur estime un petit modèle prospectif de l'économie américaine où la crédibilité de la banque centrale est endogène. Son approche se démarque de plusieurs façons de celle de ses prédécesseurs. Tout d'abord, l'auteur endogénéise et estime des paramètres de crédibilité en postulant que les anticipations d'inflation traduisent le fait que certains agents ont un comportement adaptatif et d'autres un comportement prospectif. Deuxièmement, il intègre dans ses modèles deux types de crédibilité : l'une fondée sur les résultats obtenus par les autorités monétaires dans le passé et l'autre sur les effets anticipés de leur action. Troisièmement, il estime une relation non linéaire entre la crédibilité de la politique monétaire et les écarts de l'inflation par rapport à son niveau cible, lequel varie par hypothèse dans le temps. Enfin, l'auteur a recours à des indices de crédibilité non dichotomiques, qui peuvent prendre un continuum de valeurs. Il observe des effets de crédibilité probants, stables et statistiquement significatifs qui induisent une forte inertie de l'inflation. D'après ses résultats, la valeur des indices de crédibilité endogène a augmenté continuellement sous les différents régimes de politique monétaire.

Classification JEL : E52, C32
Classification de la Banque : Transmission de la politique monétaire; Méthodes économétriques et statistiques; Inflation et prix

1. Introduction

The linkages between inflation and the economy's cyclical position are thought to be strongly affected by the credibility of monetary authorities. When confidence in the central bank's ability to maintain its nominal anchor is high, inflation expectations should react less to demand shocks. Given its endogenous nature, the credibility of monetary policy is difficult to model and introduce into both the inflation-generating process and the transmission mechanism. Notwithstanding these difficulties, there are reasons to believe that high policy credibility may partly explain the stability and the low level of inflation observed during the second half of the 1990s, despite the fluctuation of the output gap. This outcome may be the result of a shift to a monetary regime characterized by greater policy credibility.

This paper, like most of the literature, addresses this issue in the context of a Phillips curve. Bomfim and Rudebusch (1998) examine different disinflation strategies in the context of endogenous credibility. They define two concepts of credibility: outcome and action credibility. Outcome credibility is a backward-looking concept in which agents assign a high degree of credibility to the monetary authority if it has recently succeeded in meeting its nominal target (i.e., inflation target). Action credibility is a forward-looking concept in which agents assign credibility if they expect that the central bank will take necessary actions to meet its nominal target in the future. Therefore, outcome credibility relies on the past gap between inflation and its target, whereas action credibility relies on the gap between expected inflation and the target. Although interesting, Bomfim and Rudebusch's paper only postulates that credibility effects exist, rather than test for them. They also assume that the link between credibility and the distance of inflation from its target is linear. Finally, they suppose that credibility is based either on outcomes or actions, but not on a combination of the two.

Isard, Laxton, and Eliasson (2001) estimate a small macro model with endogenous policy credibility. In their model, agents evaluate the probability of being in a regime where long-term inflation is anchored to the target relative to a situation where inflation expectations are anchored to a higher level of inflation. They have a different forecasting rule for the two regimes. Laxton and N'Diaye (2002) estimate models for 17 industrialized countries with endogenous monetary policy designs in a fashion similar to Isard, Laxton, and Eliasson (2001). These models are backward looking and the level of credibility is based on long-run interest rates.

The goal of this paper is to complement existing research by estimating a small forward-looking model of the U.S. economy with endogenous central bank credibility. This paper differs from the existing literature in several ways. First, I *endogenize* and *estimate* credibility parameters, allowing inflation expectations to be a mix of backward-looking and forward-looking agents.

Second, my models include both *outcome*- and *action*-based credibility. Third, I estimate a *non-linear* relation between policy credibility and divergences of inflation from target, which is also assumed to change over history. Finally, the non-linear time-varying credibility indexes presented in this paper do not rely on a two-regime definition, but on a *continuum of credibility regimes*. My goal is not to find the best Phillips curve in terms of forecasting capability, but to find evidence of endogenous credibility. In particular, I seek to identify the impact of outcome and action credibility on the linkages between inflation and the economy's cyclical position.

In my Phillips curve, endogenous credibility is inserted into inflation expectations that are a mix of backward- and forward-looking agents. Inflation expectations are partly a function of a time-varying weight on the inflation target, which fluctuates between 0 and 1. This time-varying weight is a function of the gap between inflation expectations and the inflation target. The link between this gap and credibility is highly non-linear; small gaps have only a small impact on credibility, and large and persistent deviations of inflation expectations from the target can push the credibility index to zero.

My results show strong, stable, and statistically significant outcome- and action-credibility effects that generate important inflation inertia. Inflation reacts weakly to movements of less than 2 percentage points in the output gap, and the link between inflation and the output gap is highly non-linear. According to my results, there is a non-zero explicit weight on the inflation target in inflation expectations for the recent and/or expected gap between the inflation rate and its target of up to 0.8 percentage points (in the case of the consumption deflator), and 1.5 percentage points (in the case of the GDP deflator). Persistent differences between inflation and its target above these values eliminate all policy credibility. In these circumstances, the monetary authority must respond aggressively to return inflation to its target and rebuild its credibility at the cost of lost output and higher variance of key macro variables. According to the results, the value of the endogenous credibility indexes has risen steadily across the different monetary policy regimes. These key results are generally robust to several factors: the estimation period; the specification of the form of credibility (outcome or both outcome and action); the choice of dates of breaks in the level of the nominal anchor; the measure of inflation (consumption excluding food and energy or GDP deflators); and the choice of key disequilibrium variables introduced into the Phillips curve (output or NAIRU[1] gaps).

To draw conclusions on the policy implications of this paper, I would have to generate an optimum monetary policy rule consistent with the Phillips curve presented in this paper. That is left for future research. Nevertheless, I draw the following conclusions for monetary authorities:

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[1] NAIRU: Non-accelerating-inflation rate of unemployment.

- Monetary autorities should account for a potentialy non-linear relationship between inflation and its determinants. As a consequence, linear Phillips curves are likely, ceteris paribus, to overreact to small shocks (to the output gap, price of oil, or exchange rate) and underreact to large shocks. The impact on inflation strongly depends on the conditions under which the shock occurs.
- Even if credibility is very high, central banks should react to any types of shock that affect inflation expectations in order to protect their credibility. The size of the reaction depends strongly on the conditions under which the shock occurs, and on the size and the persistence of the shock. Consider the example of a positive shock to the output gap: if initial credibility is high, the impact on real interest rates will be smaller than if credibility is low when the shock occurs. In the latter case, the monetary authority has to sharply raise real interest rates to regain credibility.

This paper is organized as follows. Section 2 describes the specification of the Phillips curve, including the different credibility indexes and inflation expectations. Sections 3 and 4 describe the IS curve and the reaction function used for simulation purposes only. Sections 5 and 6 show estimation and simulation results, respectively, and section 7 concludes.

2. The Phillips Curve with Endogenous Credibility

I assume a standard Phillips curve, in which inflation is a function of expected inflation, the output gap, changes in the real effective exchange rate, and changes in real oil prices[2]:

$$\pi_t = \pi_t^e + \lambda gap_t + \zeta \Delta er_t + \delta \Delta poil_t . \quad (1)$$

With the exception of expected inflation, the regressors could include both lagged and contemporaneous values.

I assume a constant share of backward-looking agents, β, and a constant share, $(1-\beta)$, of forward-looking agents. Therefore, inflation expectations can be rewritten as follows:

$$\pi_t^e = \beta \pi_{b_t}^e + (1-\beta)\pi_{f_t}^e . \quad (2)$$

Backward-looking agents assign a time-varying weight, ψ_t^b, to the monetary authority's inflation target, π^*, in forming their expectations. Therefore, the weight on the recent inflation rate is $(1-\psi_t^b)$:

---

[2] The output gap used is derived using the methodology of Gosselin and Lalonde (2003). Their approach consists of combining the equilibrium paths generated by a Hodrick-Prescott filter and a structural vector autoregression (SVAR) for labour input and labour productivity. I use the Federal Reserve's inflation-adjusted major currencies index for the real exchange rate.

$$\pi^e_{b_t} = \psi^b_t \pi_t^* + (1-\psi^b_t)\pi_{t-1} . \tag{3}$$

The time-varying weight, ψ^b_t, on the inflation target fluctuates between 0 and 1 (see equation (4)). It is a function of the moving average of the gap between recent inflation and the target (equation (5)), and has the following specification:

$$\psi^b_t = e^{\frac{\left(-\pi^{b\,2}_{g_t}\right)}{2\theta^{b2}}} , \tag{4}$$

$$\pi^b_{g_t} = MA(\pi_{t-1} - \pi^*{}_{t-1}) . \tag{5}$$

The closer the inflation rate is to the target, the greater the weight placed on the inflation target in expected inflation. This is outcome credibility, since it depends on the central bank's ability to meet the inflation target in the past. The time-varying credibility index (ψ^b_t) can be interpreted as the probability that the backward-looking agents expect the monetary policy to meet its target in the near future. The functional form of the credibility index has several implications:

- It is symmetric: the direction of deviation of inflation from its target does not affect the loss of credibility.
- A small deviation of inflation from the target will have less negative consequences on credibility than a more substantial departure.
- The field of application of credibility depends critically on the estimated coefficient, θ.[3] For instance, Figure A1 of Appendix A shows that, if $\theta = 0.25$, a persistent deviation of more than 0.8 percentage points of inflation relative to the target would reduce the weight on the target to practically 0. If $\theta = 0.48$, the same threshold is located at a deviation of 1.5 percentage points around the target.

Given equations (2) and (3), the weight on the target in inflation expectations equals:

$$\beta\psi^b_t . \tag{6}$$

Finally, inflation expectations of the forward-looking agents are model-consistent:

---

[3] If the credibility parameter is close to zero, then the credibility index will be different from 0 and equal to 1 only when there is no gap between the inflation expectation and the target. Furthermore, once inflation expectations deviate by an infinitesimal number from the target, the credibility index will instantaneously fall to 0. Therefore, when the credibility parameter is close to 0, there is no endogeneous credibility effect.

$$\pi^e_{f_t} = E\pi_{t+1}\,. \tag{7}$$

Since backward-looking agents assign some weight to the target, forward-looking agents indirectly put some weight on the target in the formulation of their expectations, because the model-consistent forecast incorporates the behaviour of backward-looking agents. In other words, rational agents must take into account the fact that the backward-looking agents place some weight on the target in their expectations.

