Determining Output and Inflation Variability with Forward-looking and Open-economy Models

Takashi Senda

1 Introduction

The natural-rate hypothesis that no long-run trade-off exists between inflation and unemployment has won over most macroeconomists. A new trade-off, the trade-off between the variability of inflation and the variability of output, has lately attracted considerable attention. Instead of minimizing a weighted sum of the *levels* of inflation and unemployment, the central bank's objective function minimizes a weighted sum of the *variances* of inflation and output. Given this loss function for the central bank, a great deal of theoretical research has been done on which type of monetary policy rule is both efficient and robust. Clarida, Gali, and Gertler (1999) and an edited volume by Taylor (1999b) investigate various monetary policy rules.

Although there have been numerous theoretical investigations, there is a lack of empirical evidence that considers this question. Several researchers including Taylor (1999a) and Cecchetti and Ehrmann (1999) have undertaken empirical studies of monetary policy rules, but no consensus has yet emerged. The purpose of this paper is to investigate the determinants of inflation and output variability. This research is based on the theoretical studies of McCallum (2001a) and Ball (1999b, 2000) and provides empirical evidence to support these earlier theoretical results.

The models consist of three equations: an IS equation, a Phillips curve equation and a monetary policy reaction function. The parameters of these three equations determine the variability of inflation and output. In particular, this paper focuses on estimating the parameters of the monetary policy reaction function and on estimating the slope parameter of the Phillips curve. By analyzing data of 20 Organization for Economic Co-operation and Development (OECD) countries, this study provides cross-country evidence regarding both the relationship between the policy parameters of the monetary policy reaction function and inflation and output variability, and the relationship between the slope parameter of the Phillips curve and inflation and output variability.

There are two main findings. First, inflation will be low and stable in countries where the monetary policy rule has large reaction coefficients, and second, output will have large fluctuations in countries where the Phillips curve is relatively flat. Senda (2005) stresses the results for a backward-looking Svensson (1997) and Ball (1999a) model, and this paper extends along several dimensions to test the robustness of the results. This paper considers two alternative models. The first model incorporates forward-looking behavior into the backward-looking Svensson-Ball model. The second model assumes an open economy instead of a closed economy.

The rest of the paper contains five sections. Sections 2 and 3 provide an overview of the McCallum and Ball models, respectively. The relationship between the model's parameter values and inflation and output variability is explored through simulations. Section 4 describes the empirical data for the 20 OECD countries and reports the estimated parameters of the models. Section 5 presents the results of the cross-country regressions that are used to evaluate the determinants of inflation and output variability. Finally, Section 6 offers conclusions.

2 Forward-looking Model

2. 1 Assumptions

The behavioral equations in the Svensson-Ball model are "backward looking," since aggregate demand responds to the lagged ex post real interest rate, and inflation responds to the lagged output gap. These assumptions preclude monetary policy from influencing inflation and aggregate demand through an expectations channel. I allow for forward-looking behavior in the model.

McCallum (2001a) has a model that assesses the effect of forward-looking behavior on macroeconomic performance. I employ a version of his model. The model consists of three equations:

$$(1+\gamma)y_t = -\beta(i_t - E_t\pi_{t+1} - r^*) + E_t y_{t+1} + \gamma y_{t-1} + u_t, \quad (1)$$

$$\pi_t = (1-\emptyset)E_t\pi_{t+1} + \emptyset\pi_{t-1} + \alpha(y_t - y_t^*) + e_t, \quad (2)$$

$$i_t = (1-\rho)\{\pi_t + g(y_t - y_t^*) + h(\pi_t - \pi^*) + r^f\} + \rho i_{t-1} + v_t, \quad (3)$$

where y_t^* is the full employment level of output, i_t is the short-term nominal interest rate, π_t is the inflation rate, and e_t, v_t and u_t are white-noise shocks. The parameters of the model, which are all positive, are π^*, r^f, r^*, α, β, γ, ρ, and $\emptyset$.

Equation (1) is a forward-looking IS equation with habit formation in consumption. McCallum (2001b) shows how an IS function can be justified by optimization analysis. Similarly, one can derive equation (1). Consider a consumption Euler equation

$$\log\frac{C_t}{C_{t-1}^{\gamma}} = b_0' + E_t\log\frac{C_{t+1}}{C_t^{\gamma}} + b_1' r_t + u_t', \quad (4)$$

and the overall resource constraint for the economy with constant capital

$$\log Y_t = (c/Y)\log c_t + (G/Y)\log G_t, \quad (5)$$

where G_t is government expenditure, and (c/Y) and (G/Y) are steady state shares. Substitution of (5) into (4) yields

$$(1+\gamma)\log Y_t = b_0 + b_1 r_t + E_t\log Y_{t+1} + \gamma\log Y_{t-1} + u_t, \quad (6)$$

Here u_t reflects tastes and fiscal policy, and thus equation (1) is justified. Habit formation implies that current period utility depends on not just current consumption, C_t, but rather on the ratio of current consumption to lagged consumption, C_t/C_{t-1}^{γ}. Habit formation is added to the standard optimizing equation in order to generate the high persistence in output that is observed in the data.

Equation (2) is a price adjustment relationship suggested by Fuhrer and Moore (1995). By introducing a backward-looking term into a purely forward-looking price adjustment equation, Fuhrer and Moore produce inflation inertia.

Equation (3) is a monetary policy reaction function and the parameter ρ reflects the central bank's desire to smooth the nominal interest rate.

2.2 Model Simulation

This section investigates the determinants of inflation and output variability in the McCallum model. I numerically derive the effects of changing the parameter values on output and inflation variability.

2.2.1 Calibration

First, a set of base parameter values is specified to analyze the model. Similar to McCallum (2001a), this study assumes that the model's baseline parameters are $\gamma=0.8$, $\beta=0.4$, $\emptyset=0.5$, $\alpha=0.03$, $\rho=0.8$. Also, u_t, e_t, v_t, and y_t^* are assumed to be AR(1) processes with AR parameters 0.0, 0.0, 0.0, and 0.95, respectively, and innovation standard deviations of 0.03, 0.002, 0.0017, and 0.007.

2.2.2 Derivation of the Variances of Output and Inflation

In order to compute the standard deviations of inflation, π_t, and the output gap, $\tilde{y}_t = y_t - y_t^*$, I follow the procedures devised by McCallum (1998). The setup of McCallum's procedure is as follows. Let x_t be a $M\times1$ vector of non-predetermined variables, k_t be a $K\times1$ vector of predetermined variables, and ξ_t be a $N\times1$ vector of exogenous variables. The model can then be written as

$$A_{11}E_t x_{t+1} = B_{11}x_t + B_{12}k_t + C_1\xi_t \qquad (7)$$
$$k_{t+1} = B_{21}x_t + B_{22}k_t + C_2\xi_t$$
$$\xi_t = R\xi_{t-1} + \varepsilon_t$$

where A_{11} and B_{11} are square matrices while ε_t is a $N\times 1$ white noise vector. McCallum shows that in this setting an undetermined-coefficients solution is of the form

$$x_t = \Omega k_t + \Gamma\xi_t \qquad (8)$$
$$k_{t+1} = \Pi_1 k_t + \Pi_2\xi_t,$$

where the Ω, Γ, Π_1, and Π_2 matrices are real.

