

Monetary policy with NAIRU uncertainty and endogenous credibility: perspectives on policy rules and the gains from experimentation and transparency

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The performance of simple monetary policy rules is analysed in a model with endogenous credibility and monetary authorities who update their estimates of the NAIRU period by period using information about unemployment, inflation, and the model structure. Stochastic simulations are employed to illustrate some differences between alternative forms and calibrations of the rules when NAIRU uncertainty and endogenous credibility are taken explicitly into account. The paper then addresses the case for “experimentation” with departures from a well-performing rule for purposes of acquiring additional information about the NAIRU. It also provides quantitative perspectives on the gains from transparency.

1.0 Introduction

The growing popularity of inflation targeting as a monetary policy strategy has stimulated a large volume of formal research into the comparative performances of different types of “inflation targeting” rules in different hypothetical models of macroeconomic behaviour.¹ Because there is no

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¹ In addition to the papers prepared for this conference volume, recent examples include a number of the papers that were presented at the NBER Conference on Monetary Policy Rules (January 15–17, 1998), the Federal Reserve Bank of San Francisco Conference on Central Bank Inflation Targeting (March 6–7, 1998), the Bank of Sweden Conference on Monetary Policy Rules (June 12–13, 1998), and the 1998 Symposium on Computational Economics at Cambridge University (June 29–July 1, 1998).

strong consensus about the “true” model of macroeconomic behaviour, one of the themes that has emerged in the literature is the view that the evaluation of policy rules should focus, *inter alia*, on the robustness of their performances across different classes of plausible models.²

In considering the issue of robustness, it may be noted that the testing of monetary policy rules has been based almost exclusively on models that abstract from endogenous policy credibility,³ that make unrealistically strong assumptions about the monetary authority’s knowledge of the NAIRU,⁴ and that ignore possible convexity of the short-run Phillips curve. Thus, the analysis to date has abstracted from several important elements of reality. Most central bankers regard endogenous policy credibility and NAIRU uncertainty as fundamental characteristics of the worlds in which monetary policy must be conducted, and we regard convex short-run Phillips curves both as considerably more plausible than linear Phillips curves and as a strategically more appropriate assumption for policy analysis.⁵

This paper attempts to extend the literature by analysing the performance of simple monetary policy rules in a model with endogenous policy credibility, a convex Phillips curve, and monetary authorities who update their estimates of the NAIRU period by period using information about unemployment, inflation, and the structure of the model.⁶ As a companion to other papers in which we focus more extensively on comparing alternative forms and calibrations of simple policy rules,⁷ here we illustrate some key differences between a few selected rules, identify a base-case rule that performs relatively well in the context of our particular model, and then analyse the case

² See McCallum (1988).

³ Inflation expectations are often modeled as a weighted sum of backward- and forward-looking components, and in this context a number of studies have followed Freedman (1996) in defining the forward-looking component as the announced inflation target and in interpreting the weight on this component as a measure of policy credibility. Within this framework, Amano, Coletti, and Macklem (1998) have analysed the implications for monetary policy of “exogenous” changes in credibility. In addition, Tetlow, von zur Muehlen, and Finan (1998) have analysed the optimal form of simple rules when private agents have to learn about the rule. To our knowledge, however, few if any evaluations of policy reaction functions have modeled credibility as a variable that responds endogenously to the monetary authority’s performance in delivering macroeconomic stability.

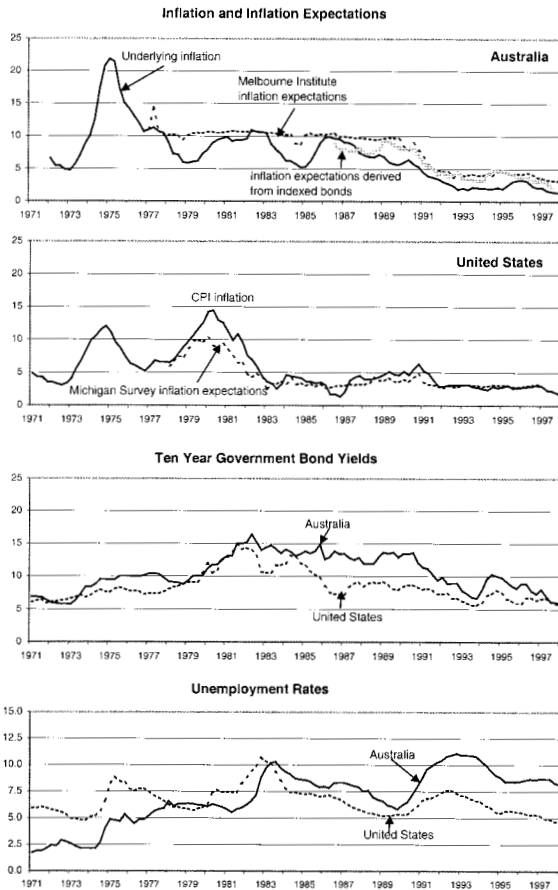
⁴ Indeed, this conference volume, and most of the papers prepared for it, were motivated by the need for deeper analysis of the implications of uncertainty for monetary policy.

⁵ We have argued these points, among other places, in Isard and Laxton (1996), Clark and Laxton (1997), and Laxton, Rose, and Tambakis (1998). Laxton, Rose, and Tambakis (1998) show that previous tests for asymmetry in the Phillips curve have been biased because the filtering techniques that researchers have employed to measure the NAIRU have been inconsistent with the existence of asymmetries. See also Summers (1988), who questions the value of basing policy analysis on models in which monetary policy is incapable of influencing the average rate of unemployment.

⁶ Smets (1998) and Drew and Hunt (1999) also explore the implications of uncertainty about the NAIRU (or the output gap), while Shuetrim and Thompson (1998) and Brigden, Martin, and Salmon (1998) consider the implications of other types of model uncertainty.

⁷ Isard, Laxton, and Eliasson (1998) and Eliasson, Isard, and Laxton (1998).

Figure 1
Selected economic indicators for Australia and the United States (in percent)



for “experimental” departures from the rule aimed at pushing unemployment lower in the short run to gain more accurate information about the NAIRU. We also provide some quantitative perspectives on the gains from transparency.

It may be helpful at the outset to note several points about the relatively novel or unconventional features of our analysis. First, we see no need to justify the case for evaluating rules in a stochastic environment in which the monetary authorities are assumed to explicitly update their estimates of the NAIRU period by period using information about unemployment, inflation, and the structure of the model. Indeed, analysis that fails to allow for such behaviour on the part of the monetary authorities reflects the unattractive implicit assumption that the authorities do not make good use of the information available to them. Second, because we recognise that the choice between linear and convex specifications of the short-run Phillips curve remains controversial, we have analysed

the relevant issues using both variants of Phillips curves and discuss the sensitivity of our results to the chosen specification.⁸

As a third point, we would note that our interest in exploring the relevance of endogenous policy credibility has been motivated in part by observable phenomena that are difficult to explain with models that either ignore credibility or treat it as exogenous. This can be illustrated using figure 1, which plots quarterly data on selected economic indicators for Australia and the United States. The top two panels show recorded inflation rates and survey measures of inflation expectations. The survey measures of Australian inflation expectations have remained persistently above recorded inflation rates during the past decade, while survey measures of US inflation expectations have tracked recorded inflation rates fairly closely. Moreover, with similar recorded inflation rates in Australia and the United States during the 1990s, long-term Australian government bonds have required an interest premium relative to the yield on US government bonds, as shown in the third panel; this is consistent with the expected inflation differential.⁹ And finally, despite experiencing similar and fairly stable rates of inflation during the 1990s, the two countries have significantly different unemployment rates, as indicated in the bottom panel.

What can explain why these variables have behaved differently in Australia and the United States? One plausible explanation is that the relatively slow decline and small-sample bias of inflation expectations in Australia, compared with the rapid decline and relative unbiasedness of inflation expectations in the United States, is a reflection of imperfect policy credibility that differs across countries. Imperfect policy credibility may not be the entire explanation, but it is a leading candidate that warrants explicit consideration in modeling the monetary policy transmission mechanism.¹⁰

We now turn toward the substance of the paper, which is organised as follows. Section 2 describes the model of the unemployment-inflation process, including our treatment of endogenous policy credibility and inflation expectations. Section 3 presents some deterministic simulations to illustrate the effects of monetary policy (under both convex and linear Phillips curves) and to begin to address the issue of experimentation. Section 4 describes the stochastic simulation framework that we rely on for most of our analysis. Sections 5 and 6 specify some alternative policy rules and provide perspectives on their comparative performances in a stochastic environment. Section 7 then ex-

⁸ See Isard, Laxton, and Eliasson (1998) for details on the comparisons between linear and convex specifications.

⁹ Economists have been skeptical about survey measures of inflation expectations because survey respondents do not have strong incentives to provide accurate responses. While the survey measures for Australia and the United States might therefore be expected to contain significant measurement errors, they have nevertheless been found to have significant information content for explaining the unemployment-inflation process in both countries, as well as long-term interest rate differentials between the two countries—see Callen and Laxton (1998).