It is also possible to directly introduce a weight on the target in the forward-looking expectations. In this case, the type of credibility is called "action credibility," because it depends on the ability of the monetary authority to take the action in order to meet its target in the future. Consequently:

$$\pi^e_{f_t} = \psi^f_t \pi_t{}^* + (1 - \psi^f_t) E\pi_{t+1}\,. \tag{8}$$

The time-varying weight, ψ^f_t, on the inflation target has the same functional form as the outcome credibility (equation (9)). It is a function of a moving average of the gap between the expected inflation rate over the next 4 quarters and the target (equation (10)):

$$\psi^f_t = e^{\frac{\left(-\pi^{f}_{g_t}{}^2\right)}{2\theta^{b2}}}\,, \tag{9}$$

$$\pi^f_{g_t} = MA(\pi_{t+1} - \pi^*{}_{t+1})\,. \tag{10}$$

The action-credibility parameter index, ψ^f_t, can be interpreted as the probability that the forward-looking agents expect the monetary policy to meet its target in the next 4 quarters.

Combining outcome and action credibility creates a total credibility index, which is also the weight on the target in inflation expectations. The total credibility index is equal to:

$$CRED_t = \beta\psi^b_t + (1 - \beta)\psi^f_t\,. \tag{11}$$

Thus, the total credibility index ($CRED_t$) can be interpreted as the probability that all economic agents place on the monetary authorities meeting its target in the near future.

3. The IS Curve

To simulate shocks and examine the behaviour of the economy with endogenous credibility, I estimate an IS curve that captures the monetary policy transmission mechanism. Similar to Gosselin and Lalonde (2003),[4] I use the following specification:

$$\Delta y_t = \phi \Delta y^*_t + (1-\phi)\Delta y_{t-1} - \Omega ygap_{t-1} - \partial(rfed_{t-2} - rfed^*), \tag{12}$$

where Δy_t and Δy^*_t are the growth rates of GDP and potential GDP, respectively. Therefore, for a parameter, ϕ, less than 1, this IS curve features a gradual adjustment of demand to a shock to potential GDP. Monetary policy is one of the mechanisms by which the level of GDP converges to the level of potential GDP. This is done via the second lag of the real federal funds interest rate gap ($rfed_{t-2} - rfed^*$).[5] The equilibrium real interest rate ($rfed^*$) is constant. To account for missing variables or any other adjustment mechanisms that make the level of GDP converge to the level of potential GDP, I introduce a cointegration term between output and potential output into the equation ($ygap_{t-1}$).[6]

4. The Reaction Function

To do simulations and to fully capture the monetary policy transmission mechanism, I use the reaction function estimated by English, Nelson, and Sack (2002).[7] Aside from being forward looking, a necessary condition in this model, this reaction function has many interesting features. First, the monetary authority targets a forward-looking version of the Taylor rule, as in equation (13). Second, it deviates from that rule for two different reasons: because uncertainty surrounding the future path of the economy leads the monetary authority to smooth the profile of interest rates given by the forward-looking Taylor rule (equation (14)), and because the monetary authority often takes unobserved factors, other than the inflation and output gaps, into account when making policy decisions. These factors can contaminate the estimation of a rule that includes only inflation and output gaps. English, Nelson, and Sack therefore introduce autocorrelated errors (equation (15)) to represent these deviations. Finally, according to their results, the monetary authority places more weight on a deviation of inflation from its target than on a deviation of output from potential output:

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[4] Murchison (2001) uses a similar specification.

[5] The use of the second lag may reflect the lag associated with the monetary policy transmission mechanism.

[6] Simulations done with the new Bank of Canada U.S. projection model (MUSE, for Model of the U.S. Economy) in which output is disaggregated generate essentially the same results as those obtained with this simple IS curve. This result indicates that the coefficient of the lagged output gap provides a good approximation of the adjustment mechanisms other than the endogenous response of monetary policy. It also indicates that the monetary policy transmission mechanism is well captured.

[7] I also performed simulations using a simpler reaction function that I have estimated. In this reaction function, the gap between the real interest rate and its equilibrium is a function of the first lag (i.e., smoothing), the contemporaneous output gap, and the gap between inflation expected in 4 quarters (as captured by a survey done by the Federal Reserve Bank of Philadelphia) and the target. Results were almost identical.

$$rnfed^*_t = (1 + rfed^*)(1 + \pi^e_t) + 0.66ygap_t + 2.71E(\pi_{t+4} - \pi^*_{t+4}), \tag{13}$$

$$rnfed_t = (1 - 0.66)rnfed^*_t + 0.66rnfed_{t-1} + \upsilon_t, \tag{14}$$

$$\upsilon_t = 0.67\upsilon_{t-1} + \varepsilon_t. \tag{15}$$

5. Results

5.1 The Phillips curve

To consider the case of outcome credibility, I substitute equations (2), (3), and (4) into equation (1) to obtain:

$$\pi_t = \beta\left(\left(e^{\frac{\left(-\pi^{b}_{g_t}{}^{2}\right)}{2\theta^{b^2}}}\right)\pi_t^* + \left(1 - \left(e^{\frac{\left(-\pi^{b}_{g_t}{}^{2}\right)}{2\theta^{b^2}}}\right)\right)\pi_{t-1}\right) + (1-\beta)E\pi_{t+1} + \lambda gap_t + \zeta\Delta er_t + \delta\Delta poil_t. \tag{16}$$

Parameters β, θ, λ, ζ, and δ are to be estimated. As a proxy for the forward-looking inflation expectations, I use the results of the Inflation Expectations Survey conducted by the Federal Reserve Bank of Philadelphia. To test and identify historical shifts of inflation targets, I use a Bai-Perron test for endogenous structural breaks. The test identifies two breaks: the first in 1983Q1 and the second in 1992Q4 (see Appendix B). Instead of having a complex lag structure, I use moving averages for the output gap, the real effective exchange rate, and the real price of oil.[8] Key results are almost unaffected by the use of moving averages. In the case of the GDP deflator, the output gap is simply introduced in time *t*. Finally, given the non-linear nature of this equation, I estimate equation (16) using non-linear least squares. For the case of combined outcome and action credibility, I substitute equations (2), (3), (4), (8), and (9) into equation (1) to obtain:

---

[8] Moving averages of 4, 5, and 2 lags were used for the output gap, the exchange rate, and the price of oil, respectively.

$$\pi_t = \beta\left(\left(e^{\frac{\left(-\pi_{g_t}^{b\,2}\right)}{2\theta^{b2}}}\right)\pi_t^* + \left(1 - \left(e^{\frac{\left(-\pi_{g_t}^{b\,2}\right)}{2\theta^{b2}}}\right)\right)\pi_{t-1}\right) + (1-\beta)\left(\left(e^{\frac{\left(-\pi_{g_t}^{f\,2}\right)}{2\theta^{b2}}}\right)\pi_t^* + \left(1 - \left(e^{\frac{\left(-\pi_{g_t}^{f\,2}\right)}{2\theta^{b2}}}\right)\right)\pi_{t+1}\right) + \lambda gap_t + \zeta\Delta er_t + \delta\Delta poil_t. \tag{17}$$

Tables 1 and 2 show the estimation results for equations (16) and (17) for the historical periods 1972Q3–2003Q4 and 1979Q3–2003Q4, respectively. These periods are chosen because they show the whole post–Bretton Woods era, 1972Q3–2003Q4, and the Volcker-Greenspan period, 1979Q3–2003Q4. I provide results for two inflation measures: the consumption deflator (excluding food and energy) and the GDP deflator. Because of residual autocorrelation problems, I do not provide results for the regressions using the GDP deflator during the whole post–Bretton Woods period, 1972Q3–2003Q4 (Table 1). Aside from that case, there is no autocorrelation in the residuals. Using generalized method of moments (GMM) estimation, all the regressors are introduced in time *t*.

All the coefficients have the expected sign and are statistically significant. For the two estimation periods, results show that the value of the output-gap parameter (λ) is between 0.11 and 0.13 for the consumption deflator and equal to 0.22 for the GDP deflator.[9] Given the larger variance of the GDP deflator compared with the core consumption deflator, this result was expected. As predicted, the parameter on the real effective exchange rate (ζ) has a negative sign and the coefficient associated with the real price of oil (δ) has a positive sign. For the consumption deflator, the share of the backward-looking agents (β) is around 75 per cent for the post–Bretton Woods period as a whole, and between 56 and 58 per cent for the Volcker-Greenspan period. For the GDP deflator, this share is 66 per cent.

The key credibility parameter (θ) is roughly equal to 0.25 for the consumption deflator (for both the post–Bretton Woods and Volcker-Greenspan periods) and between 0.38 and 0.48 for the GDP deflator. The finding that the credibility parameter is larger for the GDP deflator was expected, given the larger variance of the GDP deflator than the core consumption deflator. The GDP deflator credibility parameter is 72 per cent higher than the one obtained with the core consumption deflator. Furthermore, the output-gap parameter associated with the GDP deflator is 66 per cent higher than with the case of the consumption deflator. Consequently, a shock to the output gap will have almost the same effect on the time-varying credibility index (ψ_t) in both price deflators. The higher credibility parameter is almost perfectly cancelled by a higher output-gap parameter.

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[9] These results are consistent with those found by Kozicki and Tinsley (2002) and Dupuis (2003).

The credibility parameters are almost unaffected by the assumption I make on the type of credibility (outcome credibility or combined outcome and action credibility). I find the biggest difference for the GDP deflator (0.38 vs. 0.48). Finally, as Appendix C shows, the key parameters are very stable across the last inflation-target regime (1992Q4–2003Q4). The results are qualitatively the same if I introduce the two permanent changes in the inflation target up to 8 quarters before the date given by the Bai-Perron structural break tests. Concerning outcome credibility, results are also almost unaffected if I exclude the forward-looking agents from the model (when beta is equal to 1).

