Bank of Canada Banque du Canada

Working Paper 2002-25 / Document de travail 2002-25

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ISSN 1192-5434

Printed in Canada on recycled paper

Bank of Canada Working Paper 2002-25

September 2002

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Acknowledgements

The author would like to thank Robert Amano, Walter Engert, Michael Gail, Scott Hendry, Jinill Kim, Jean-Paul Lam, Césaire Meh, Kevin Moran, Michel Normandin, Louis Phaneuf, and seminar participants at the Bank of Canada, SCSE, Canadian Economic Association, and T2M conferences for very helpful comments and suggestions. I also thank Veronika Dolar for her assistance. Of course, the author is solely responsible for any remaining errors.

Abstract

This paper develops and estimates a dynamic, stochastic, general-equilibrium model with price and wage stickiness to analyze monetary policy in Canada. A monetary policy rule allows the Bank of Canada to systematically influence the short-term nominal interest rate and money growth in response to inflation and output deviations. The structural parameters of the model are estimated econometrically using a maximum-likelihood procedure with a Kalman filter. The estimates reveal that either price or wage rigidities are key nominal frictions that generate real monetary effects. Furthermore, the simulation results show that the Bank has, since 1981, increased the short-term nominal interest rate in response to exogenous positive demand-side disturbances, and used modest but persistent reductions to accommodate positive technology shocks.

JEL classification: E31, E32, E52
Bank classification: Monetary policy framework

Résumé

Dans la présente étude, l’auteur élabore et estime un modèle d’équilibre général dynamique et stochastique avec rigidités nominales des prix et des salaires nominaux pour analyser la politique monétaire au Canada. Une règle monétaire permet à la Banque du Canada d’influencer systématiquement le taux d’intérêt nominal de court terme et la croissance monétaire en réponse aux écarts qu’enregistrent l’inflation et la production par rapport à leur tendance. L’auteur estime les paramètres structurels du modèle avec des données canadiennes, en utilisant la méthode du maximum de vraisemblance et le filtre de Kalman. Les résultats d’estimation montrent que ces deux types de rigidité nominale constituent les frictions nominales majeures permettant la reproduction des effets réels de chocs nominaux. De plus, les résultats de simulations montrent que la Banque augmente le taux d’intérêt nominal de court terme en réponse aux perturbations exogènes et positives de la demande globale et procède à des réductions modestes mais persistantes pour faire face aux chocs technologiques positifs.

Classification JEL : E31, E32, E52
Classification de la Banque : Cadre de la politique monétaire

1 Introduction

In recent years, an extensive literature has emerged on the role of nominal rigidities in shaping key features of the business cycle and in evaluating short-run dynamic monetary policy effects on aggregate variables. Researchers have generally used dynamic, stochastic, general-equilibrium (DSGE) models in which price and/or nominal wages are sticky. These models act on the assumptions that private agents have rational expectations and that their optimizing behaviour determines the time paths of nominal and real variables, such as output and inflation. Furthermore, in contrast to the previous generation of models, these new models predict that the real effects of monetary policy shocks would differ sharply under sticky prices and sticky wages.[1] Chari, Kehoe, and McGrattan (2000) show that staggered price-setting alone does not generate endogenous persistence in an economy of imperfectly competitive price-setters. Christiano, Eichenbaum, and Evans (2001) find that a version of the DSGE model that has only nominal-wage rigidities does almost as well as a model with price and wage rigidities, while the version of their model that has only nominal-price rigidities gives very poor results. Erceg, Henderson, and Levin (2000), Kim (2000), Huang and Liu (2002), and Huang, Liu, and Phaneuf (2000) find that combining staggered wages and imperfectly competitive households generates more output persistence in response to monetary policy shocks.