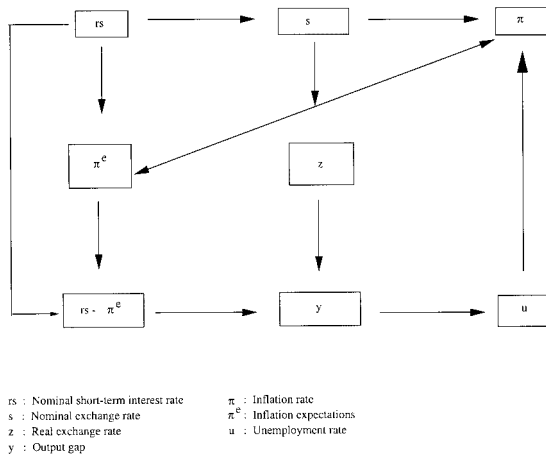
¹⁰ It may also be noted that the observation of different unemployment rates in the two countries, despite similar and relatively stable inflation rates, is consistent with the paradigm of an expectations-augmented Phillips curve, since expected inflation is still higher than actual inflation in Australia but comparable to actual inflation in the United States. By itself, such evidence could be consistent with either a linear or a nonlinear relationship between unemployment and inflation.

plores the case for experimentation—aimed at pushing unemployment lower to gain information about the NAIRU—relative to a rule specification that delivers a reasonably attractive macroeconomic performance in the context of our particular model. Section 8 provides some quantitative perspectives on the gains from transparency. Section 9 concludes.

2.0 A model of the unemployment-inflation process

The analysis in this paper relies on an open-economy model of the unemployment-inflation process that embodies the monetary policy transmission mechanism depicted in figure 2. The authorities are assumed to control a short-term interest rate (rs) with the objective of influencing the rates of inflation (p) and unemployment (u). Changes in the policy instrument are transmitted to the policy target variables through several channels. Adjustments in the nominal interest rate can trigger movements in the nominal exchange rate(s), which are transmitted fairly directly to tradeable goods prices and inflation and indirectly to unemployment through their effects on the real exchange rate (z) and the gap (y) between actual and potential domestic output. Changes in the nominal interest rate also affect the real interest rate ($rs - p^e$), both directly and through the response of inflation expectations (p^e); changes in the real interest rate in turn influence unemployment through their effects on aggregate demand and the domestic output gap; and changes in the output gap and

Figure 2
The monetary policy transmission mechanism



unemployment rate influence the inflation rate through channels summarised by the Phillips curve. In addition, as also depicted in figure 2, an important two-way feedback mechanism is superimposed on the transmission process, with inflation expectations responding inter alia to the history of inflation while inflation is influenced in turn by changes in inflation expectations.

Our specific model of these linkages, which has been developed by Callen and Laxton (1998) and estimated using quarterly data for Australia,¹¹ is presented in several parts. We focus first on table

¹¹ For most equations the sample period runs from the early 1980s through the mid-1990s.

1, which describes the assumed behaviour of domestic demand, exports, imports, the unemployment rate, the nominal exchange rate, and the rate of inflation. The treatment of endogenous credibility and inflation expectations is described later, along with an important component of the model that is not depicted in figure 2—namely, the “rule” that the monetary authorities implement in reacting to observed and anticipated changes in unemployment, inflation, and possibly other macroeconomic variables for purposes of promoting macroeconomic stability.

The conceptual underpinnings of the equations in table 1 are relatively familiar; here we review them briefly and refer readers to Callen and Laxton (1998) for additional discussion and econometric details. The top three equations focus on components of the national income accounts, where domestic demand represents the aggregate domestic expenditures of consumers, investors, and governmental units. The dependent variables refer to *detrended* measures of domestic demand, exports, and imports.¹² The estimated equations suggest that aggregate (detrended) domestic demand (d) exhibits a high degree of persistence (a weight of nearly unity on the lagged dependent variable); it also depends negatively on the (two-quarter lagged) level of the real interest rate (r) and positively on a relevant measure of national wealth (a)—namely, the stock of net claims on the rest of the world (as a percent of domestic GDP). Exports (x) exhibit a substantial degree of persistence (a coefficient of 0.48 on the lagged dependent variable) and also depend importantly on the real exchange rate (z , an increase in which represents a real depreciation). Imports (m) likewise exhibit substantial persistence and depend in a conventional manner on domestic demand, exports, and the real exchange rate. Together, the equations for detrended domestic demand, exports, and imports describe the behaviour of aggregate output relative to trend, which is used as a measure of the output gap (y , defined as actual output minus potential output). An important property of these equations is that changes in real monetary conditions (that is, the real interest rate and the real exchange rate) have significant *lagged* effects on the output gap.

The fourth equation in table 1 describes the behaviour of a labour market tightness measure—defined as the amount by which the unemployment rate (u) falls below the NAIRU \bar{u} .¹³ The estimated relationship shows a high degree of persistence along with positive dependence on the output gap. The coefficient on the output gap is significantly less than one, which is consistent with casual empiricism: firms hoard labour over the business cycle and, because of hiring and firing costs, adjust labour inputs slowly in response to changes in the demand for their products.

In the exchange rate equation, the left-hand-side variable represents the one-period forward exchange rate, which, under covered interest parity, equals the prevailing spot exchange rate appropriately adjusted for the interest rate differential.¹⁴ The right-hand side of the equation is a standard backward- and forward-looking components model of the expected future spot exchange rate S_{t+1}^e where S_{t+1}^{mc} represents the model-consistent solution and the backward-looking compo-

¹² The variables were detrended using the HP filter with a smoothing parameter of 1600; see Hodrick and Prescott (1981).

¹³ The specification explicitly treats $u - \bar{u}$ as a zero mean process.

¹⁴ The appropriate interest factor corresponds to one plus the per-annum interest rate differential expressed as a quarterly rate.

Table 1

A small model of the Australian inflation process: part 1

Domestic demand:

$$d_t = -0.33r_{t-2} + 8.40\alpha_t + 0.95d_{t-1} + \varepsilon_t^d \quad (1)$$

Exports:

$$x_t = 0.06z_t + 0.48x_{t-1} + \varepsilon_t^x \quad (2)$$

Imports:

$$m_t = 0.33x_t + 1.35d_t - 0.09z_t + 0.41m_{t-1} + \varepsilon_t^m \quad (3)$$

Labour market tightness:

$$(\bar{u}_t - u_t) = 0.20y_t + 0.77(\bar{u}_{t-1} - u_{t-1}) + \varepsilon_t^{(\bar{u}-u)} \quad (4)$$

Exchange rate:

$$s_t \left[1 + rs_t - rs_t^{US} \right]^{15} = 0.38s_{t+1}^{mc} + (1 - 0.38) \left[s_{t-1} \left(1 + E_t \pi 4_{t,t+4} - E_t \pi 4_{t,t+4}^{US} \right)^5 \right] + \varepsilon_t^s \quad (5)$$

Phillips curve:

$$n_t = \bar{\pi}_t^c + 2.14 \frac{[u_t^* - u_t]}{u_t - \phi_t} + \varepsilon_t^n \quad (6)$$

where:

$$\bar{\pi}_t^c = 0.73\bar{\pi}_t^d + (1 - 0.73 - 0.04 - 0.02)\bar{\pi}_{t-1} + 0.04\bar{\pi}_t^m + 0.02\bar{\pi}_{t-1}^m \quad (7)$$

and:

$$\bar{\pi}_t^c = 0.25 \left[E_{t-1} \pi 4_{t,t+3} + E_{t-2} \pi 4_{t,t+2} + E_{t-3} \pi 4_{t,t+1} + E_{t-4} \pi 4_t \right] \quad (8)$$

ment is simply the lagged spot rate adjusted for the expected inflation differential.¹⁵ The measures of inflation expectations are based on surveys (conducted in quarter $t-1$) of the rates of inflation expected in Australia and the United States over the year ahead. We use the notation p4 to refer to inflation over four quarters and p to refer to annualised rates of inflation over one quarter; $E_t \pi 4_{t,t}$ is the public's expectation in quarter t of the rate of inflation over the year through quarter $t+4$. In estimating this equation, Callen and Laxton (1998) found a large weight on the backward-looking

¹⁵ Adjustment for the expected inflation differential is a necessary condition for ensuring that the behaviour of the real exchange rate is independent of the target rate of inflation.

component, consistent with other evidence that high proportions of the short-run behaviour of exchange rates (and other asset prices) cannot be explained by fundamentals, but rather are conditioned by the recent behaviour of exchange rates (or other asset prices).¹⁶

The Phillips curve is a variant of the convex specification in Debelle and Laxton (1997) and Debelle and Vickery (1997). For expositional convenience, equation (6) consolidates several terms into a composite “core” rate of inflation (p^c), which is spelled out in equation (7). The first two terms on the right hand side of equation (7) describe the rate of inflation expected over the year ahead. Expectations are assumed to influence inflation dynamics through a wage-and-price setting framework in which the standard contract has a four-quarter horizon, with one-fourth of the contracts respecified every quarter. This is reflected in the $\bar{\pi}^e$ term, which is defined in equation (8) as the average of the one-year-ahead inflation expectations that economic agents held during the four quarters in which currently-prevailing contracts were written. Expected inflation is also assumed to depend on the lagged inflation rate (the second term on the right hand side of equation (7)), which can be viewed as a summary indicator of the incentives to incur the costs of revising price or wage contracts before their specified expiration dates. The third and fourth terms on the right hand side capture the influence on consumer price inflation of the contemporaneous and one-quarter-lagged rates of change in import prices (p^m).