Table 1: Phillips Curve Estimation (1972Q3–2003Q4)

Parameters	Estimated coefficients (*T*-statistic)			
	Outcome credibility		Outcome and action credibilities	
	Consumption deflator	GDP deflator	Consumption deflator	GDP deflator
λ	0.118 (4.01)	-	0.121 (4.10)	-
ζ	-0.063 (-4.21)	-	-0.061 (-3,99)	-
δ	0.019 (2.79)	-	0.020 (2.81)	-
β	0.755 (10.65)	-	0.746 (10.88)	-
θ	0.259 (3.92)	-	0.269 (4.05)	-
LB-Q(1) LB-Q(4) LB-Q(8)	0.49 0.67 0.49	-	0.60 0.77 0.58	-

To summarize, I find an important and statistically robust credibility effect. In the case of the consumption deflator, θ equals 0.25 and β equals 0.6. A persistent deviation of more than 0.8 percentage points of inflation relative to the target will make the credibility index almost equal to zero, as shown by the solid line in Figure A1 of Appendix A. Once the inflation rate expectation deviates by more than 0.5 percentage points from the target, the value of the time-varying credibility index is nevertheless very small. Thus, the zone where monetary policy has a "quasi" free lunch is fairly small. The zone is somewhat larger in the case of the GDP deflator, shown by the dashed line in Figure A1 of Appendix A, but the variance of the GDP deflator is also bigger than the variance of the core consumption deflator. In that case, θ equals 0.48 and β equals 0.66, and I find that a persistent deviation of more than 1.5 percentage points (instead of 0.8) of inflation relative to the target will make the credibility index almost zero. Nevertheless, once the inflation rate deviates by more than 1.0 percentage point from the target (instead of 0.5), the weight on the target is negligible.

Table 2: Phillips Curve Estimation (1979Q3–2003Q4)

Parameters	Estimated coefficients (*T*-statistic)			
	Outcome credibility		Outcome and action credibilities	
	Consumption deflator	GDP deflator	Consumption deflator	GDP deflator
λ	0.116 (3.49)	0.190 (7.83)	0.130 (4.11)	0.218 (7.35)
ζ	-0.080 (-5.75)	-0.107 (-3.85)	-0.076 (-5.27)	-0.097 (-3.75)
δ	0.008 (1.17)	-	0.010 (1.46)	-
β	0.560 (6.16)	0.662 (8.28)	0.581 (6.76)	0.658 (7.26)
θ	0.217 (2.92)	0.377 (4.95)	0.254 (3.26)	0.481 (5.14)
LB-Q(1)	0.74	0.68	0.96	0.83
LB-Q(4)	0.69	0.32	0.73	0.41
LB-Q(8)	0.52	0.26	0.47	0.39

Figure A2 of Appendix A shows the historical path of the outcome credibility index based on the consumption deflator. As estimated, the key credibility parameter (θ) is fixed at 0.25 per cent. As expected, before 1982, credibility is very low. I also find that the credibility index is quite variable across history.[10] Recall that the credibility index corresponds to the probability that the monetary authority will meet its target in the near future, not at the steady state. Nevertheless, simulation results provided in section 6 show that, even if θ equals 0.25, the impact of endogenous credibility on the economy is very important. The credibility index becomes more stable once I introduce both outcome and action credibility together. The results are shown in Figure A3 of Appendix A: the GDP deflator action- and outcome-credibility index (i.e., $CRED_t$) is less volatile, because both the forward- and backward-looking agents put some explicit time-varying weights on the inflation target.

Table 3 shows that the average values of the credibility indexes have risen steadily across the different monetary policy regimes. The average value of the action- and outcome-credibility index (i.e., $CRED_t$), computed with the GDP deflator, was 0.21 between 1972Q2 and 1979Q2. During the Volcker period, the index rose by 71 per cent to reach 0.36. Finally, since Greenspan has been Chairman of the Board of Governors of the Federal Reserve, the index has risen by another 102 per cent and equalled, on average, 0.73. To a lesser extent, I find similar results for the outcome credibility index computed with the consumption deflator. Table 3 also shows that, during the second half of the 1990s, the so-called U.S. miracle period, monetary policy credibility was very high.

Table 3: Evolution of Credibility Indexes (see Appendix B)

Period	Average value of credibility indexes	
	GDP deflator action and outcome credibility	Consumption deflator outcome credibility only
1972Q2–1979Q2	0.21	0.27
1979Q3–1987Q2	0.36	0.47
1987Q3–2003Q4	0.73	0.66
1995Q1–2000Q4	0.79	0.56

---

[10] The variability of the credibility index depends critically on the value of the credibility parameter (θ). With a value of 0.25, as in the case of the consumption deflator, any persistent deviation of the inflation expectation from the target larger than 0.50 percentage point will drop the value of the index to less than 0.1, close to the minimal value. Such episodes occurred even in the post-1996 period, but they were not very persistent.

5.2 The IS curve

Table 4 reports results of the small IS curve. Despite the simplicity of the IS curve, the R^2 is surprisingly high and there is no correlation in the residuals. The results confirm that demand adjusts gradually to a shock to potential output ($\phi = 0.77$). The coefficient of the real interest rate gap is highly significant and negative. The fact that the coefficient associated with the lag of the output gap is negative and statistically significant means that there are factors other than monetary policy that make the level of real GDP converge to the level of potential GDP. The gradual adjustment of wages and prices, the real exchange rate, and fiscal policy could be among those factors. Therefore, aside from fiscal policy, it is fair to say that these factors are mainly linked to market-driven/endogenous adjustment mechanisms.

Table 4: The IS Curve (dependent variable: Δy_t)

Regressors	Coefficients	*T*-statistic
Δy_{t-1}	0.225	-
Δy^*_t	0.775	7.49
$ygap_{t-1}$	-0.112	-2.85
$(rfed_{t-2} - rfed^*)$	-0.129	-2.65
R^2		0.310
LB-Q(1): LB-Q(4): LB-Q(8):		0.97 0.30 0.33

6. Simulations

The purpose of the simulations presented in this section is to analyze the impact of non-linear endogenous credibility on the behaviour of inflation, the interest rate, and the output gap. More specifically, I seek to answer the following questions:

- Given the non-linear feature of endogenous credibility, what deviation of output from potential is needed to induce a large deviation of inflation from the target? What size of shock is needed to significantly reduce credibility? In that context, how much larger does the monetary reaction need to be to restore credibility, and at what price, in terms of deviation of output and inflation from their targets?

- With high initial credibility, what deviations of output from potential are relatively benign for inflation?
- When the initial level of credibility is high, does the monetary authority need to react to a small shock to the output gap?

This section is divided into three subsections. The first deals with some calibration issues. The second reports the results. The last addresses some issues regarding the specification of the IS curve.

6.1 Calibration

To simulate the model, I set the values of the key parameters (see Table 5). I calibrate the model according to the results obtained with the consumption deflator because it is the price deflator that the Federal Reserve focuses on. As stated in the previous section, if the model was calibrated based on the estimates of the GDP deflator model, the conclusion would be almost identical, because the larger coefficient of the output gap in the Phillips curve would almost perfectly offset the higher credibility parameter. Consequently, a shock to the output gap will have almost the same effect on the time-varying credibility index in both price deflators.

Based on the estimation results in Tables 1 and 2, the share of backward-looking agents is set to 60 per cent and the credibility parameter is set to 0.25. I choose an equilibrium real interest rate of 2.8 per cent and an inflation target of 2.0 per cent. For the purpose of these simulations, the calibration of the growth rate of potential GDP is irrelevant. Furthermore, unless I analyze the issue of a lower nominal interest rate bound, calibration of the equilibrium interest rate and inflation target is also irrelevant.

Table 5: Calibrated Values

Parameters	Calibrated values
λ	0.13
β	0.60
θ	0.25
ϕ	0.75
Ω	-0.11
∂	-0.13
$rfed^*$	2.80
π^*	2.00

6.2 Non-linearity and response of the model to different shocks to the output gap

This section illustrates the non-linear impacts of endogenous credibility on macroeconomic outcomes by presenting simulations using output-gap shocks of different sizes in a model that includes only outcome credibility. The key parameters are calibrated according to the values reported in Table 5. Appendix D shows the response of the model to a positive, 1 percentage point shock to the output gap. The economy is initially at steady state, the output gap is equal to 0, the inflation rate and the inflation expectation are equal to the target, and the real interest rate is equal to the equilibrium values. Therefore, before the shock occurs, credibility is perfect (credibility indexes are equal to 1). These initial conditions explain why the shock to the output gap induces only a small increase in inflation (0.16 per cent). The impact on inflation is so small that the inflation rate stays in the high-credibility zone. The monetary authority achieves this result, partly because of its initial high credibility and also because it protects its credibility by increasing the real interest rate by close to 75 basis points. Therefore, the 1 per cent shock to the output gap has only a small negative effect on the credibility index.

Appendix E shows the response of the models to a positive, 2 percentage point shock to the output gap. This shock pushes the inflation rate into a zone that begins to endanger the credibility of the monetary authority. The credibility index falls by 40 per cent. Appendix F shows the response of the model to a positive, 3 per cent shock to the output gap. This shock is large enough to push the inflation rate into a zone where the credibility is almost completely lost. The weight on the target falls to almost zero. To regain credibility by pushing the inflation rate closer to the target, the monetary authority has to increase the real interest rate by close to 250 basis points.

Appendix G shows that the effect of an output-gap shock on the inflation rate is highly non-linear and strongly depends on the conditions of the economy before the shock occurs. In this appendix, I show the result of three different simulations. All these simulations illustrate the response of the model to a positive, 1 per cent shock to the output gap, but they use different initial conditions. In the first simulation (solid lines), the economy is initially at its steady state, the inflation rate is equal to its target, and credibility is at its maximum. The second simulation (dotted lines) starts with an initial excess demand of 1 per cent and the third (dashed lines) at an initial excess demand of 2 per cent. Appendix G shows the results for outcome credibility.

For the outcome-credibility model, if the shock to the output gap occurs in a situation where the economy is at steady state (solid lines) and credibility is high, its impact on inflation is small, with a peak response of only 0.16 per cent. As noted earlier, the monetary authority achieves this result partly because of its high credibility and also because it protects its credibility by raising the real interest rate by close to 75 basis points. If the same shock occurs when the economy is already in excess demand of 2 per cent and credibility is low, the peak response of inflation is 0.50 per cent (instead of 0.16). In this situation, inflation is already high relative to the target when the shock occurs. Therefore, the weight on the target in inflation expectations is low. In fact, the shock further decreases credibility by almost 70 per cent. The monetary authority does not get any "free lunch." To regain credibility by pushing the inflation rate to a level consistent with the initial conditions (excess demand of 2 per cent), the monetary authority has to increase the real interest rate by close to 125 basis points (instead of 75 when the economy is initially at steady state).