The Bank of Canada influences short-term nominal interest rates to control inflation. Figure 1 shows short-run dynamic relationships between short-term nominal interest rates, as measured by the three-month treasury-bill rate; inflation, as measured by quarterly changes in the GDP deflator; and M2 money growth for the Canadian

[1] An example of this previous generation of models is given in Taylor (1980). Kiley (2002) compares Taylor-style staggered price-setting to Calvo staggering in a small optimizing IS/LM model.

economy. The data used in the figure are quarterly, from 1980Q1 to 2000Q4. The inflation rate has fallen significantly from its peak in 1981 and has remained low and stable since then. Moreover, the longer-run inflation rate decline has been accompanied by a longer-run decline in the short-term nominal interest rate and money growth. Several episodes of rising short-term nominal interest rates and money growth have interrupted this longer-run trend; in particular, the short-term nominal interest rate rose as inflation and money-growth rates increased during 1988–90 and 1993–94.[2] Nevertheless, during the periods 1983–86, the money-growth rate jumped higher; this movement was accompanied by a slight increase in the inflation rate and by a significant decrease in the short-term nominal interest rate.[3] Dynamic relationships, however, between the nominal interest rate, money growth, and inflation may reflect both the way in which the monetary policy authority responds to economic disturbances and the way in which private agents respond to those same disturbances, particularly to monetary policy, money demand, technology, and preference shocks.

Following Christiano, Eichenbaum, and Evans (2001), Dib (2001), Dib and Phaneuf (2001), Ireland (1997, 2001a), Kim (2000), and Rotemberg and Woodford (1997), I develop and estimate an optimization-based model for the Canadian economy. The model features monopolistic competition between firms and between households, nominal rigidities in the form of price- and wage-adjustment costs, and a real rigidity modelled as convex costs of adjusting capital. The model includes four sources of disturbance: monetary policy, money demand, technology, and preference shocks. Temporary rigidities in nominal prices and wages allow the Bank to affect the behaviour of real variables in the short term. Furthermore, under these nominal rigidities, ex-

[2]The Bank may have increased the nominal interest rate to respond to inflation pressures caused by money demand increasing, as occurred after 1987, or to defend the Canadian dollar, as in 1994.

[3]The interest rate has typically increased prior to inflation and money-growth downturns.

ogenous money-demand shocks become a significant source of aggregate fluctuations. Empirical work shows that such shocks are large and highly persistent.[4]

This paper follows Taylor (1993), who describes Federal Reserve behaviour with a monetary policy rule that adjusts the short-term nominal interest rate in response to output and inflation deviations. I generalize Taylor's specification, however, by allowing the Bank of Canada to respond to deviations of money growth as well. Such a policy implies a restricted, endogenous money supply.[5] An increase in inflation allows the interest rate to rise, reducing nominal asset demand and restraining money growth. Similarly, if money growth increases, reserve demand will rise, and the Bank will increase the nominal interest rate, which should automatically reduce aggregate money demand.[6]

Money growth in such a policy can be considered to represent omitted variables to which the Bank would normally respond, such as the exchange rate or other financial variables. Alternatively, the Bank's monetary policy can be characterized as influencing a linear combination of the short-term nominal interest rate and money growth in response to changes in output and inflation. Poole (1970) gives the classic analysis of the choice between employing an interest rate, a monetary aggregate, or any linear combination of the two as the principal central bank monetary policy instrument. He shows how the stochastic structure of the economy—the nature and relative importance of different types of disturbances—would determine the optimal instrument. Thus, if a

[4]Examples of such work are Dib (2001) for the Canadian economy, and Dib and Phaneuf (2001) and Ireland (1997, 2000) for the U.S. economy.

[5]Under such a policy, the response of money growth to exogenous disturbances is restricted. Under a standard Taylor (1993) set-up, however, the money supply is perfectly endogenous and freely responds to exogenous disturbances.

[6]If the money stock were growing faster than desired, the Bank would increase the nominal interest rate. This would in turn reduce money demand and tend to bring the money stock back to its starting point.

central bank implements monetary policy by manipulating short-term nominal interest rates or any linear combination of the nominal interest rate and money growth, the nominal stock of money is endogenous but restricted. It is affected by monetary policy actions as well as by other shocks that hit the economy.