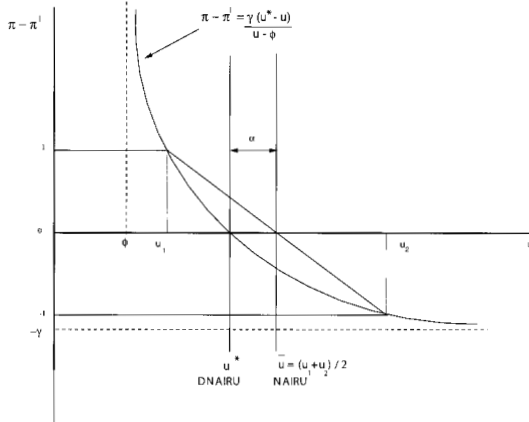
Note that the coefficients in equation (7) sum to unity, consistent with the long-run natural rate hypothesis. Figure 3 plots the difference between observed inflation and core inflation (vertical axis) against the unemployment rate (horizontal axis). For purposes of the discussion here, we make the simplifying assumption that core inflation and expected inflation coincide, so that the figure can be viewed as an expectations-augmented Phillips curve. Consistent with the specification in equation (6), the short-run Phillips curve is convex with vertical asymptote at $u = \phi$ and horizontal asymptote at $\pi - \pi^e = -\gamma$.¹⁷ The magnitude of u^* corresponds to the unemployment rate at which actual inflation and expected inflation coincide, such that there would be no systematic pressure for inflation to rise or fall *in the absence of stochastic shocks*. This corresponds to the non-accelerating-inflation rate of unemployment in a *deterministic* world, and we often refer to u^* as the DNAIU.

An important point is that the DNAIU is not a feasible stable equilibrium in a *stochastic* world with a convex Phillips curve. The average rate of unemployment consistent with non-accelerating-inflation in a stochastic world, denoted by \bar{u} and referred to as the NAIRU, must be greater than the DNAIU. This can be illustrated in figure 3 by assuming that actual inflation turned out to be uniformly distributed between plus and minus one percentage point of core (or expected) inflation, which would imply an average rate of unemployment of $\bar{u} = 0.5 (u_1 + u_2)$. The fact that the difference between the NAIRU and DNAIU depends, in a nonlinear world, on the degree to which the authorities succeed in stabilising inflation has important implications for monetary policy, as discussed below.

¹⁶ See Isard (1995).

¹⁷ In equation (6) the estimated value of γ is 2.14.

Figure 3
The convex Phillips curve



For the most part, the simulation experiments performed with the model start with the economy in a hypothetical equilibrium state. Given the model equations, the simulation results do not depend on historical data, which we generate somewhat arbitrarily. The following points may be noted, however, about the historical data used by Callen and Laxton (1998) in estimating the model equations. The data on inflation expectations for Australia reflect median responses taken from the Westpac bank Melbourne Institute Survey, which asks households for their expectations of inflation one year ahead.¹⁸ The analogous data for the United States represent median responses from the Michigan consumer survey of one-year ahead changes in the US consumer price index. And the data on the NAIRU and DNAIRU were constructed by Callen and Laxton (1998) in a manner consistent with the structure of the Phillips curve and historical movements in inflation, inflation expectations, unemployment, and import prices.¹⁹

We next describe the manner in which we model endogenous credibility and the behaviour of inflation expectations, which is summarised in table 2. These are aspects of the model that attempt to extend the basic conceptual framework for analysing monetary policy issues.

Equation (9) in table 2 focuses on explaining the survey measures of inflation expectations. As noted above, a four-quarter average of these survey measures was assumed in specifying the Phillips curve relation described in table 1, and the simulation experiments described below use forecasts from equation (9) as hypothetical survey measures of inflation expectations. The first two terms in the equation are intended to represent a weighted average of a forward-looking model-consistent inflation measure and the one-quarter lag of the survey measure of inflation expectations. For purposes of this paper, the former measure is derived from a proxy for the model—namely, as the

¹⁸ The data are based on monthly surveys of 1200 randomly selected adults. Our time series was constructed by averaging the median responses over the three months of each quarter.

¹⁹ The methodology employed to develop the historical data for u^* and \bar{u} involves using a Kalman filter to solve a system of equations that includes two Phillips curves and an unemployment equation; see Callen and Laxton (1998).

Table 2
 A small model of the Australian inflation process: part 2
 Inflation expectations and policy credibility

Inflation expectations 1 year ahead:

$$E_t \pi_{t+1} = 0.13\pi_{t+1}^{HC} + (1 - 0.13)E_{t-1} \pi_{t+1} + b_t + \varepsilon_t^E \quad (9)$$

Low inflation forecasting rule:

$$\pi_{t+1}^L = 2.5(1 - 0.34) + 0.34\pi_{t+1} + \varepsilon_t^L \quad (10)$$

High inflation:

$$\pi_{t+1}^H = 8.4(1 - 0.81) + 0.81\pi_{t+1} + \varepsilon_t^H \quad (11)$$

$$b_t = 0.04 \left[(1 - c_t) \left[E_t \left\{ \pi_{t+1}^H | \pi_{t+1} \right\} - E_t \left\{ \pi_{t+1}^L | \pi_{t+1} \right\} \right] \right] \quad (12)$$

Policy credibility:

$$c_t = 0.83c_{t-1} + 0.17w_{t-1} + \varepsilon_t^C \quad (13)$$

where:

$$w_t = \frac{\left[\varepsilon_t^H \right]^2}{\left[\varepsilon_t^H \right]^2 + \left[\varepsilon_t^L \right]^2} \quad (14)$$

fitted values of an auxiliary equation that predicts observed inflation over the year ahead using four lagged values each of the unemployment rate, a long-term interest rate, the survey measure of inflation expectations, and the inflation rate. The third term in equation (9) is intended to capture the expectations bias (b) attributable to imperfect policy credibility.

In modeling imperfect policy credibility and quantifying the expectations bias term, we start from the notion that agents who have experienced high inflation in the past are likely to attach a time-varying probability to the prospect that the monetary authorities will remain truly committed and capable of delivering low inflation in the future. To develop this notion in a simple way, we adopt the following paradigm. It is assumed that economic agents, in forming their inflation expectations, distinguish between two scenarios. Under one scenario, monetary policy is successful in achieving and maintaining price stability, and the inflation rate either remains at, or gravitates toward, the authorities' target rate of inflation. Under the second scenario, policy is less successful in maintaining price stability and inflation gravitates toward a higher steady-state rate. In each

scenario the expected inflation rate (ie the value of the forecasting rule with an expected error of zero) is assumed to reflect a weighted average of the steady-state inflation rate and the most recently observed inflation rate; this implies that the expected inflation rate exhibits persistence, adjusting each quarter in proportion to, but by a smaller amount than, the observed change in the (lagged) inflation rate. For an inflation target of 2.5 percent, the inflation rate expected under the low-inflation scenario can be described by equation (10), where 0.34 is an estimated parameter. Analogously, under the assumption that the steady-state inflation rate for the high-inflation scenario is 8.4 percent, the inflation rate expected under the high-inflation scenario can be described by equation (11).²⁰

Equation (12) defines the measure of expectations bias, where the terms in square brackets measure the discrepancy between the inflation target (p^{TAR}) and a weighted average of the inflation forecasts under the two scenarios. As reflected in equation (13), the weight on the low-inflation scenario (c) is treated as a time-varying parameter that exhibits a high degree of persistence (as implied by the model estimates) but changes from period to period by an amount that reflects the extent to which inflation outcomes are more consistent with the low inflation scenario than with the high inflation scenario. The term, ψ as defined in equation (14), provides our measure of the extent to which inflation outcomes are consistent with the low-inflation scenario.²¹ Note that if inflation outcomes are repeatedly completely consistent with the low-inflation scenario, $\varepsilon^L = 0$ and $\psi = 1$, so c converges to unity. Likewise, if inflation outcomes are repeatedly completely consistent with the high inflation scenario, $\varepsilon^H = 0$, $\psi = 0$, and c converges to zero.

The above two-scenario paradigm bears a resemblance to a two-state regime-switching model with time-varying transition probabilities.²² Note that the inflation target coincides with the steady-state outcome under the low inflation scenario (ie the model is estimated and simulated with $p^{TAR} = 2.5$); that c_t can be interpreted as the subjective probability attached to the low inflation state; and that in the limiting case of $c_t = 1$, long-run inflation expectations coincide with the inflation target. Based on the latter two properties, we regard c_t as a measure of the stock of credibility at time t .

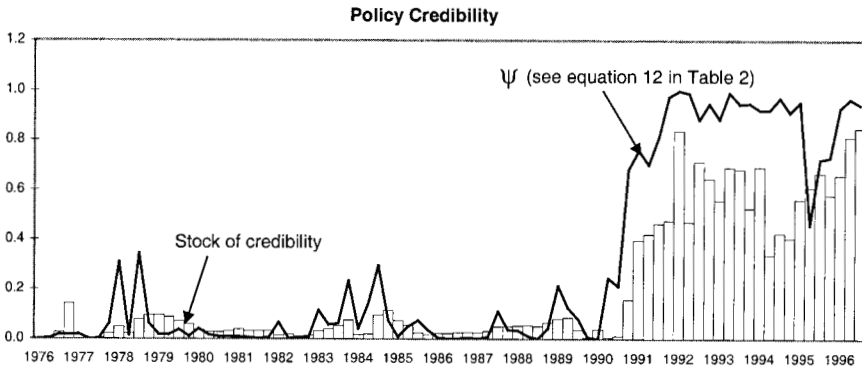
²⁰ The model for the high-inflation state is based on work by Tarditi (1996); see the discussion in Callen and Laxton (1998), who note that the estimated persistence parameters in equations (10) and (11) are consistent with other estimates from the literature. Note also that the 8.4 percent steady-state inflation rate used in the high inflation forecasting rule corresponds roughly to the average rate of inflation in Australia during the 1980s (recall figure 1).