6.3 Convergence of the level of real GDP to the level of real potential GDP

In the model, two different channels make real GDP converge to real potential GDP—the monetary policy and the "natural" adjustment mechanisms—but only monetary policy makes the inflation rate converge to the target. What happens if monetary policy is the only channel by which both real GDP and inflation converge to the steady state? Simulation results shown in Appendixes H and I try to answer this question. Appendix H shows, using the outcome-credibility model, the responses of the output gap, the inflation rate, and the real interest rate to a 1 percentage point shock to the output gap with and without the economy's "natural" adjustment mechanisms in effect; i.e., setting $\Omega = -0.11$ or $\Omega = 0$, respectively. Because some adjustment mechanisms are turned off, and because it takes time for monetary policy to affect output, the response of the output gap (and therefore the inflation rate) to the shock is quite persistent.

Furthermore, because all the adjustment depends on monetary policy, the response of the real interest rate is also larger and more persistent. Overall, for a shock of that size, the outcome is nevertheless benign. Even if the "natural" adjustment mechanisms are turned off, the peak response of inflation to a 1 percentage point shock to the output gap is only 0.24 percentage point, instead of 0.16. The situation is different for a larger shock. Indeed, Appendix I shows that, if I exclude the natural adjustment mechanisms from the model, a shock of 2 per cent on the output gap has a bigger impact on inflation than a shock of 3 per cent when these mechanisms are present. Therefore, without natural adjustment mechanisms, the economy can more rapidly reach the level of deviation of inflation from its target where there are important negative effects on the credibility of the monetary authority.

7. Conclusion

In this paper, I have found strong, stable, and statistically significant outcome- and action-credibility effects. These effects contribute to creating important inertia and small fluctuations in inflation for cycles of the output gap smaller than about 2 percentage points. Therefore, in these models the link between inflation and the output gap is strongly non-linear. According to my results, there is a non-zero weight on the target in the inflation expectation for a recent and/or expected gap between the inflation rate and the target of up to 0.8 per cent (for the consumption deflator) and 1.5 percentage points (for the GDP deflator). Any persistent gap higher than these values eliminates the credibility effect on inflation. In these circumstances, monetary policy will have to work harder to achieve its target and to rebuild its credibility at a higher cost in terms of lost output and higher variance of key macro variables. When I allow for joint outcome and action credibility, I find that, during the so-called U.S. miracle period (the second half of the 1990s), the Federal Reserve Bank's credibility was very high (0.79 per cent). Given the simulation results reported in this paper, this could, at least partly, explain why there was an apparent weakening of the link between the output gap and the inflation rate over that period.

Further research needs to be done on the topic of endogenous credibility. First, methods other than the Bai-Perron endogenous structural break test could be used to identify the historical changes in inflation targets. Second, functional forms other than the normal distribution for the time-varying weight on the inflation target could be used: for example, asymmetric distribution where agents assign more weight to a positive than to a negative deviation of inflation from the target. Third, the approach used in this paper could be applied within a Neo-Keynesian Phillips curve that is based on marginal cost instead of the output gap. Finally, it would be interesting to identify the optimal monetary policy rule that corresponds to the endogenous monetary policy credibility Phillips curve presented in this paper.

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Appendix A: Endogenous Credibility Effect

Figure A1: Credibility Index and the Gap Between the Inflation Expectation and the Target

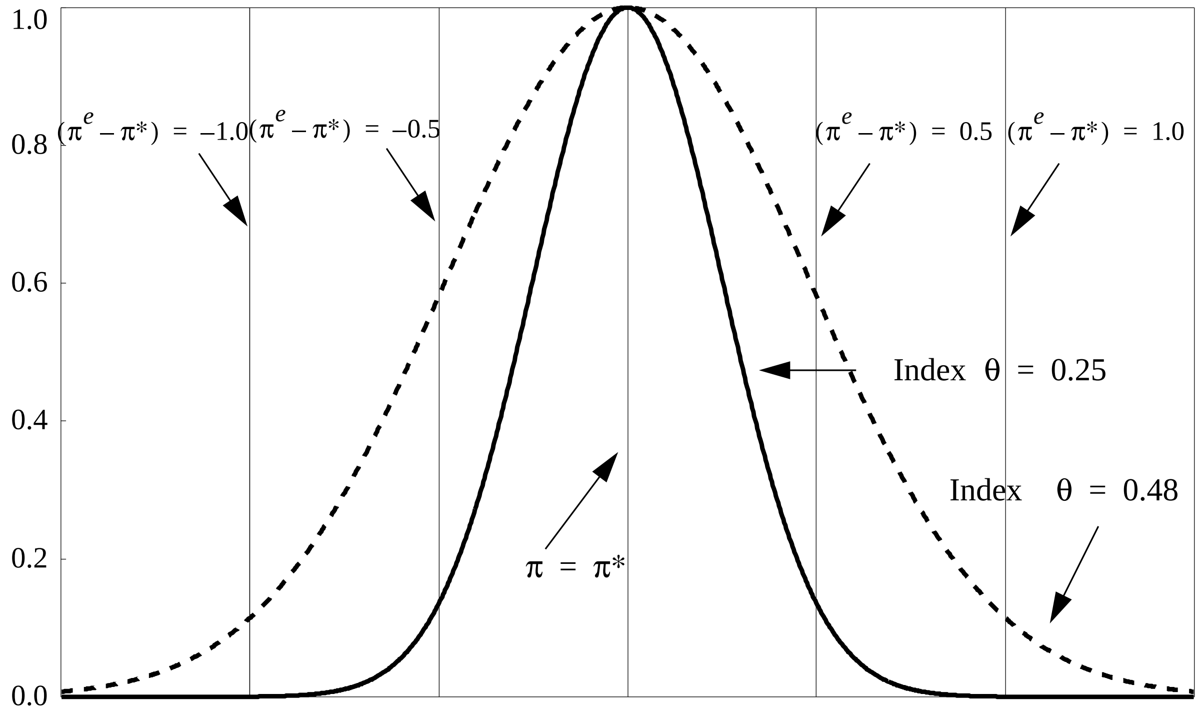


Figure A2: Consumption Deflator: Historical Path of the Credibility Index (Outcome Credibility)

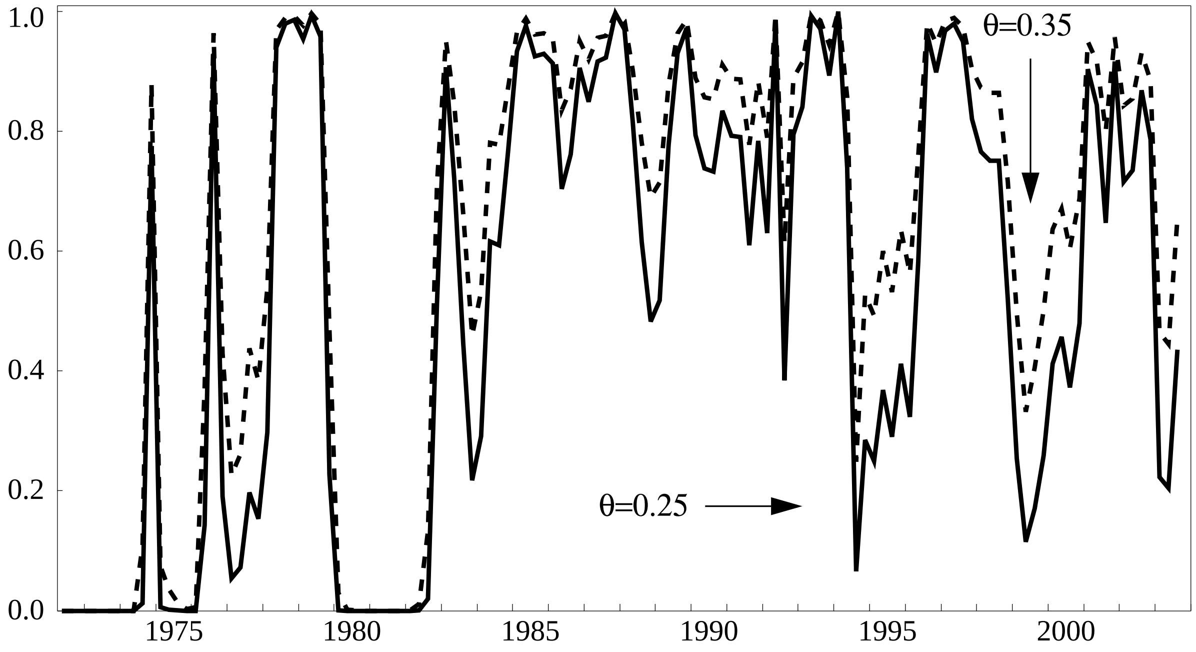
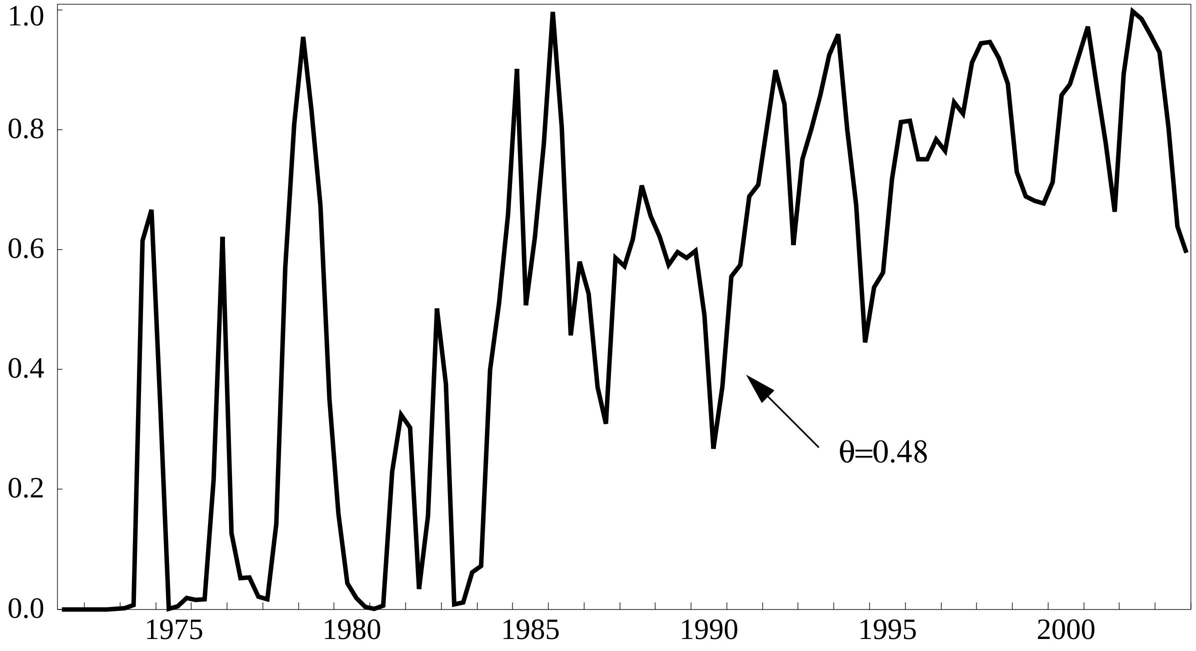