To evaluate empirically this monetary policy under nominal rigidities, three versions of a DSGE model with quadratic price- and wage-adjustment costs are estimated using a maximum-likelihood procedure with a Kalman filter applied to the state-space forms. Quarterly data on consumption, the three-month treasury-bill rate, inflation, and the nominal monetary aggregate (M2) are used. Since the Bank effectively abandoned M1 growth targeting by the middle of 1981, the data used cover the period 1981Q3 to 2000Q4. The estimates reveal that price- and wage-adjustment cost parameters are quite substantial and significant. Furthermore, the estimated values imply that, on average, prices remain unadjusted for more than two quarters in the standard sticky-price model, but that they are almost completely flexible when price and wage rigidities are combined. The average estimated duration of unadjusted nominal wages, however, is about five quarters in models that include wage stickiness.[7] Moreover, the estimates of the capital-adjustment cost parameter indicate that it is costly to adjust capital, and this form of real rigidity helps to produce endogenously significant persistence in the response of real variables to exogenous shocks.

The estimates of the monetary policy rule coefficients indicate that the Bank has responded positively to inflation, real output, and money-growth deviations by increasing the nominal interest rate to control inflation. Thus, monetary policy during this period can be better described as following a modified Taylor (1993) rule that adjusts the short-term nominal interest rate in response to deviations of inflation, output, and

[7]The introduction of the nominal price and wage rigidities using quadratic adjustment costs functions is equivalent to Calvo (1983)-style nominal price and wage contracts; see Appendix C.

money growth from their steady-state levels. Ireland (2001a,b) finds a similar result for the U.S. economy. Alternatively, monetary policy can be described as influencing a linear combination of the nominal interest rate and the money-growth rate to achieve a target for inflation.

The simulation results show that, using the short-term nominal interest rule, the Bank has successfully reduced the effects of negative money-demand shocks on aggregate output by modestly increasing the short-term nominal interest rate. More importantly, the Bank has also reduced the short-term nominal rate to accommodate technology shocks, illustrating how this policy appears to focus more on the behaviour of inflation than on independent developments in the real economy.

This paper is organized as follows. Section 2 describes the monopolistic competition model with price, wage, and capital rigidities. Section 3 describes the data, the calibration procedure, and the econometric method used to estimate the models. Section 4 describes and discusses the empirical results. Section 5 concludes.

2 The Model

The model's structure is inspired by Dib (2001), Ireland (1997, 2001a), Kim (2000), and Christiano, Eichenbaum, and Evans (2001). It is assumed that the economy is populated by a continuum of households, a representative final-good-producing firm, a continuum of intermediate-good-producing firms, and the Bank. Each household offers a distinct labour service in a monopolistically competitive market. Households also pay two distinct costs for adjusting nominal wages and the capital stock. The final-good-producing firm produces a final good, which sells in a perfectly competitive market. Each intermediate-good-producing firm, however, produces a distinct, perishable intermediate good, which is sold in a monopolistically competitive market.

Intermediate-good-producing firms also pay a finite cost for changing their nominal prices.

2.1 The household

Household i derives utility from consumption, c_{it}, real money balances, M_{it}/p_t, and leisure, $(1 - h_{it})$, where h_{it} represents labour input. The household's preferences are described by the expected utility function,

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t u \left(c_{it}, \frac{M_{it}}{p_t}, h_{it} \right), \tag{1}$$

where $\beta \in (0,1)$ is the discount factor and the single-period utility function is specified as:

$$u(\cdot) = \frac{\gamma z_t}{\gamma - 1} \log \left[c_{it}^{\frac{\gamma-1}{\gamma}} + b_t^{1/\gamma} \left(\frac{M_{it}}{p_t} \right)^{\frac{\gamma-1}{\gamma}} \right] + \eta \log \left(1 - h_{it}\right), \tag{2}$$

where γ and η are positive structural parameters, and z_t and b_t are both serially correlated shocks. As in Ireland (2001b), the preference shock, z_t, enters into the Euler equation, linking the household's consumption growth to the real interest rate, and it evolves according to