²¹ The measures of ε^H and ε^L are constructed by substituting the realised inflation outcomes into the left-hand-sides of equations (10) and (11), respectively. Such measures correspond to the ex-post errors associated with interpreting the realised inflation outcomes as ex ante forecasts of inflation under each scenario.

²² Flood and Garber (1983) presented an early model of stochastic switching in policy regimes, and Hamilton (1988, 1989) also contributed importantly to catalysing the use of regime-switching models. See Laxton, Ricketts, and Rose (1994) for an application to the analysis of learning

Although the associated measure of bias is derived from a relatively simple model of learning²³ and might not remain reasonable if the monetary authorities shifted their inflation target significantly away from 2.5, it has the attractive features of behaving in a stable manner (not subject to multiple equilibria) and converging to zero as c converges to one. Furthermore, the estimated behaviour of c_t and ψ from the mid-1970s through the mid-1990s seems plausible; see figure 4. The paradigm thus seems to provide a reasonable way of introducing endogenous policy credibility into a formal model for analysing monetary policy issues.

Figure 4
The estimated historical value of C and ψ



3.0 The effects of monetary policy: perspectives from deterministic simulations

Monetary authorities generally regard price stability as their primary policy objective, but most central banks are also oriented toward reducing unemployment and stimulating growth as much as is consistent with the maintenance of price stability. Thus, in a deterministic world with no long-run tradeoff between inflation and unemployment, as is commonly assumed in models with Phillips curves, the role of the policymaker would be to achieve price stability and maintain the unemployment rate at the DNARIU. This is essentially synonymous with maintaining a zero gap between actual and potential output.

The role of the policymaker is much more complicated in a stochastic world with uncertainty about the DNARIU, particularly to the extent that the Phillips curve is convex. Once inflation has been

²³ In a more sophisticated model of learning, the measures of ε^H and ε^L would be adjusted for the public's estimates of the authorities' control errors. However, the development of such a learning model is beyond the scope of this paper, which simply aims to illustrate that endogenous policy credibility is a relevant consideration in the design of monetary policy rules. and endogenous monetary policy credibility in Canada; see Kaminsky and Leiderman (1998) for an application to developing countries.

subdued, the challenge for policy is to determine how much the unemployment rate can be lowered without precipitating an acceleration of inflation. Delay in reaching such a determination can result in significant cumulative losses of output and employment. This suggests a case for experimenting with lower unemployment in the short run for purposes of pinpointing the DNAIRU. But it can be dangerous to experiment too aggressively in a world in which the Phillips curve is convex. In particular, when the effects of monetary policy are only visible with a lag, aggressive experimentation runs the risk of allowing unemployment to fall significantly below the DNAIRU before it becomes evident that the economy has overheated and inflation has accelerated.

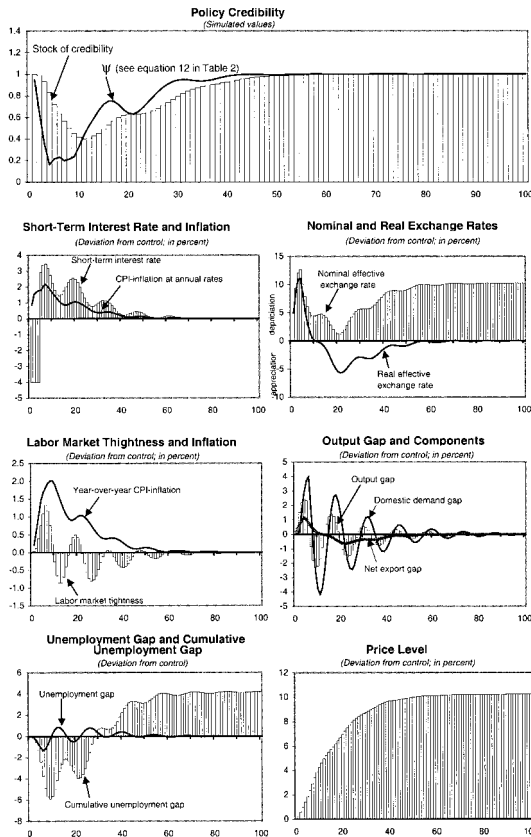
Pushing the unemployment rate significantly below the DNAIRU would not have large welfare costs in a world with a linear Phillips curve and perfect policy credibility. Although inflation would accelerate in the short run, by subsequently engineering a rise in unemployment to a rate temporarily above the DNAIRU the authorities could achieve their target rate of inflation on average over time with little cumulative loss of output and employment. This suggests that monetary policy would not be very difficult or important in a linear world with perfect policy credibility, where any policy errors in the short run could simply be offset over time with no first-order welfare consequences.²⁴

Policy errors can be much more costly, and monetary policy considerably more difficult and important, in a more realistic world with a convex Phillips curve and imperfect policy credibility. This can be seen with the help of figure 5 (overleaf), which describes a deterministic simulation of the model presented in tables 1 and 2. For purposes of illustration, it is assumed that the economy starts in an equilibrium position, with the unemployment rate at the DNAIRU and the inflation rate at its target. The economy is then shocked by lowering the short-term interest rate by 4 percentage points for a period of four quarters. Beginning in quarter five, the interest rate is governed by a Taylor rule.²⁵ The simulation shows that inflation accelerates during the first and second years and that the acceleration of inflation is closely associated with labour market tightening, with the unemployment rate falling considerably below the NAIRU. Domestic demand and output also rise sharply relative to potential output. Following the tightening of monetary policy in the second year, the inflation rate returns gradually to its target level and the economy cools fairly rapidly. The nominal exchange rate, after depreciating during the first year in response to the lower interest rate and the rise in inflation expectations, begins to strengthen at the beginning of the second year—ahead of

²⁴ Indeed, the implication that monetary policy is incapable of influencing the average levels of output and employment in linear models led Summers (1988) to ask whether Keynesian economics should dispense with the Phillips curve; see the discussion in Clark and Laxton (1997). Stiglitz (1997) has recently argued that the Phillips curve may be concave in the United States. This is a very controversial suggestion, since concavity would imply that policymakers can reduce the average rate of unemployment by acting to magnify, rather than mitigate, the amplitude of the business cycle. Debelle and Vickery (1997) find that a convex Phillips curve fits better than a linear one in a model of the Australian economy, but they did not include a concave Phillips curve in their comparisons.

²⁵ The specific reaction function corresponds to equation (15) below with $(\alpha, \gamma) = (0.5, 1)$. The deterministic simulations described here also assume that the DNAIRU remains constant and treat the NAIRU and DNAIRU as identical (given the deterministic environment).

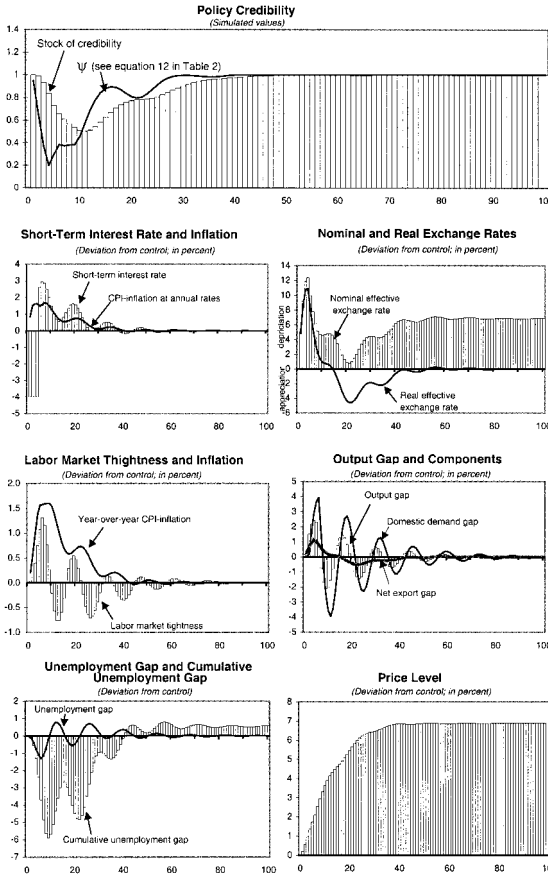
Figure 5
 Nonlinear model responses to aggressive probing
 (400 basis points, 4 quarters)



the deceleration of inflation. Over the long run, the real exchange rate returns to its initial steady-state value, with the price level about 10 percent higher than its initial position and the nominal exchange rate about 10 percent depreciated.²⁶ Notably, policy credibility declines sharply during the first year and takes another thirteen years to become fully restored. The first-order welfare costs

²⁶ The convergence of the real exchange rate to its initial value reflects a simplification in specifying the balance of payments condition as an equality between the change in net foreign assets and the trade balance; this essentially constrains the (detrended) net foreign asset position to return to its initial level in the steady state. In a more general specification that included international interest payments in the current account, the real exchange rate would converge to a steady state level, but not necessarily to its initial level.