For our model, constant terms can be ignored in the simulations and we can take

$$x_t = \begin{bmatrix} y_t \\ \pi_t \end{bmatrix},\ k_t = \begin{bmatrix} i_{t-1} \\ y_{t-1} \\ \pi_{t-1} \end{bmatrix},\ \xi_t = \begin{bmatrix} u_t \\ e_t \\ v_t \\ y_t* \end{bmatrix},$$

$$A_{11} = \begin{bmatrix} -1 & -\beta \\ 0 & -(1-\phi) \end{bmatrix},$$

$$B_{11} = \begin{bmatrix} -\beta(1-\rho)g-(1+\gamma) & -\beta(1-\rho)(1+h) \\ \alpha & -1 \end{bmatrix},$$

$$B_{12} = \begin{bmatrix} -\beta\rho & \gamma & 0 \\ 0 & 0 & \phi \end{bmatrix},$$

$$C_1 = \begin{bmatrix} 1 & 0 & -\beta & \beta(1-\rho)g \\ 0 & 1 & 0 & -\alpha \end{bmatrix},$$

$$B_{21} = \begin{bmatrix} (1-\rho)g & (1-\rho)(1+h) \\ 1 & 0 \\ 0 & 1 \end{bmatrix},\ B_{22} = \begin{bmatrix} \rho & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix},$$

$$C_2 = \begin{bmatrix} 0 & 0 & 1 & -(1-\rho)g \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix},$$

$$R = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.95 \end{bmatrix}.$$

The undetermined-coefficients solution was then obtained by using a computer program developed by Klein (2000) and Söderlind (1999).

2.2.3 Quantitative Results

Next, I investigate how the variability of inflation and output behave as the parameter values of the monetary policy rule change. I want to determine if robust economic relationships exist as the parameters take on different values. I use a range of values that are actually observed in the data.[1]

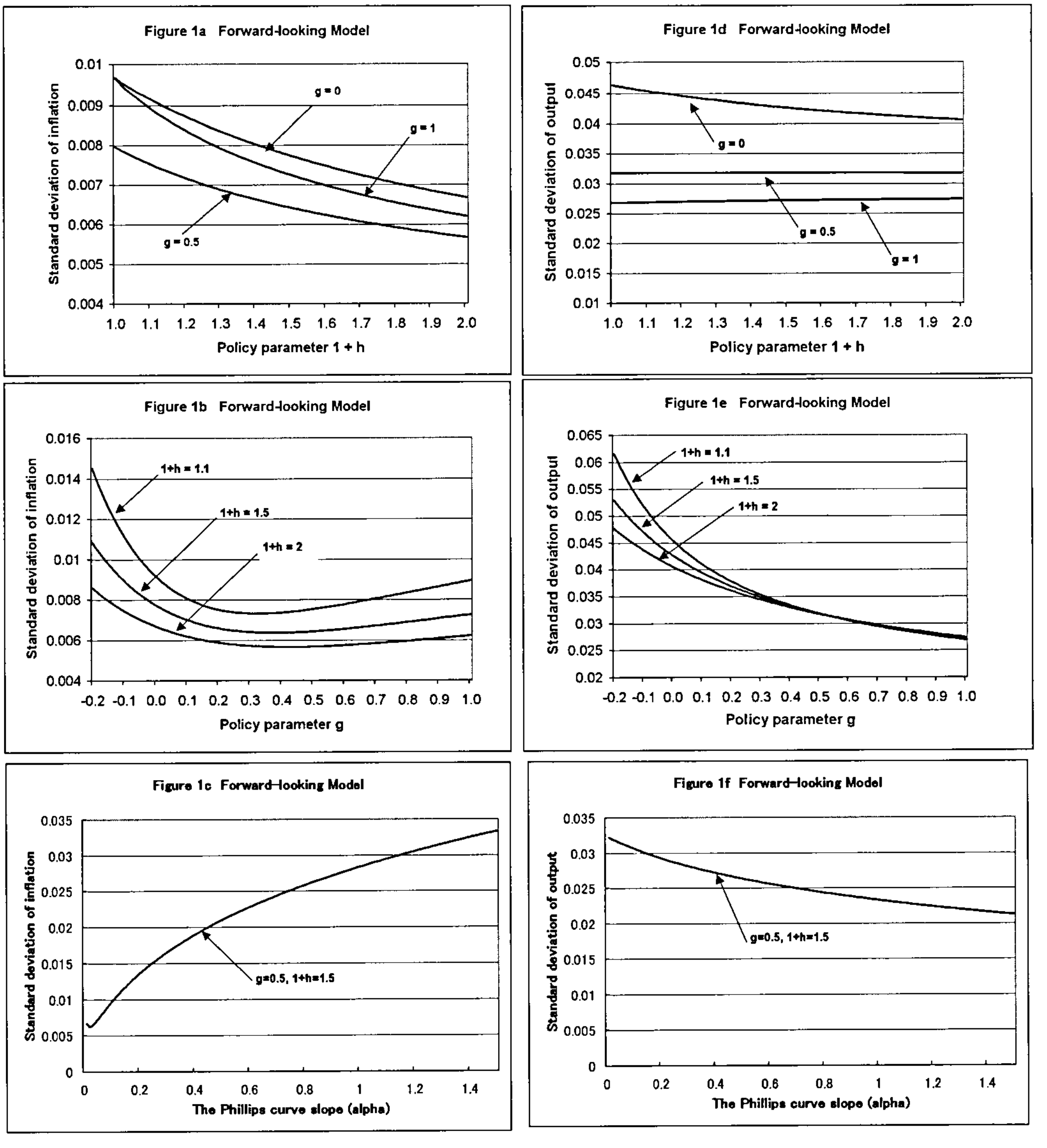
The results for the McCallum model are presented in figure 1. Figures 1a, 1b, and 1c illustrate the relationship between the parameters ($1+h$, g, and α) and inflation variability and figures 1d, 1e, and 1f show the behavior of output variability. Figure 1a indicates that an increase in $1+h$ reduces inflation variability. Figure 1b shows that an increase in g also reduces inflation variability except when the value of g is very large. In figures 1d and 1e, an increase in g leads to smaller output variability, whereas the relationship between $1+h$ and output variability is ambiguous. Finally, figures 1c and 1f show the effect of changes in the coefficient α on the variances of output and inflation. As α approaches zero, the variability of inflation is reduced; however, the variability of output increases.