Figure A3: GDP Deflator: Historical Path of the Credibility Index (Outcome and Action Credibility)



Appendix B: Bai-Perron Endogenous Structural Break Tests and the Gap Between the Inflation Rate and the Target

Figure B1: Inflation Rate and Inflation Target (Bai-Perron Endogenous Structural Break Approach)

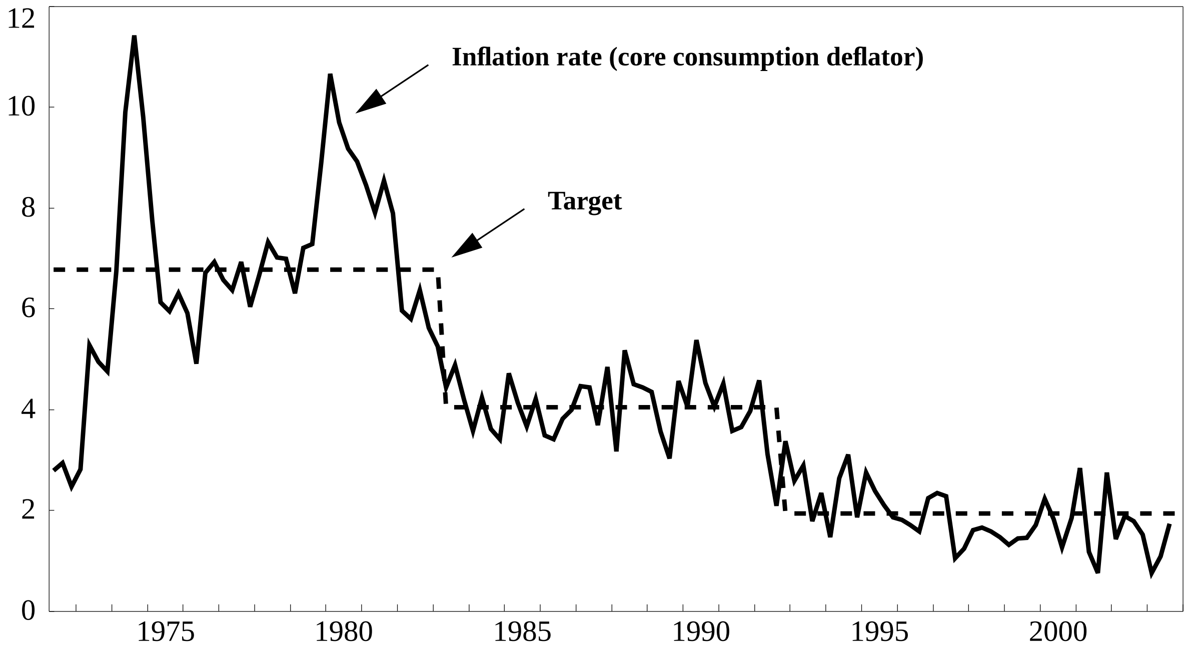
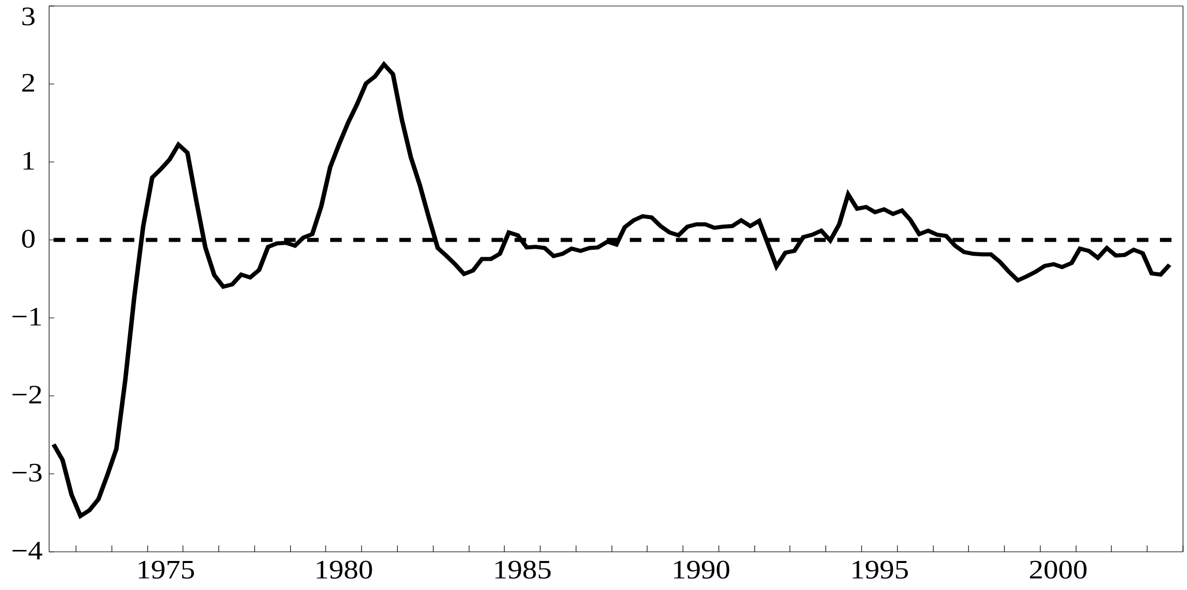


Figure B2: Eight Quarters Moving Average of the Gap Between the Inflation Rate and the Target



Appendix C: Parameter Stability

Figure C1: Parameter Stability (Rolling Regressions, 1992Q4–2002Q3)

Consumption deflator (beginning of estimation 1972Q3)

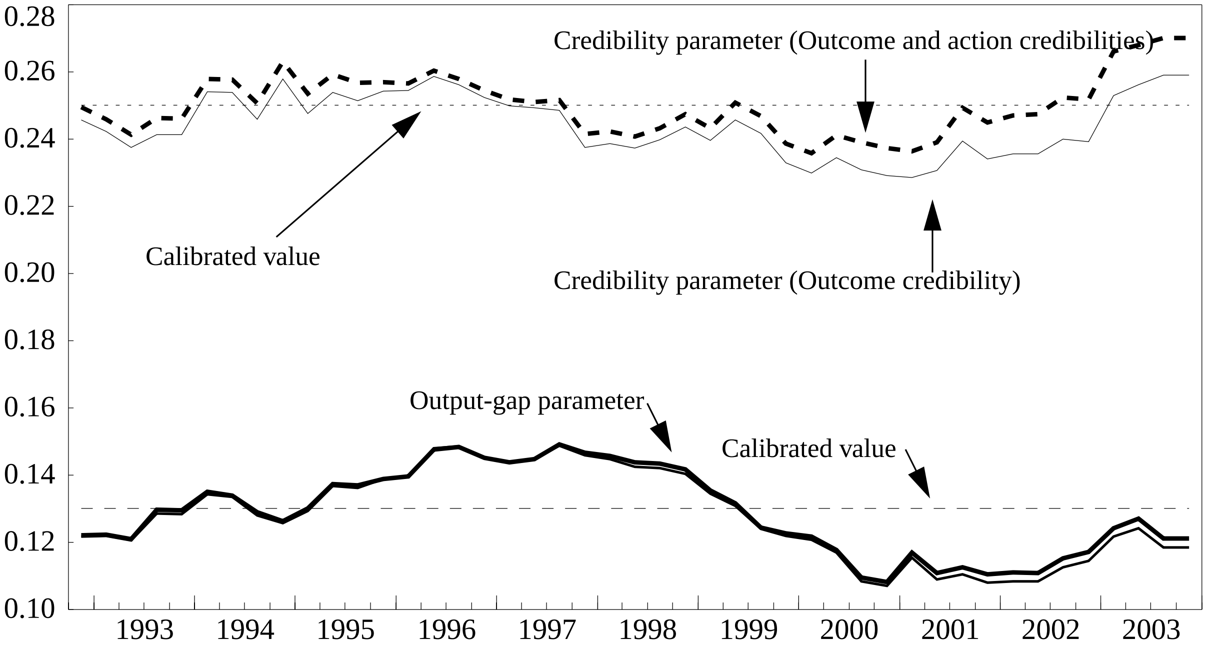
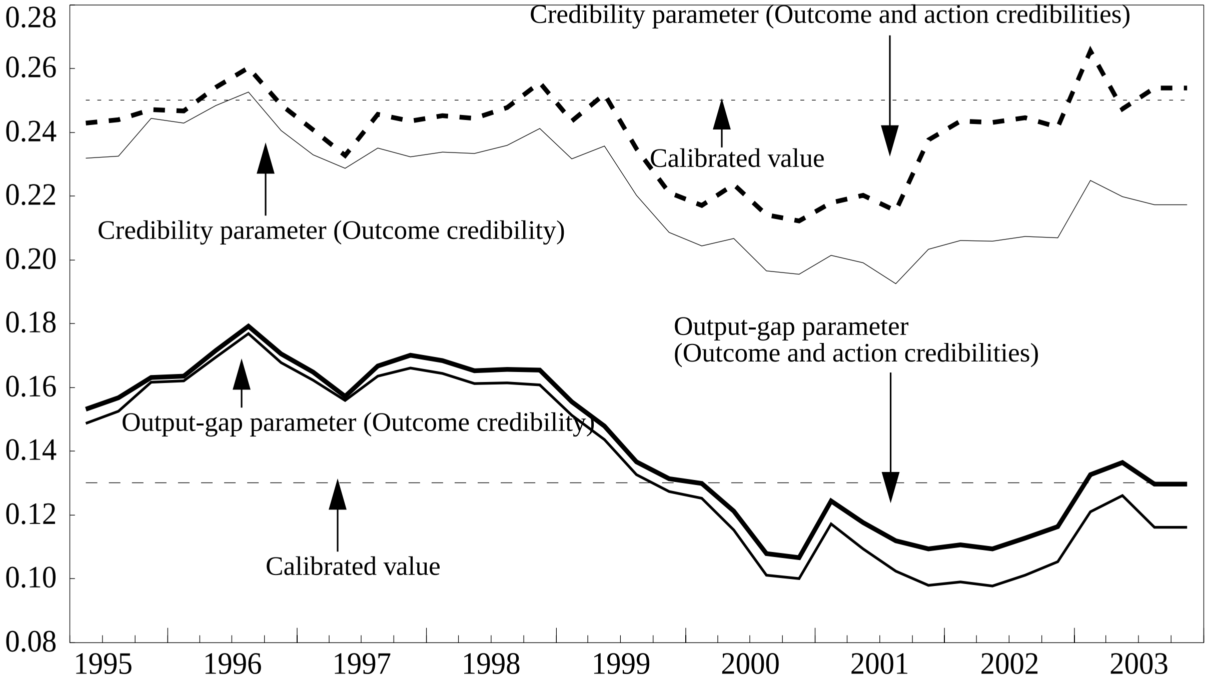