Figure 6
 Linear model responses to aggressive probing
 (400 basis points, 4 quarters)



can be seen in the cumulative unemployment gap, which amounts to about 4 percent of the labour force.²⁷

The above simulation highlights the dangers of aggressive policy experimentation to find the DNairu in a nonlinear world with endogenous policy credibility. To illustrate an earlier point, figure 6 shows the consequences of the same policy experiment in a model that includes a linear Phillips curve but is otherwise identical to that used to generate figure 5. Note that the cumulative unemployment gap shown in figure 6 is less than one percent of the labour force, suggesting that aggressive experimentation would have relatively low costs in a linear world.

²⁷ The size of the labour force is assumed to remain constant over time, so the sum of the annual unemployment gaps, in percentage points, is equivalent to the cumulative loss of employment as a percent of the labour force.

Figure 7
 Nonlinear model responses to modest probing
 (100 basis points, 4 quarters)

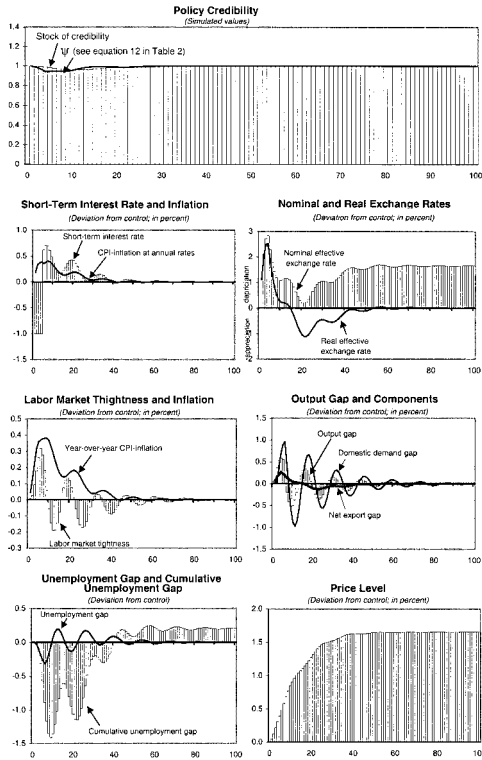


Figure 7 returns to the nonlinear model and describes the results of a similar policy experiment on a more modest scale—a lowering of short-term interest rates by 1 percentage point for four quarters. The simulation shows that although the scale of the interest-rate shock is four times smaller than the case of aggressive experimentation, the cumulative unemployment gaps are lower by a factor of about 20, while the long-run effects on the price level are lower by a factor of about 6. Furthermore, the loss of policy credibility from modest experimentation is much less severe than that from aggressive experimentation, and full policy credibility is also regained more rapidly in the case of modest experimentation.

These hypothetical policy experiments take a first step in addressing the question of whether, and how aggressively, policymakers should experiment with lower unemployment to improve their information about the NAIRU. We provide additional analysis below. First we describe the design of our stochastic simulation framework, provide some perspectives on the comparative performances of different types and calibrations of policy rules in a stochastic environment, and identify a rule

specification that can be expected to deliver a reasonably attractive macroeconomic performance in the context of our particular model.

4.0 The stochastic simulation framework

The assumptions underlying our Monte Carlo experiments are as follows:

1. The “true model” of macroeconomic behaviour consists of the equations in tables 1 and 2, together with the monetary policy rule and a process (described in appendix I) that generates the evolution of the DNAIRU and NAIRU over time.
2. The DNAIRU follows a bounded random walk²⁸ with floor at 4 percent and ceiling at 10 percent. Conditional on not hitting either bound, the DNAIRU changes from one quarter to the next by a random amount drawn from a normal distribution with mean zero and standard deviation corresponding to that of the distribution of estimated DNAIRUs during the historical sample period;²⁹ for cases in which the DNAIRU could not change by the full amount of the random draw without moving below 4 percent or above 10 percent, the DNAIRU moves to its floor or ceiling, respectively.
3. In each period t , the monetary authorities update their estimate of the DNAIRU and set the period- t interest rate based on an information set O_t that includes: the complete specification of the true model except for the process that generates the DNAIRU and NAIRU (ie complete information about equations (1)-(3) and (5)-(14)); the history of all observable variables (including the survey measures of inflation expectations) through period $t-1$, as well as the inflation rate for period t ; and the probability distributions (but not the realisations) of the shocks for period i and all future periods. This implicitly assumes that the inflation rate is the first relevant period- t statistic that becomes known to the authorities, and that the period- t interest rate is set immediately following the arrival of information about the period- t inflation rate.³⁰ Although the authorities do not know the true processes that generate the DNAIRU and NAIRU, they update their estimates of these parameters each period on the basis of their information about the structure of the model and the history of unemployment and inflation.³¹

²⁸ The assumption of boundedness seems conceptually appropriate. The results we report in this paper are based on simulations that are all initialised with the DNAIRU at 7.0, and in which the DNAIRU rarely if ever hits its floor or ceiling.

²⁹ Callen and Laxton (1998) describe the methodology employed to develop the historical estimates of the DNAIRU and NAIRU.

³⁰ From technical and strategic perspectives, giving the authorities knowledge of the period- t inflation rate reduces the incidence of unstable stochastic simulations for the Taylor rule cases and appears to act in the direction of understating the extent to which IFB rules dominate conventional Taylor rules in our simulation experiments.

³¹ The procedure that the authorities are assumed to use to update their estimates of DNAIRU and NAIRU is described in appendix 1.

4. The exogenous shocks are drawn from independent normal distributions with zero means and standard deviations that reflect the unexplained variances of the dependent variables during the historical periods over which the equations were estimated.
5. The authorities use a prespecified policy rule, along with the assumption that the realisations of random shocks beyond period t will coincide with their expected values of zero, to determine the interest rate setting for period t and to generate forecasts of the complete future timepaths of all the macroeconomic variables in the model, including interest rates and the DNAIRU.

Given these assumptions, for each candidate policy rule we simulate a hypothetical path of the economy over a horizon of 100 quarters. Starting in period t , the monetary authorities observe data through period $t-1$, update their forecasts for all variables through the end of a 50-quarter horizon,³² including their forecasts for the period- t values of the variables that enter the policy rule (with perfect foresight or advanced knowledge of the period- t inflation rate), and determine the period- t interest rate setting. After the forecasts are generated and the interest rate is set, the shocks for period t are drawn randomly (but consistently with the prespecified probability distributions) and the period- t values of relevant variables are determined from the true model. The determination of the period- t solution is based on the assumptions that the (expected) future path of the real interest rate coincides with the authorities' forecast, and that the NAIRU follows the process described by the true model. After the period- t solution is added to the hypothetical history of the economy, the authorities generate updated forecasts (including updated estimates of the NAIRU) and set the interest rate for period $t+1$. And so forth.

The process of generating 100-quarter simulations was conducted 16 times for the given policy rule, starting each time from the same initial position of the economy. Together the 100 simulations provide 1,600 observations for each variable in the model. The process is then replicated for the other policy rules, using the same 16 sequences of randomly drawn shocks. Since the simulations for each rule start from the same initial position and reflect identical sequences of shocks, the relative attractiveness of the different rules can be evaluated by comparing the simulated sample means and standard deviations of inflation, unemployment, and other economic indicators.

5.0 The specification of policy rules

Formal analysis of monetary policy strategies has identified various classes of policy reaction functions with "inflation targeting" or "inflation-forecast targeting," broadly defined as strategies in which the monetary policy instrument—most typically a short-term interest rate—is adjusted in response to, but not necessarily only in response to, deviations of the inflation rate (or an inflation forecast) from an explicit target. Under one prominent class of reaction functions, advocated by Taylor (1993) among others, the interest rate setting is linked to both the deviation of inflation from

³² A value of 50 quarters is sufficiently long to ensure that errors in the terminal conditions will not induce errors in the variables of interest. Under inflation targeting, the price level has a unit root, and the procedure for period-to-period updating of the authorities' forecasts also involves period-to-period updating of the terminal conditions.

target and the deviation of the unemployment rate from the NAIRU.³³ Under a second class of rules, proposed by Laxton, Rose, and Tetlow (1993), the interest rate setting is conditioned by an inflation forecast (relative to target) rather than the most recently observed inflation rate. We follow Haldane and Batini (1998) and Amano, Coletti, and Macklem (1998) in referring to the latter as *inflation forecast based* (IFB) rules.³⁴

Much of the motivation for focusing on these simple classes of policy rules is pragmatic.³⁵ In addition, simple classes of rules are transparent and relatively appealing to policymakers, Taylor rules have been popular in the literature since the early 1990s, and IFB rules have been shown to deliver reasonable economic performances over a wide range of disturbances.³⁶ By focusing on the deviation from target of the authorities' inflation forecast, IFB rules have the appealing feature (in comparison with Taylor rules) of inducing the authorities to condition their interest rate settings on the determinants of inflation, given their information/assumptions about the structure of the model.