---

[1] My previous experiment yields two results. First, within a realistic range of parameter values as policymakers care more about inflation or there is an increase in the inflation coefficient $1+h$ the variability of inflation decreases but the variability of output increases. Second, an increase in the output coefficient g or caring more about output reduces the variances of both inflation and output.

The other important parameter in the Svensson-Ball model is the slope of the Phillips curve, α. In particular, I want to determine what happens to the variability of inflation and output as the slope, α, approaches zero. Unfortunately, this model offers a somewhat trivial answer. Since this model is unstable if the slope is non-positive the variances of both inflation and output approach infinity as the slope approaches zero.

Figure 1



3 Open-economy Model

3.1 Assumptions

It may be misguided to apply the closed-economy Svensson-Ball model to many of the OECD countries included in this analysis. For open economies the Svensson-Ball model is modified so that it can capture the transmission channel arising from endogenous movements in the exchange rate. Different results may be obtained from an open model because monetary policy affects the economy through the exchange-rate channel as well as the interest-rate channel. I test the robustness of the relationship between the policy parameters and inflation and output variability by reexamining the experiment with the open economy model of Ball (1999b, 2000).

There are four equations:

$$\tilde{y}_t = -\beta(i_{t-1} - \pi_{t-1} - r^*) - \delta\tilde{\omega}_{t-1} + \lambda\tilde{y}_{t-1} + u_t, \quad (9)$$

$$\pi_t = \pi_{t-1} + \alpha\tilde{y}_{t-1} - \mu(\tilde{\omega}_{t-1} - \tilde{\omega}_{t-2}) + e_t, \quad (10)$$

$$\tilde{\omega}_t = \theta(i_t - \pi_t - r_\omega) + \eta_t, \quad (11)$$

$$i_t=\pi_t+g\tilde{y}_t+h\{(\pi_t-\pi^*)+\mu\tilde{\omega}_{t-1}\}-f\tilde{\omega}_t+r^f+v_t, \quad (12)$$

where $\tilde{\omega}_t=\omega_t-\bar{\omega}$ is the detrended real exchange rate (an increase in ω_t indicates an appreciation of the domestic currency), and u_t, e_t, and η_t are shocks.

Equations (9) and (10) are an open-economy IS curve and an open-economy Phillips curve, respectively. Equation (10) directly includes the exchange rate and equation (9) includes lagged inflation, which is influenced by the exchange rate. Equation (10) indicates that changes in real exchange rate affect inflation directly through import prices. Equation (11) implies a positive relationship between real interest rates and exchange rates. Finally, equation (12) is the open-economy monetary policy rule. The exchange rate now appears on the right-hand side of the monetary policy reaction function implying that policymakers adjust nominal interest rates in response to exchange rates as well as output and inflation. The combination of inflation and the lagged exchange rate, $(\pi_t-\pi^*)+\mu\tilde{\omega}_{t-1}$, can be viewed as a "monetary conditions index" (MCI), which helps policymakers set nominal interest rates.[2]

3.2 Model Simulation

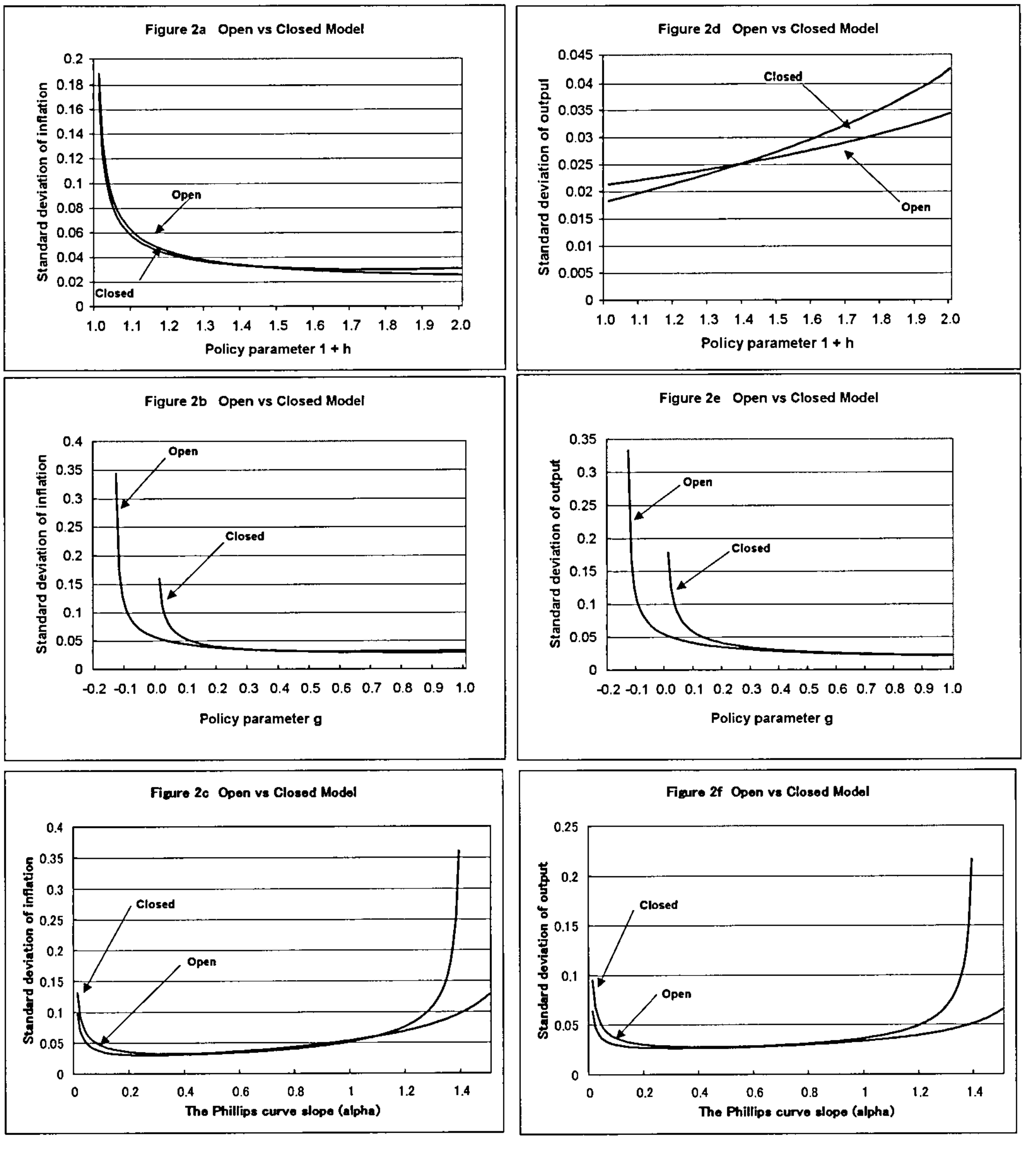
The baseline parameter values, $\beta=0.6$, $\delta=0.2$, $\lambda=0.8$, $\alpha=0.4$, $\mu=0.2$, $\theta=2.0$, and $f=1/3$ are borrowed from Ball (1999b). The standard deviations of shocks $\sigma_u=0.0184$, $\sigma_e=0.0110$, and $\sigma_\eta=0.0846$ are obtained by estimating equations (9)-(11) for the US postwar period. The results for the open-economy model are compared to those for the closed-economy model in figure 2. The open-economy model does not alter the relationship between the policy parameter values and inflation and output variability. Also the relationship between the slope of the Phillips curve and the variability of inflation and output is similar in the open economy model to the results obtained under the closed economy model as shown in figures 2c and 2f.