Figure C2: Parameter Stability (Rolling Regressions, 1995Q2–2002Q3)

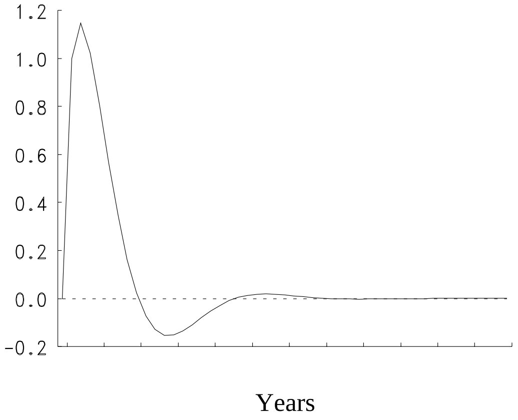
Consumption deflator (beginning of estimation 1979Q3)



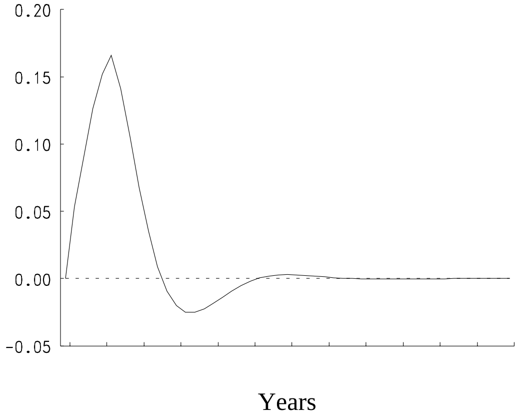
Appendix D: Outcome Credibility

Results from a 1 per cent demand shock (all in shock minus control)

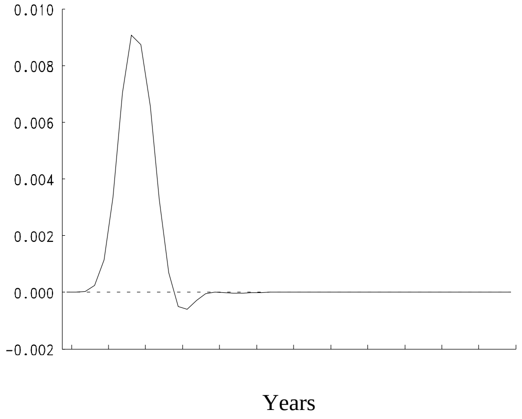
Output Gap (1%=1)



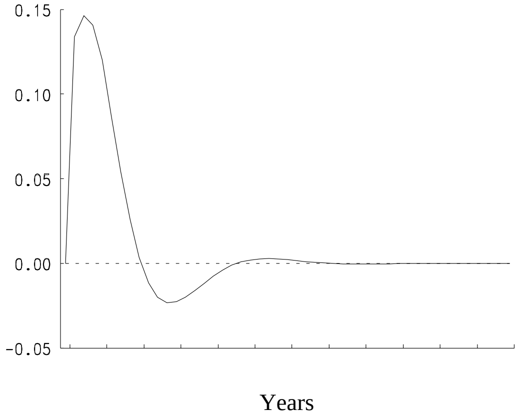
Reference Inflation Rate (Q/Q at annual rate; 1%=1)



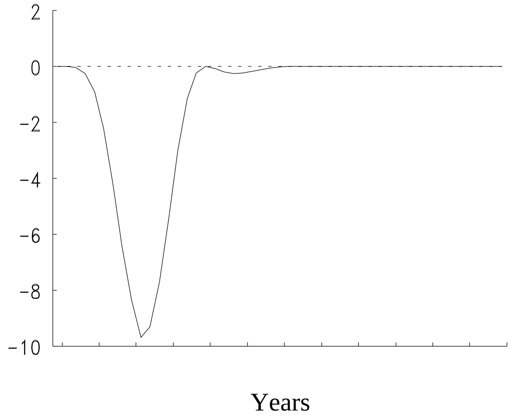
Inflation Expectation: Backward-Looking Agents (1%=1)



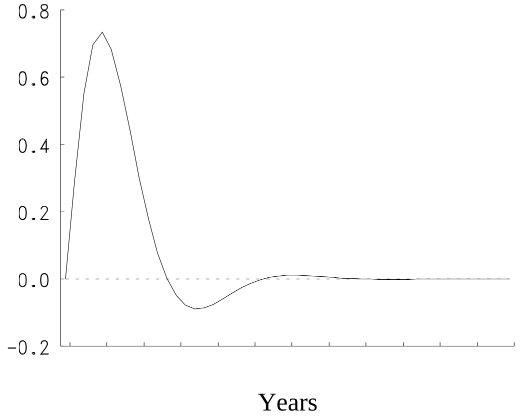
Inflation Expectation: Forward-Looking Agents (1%=1)



Effect on Credibility (1%=1)



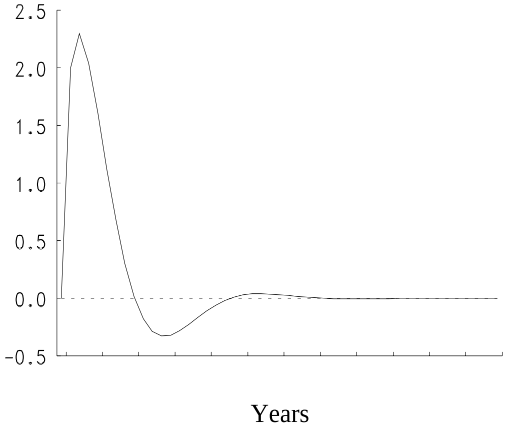
Real Fed Fund Interest Rate (100 bp = 1)



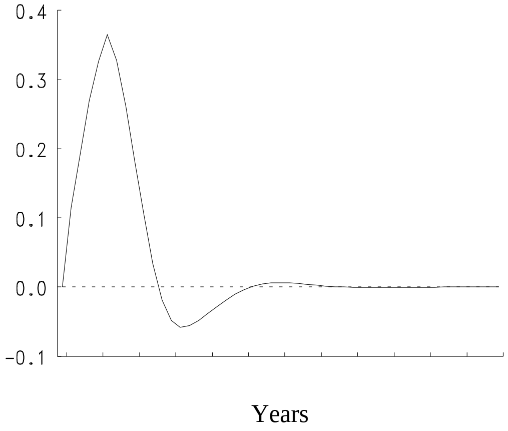
Appendix E: Outcome Credibility

Results from a 2 per cent demand shock (all in shock minus control)

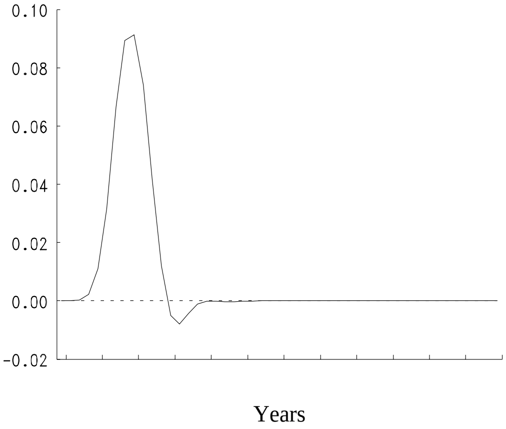
Output Gap (1%=1)



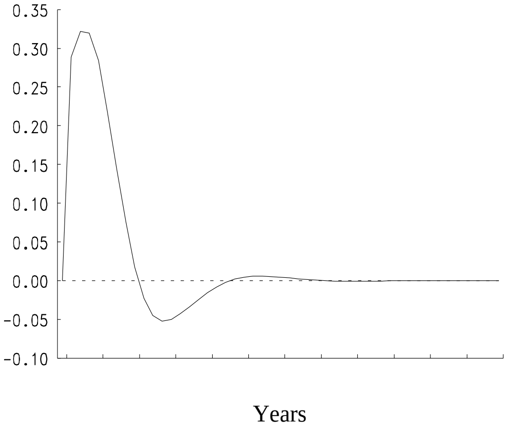
Reference Inflation Rate (Q/Q at annual rate; 1%=1)



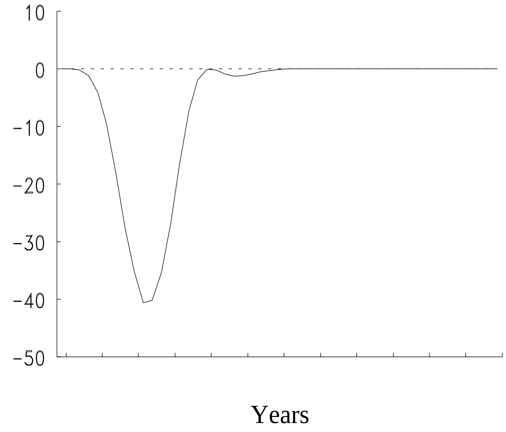
Inflation Expectation: Backward-Looking Agents (1%=1)