The Taylor rules that we consider have the general form while the IFB rules are described by

$$r_t = r^* + \bar{E}_t \left\{ \alpha (\pi_{t+1} - \pi^{TAR}) + \beta (E_t \pi_{t+1} - \pi^{TAR}) + \gamma (\bar{u}_t - u_t) \right\} \quad (15)$$

where

$$r_t = r_{TAR} + \bar{E}_t \left\{ E_t \pi_{t+1} - \Omega_t \right\} \quad (16)$$

³³ For the most part, analysis of the relative effectiveness of different monetary policy rules has been conducted in the context of linear models with perfect policy credibility. These are cases in which the NAIRU and DNAIUR coincide.

³⁴ Forward-looking IFB rules have been used for almost a decade at the Bank of Canada to solve nonlinear macroeconomic models designed for policy analysis. With the development of more robust and efficient solution methods, these rules are now starting to be used in other policymaking institutions—see Armstrong and others (1998) and Juillard and others (1998) for a discussion of the algorithms that can be used to solve models that embody forward-looking IFB rules.

³⁵ We regard the conceptual ideal of a policy rule that optimises some explicit loss function conditional on assumptions about the macroeconomic model as having little if any practical relevance when there is no strong consensus on the appropriate model (or loss function) and when for many plausible models the optimal policy rule is technically very difficult to derive and too complex in form to be easily comprehended by policymakers or the public. We also agree with Taylor (1993, p.213) that “simple, algebraic formulations of . . . [policy] rules cannot and should not be mechanically followed by policymakers,” but that analysis of the hypothetical performances of mechanical rules within simple but fairly realistic macroeconomic models can nevertheless provide valuable guidance about the general types of policy reactions that are likely to be relatively effective for achieving and maintaining macroeconomic stability in the real world.

³⁶ For recent analyses of IFB rules, see Haldane and Batini (1998), Amano, Coletti, and Macklem (1998), and Rudebusch and Svensson (1998).

Here r_t is the nominal interest rate setting at time t ; r_t is the concept of the real interest rate on which aggregate demand depends;³⁷ $E\pi_{t+t}$ denotes the public's expectations at time t of the inflation rate over the year ahead; r^* is a constant corresponding to the equilibrium real interest rate in a deterministic world under the prespecified initial conditions of the economy; π^{TAR} denotes the target rate of inflation; $\bar{E}_t \pi_{t+1}$ denotes a model-consistent forecast at time t based on the authorities information set Ω_t , which includes information about the model along with the observed values of the inflation rate through period t and all other economic variables through quarter $t-1$; π_t and u_t represent the rates of inflation and unemployment; and \bar{u}_t is the authorities' estimate of the NAIRU based on observed data through period $t-1$ (see appendix I).

The bracketed terms in equation (15), and the first and third bracketed term in equation (16), are relatively traditional components of the policy reaction functions discussed in the literature, corresponding to the deviation of inflation (or the *authorities'* inflation forecast) from target and the deviation of the unemployment rate from the NAIRU. The second bracketed term in equation (16)—the deviation of the *public's* inflation expectations from the inflation target—provides a mechanism for monetary policy to respond directly to the bias in the public's inflation expectations, or to the degree to which policy credibility is imperfect. Although the forecast horizon embodied in the first bracketed term in equation (16) was chosen somewhat arbitrarily, experimentation suggested that specifying the IFB rules in terms of a three-quarter-ahead forecast was capable of producing reasonable macroeconomic stability.³⁸

Note that the policy reaction functions are specified in the form of rules for real interest rate adjustment. Although monetary policy operates by setting the nominal interest rate, in our model (and most others) the extent to which monetary policy adjustment stimulates or restrains aggregate demand depends on the change in the real interest rate. It would thus make no sense to propose that policy be guided by a nominal interest rate rule that could not be explicitly translated into an economically reasonable rule for the real interest rate on which aggregate demand depends.

6.0 Comparisons of selected rules

Our efforts to search for optimal calibrations of Taylor rules and IFB rules are reported elsewhere.³⁹ Here we focus on two calibrations of IFB rules that perform relatively well, along with one selected Taylor rule. The calibration of the latter, $(\alpha, \gamma) = (.5, 1)$, corresponds roughly to the weights originally suggested for the US case by Taylor (1993), after adjusting γ for the fact that Taylor specifies his rule

³⁷ Taylor's (1993) version of the Taylor rule used a backward looking measure of inflation expectations to measure the real interest rate.

³⁸ We have not undertaken an extensive search for the optimal inflation forecast horizon. It may be noted that three quarters is roughly half the time that is generally believed to be required for interest rates to have their full effects on the economy.

³⁹ Isard, Laxton, and Eliasson (1998) reports stochastic simulations for a range of rule calibrations using the model analysed in this paper. Eliasson, Isard, and Laxton (1998), in preparation, will report on grid searches of the parameters for each class of rule using a small model of the US economy.

in terms of the output gap rather than the unemployment gap, which tends to vary about half as much over business cycles as the output gap. The two selected calibrations of IFB rules are $(\alpha, \beta, \gamma) = (2, 0, 1)$ and $(\alpha, \beta, \gamma) = (1, 1, 1)$. We found that the former performs relatively well among the set of conventional IFB rules with $\beta = 0$, and we wanted to focus as well on a novel form of IFB rule with the same value of $\alpha + \beta$ but with $\beta \neq 0$.

Table 3 summarises the results of stochastic simulations based on these three rules.

Table 3
Stochastic simulations with selected policy rules

	IFB Rules (Equation 15)				Taylor rules (Equation 16)	
	(α, β, γ)				(α, γ)	
	(1, 1, 1)	(1, 0, 1)	(2, 0, 1)	(1, 1, 0)	(.5, 1)	(1, 1)
Sample means						
DNAIRU	7.00	7.00	7.00	7.00	7.05	7.00
u	7.50	7.12	7.53	7.57	7.82	7.82
π	2.60	2.95	2.63	2.52	4.01	3.20
π^e	2.70	3.22	2.76	2.63	4.43	3.53
c	0.90	0.75	0.87	0.87	0.54	0.70
$r - \pi^e$	2.24	2.35	2.25	2.17	2.46	2.42
Sample standard deviations						
DNAIRU	0.37	0.37	0.37	0.37	0.38	0.37
u	1.14	1.15	1.10	1.26	1.18	1.25
π	0.74	0.96	0.77	0.88	1.62	1.06
π^e	0.94	1.22	1.01	0.96	1.94	1.37
c	0.08	0.16	0.09	0.11	0.26	0.19
$r - \pi^e$	1.50	1.13	1.46	1.39	0.94	1.08
Changes in DNAIRU						
	0.10	0.10	0.10	0.10	0.10	0.10
Change in estimated DNAIRU						
	0.12	0.11	0.11	0.13	0.11	0.12

Note first that the two IFB rules strongly outperform the selected Taylor rule in terms of delivering relatively low means and standard deviations of unemployment and inflation. As we have shown

elsewhere,⁴⁰ much of the difference in performance reflects the fact that the sum of the reaction parameters in the Taylor rule ($\alpha + \gamma = 1.5$) is less than the sum of the weights in the two IFB rules ($\alpha + \beta + \gamma = 3.0$). But a significant part of the difference also reflects the higher relative weight (ie value of γ relative to $\alpha + \beta$) that the Taylor rule places on the unemployment gap.⁴¹

Some intuition for these results comes from the following points. First, with endogenous credibility or other nonlinearities in the model, it is important to respond with adequate force to some weighted average of the deviation from the inflation target and the unemployment gap; otherwise, credibility may be eroded and result in first-order welfare losses over time. Second, and for similar reasons, endogenous policy credibility and convexity in the Phillips curve can also magnify the costs of responding slowly to emerging inflation, thus magnifying the advantages of forward looking IFB rules over conventional Taylor rules. Third, for any given relative weights that society (and/or the policy loss function) places on the unemployment gap and the deviation of inflation from target, the optimal calibration of a simple IFB rule is likely to depend on the degree of uncertainty about the NAIRU. In general, with considerable uncertainty about the NAIRU, policymakers are bound to make significant errors in estimating the unemployment gap, and such errors are likely to be positively autocorrelated, with systematic errors in estimating the unemployment gap transmitted through the Phillips curve into changes in the inflation rate. Our conjecture, based on comparisons over a limited number of rule calibrations, is that the greater the uncertainty that surrounds estimates of the unemployment gap, the stronger should be the policy reaction to inflation relative to unemployment, other things equal.⁴²

It may be noted that because our treatment of endogenous credibility introduces a nonlinearity into the unemployment-inflation process, our conclusions about the comparative performances of Taylor rules and IFB rules remain qualitatively unchanged in a variant of the model that includes a linear short-run Phillips curve. By contrast, in completely linear models of the unemployment-inflation process, the choice of policy rule mainly affects the variances of unemployment and inflation, with no significant effects on their means,⁴³ and differences between the performances of Taylor rules and IFB rules tend to be less significant.

Turning to a comparison of the performances of the two IFB rules, it may be noted from table 3 that the IFB rule that responds directly to the bias in the public's inflation expectations, as well as to the unemployment gap and the deviation from target of the authorities' inflation forecast (column 1), does somewhat better than a comparable IFB rule that responds only to the unemployment gap

⁴⁰ Isard, Laxton, and Eliasson (1998).

⁴¹ A small part of the differences in performance may reflect the fact that the results for the Taylor rule are based on only 14 of the 16 simulations, reflecting convergence failure in the other two cases.

⁴² We are exploring this conjecture more thoroughly in Eliasson, Isard, and Laxton (1998). See also Smets (1998) and Drew and Hunt (1999).