The alternative models' results support the original relationships between the model parameters and inflation and output variability.[3] Adding either an expectations channel or an exchange-rate channel to the Svensson-Ball model does not alter the response of output variability and inflation variability.

[2] Ball (1999b).

[3] There are some exceptions under the forward-looking model. There are an ambiguous effect of $1+h$ on σ_y and an opposite effect of α on σ_π.

Figure 2



4 Model Estimates

In the previous section, I employed two models to obtain the relationships between the model parameters and the variability of inflation and output. In this section, I examine these relationships empirically with data from 20 OECD countries.

4.1 Data and Descriptive Statistics

The data are from the International Monetary Fund's *International Financial Statistics* and the *OECD Main Economic Indicators* and are annual averages. The output gap, $\tilde{y}_t$, is defined as the detrended log of real GDP; the trend is measured by the Hodrick-Prescott filter with a smoothing parameter equal to 100. For each country, the entire available time series is used in the estimation of trend. Inflation is the percentage change of the GDP deflator. The nominal interest rate is a representative short-term interest rate such as the money market rate or the Treasury bill rate.

The 20 OECD countries are listed in table 1, together with the sample periods. Table 1 also presents the standard deviations of inflation and

Table 1. Descriptive Statistics on Inflation and Output, Various Countries, Selected periods, 1960-2000

σ_y = Standard deviation of output. σ_π = Standard deviation of inflation.

σ_π/σ_y = Variability ratio. $\bar{\pi}$ = Mean inflation.

A. First subsample

Country	*Sample period*	σ_y	σ_π	σ_π/σ_y	$\bar{\pi}$
Australia	1960-82	0.0171	0.0474	2.7719	0.0728
Austria	1960-80	0.0177	0.0208	1.1751	0.0509
Belgium	1960-78	0.0170	0.0322	1.8941	0.0520
Canada	1960-77	0.0180	0.0338	1.8778	0.0518
Denmark	1960-79	0.0154	0.0274	1.7792	0.0764
Finland	1960-79	0.0293	0.0524	1.7884	0.0815
France	1960-80	0.0104	0.0335	3.2212	0.0700
Germany	1960-79	0.0439	0.0418	0.9522	0.0452
Ireland	1960-79	0.0189	0.0641	3.3915	0.0893
Italy	1960-82	0.0209	0.0687	3.2871	0.1061
Japan	1960-85	0.0310	0.0451	1.4548	0.0531
Netherlands	1960-78	0.0242	0.0308	1.2727	0.0656
New Zealand	1960-79	0.0263	0.0564	2.1445	0.0764
Norway	1960-79	0.0158	0.0541	3.4241	0.0591
Portugal	1960-79	0.0279	0.0824	2.9534	0.0834
Spain	1960-79	0.0304	0.0622	2.0461	0.1067
Sweden	1960-79	0.0157	0.0333	2.1210	0.0666
Switzerland	1960-86	0.0317	0.0226	0.7129	0.0459
United Kingdom	1960-80	0.0154	0.0664	4.3117	0.0879
United States	1960-79	0.0215	0.0302	1.4047	0.0457
Mean		0.0224	0.0453	2.1992	0.0693

B. Second subsample

Country	*Sample period*	σ_y	σ_π	σ_π/σ_y	$\bar{\pi}$
Australia	1983-2000	0.0211	0.0321	1.5213	0.0393
Austria	1981-2000	0.0137	0.0153	1.1168	0.0289
Belgium	1979-2000	0.0168	0.0192	1.1429	0.0337
Canada	1978-2000	0.0260	0.0317	1.2192	0.0416
Denmark	1980-2000	0.0182	0.0276	1.5165	0.0440
Finland	1980-2000	0.0433	0.0331	0.7644	0.0471
France	1981-2000	0.0162	0.0352	2.1728	0.0393
Ireland	1980-2000	0.0241	0.0513	2.1286	0.0569
Italy	1983-2000	0.0147	0.0337	2.2925	0.0605
Japan	1986-2000	0.0236	0.0113	0.4788	0.0099
Netherlands	1979-2000	0.0198	0.0193	0.9747	0.0219
New Zealand	1980-2000	0.0252	0.0604	2.3968	0.0654
Norway	1980-2000	0.0209	0.0442	2.1148	0.0520
Portugal	1980-2000	0.0234	0.0966	4.1282	0.1265
Spain	1980-2000	0.0256	0.0379	1.4805	0.0734
Sweden	1980-2000	0.0234	0.0366	1.5641	0.0535
Switzerland	1987-2000	0.0192	0.0189	0.9844	0.0221
United Kingdom	1981-2000	0.0270	0.0241	0.8926	0.0469
United States	1980-2000	0.0202	0.0233	1.1535	0.0386
Mean		0.0222	0.0343	1.5812	0.0474

output, the variability ratio (defined as the ratio of the standard deviation of inflation to the standard deviation of output), and the average inflation rate for the two subsamples. The first subsample includes data through a break point and the second subsample includes data after the break point.[4]

Since this study is an investigation of the relationship between monetary policy rules and economic performance it is appropriate to define a break point as the year when a structural change in the monetary policy rule is most likely to have occurred. Therefore, I follow King, Stock, and Watson (1995) and estimate country-specific breakpoints. I calculate the standard Chow likelihood ratio (LR) statistic for every year for the monetary policy reaction function in the forward-looking Svensson-Ball model (equation (3)). A break point is defined as the year that yields the largest LR-statistic. For each subsample, I do not estimate the model if the sample has fewer than 14 years.

Important aspects of inflation and output variability can be uncovered by estimating the model for each subsample. For example, Taylor (1999a) examines the relationship between monetary policy rules and economic performance of three monetary eras in the United States: the international gold standard period (1879-1914), the Great Inflation period (1960-79), and the recent period (1987-97). Of the three, Taylor finds that the gold standard period is the least economically stable and the 1987-97 period is the most stable. Comparing the monetary policy rules the gold standard period has the least responsive policy rule and the recent period has the most responsive policy rule.[5] Based on the correlation he finds between the monetary policy rule and macroeconomic stability, he concludes that more responsive policy rules lead to greater economic stability.