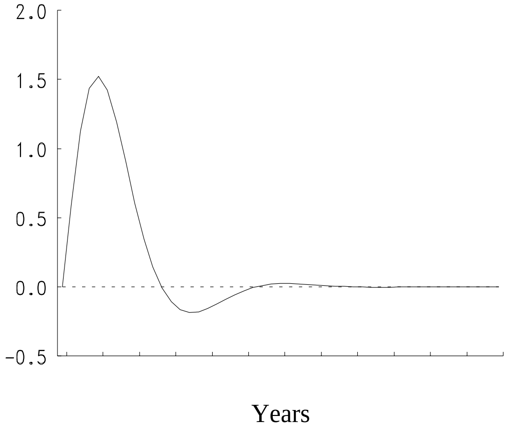
Inflation Expectation: Forward-Looking Agents (1%=1)



Effect on Credibility (1%=1)

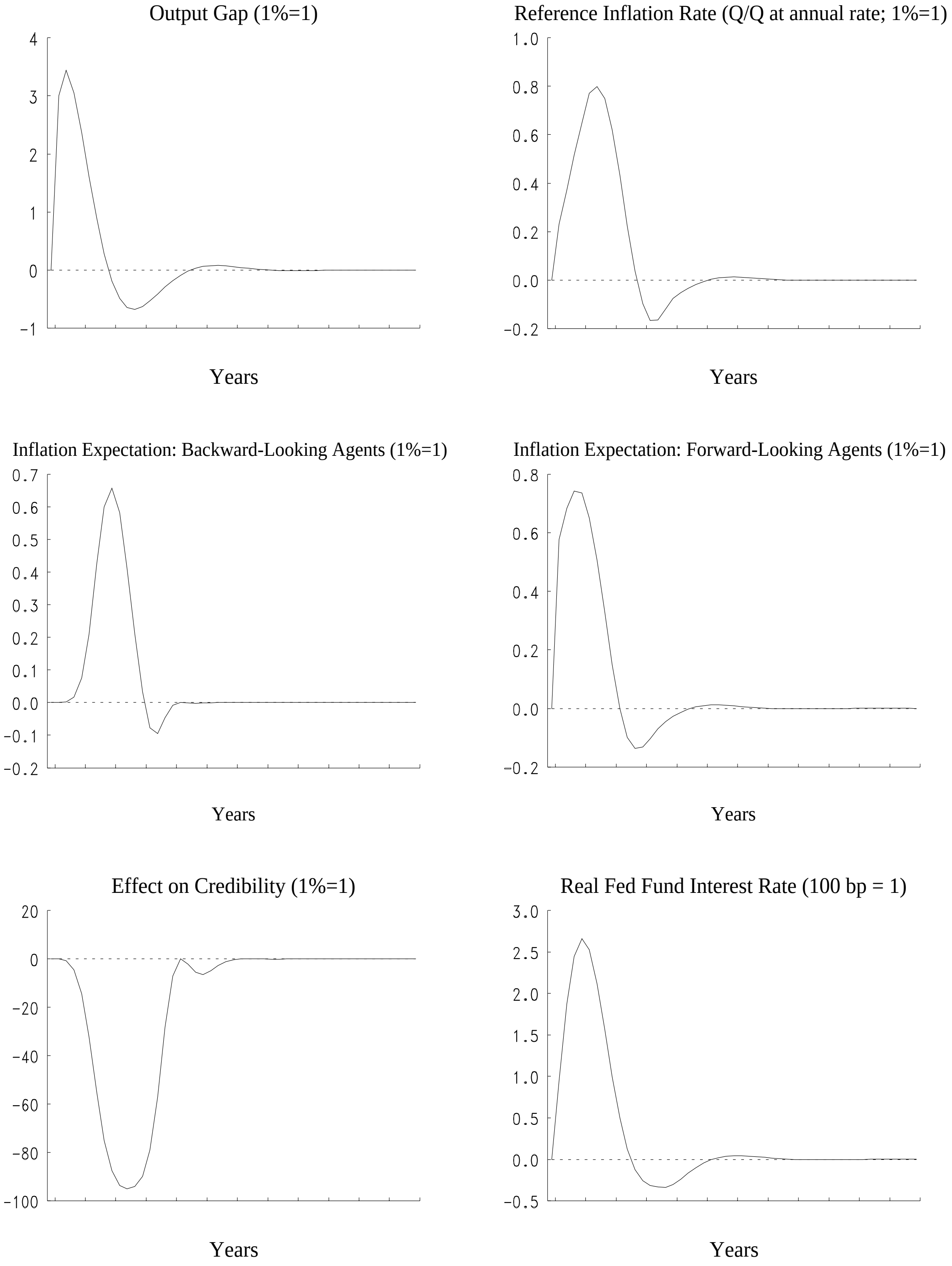


Real Fed Fund Interest Rate (100 bp = 1)



Appendix F: Outcome Credibility

Results from a 3 per cent demand shock (all in shock minus control)

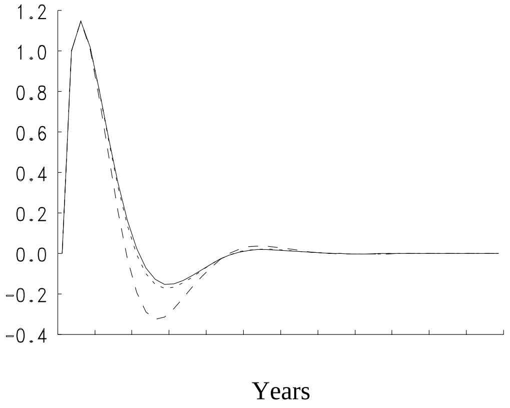


Appendix G: Outcome Credibility

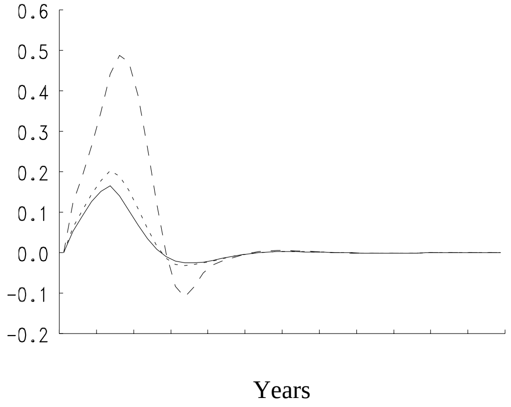
Endogenous Credibility Effect, Non-linearity and Initial Conditions

Results from a 1 per cent demand shock (all in shock minus control)
Initial conditions: Solid=Steady state, Dotted=Excess demand of 1%,
Dashed=Excess demand of 2%

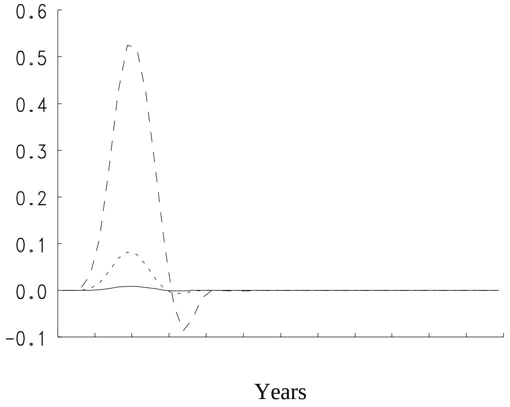
Output Gap (1%=1)



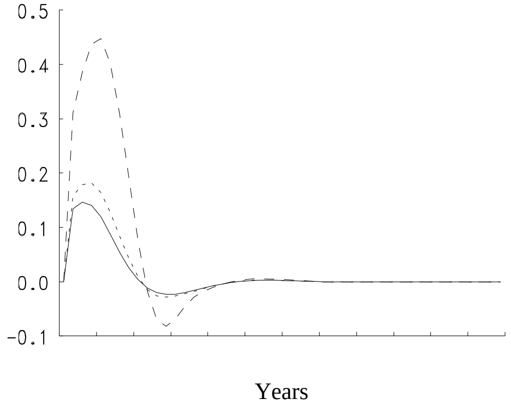
Reference Inflation Rate (Q/Q at annual rate; 1%=1)



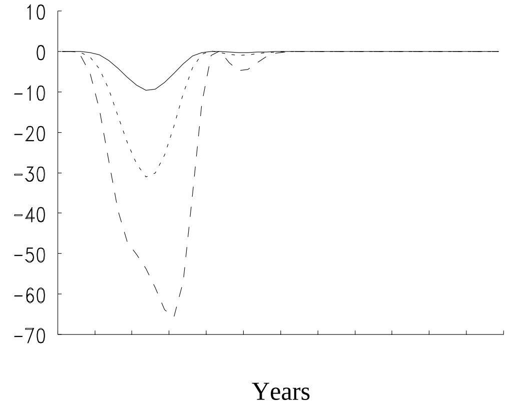
Inflation Expectation: Backward-Looking Agents (1%=1)



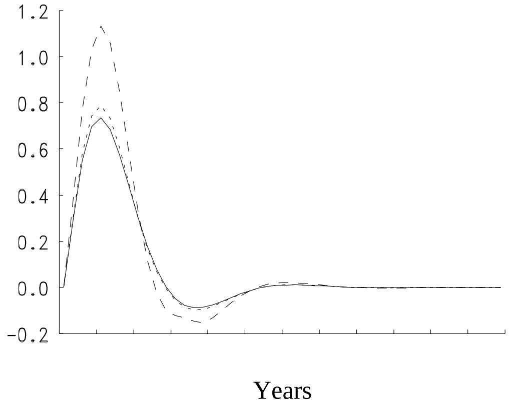
Inflation Expectation: Forward-Looking Agents (1%=1)



Effect on Credibility (1%=1)