⁴³ Other papers that have employed stochastic simulations to evaluate the performances of alternative monetary policy rules have focused almost exclusively on linear models, with the performance of each rule summarised by a point on a two-dimensional plot of the standard deviations of unemployment and inflation.

and the deviation from target of the authorities' inflation forecast (column 2). In particular, the former rule delivers a higher average stock of credibility (c), which contributes to lower means of unemployment, inflation, inflation expectations, and the real interest rate, as well as lower standard deviations of inflation and inflation expectations.⁴⁴

7.0 Are there gains from experimentation?

Are there gains from experimenting with lower unemployment for purposes of pinpointing the NAIRU? The deterministic simulations discussed in section 3 illustrated the dangers of aggressive experimentation but left open the question of whether modest experimentation can be welfare enhancing. In this section we explore the issue further under the assumption that monetary policy is guided—absent experimentation—by an IFB rule that we have found to perform relatively well in our particular model, namely the calibration $(\alpha, \beta, \gamma) = (1, 1, 1)$.

We continue to restrict attention to the case in which the monetary authorities' uncertainty is limited to uncertainty about the NAIRU, the DNAIURU, and future realisations of the stochastic shocks. The idea of probing to find the NAIRU has been elevated into policy discussions by the experience of the United States during recent years. It was not so long ago that US policymakers regarded 6 percent as a reasonable estimate of the NAIRU. Yet over the past few years, the Federal Reserve has been able to prevent inflation from accelerating while allowing the unemployment rate to decline gradually to less than 4½ percent.

Traditional thinking, linked to an important contribution by Brainard (1967), suggests that monetary policy should deal with uncertainty by exercising more caution (relative to the no-uncertainty case) in the degree to which policy instruments are adjusted in response to indications (typically in the form of forecast errors) that the economy has been “shocked.” By contrast, a new line of thinking hypothesizes that well-designed experimental adjustments of policy instruments may enable monetary authorities to reduce their uncertainty. Wieland (1996) has explored this issue,⁴⁵ and argued the case for modest experimentation, in a model with a linear Phillips curve, backward-looking inflation expectations, and quadratic preferences that are symmetric around the NAIRU. As emphasised, however, by Laxton, Rose, and Tambakis (1998), Wieland's conclusions are not robust to the specification of policy preferences. To the extent that policymakers generally prefer reductions in the unemployment rate, other things equal, linear models of the inflation process imply a case for aggressive experimentation, since the consequences of inadvertently pushing unemployment significantly below the NAIRU would not lead to first-order welfare costs. This is because policy errors that resulted in deviations of unemployment from the NAIRU could simply be offset over time with no effects on the average rates of inflation or unemployment.

⁴⁴ As a separate and more technical point, it may be noted from the bottom two rows of the table that the standard deviations of the changes in the “true DNAIURU” and “estimated DNAIURU” (see appendix I) are quite similar in magnitude for each of the rules, suggesting that the updating process used to generate the estimated DNAIURU has a well-chosen value for the Kalman filter parameter.

⁴⁵ See also Bean (1996).

In this section we describe some simulated implications of experimentation—within the context of our nonlinear model with imperfect policy credibility—for the means and variances of inflation and unemployment. The analysis is oriented toward presenting “possibility sets” and avoiding specific assumptions about the nature of policy preferences.

Our experimentation takes the form of deviations from the rule-based policy settings, with the random probing oriented exclusively toward stimulating the economy and confined to periods during which the observed inflation rate lies below a specific threshold. The reason for defining experimentation in terms of random deviations from a policy rule, rather than deviations with non-random magnitudes linked to observed economic variables, is that the latter design would simply be equivalent to experimenting with a different policy rule. We incorporate such experimentation into our stochastic simulation framework by adding the term $EXPER_t$ to equation (16), where

$$EXPER_t = \begin{cases} \omega EXPER_{t-1} - ABS(\theta_t) & \text{if } \pi_{4,t-1} < 2.5 + \lambda \\ 0 & \text{otherwise} \end{cases}$$

The term $2.5 + \lambda$ represents the threshold for the four-quarter inflation rate ($\pi_{4,t-1}$) below which the authorities undertake experimentation, θ_t is drawn randomly from a normal distribution with zero mean and prespecified variance σ_θ^2 , and $ABS(\theta_t)$ is the absolute value of θ_t . Note that $EXPER$ is always less than or equal to zero, and that by assigning a magnitude to the parameter ω , the experimentation process can be defined to exhibit a prespecified degree of persistence.

The stochastic simulations that we use to analyse experimentation are similar in design to those described earlier, but with three additional parameters—namely, λ , ω , and σ_θ^2 . Figures 8 and 9 present simulation results corresponding to a grid of values for λ and σ_θ^2 (with $\omega = 0.75$).

None of the experimentation outcomes succeeds in lowering the means of both the unemployment and the inflation rates. Experimentation, however, could lead to small declines in average unemployment at the cost of small increases in average inflation, and in association with declines in average policy credibility. Reducing the average unemployment rate by 0.02 percentage points (from 7.51 to 7.49) comes at the cost of raising the average inflation rate by more than 0.1 percentage point (from 2.6 to above 2.7). This finding suggests that society would need relatively strong preferences for lower unemployment at the margin for experimentation to be welfare enhancing.

By suggesting that any prospective gains from experimentation are relatively small, these simulation results lead to the conclusion that experimental probing for the NAIRU does not warrant serious attention from policymakers.⁴⁶ This further suggests that a strategy that continuously up-

⁴⁶ As a more technical perspective on the simulation results, it appears that adding noise to the economy through random experimentation would not significantly improve the authorities’ ability to identify the NAIRU, given the level of noise to which the economy has historically been subjected. This finding does not necessarily argue against experimentation to try to resolve issues other than the location of the NAIRU. More specifically, our results do not speak to the case for probing the economy experimentally for the purpose of trying to resolve radically different views about the long-run tradeoff between unemployment and inflation or the shape of the Phillips curve.

Figure 8
Average inflation and unemployment rates under alternative degrees of experimentation

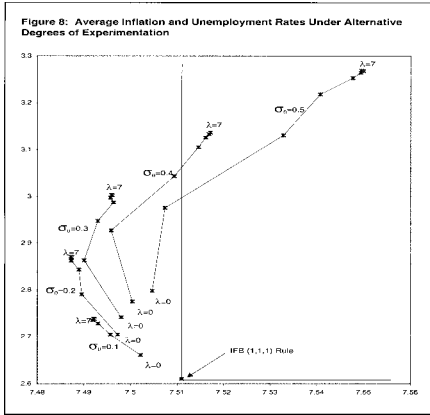
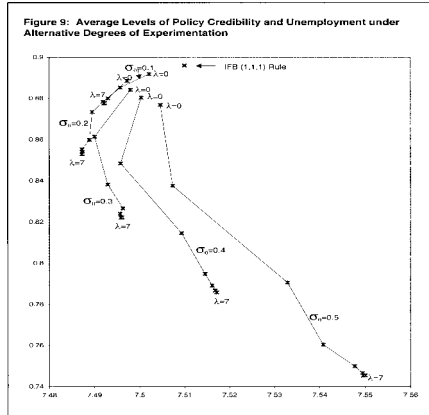


Figure 9
Average levels of policy credibility and unemployment under alternative degrees of experimentation



dates measures of the NAIRU based on new information about inflation and unemployment is more appropriate than biased policies that continuously “test the waters” and probe for lower unemployment rates.

Are the simulation results plausible? How can we reconcile the small estimated effects of experimentation with the experience of the United States in recent years? It is important to note that even if modest experimentation does not yield benefits, on average, compared to a rule where policymakers form unbiased estimates of the NAIRU, there will always be circumstances based on specific episodes, or on small samples of random shocks, where even aggressive experimentation would have improved welfare. Thus, following periods in which the NAIRU has fallen, there may be a tendency for pundits to use hindsight to argue that more aggressive experimentation was warranted because it would have enabled policymakers to learn more rapidly about downward shifts in the underlying NAIRU.

But policymaking should be based on the best information available ex ante, and should not be based simply on how the economy would respond under a favorable sequence of shocks. The stochastic simulation results reflects the effects of experimentation averaged over many hypothetical situations where the NAIRU is both rising and falling and the economy is continuously subjected to random shocks that make it difficult to infer the true NAIRU.