There are changes in inflation and output statistics for the sample as well. The last row of each sub-table in table 1 provides the sample averages of the standard deviations of inflation and output, the variability ratio, and mean inflation. Both inflation and output are less volatile after the break suggesting that aggregate supply shocks may be smaller in the recent period. The standard deviations of output and inflation have fallen from 0.0224 to 0.0222 and from 0.0453 to 0.0343, respectively. On average inflation variability is reduced more than output variability. The sample average of the variability ratio has dropped to 1.58 from 2.20, indicating that output has become relatively more volatile than inflation. Mean inflation $\bar{\pi}$ has decreased from 6.9 percent to 4.7 percent.

In sections 2 and 3, I derived that the variances of inflation and output depend on the monetary policy reaction function and the slope of the Phillips curve. Now I examine if the policy parameters ($1+h$ and g) and the Phillips curve slope (α) have changed over time and if they have changed does this explain the decrease in the variability ratio and mean inflation seen over the last forty years.

4.2 Policy Parameters and the Phillips Curve Slope

The policy parameters are estimated with models that are closely related to the theoretical models discussed in section 2. First, I include the lagged interest rate in the Taylor Rule, following the McCallum's model in section 2.1.[6] The estimated equation is now

$$i_t=(1-\rho)\{\pi_t+g\tilde{y}_t+h(\pi_t-\pi^*)+r^f\}+\rho i_{t-1}+v_t, \tag{13}$$

where ρ is an interest rate smoothing coefficient.[7]

---

[4] Most of the sample periods begin in 1960 and end in 2000.

[5] A more responsive monetary policy rule implies larger values for the policy coefficients, $1+h$ and g.

[6] To check the robustness of this paper's findings, empirical exercises were done with alternative detrending method for several variables. HP-filtering with a smoothing parameter equal to 100 is used to calculate a time-varying inflation target π_t^* and an equilibrium real interest rate r_t^* as well as potential output y_t^*. Appendix reports the results. The results in Appendix are similar to those in tables 4a, 4b, 5, and 6, and thus the choice of the detrending method does not seem to have a large effect on the empirical results of section 5.

The results are reported in table 2a. In table 2a the sample average of the coefficient on inflation ($1+h$) has substantially increased to 1.20 from 0.50. The sample average of the coefficient on output has also increased: the average is 0.92 in the second sample whereas it was 0.52 in the first sample.

Next, I use Ball's open-economy model from section 3.1 to estimate the monetary policy reaction function. The open-economy model is estimated by two-step OLS. I first estimate equation (10) with an oil-shock dummy variable and constructed MCI, $(\pi_t - \pi^*) + \mu \tilde{\omega}_{t-1}$.[8] This MCI is then used to estimate $1+h$,

Table 2a. Estimates of policy parameters, Various countries, Selected Periods, 1960-2000: (Forward-looking Model)

		First subsample		
Country	*Sample period*	$1+h$	g	ρ
Belgium	1960-78	0.270	0.495	0.144
Canada	1960-77	0.433**	0.586	0.529***
France	1960-79	0.571***	0.744	0.206
Germany	1960-79	0.097	0.095	0.409
Italy	1960-83	1.640**	1.901	0.718***
Japan	1960-78	0.764	-0.017	0.636**
Netherlands	1960-78	0.005	0.425	0.180
Sweden	1960-80	0.361	0.092	0.471
Switzerland	1960-84	0.566**	-0.227	0.090
United Kingdom	1960-78	0.220	1.890	0.639**
United States	1960-78	0.514**	0.991*	0.422*
Mean		0.495	0.519	0.404

		Second subsample		
Country	*Sample period*	$1+h$	g	ρ
Australia	1987-2000	0.786*	1.213	0.548***
Austria	1982-2000	1.028***	0.662***	0.105
Belgium	1979-2000	1.097**	2.686*	0.726***
Canada	1978-2000	1.207***	1.426	0.691***
Denmark	1980-2000	1.180**	-0.484	0.610***
Finland	1980-2000	1.835*	0.957	0.822***
France	1980-2000	1.013***	1.289**	0.564***
Italy	1984-2000	1.408***	1.914	0.711***
Japan	1979-2000	2.399***	0.060	0.542***
Netherlands	1979-2000	0.978***	1.688***	0.594***
New Zealand	1980-2000	0.705***	0.703	0.470***
Portugal	1980-2000	0.335	-1.224	0.772***
Spain	1980-2000	1.280*	0.866	0.698***
Sweden	1981-2000	0.822	0.763	0.654**
Switzerland	1985-2000	1.979	1.692	0.804***
United Kingdom	1979-2000	0.831***	0.849**	0.598***
United States	1979-2000	1.476***	0.531	0.492***
Mean		1.198	0.917	0.612

Significance at the 0.10, 0.05, and 0.01 level is indicated by *, **, and ***, respectively.

Table 2b. Estimates of policy parameters, Various countries, Selected Periods, 1976-2000: (Open Model)

Country	1+*h*	*g*
Australia	0.873***	0.487*
Austria	0.449	0.673**
Belgium	0.739***	0.656**
Canada	0.908***	0.109
Denmark	0.914***	-0.641**
Finland	-0.219	-0.154
France	0.208	0.376
Germany	0.429	0.383
Italy	0.675***	-0.931***
Japan	0.763***	0.231
Netherlands	0.599**	0.531*
New Zealand	0.569***	0.343
Norway	0.344**	-0.150
Portugal	0.126	-0.574
Spain	0.481***	-0.159
Sweden	0.299	-0.234
Switzerland	0.624*	0.050
United Kingdom	0.464***	0.089
United States	0.780***	0.056
Mean	0.539	0.080

Significance at the 0.10, 0.05, and 0.01 level is indicated by *, **, and ***, respectively.

g, and f in equation (12). Because the open-economy model incorporates the movement of exchange rates, the sample period begins in 1976. The results are shown in table 2b.

Table 3 presents the estimated value of the slope coefficient of the Phillips curve. The slope coefficients are estimated for the two models.