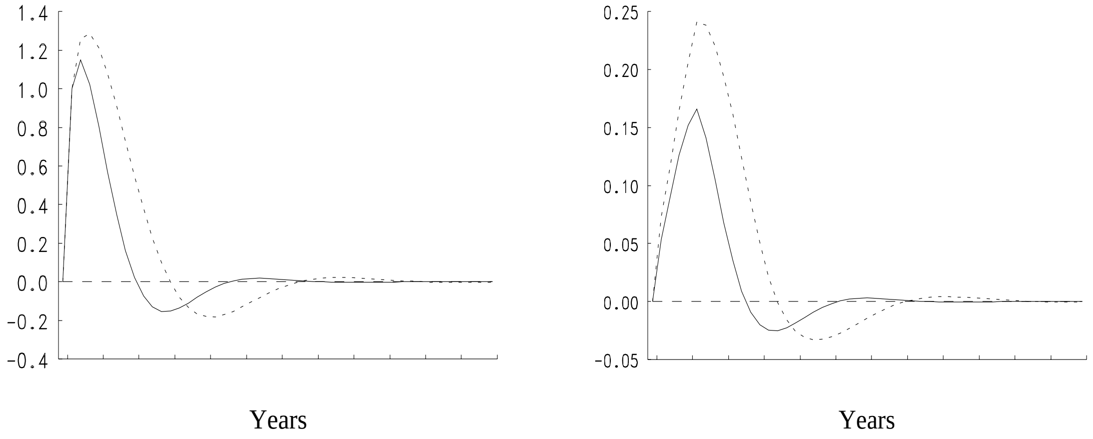
Real Fed Fund Interest Rate (100 bp = 1)



Appendix H: The Convergence of the Real Economy

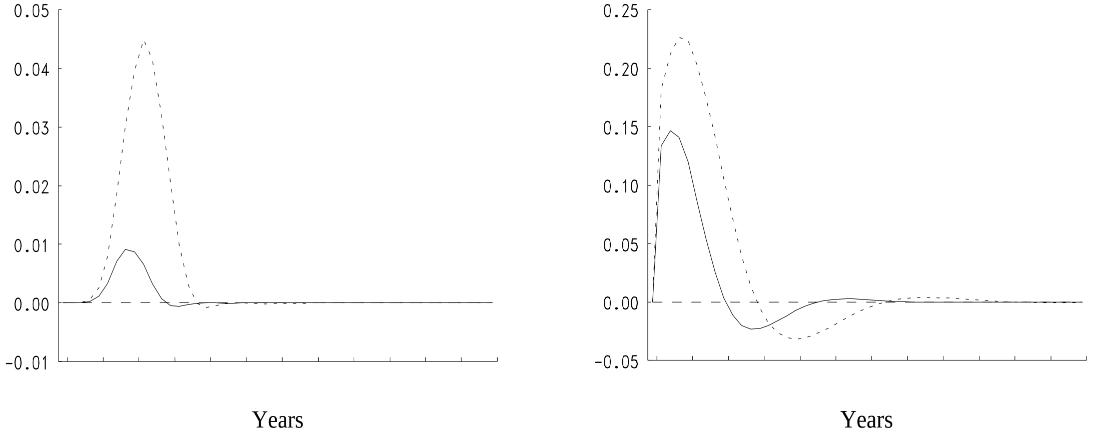
(Outcome Credibility)

Results from a 1 per cent demand shock (all in shock minus control)
Solid: with the natural adjustment mechanisms
Dotted: without the natural adjustment mechanisms



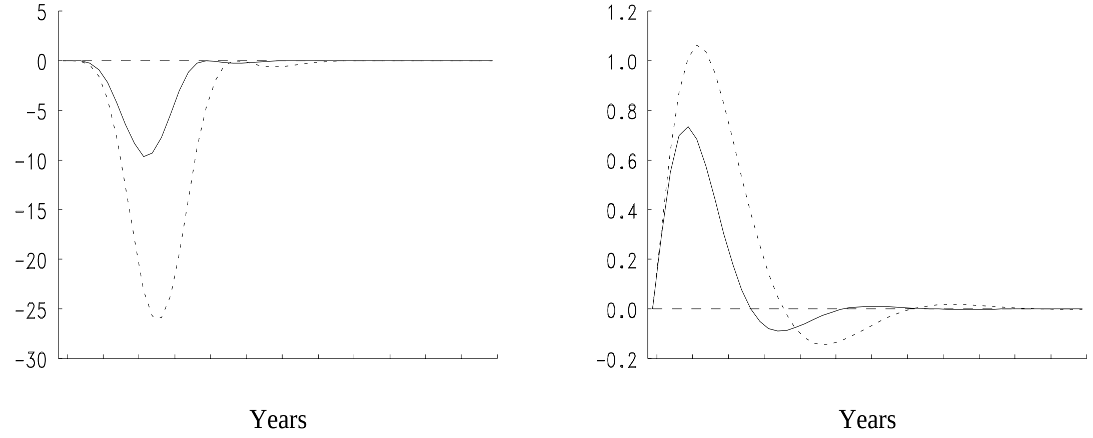
Output Gap (1%=1)

Reference Inflation Rate (Q/Q at annual rate; 1%=1)



Inflation Expectation: Backward-Looking Agents (1%=1)

Inflation Expectation: Forward-Looking Agents (1%=1)



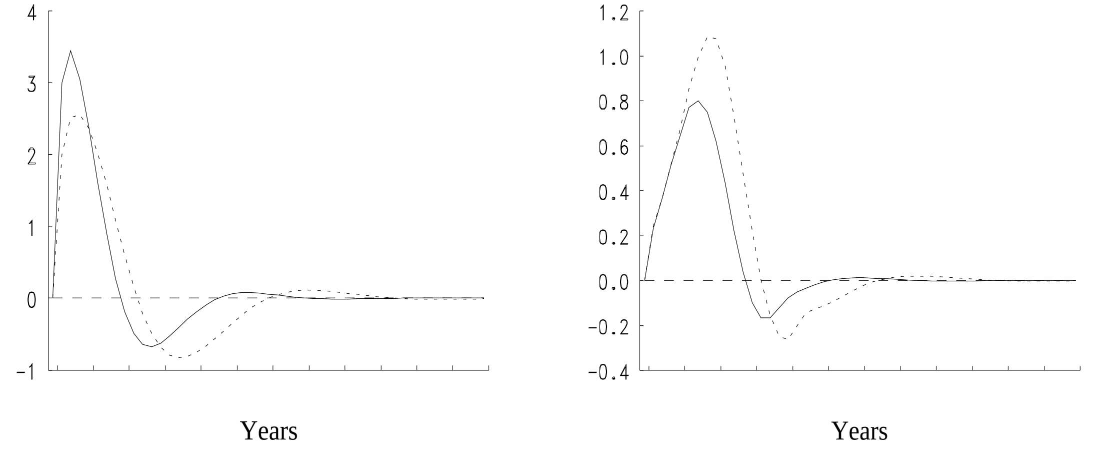
Effect on Credibility (1%=1)

Real Fed Fund Interest Rate (100 bp = 1)

Appendix I: The Convergence of the Real Economy

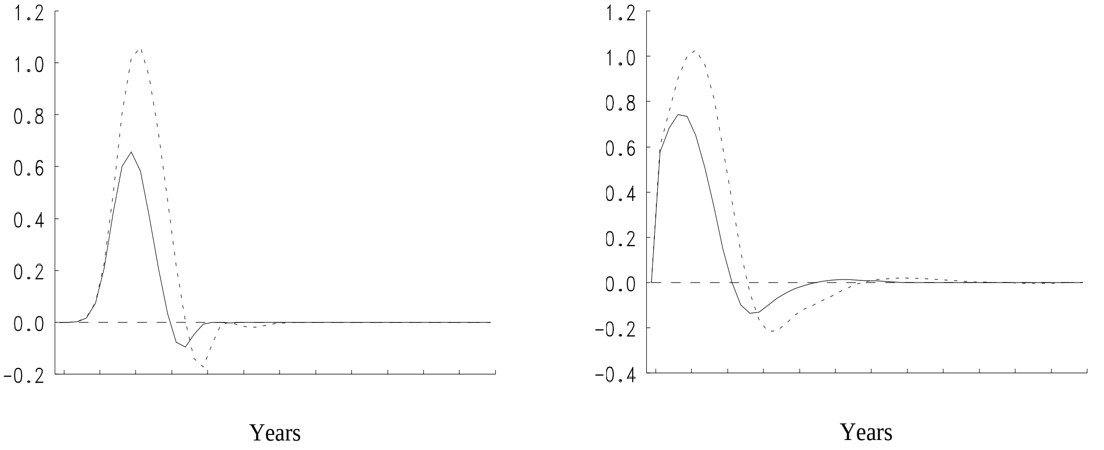
(Outcome Credibility)

Solid: Results from a 3 per cent demand shock (with the natural adjustment mechanisms)
Dotted: Results from a 2 per cent demand shock (without the natural adjustment mechanisms)



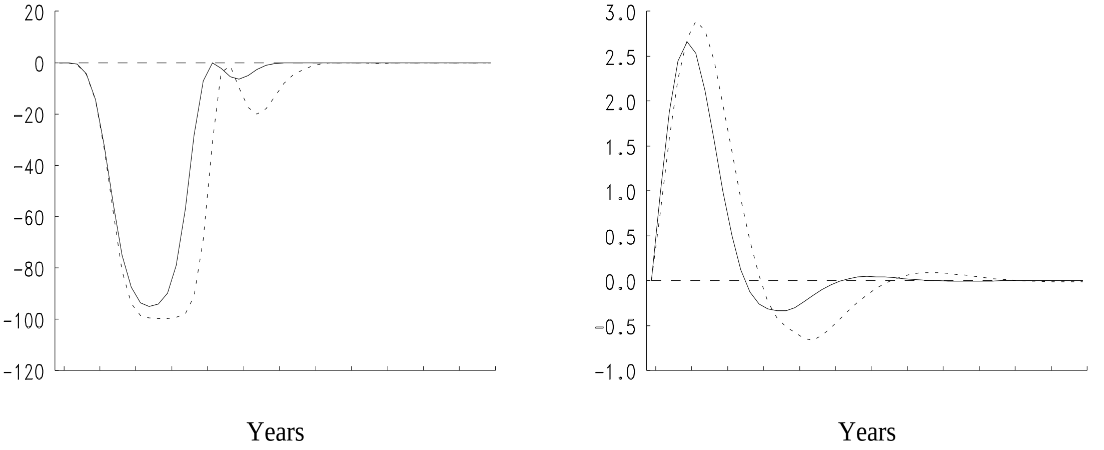
Output Gap (1%=1)

Reference Inflation Rate (Q/Q at annual rate; 1%=1)



Inflation Expectation: Backward-Looking Agents (1%=1)

Inflation Expectation: Forward-Looking Agents (1%=1)



Effect on Credibility (1%=1)

Real Fed Fund Interest Rate (100 bp = 1)

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