8.0 The gains from transparency

In describing the attractiveness of inflation-targeting and inflation-forecast targeting strategies, proponents in policymaking institutions have emphasised that such strategies can help increase the transparency of monetary policy. Economists have only just begun to try to analyse the gains from transparency in formal models.⁴⁷

An attempt to extend the formal analysis of transparency is beyond the scope of this paper. To provide some quantitative perspectives, however, we describe stochastic simulations that illustrate

Table 4
Stochastic simulations with selected policy rules

	IFB Rules (1.0, 1.0, 1.0)			Taylor rules (0.5, 1.0)		
	$b \neq 0$	($b = 0$)	Difference	$b \neq 0$	$b = 0$	Difference
	Sample means					
DNAIRU	7.00	7.00	+0.00	7.05	7.00	-0.05
u	7.50	7.32	-0.18	7.82	7.19	-0.63
π	2.60	2.60	+0.00	4.01	2.80	-1.21
π^e	2.70	2.58	-0.12	4.43	2.76	-1.67
$r - \pi^e$	2.24	2.16	-0.08	2.46	2.10	-0.36
	Sample standard deviations					
DNAIRU	0.37	0.37	+0.00	0.38	0.37	-0.01
u	1.14	1.09	-0.05	1.18	0.97	-0.21
π	0.74	0.76	+0.02	1.62	1.23	-0.39
π^e	0.94	0.92	-0.02	1.94	1.33	-0.62
$r - \pi^e$	1.50	1.52	+0.02	0.94	0.92	-0.02
Changes in DNAIRU	0.10	0.10	0.00	0.10	0.10	0.00
Change in estimated DNAIRU	0.12	0.11	-0.01	0.11	0.11	0.00

⁴⁷ Faust and Svensson (1998) have provided a formal analysis in which transparency is taken to connote the degree to which the public is able to infer the monetary authorities' intentions, formally defined as the share of the monetary authorities' control errors that the public can "observe." Dillén and Nilsson (1999) distinguish between "path transparency" and "instrument transparency."

the potential gains from eliminating the bias in inflation expectations. Such bias would presumably disappear if the public was able to perfectly infer the monetary authorities' intentions.

Table 4 presents stochastic simulations for our base-case IFB rule and our selected Taylor rule. For each rule the first column of simulation results is replicated from table 3, while the second set of results shows the implications of removing the bias term from the model of inflation expectations. The gains from extinguishing inflation expectations bias are shown in the third and sixth columns of the table. The difference in the average unemployment rate is 19 basis points under the IFB rule and 63 basis points under the Taylor rule, the difference in the average inflation rate is more than 1 percentage point under the Taylor rule, and the standard deviations of unemployment, inflation, and inflation expectations are reduced considerably under the Taylor rule.

In reality, the degree of inflation expectations bias in countries where monetary policy is not transparent may be considerably larger than the magnitudes in our model. This reflects the fact that monetary authorities have multiple objectives and may often be tempted to deviate from announced policy rules. Transparency about the policy framework, and the enhanced accountability that goes with it, can substantially increase the credibility of policy and substantially reduce the magnitude of inflation expectations bias.⁴⁸ Thus, to the extent that the degree of inflation expectations bias in our model may considerably *understate* the magnitudes that tend to emerge under relatively nontransparent monetary policy regimes, the prospective gains from transparency—measured in terms of the effects on average unemployment and inflation rates—may be considerably understated by the numbers in table 4.

9.0 Conclusions

This paper reflects an effort to extend the evaluation of simple monetary policy rules to a world with NAIRU uncertainty and endogenous policy credibility. The analysis assumes that the monetary authorities update their estimates of the NAIRU period by period, using information about unemployment, inflation, and the structure of the model. It is also assumed that the public's inflation expectations are sensitive to the track record of the monetary authorities in pursuing their announced inflation target, in contrast to most other contributions to the literature, which either ignore credibility or treat it as exogenous.

The paper has provided some perspectives, based on stochastic simulation analysis, on the comparative performances of selected examples of conventional Taylor rules and inflation-forecast based (IFB) rules, including a new variant of IFB rule in which the monetary authorities react directly to the degree of bias in the *public's* inflation expectations, as well as to the unemployment gap and the deviation from target of the *authorities'* inflation forecast. In contrast to much of the existing literature on monetary policy rules, which has based its analysis almost exclusively on linear models, our results emphasise that in models with nonlinearities (reflecting in our case both the behaviour of endogenous credibility and convexity in the Phillips curve), the choice of rule for pursuing a given inflation target can have substantial first-order effects on the average levels of unemployment and

⁴⁸ Green (1996) provides a recent discussion of these issues.

inflation. Our stochastic simulations indicate that forward-looking IFB rules tend to be significantly more effective than conventional Taylor rules in maintaining a relatively high level of policy credibility on average, and in delivering relatively low average rates of unemployment and inflation. We also find that our novel IFB rule performs somewhat better than its counterpart among the more conventional specifications of IFB rules.

After identifying an IFB rule that performs relatively well in the context of our particular model, the paper analysed the case for experimental departures from the rule in the direction of lowering unemployment as a strategy for trying to reduce uncertainty about the NAIRU. To the extent that adding variance to the economic data allows the authorities to estimate the NAIRU more accurately, such experimentation can help avoid periods of excess unemployment. It also runs the risk, however, of pushing unemployment significantly below the NAIRU and allowing inflation to accelerate, which can lead to first-order welfare losses in a nonlinear world.

The analysis first illustrated the dangers of aggressive experimentation and then explored the prospective gains from modest experimentation. The stochastic simulations indicated that experimental departures from a relatively attractive inflation-forecast based rule would not substantially improve macroeconomic performance. We interpret this result as suggesting that adding noise to the economy through random experimentation would not substantially improve the authorities' ability to identify the NAIRU, given the amount of noise to which the economy is already subjected. Modest experimentation could succeed in reducing the average unemployment rate very slightly at the cost of somewhat higher inflation, but this would only be welfare enhancing if society placed a fairly high value on marginal reductions in unemployment relative to marginal increases in inflation.

As a final exercise, the paper provided estimates of the gains that would be derived if inflation expectations bias was eliminated. The analysis suggests a potential for moderate welfare gains through increases in policy credibility. This in turn suggests that monetary authorities can enhance macroeconomic performance substantially by being transparent about their policy preferences, their reaction function, and their model of how the economy works.

Appendix: An updating procedure for estimating the NAIRU

We assume that in each period t the monetary authorities construct estimates of the DNAIU and NAIRU in a model-consistent manner based on their knowledge of the structure of the model and the histories of both the unemployment rate and the inflation rate. To investigate the implications of uncertainty about the NAIRU, it is assumed that the authorities know the true structure of the Phillips curve embodied in equation A1,

$$\pi_t = \pi_t^e + 2.14 \frac{(u_t^* - u_t)}{(u_t - \phi_t)} + \varepsilon_t^\pi$$

but they are unable to observe u_t^* , ϕ_t , or the error term of the Phillips curve ε_t^π .

Inferences about these unobservable variables can be derived from information about the structure of the Phillips curve as well as historical information about movements in π , π^e , and u . However, it is well known that because of significant measurement error in the Phillips curve relationship (ε_t^π in equation A1), there can be significant errors in the estimates of u_t^* derived directly from Phillips curve. For this reason it has been common for researchers in policy making institutions to also base their estimates of the NAIRU on trend movements in unemployment rates.

The updating process for the DNAIU (and the NAIRU), which takes account of historical information about both unemployment and inflation, can be formulated as an explicit Kalman filtering problem in which the monetary authorities are assumed to gradually learn about shifts in the underlying DNAIU. For our purposes, we assume that the authorities operate under the assumption that the DNAIU is subjected to permanent shocks, or that the change in the DNAIU follows a random walk according to

$$u_t^* = u_{t-1}^* + \varepsilon_t^{u^*}$$

where $\varepsilon_t^{u^*}$ is distributed as $N(0, \sigma_{u^*})$, with σ_{u^*} measuring the degree of volatility in the underlying DNAIU. In addition, the monetary authorities are assumed to know that for a given policy rule, there will be a constant difference (α) between the NAIRU and DNAIU.

$$\alpha = \bar{u}_t - u_t^*$$

Finally, the monetary authorities are assumed to know that the business cycle component of unemployment, ε_t^u is a stationary process with a fixed mean of zero.

$$u_t = \bar{u}_t + \varepsilon_t^u$$

As shown in Callen and Laxton (1998), these equations can be solved as a Kalman filtering problem where the monetary authorities continuously update their estimates of the DNAIRU and the NAIRU, as well as other interesting parameters such as the degree of convexity in the Phillips curve. For our purposes here, the estimation process has been simplified by assuming that the monetary authorities know the true parameters of the Phillips curve as well as the “true” degree of volatility in the underlying DNAIRU estimates. This results in an orderly updating process for the DNAIRU and NAIRU, where the monetary authorities make mistakes estimating the NAIRU and gradually improve their historical estimates over time as new data are released on inflation and unemployment developments.

The solution technique in the Monte Carlo experiments involves the following process.

The solution at the beginning of period t provides estimates of the histories of the DNAIRU and NAIRU through period $t-1$, along with forecasts of the DNAIRU and NAIRU through a terminal simulation horizon T . The forecasts are based on the assumption that realisations of all future shocks coincide with the zero means of the probability distributions of the shocks. Thus, in period t the DNAIRU and NAIRU are forecasted to remain unchanged at their estimated period t values.⁴⁹

In the context of the stochastic simulations, after the Kalman filtering problem has been solved at the beginning of period t , hypothetical realisations of the period t shocks are randomly drawn using Monte Carlo techniques, and the true model is then solved for the period t variables. Then the process is repeated, as the authorities again solve the Kalman filtering problem using the additional period of “historical data” to update their historical estimates and forecasts of the DNAIRU and NAIRU.

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⁴⁹ In the true model we assume that the DNAIRU process is a bounded random walk that ranges between 4 and 10. However, for the purpose of updating the u^* and $\bar{\pi}$ estimates we make a simplifying assumption that the monetary authorities are not able to observe these bounds and therefore act as if the DNAIRU process is unbounded. An alternative would be to relax this assumption, in which case the monetary authorities would always forecast the DNAIRU to gradually return back to a fixed steady state value. This would somewhat increase the complexity of our programming problem but probably would not add much additional insight.

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