Estimation of α in the McCallum forward-looking model is done in the following way. In an empirical study, we cannot ignore constant terms in equations (1), (2), and (13). The estimated equations are

$$(1+\gamma)\tilde{y}_t=-\beta(i_t-E_t\pi_{t+1}-r^*)+E_t\tilde{y}_{t+1}+\gamma\tilde{y}_{t-1}+u_t,$$
$$\pi_t=(1-\phi)E_t\pi_{t+1}+\phi\pi_{t-1}+\alpha\tilde{y}+e_t,$$
$$i_t=(1-\rho)\{\pi_t+g\tilde{y}_t+h(\pi_t-\pi^*)+r^*\}+\rho i_{t-1}+v_t,$$

and vectors and matrices in section 2.2.2 become

$$x_t=\begin{bmatrix}\tilde{y}_t\\ \pi_t-\pi^*\end{bmatrix},\quad k_t=\begin{bmatrix}i_{t-1}-\pi_{t-1}-r^*\\ \tilde{y}_{t-1}\\ \pi_{t-1}-\pi^*\end{bmatrix},$$

$$\xi_t=\begin{bmatrix}u_t\\ e_t\\ v_t\end{bmatrix},\quad A_{11}=\begin{bmatrix}-1 & -\beta\\ 0 & -(1-\phi)\end{bmatrix},$$

$$B_{11}=\begin{bmatrix}-\beta(1-\rho)g-(1+\gamma) & -\beta\{(1-\rho)h+1\}\\ \alpha & -1\end{bmatrix}$$

[7] It is debatable whether one can interpret a partial adjustment of the policy interest rate as evidence of an interest rate smoothing behavior by central banks. Rudebusch (2002) shows that an interest rate smoothing coefficient, ρ, likely reflects serially correlated shocks that central banks face.

[8] *Oildummy$_t$* takes a value of 1 in the years of major oil price increase (1974, 1979 and 1980), -1 in the year of a major price decrease (1986), and 0 otherwise. This dummy variable is the same as is used in Ball et al. (1988).

Table 3. Estimates of the Phillips curve slope (alpha), Various countries, Selected Periods, 1960-2000

A. First subsample

Country	Forward-looking
Belgium	0.579***
Canada	0.471**
France	0.317
Germany	0.406**
Italy	0.438
Japan	0.320**
Netherlands	0.533*
Sweden	0.824*
Switzerland	0.147*
United Kingdom	2.290**
United States	0.495*
Mean	0.620

B. Second subsample

Country	Forward-looking	Open-economy
Australia	0.085	0.269
Austria	0.136*	0.224
Belgium	0.045	0.415*
Canada	0.094**	0.290**
Denmark	—	0.241
Finland	0.043*	-0.009
France	0.075**	0.297*
Ireland	—	0.272
Italy	0.146**	0.325
Japan	0.118*	0.166
Netherlands	0.111*	0.383
New Zealand	0.110	0.634*
Norway	—	0.198
Portugal	0.258	1.486**
Spain	0.037	0.304
Sweden	0.051	0.108
Switzerland	0.219**	0.098
United Kingdom	0.169***	0.417**
United States	0.062**	0.170
Mean	0.103	0.331

Significance at the 0.10, 0.05, and 0.01 level is indicated by *, **, and ***, respectively.

$$B_{12}=\begin{bmatrix}-\beta\rho & \gamma & 0\\ 0 & 0 & \phi\end{bmatrix},\ C_1=\begin{bmatrix}1 & 0 & -\beta\\ 0 & 1 & 0\end{bmatrix},$$

$$B_{21}=\begin{bmatrix}(1-\rho)g & (1-\rho)h\\ 1 & 0\\ 0 & 1\end{bmatrix},\ B_{22}=\begin{bmatrix}\rho & 0 & 0\\ 0 & 0 & 0\\ 0 & 0 & 0\end{bmatrix},$$

$$C_2=\begin{bmatrix}0 & 0 & 1\\ 0 & 0 & 0\\ 0 & 0 & 0\end{bmatrix},\ R=\mathrm{O}.$$

It follows from equation (8) that

$$E_t x_{t+1}=\Omega k_{t+1},$$

and substituting this into equation (7), we obtain Fuhrer and Moore's (1995) *observable structure*,

$$A_{11}\Omega k_{t+1}=B_{11}x_t+B_{12}k_t+C_1\xi_t. \qquad (14)$$

Having obtained the observable structure of equation (14), we next compute the value of the likelihood function. The likelihood is defined as

$$L(\Theta)=T(\log|\Im(\Theta)|-0.5\log|\hat{\Omega}(\Theta)|)$$

where T is the sample size, $\Im$ is the Jacobian of transformation, and Ω is the variance-covariance matrix of the structural residuals ξ_t. Θ is a vector of parameters, $\Theta=(\alpha, g, 1+h, \rho, \emptyset, \beta, \gamma, r^*, \pi^*)$. To conserve degrees of freedom, the estimates in table 2a are used for the policy parameters (g, $1+h$, ρ). It is also assumed that the parameters ($\emptyset, \beta, \gamma$) equal the baseline values in section 2.2.1, and $r^*=\pi^*=0.02$ as in Taylor (1993).

Several of the countries that have small variability ratios (thus relatively more volatile output) in the latter period also have experienced a sharp decrease in the slope coefficient. For example, the United Kingdom whose variability ratio decreased from 4.31 to 0.89 had its Phillips curve slope for the McCallum model decrease from 2.29 to 0.17. Japan, who has also experienced a relative decrease in its output variability (the ratio has fallen to 0.48 from 1.45), has an even flatter Phillips curve. The point estimate of the Phillips curve slope is close to zero (0.12) reduced from 0.32. A flatter Phillips curve implies that prices have become less responsive to the output gap.

After seeing that there have been widespread declines in the variances of inflation and the slope of the Phillips curve I examine if these differences in the variances of inflation and output over time can be explained by the changes in the monetary policy reaction function parameters or by changes in the Phillips curve slope. To explore this issue the next section conducts a cross-country analysis.

5 Determinants of Output Variability and Inflation Variability

In this section, I examine the parameters of the monetary policy reaction function and the slope of the Phillips curve as the possible determinants of the size of output and inflation variability. I estimate cross-country regressions based on the estimates from the second subsample in tables 2 and 3. I also estimate the regression by pooling the data using the break points discussed earlier.

5.1 The Degree of Accommodation

The cross-section regression results for σ_π are presented in table 4a for the estimates with interest rate smoothing (forward-looking model), and in table 4b for the open-economy model. The results for σ_y are not reported because there is no systematic relationship between the parameters ($1+h$ and g) and σ_y for either model.

The world economy during the first subsample seems to have suffered from larger aggregate demand and supply shocks such as the Vietnam War and two oil shocks than the second subsample. In order to control the effects of aggregate demand and supply shocks, in the pooled estimation, I include a dummy variable

$$D=\begin{cases}0 \text{ if from the first subsample}\\ 1 \text{ if from the second subsample}\end{cases}$$

as an explanatory variable.

Table 4a. Determinants of Inflation Variability (Forward-looking Model)

Independent variable	Second subsample			Pooled sample		
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.063***	0.047***	0.069***	0.046***	0.043***	0.047***
	(0.010)	(0.006)	(0.009)	(0.006)	(0.006)	(0.007)
$1+h$	-0.025***		-0.022***	-0.012		-0.010
	(0.008)		(0.007)	(0.007)		(0.007)
g		-0.012**	-0.010**		-0.005	-0.003
		(0.005)	(0.004)		(0.004)	(0.004)
Dummy				0.002	-0.005	0.002
				(0.008)	(0.007)	(0.008)
Summary statistic						
R2	0.394	0.306	0.599	0.124	0.080	0.147
Standard error	0.016	0.017	0.014	0.018	0.018	0.018

Significance at the 0.10, 0.05, and 0.01 level is indicated by *, **, and ***, respectively.

The standard errors are in parentheses.

Table 4b. Determinants of Inflation Variability (Open-economy Model)

Independent variable	(1)	(2)	(3)
Constant	0.052***	0.043***	0.051***
	(0.009)	(0.004)	(0.008)
$1+h$	-0.020		-0.015
	(0.015)		(0.013)
g		-0.028***	-0.026**
		(0.009)	(0.010)
Summary statistic			
R2	0.101	0.332	0.384
Standard error	0.020	0.017	0.017

Significance at the 0.10, 0.05, and 0.01 level is indicated by *, **, and ***, respectively.

The standard errors are in parentheses.

In the case of interest rate smoothing, both coefficients have the predicted signs and are statistically significant for the second subsample and they are of the predicted sign but insignificant for the pooled sample. In the open-economy model, the coefficients on g have the expected signs and are statistically significant but the coefficients on $1+h$ are insignificant. Although the estimated effects are somewhat small, these results suggest that there exists a systematic, negative relationship between the policy parameters ($1+h$ and g) and the variability of inflation (σ_π) implying that policymakers can reduce the variability of inflation by having a strong anti-inflation preference.

5.2 The Degree of Price Stickiness

Another factor that determines macroeconomic stability is the degree of price stickiness. Based on sticky price and wage theories, Taylor (1980, 1989) argues that nominal rigidities tend to increase the size of output fluctuations. The question that arises is why do greater nominal rigidities lead to larger output variability. In practice, one reason is that higher nominal rigidities indicate that output needs to fluctuate more to induce the appropriate monetary policy response. Another reason is that higher nominal rigidities imply a greater sacrifice ratio. In sticky price and wage theories, a Phillips curve with a flatter slope implies greater price and wage rigidity. Hence countries with flatter slopes will have relatively higher variability of output.

Table 5 presents the results from the regressions determining if the slope of the Phillips curve is partially responsible for changes in output variability. Including the standard deviation of inflation of the regression I find that one of the coefficients on α is negative and significant (regression (2)). The negative coefficients on α in table 5 are consistent with sticky price theories, which state that a flatter Phillips curve increases the variability of output.

Table 5. Determinants of Output Variability

Independent variable	Forward-looking 2nd subsample (1)	Forward-looking Pooled (2)	Open (3)
Constant	0.022***	0.024***	0.018***
	(0.004)	(0.005)	(0.003)
alpha	-0.049	-0.009*	-0.008
	(0.029)	(0.005)	(0.006)
σ_π	0.158	0.122	0.148
	(0.090)	(0.092)	(0.102)
Dummy		-0.005	
		(0.004)	
Summary statistic			
R2	0.243	0.168	0.123
Standard error	0.007	0.008	0.006

Significance at the 0.10, 0.05, and 0.01 level is indicated by *, **, and ***, respectively.
The standard errors are in parentheses.

5.3 The Determinants of the Phillips Curve Slope

Finally, I examine the determinants of the slope of the Phillips curve. Countries such as Japan and the United Kingdom have seen the slopes on their Phillips curves decline significantly. This decline in slopes implies that prices in some countries have become less responsive to the output gap. Table 6 presents the results of cross-country regressions of the slope parameter, α, regressed on mean inflation, $\bar{\pi}$. These results provide some evidence that mean inflation has a large and statistically significant effect on the Phillips curve slope for the open-economy models (regression (3)), while mean inflation has a small and insignificant impact on the slope for the forward-looking model. The results in table 6 suggest that the decrease in the responsiveness of prices to the output gap has been concomitant with a decrease in the mean inflation rate of these countries.

There are two competing theories that aim to explain why the slope of the Phillips curve varies across countries and over time. The first is Lucas's (1973) imperfect-information model that implies that the slope of the Phillips curve is determined by the variance of inflation. The second is Ball, Mankiw, and Romer's (1988) sticky-price model that argues that the slope depends on the mean of inflation as well as the variance of inflation. Both theories indicate that the causality runs from the mean of inflation to the Phillips curve slope.

I find two main results from the analysis undertaken in this section. First, variability of output, σ_y, and the Phillips curve effect seem to be negatively correlated. In other words, countries with a higher degree of price

Table 6. Determinants of the Phillips-curve slope (alpha)

Independent variable	Forward-looking		Open
	2nd subsample	Pooled	
	(1)	(2)	(3)
Constant	0.070**	0.426*	-0.130
	(0.032)	(0.225)	(0.121)
Mean inflation	0.849	3.079	7.780***
	(0.599)	(3.105)	(1.840)
Dummy		-0.461***	
		(0.153)	
Summary statistic			
R2	0.126	0.358	0.513
Standard error	0.062	0.370	0.225

Significance at the 0.10, 0.05, and 0.01 level is indicated by *, **, and ***, respectively.

The standard errors are in parentheses.

stickiness, which is captured by a smaller α, may have larger variability of output. Second, there is some evidence that supports a positive relationship between the Phillips curve slope and the mean inflation rate (or the variance of inflation).

6 Conclusion

This paper investigates the determinants of inflation and output variability with forward-looking and open-economy models. The numerical and empirical studies have produced several findings.

The numerical analysis yielded three interesting results. First, an increase in the monetary policy reaction function parameters reduces the variability of inflation. Secondly, an increase in the parameter on the output gap reduces the variability of output. Thirdly, the variability of output increases as the Phillips curve slope approaches zero.

Consistent with these simulation results, countries with large parameter values in the monetary policy reaction function have low and stable inflation. By contrast, no relationship can be found between the policy parameters and output variability. Additionally, countries with flatter Phillips curves (or with a higher degree of price stickiness) seem to have larger output variability. Lastly, there is some evidence that a high degree of price stickiness is induced by low and stable inflation.

The results of this study have three policy implications. First, the central bank should make the nominal interest rate sufficiently responsive to both inflation and real output fluctuations in order to achieve low and stable inflation. This implies that monetary policy should be aggressive enough to have substantial values on the policy coefficients, $1+h$ and g. The international evidence indeed indicates that countries with large parameter values ($1+h$ and g) have low and stable inflation.

Second, the central bank should not overlook the fact that the degree of nominal rigidities in the economy can change over time. This study finds that the output fluctuations in some countries have recently become relatively more volatile as their Phillips curves have become flatter.

Third, the results of this study support monetary theories of the business cycle. It appears that the flatter Phillips curves in some countries have resulted from low and stable inflation. This finding is consistent with monetary models which imply that the slope of the short-run Phillips curve faced by central bankers depends on the mean and the variance of inflation and that the slope changes when the mean and the variance of inflation change.

Appendix

Table A1a. Determinants of Inflation Variability (Forward-looking Model)

Independent variable	Second subsample			Pooled sample		
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.022***	0.021***	0.023***	0.025***	0.025***	0.026***
	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)
$1+h$	-0.006*		-0.005	-0.003		-0.002
	(0.003)		(0.003)	(0.003)		(0.003)
g		-0.006*	-0.005*		-0.007**	-0.006**
		(0.003)	(0.003)		(0.003)	(0.003)
Dummy				-0.005	-0.004	-0.004
				(0.004)	(0.003)	(0.003)
Summary statistic						
R2	0.171	0.182	0.305	0.118	0.234	0.254
Standard error	0.009	0.009	0.009	0.010	0.009	0.009

Significance at the 0.10, 0.05, and 0.01 level is indicated by *, **, and ***, respectively.

The standard errors are in parentheses.

Table A1b. Determinants of Inflation Variability (Open-economy Model)

Independent variable	(1)	(2)	(3)
Constant	0.025***	0.020***	0.026***
	(0.006)	(0.002)	(0.004)
$1+h$	-0.010**		-0.009*
	(0.004)		(0.005)
g		-0.008	-0.005
		(0.006)	(0.006)
Summary statistic			
R2	0.248	0.086	0.275
Standard error	0.009	0.010	0.010

Significance at the 0.10, 0.05, and 0.01 level is indicated by *, **, and ***, respectively.

The standard errors are in parentheses.

Table A2. Determinants of Output Variability

Independent variable	Forward-looking 2nd subsample (1)	Forward-looking Pooled (2)	Open (3)
Constant	0.021***	0.018***	0.018***
	(0.004)	(0.004)	(0.003)
alpha	-0.011	-0.016**	-0.010
	(0.008)	(0.008)	(0.007)
σ_π	0.209	0.473***	0.333
	(0.165)	(0.144)	(0.195)
Dummy		0.000	
		(0.003)	
Summary statistic			
R2	0.152	0.311	0.157
Standard error	0.006	0.007	0.006

Significance at the 0.10, 0.05, and 0.01 level is indicated by *, **, and ***, respectively.

The standard errors are in parentheses.

Table A3. Determinants of the Phillips-curve slope (alpha)

Independent variable	Forward-looking 2nd subsample (1)	Forward-looking Pooled (2)	Open (3)
Constant	0.232*	0.260**	-0.160
	(0.111)	(0.102)	(0.114)
Mean inflation	0.862	1.884	7.414***
	(2.030)	(1.494)	(1.736)
Dummy		-0.078	
		(0.069)	
Summary statistic			
R2	0.011	0.120	0.517
Standard error	0.209	0.180	0.212

Significance at the 0.10, 0.05, and 0.01 level is indicated by *, **, and ***, respectively.

The standard errors are in parentheses.

REFERENCES

Ball, Laurence. (1999a). "Efficient Rules for Monetary Policy." *International Finance*, **2**, 63-83.

Ball, Laurence. (1999b). "Policy Rules for Open Economies." In John B. Taylor (ed.) *Monetary Policy Rules*, University of Chicago Press, 127-144.

Ball, Laurence. (2000). "Policy Rules and External Shocks." NBER Working Paper #7426.

Ball, Laurence, N. Gregory Mankiw, and David Romer. (1988). "The New Keynesian Economics and the Output-Inflation Trade-Off." *Brookings Paper on Economic Activities*, 1, 1-65.

Cecchetti, Stephen G., and Michael Ehrmann. (1999). "Does Inflation Targeting Increase Output Volatility? An International Comparison of Policymakers' Preferences and Outcomes." NBER Working Paper #7426.

Clarida, Richard, Jordi Galí, and Mark Gertler. (1999). "The Science of Monetary Policy: A New Keynesian Perspective." *Journal of Economic Literature*, **37**, 1661-1707.

Fuhrer, Jeffrey C. and George R. Moore. (1995). "Inflation Persistence." *Quarterly Journal of Economics*, **110**, 127-60.

King, Robert G., James H. Stock, and Mark W. Watson. (1995). "Temporal Instability of the Unemployment-Inflation Relationship." *Economic Perspectives of the Federal Reserve Bank of Chicago*, **19**, 2-12.

Klein, Paul. (2000). "Using the Generalized Schur Form to Solve a Multivariate Linear Rational Expectations Model." *Journal of Economic Dynamics & Control*, **24**, 1405-1423.

Lucas, Robert E. Jr. (1973). "Some International Evidence on Output-Inflation Trade-offs." *American Economic Review*, **63**, 326-34.

McCallum, Bennett T. (1998). "Solutions to Linear Rational Expectations Models: A Compact Exposition." *Economics Letters*, **61**, 143-147.

McCallum, Bennett T. (2001a). "Should Monetary Policy Respond Strongly to the Output Gaps?" *American Economic Review*, **91**, 258-62.

McCallum, Bennett T. (2001b). " Recent Developments and Issues in Monetary Policy Analysis." Mimeo.

Rudebusch, Glenn D. (2002). "Term Structure Evidence on Interest Rate Smoothing and Monetary Policy Inertia." *Journal of Monetary Economics*, **49**, 1161-1187.

Senda, Takashi. (2005). "Determining Output and Inflation Variability: Are the Phillips Curve and the Monetary Policy Reaction Function Responsible?" *Economic Inquiry*, **43**, 439-453.

Söderlind, Paul. (1999). "Solutions and Estimation of RE Macromodels With Optimal Policy." *European Economic Review*, **43**, 813-823.

Svensson, Lars E. O. (1997). "Inflation Forecast Targeting: Implementing and Monitoring Inflation Targets." *European Economic Review*, **41**, 1111-46.

Taylor, John B. (1980). "Output and Price Stability: An International Comparison." *Journal of Economic Dynamics and Control*, **2**, 109-132.

Taylor, John B. (1989). "Differences in Economic Fluctuations in Japan and the United States: The Role of Nominal Rigidities." *Journal of the Japanese and International Economies*, **3**, 127-144.

Taylor, John B. (1993). "Discretion Versus Policy Rules in Practice." *Carnegie-Rochester Conference Series on Public Policy*, **39**, 195-214.

Taylor, John B. (1999a). "A Historical Analysis of Monetary Policy Rules." In John B. Taylor (ed.) *Monetary Policy Rules*, University of Chicago Press, 319-341.

Taylor, John B. (1999b). (ed.) *Monetary Policy Rules*, University of Chicago Press.