$$\log(z_t) = \rho_z \log(z_{t-1}) + \varepsilon_{zt}, \tag{3}$$

where $\rho_z \in (-1, 1)$, and ε_{zt} is a serially uncorrelated shock normally distributed with zero mean and standard deviation σ_z. As McCallum and Nelson (1999) show, this type of disturbance resembles, in equilibrium, a shock to the IS curve in more traditional Keynesian analyses. Shock b_t, however, is interpreted as a shock to money demand, and it follows the first-order autoregressive process:

$$\log(b_t) = (1 - \rho_b) \log(b) + \rho_b \log(b_{t-1}) + \varepsilon_{bt}, \tag{4}$$

where $\rho_b \in (-1, 1)$, and the serially uncorrelated shock ε_{bt} is normally distributed with zero mean and standard deviation σ_b.

As in Kim (2000), Erceg, Henderson, and Levin (2000), and Christiano, Eichenbaum, and Evans (2001), it is assumed that household i is a monopoly supplier of a differentiated labour service, h_{it}. The household sells this service to a representative, competitive firm, which transforms it into an aggregate labour input, h_t, using the following technology:

$$h_t \leq \left(\int_0^1 h_{it}^{\frac{\theta_h - 1}{\theta_h}} di \right)^{\frac{\theta_h}{\theta_h - 1}}, \qquad \theta_h > 1, \tag{5}$$

where θ_h is the constant elasticity of substitution in the labour market. The demand curve for h_{it} is given by

$$h_{it} = \left(\frac{W_{it}}{W_t} \right)^{-\theta_h} h_t, \tag{6}$$

where W_{it} is the nominal wage of household i, and W_t is the wage index (i.e., the aggregate wage rate), which satisfies

$$W_t = \left(\int_o^1 {W_{it}}^{1-\theta_h} di \right)^{\frac{1}{1-\theta_h}}. \tag{7}$$

The household takes h_t and W_t as given and considers it to be beyond its control.

Household i enters period t with k_{it} units of capital, M_{it-1} units of money, and B_{it-1} units of treasury bonds. During period t, the household supplies labour and capital to firms and receives total factor payment $R_{kt}k_{it} + W_{it}h_{it}$, where R_{kt} is the nominal rental rate for capital and W_{it} is the individual nominal wage. Furthermore, household i receives a lump-sum nominal transfer from the Bank, T_{it}, and dividend payments from intermediate-good-producing firms, $D_{it} = \int_0^1 s_{ij} D_{jt} dj$, where s_{ij} is household i's share of the dividend payment by firm j. Household i uses some of its funds to purchase the final good at the nominal price, p_t, which it then divides between consumption and investment. Moreover, it is assumed that it is costly to intertemporally adjust the capital stock, since there are adjustment costs specified as:

$$CAC_{it} = \frac{\phi_k}{2}\left(\frac{k_{it+1}}{k_{it}} - 1\right)^2 k_{it}, \tag{8}$$

where $\phi_k > 0$ is the capital-adjustment cost parameter.

Wage stickiness is introduced through the cost of adjusting nominal wages. The functional form of these costs is assumed to be quadratic with a zero steady-state value. The real total wage-adjustment cost for household i is given by

$$WAC_{it} = \frac{\phi_w}{2}\left(\frac{W_{it}}{W_{it-1}} - \pi\right)^2 \frac{W_{it}}{p_t}, \tag{9}$$

where $\phi_w \geq 0$ is the wage-adjustment cost scale parameter, π is the steady-state value of the inflation rate, and p_t is the final-good price index.

The budget constraint of household i is given by

$$\begin{aligned} c_{it} + k_{it+1} - (1-\delta)k_{it} + CAC_{it} + WAC_{it} + \frac{M_{it} + B_{it}/R_t}{p_t} \\ \leq \frac{R_{kt}}{p_t}k_{it} + \frac{W_{it}}{p_t}h_{it} + \frac{M_{it-1} + B_{it-1} + T_{it} + D_{it}}{p_t}, \end{aligned} \tag{10}$$

where $\delta \in (0,1)$ and R_t denote the constant capital depreciation rate and the gross nominal interest rate between t and $t+1$, respectively.

Household i chooses $\{c_{it}, M_{it}, h_{it}, W_{it}, k_{it+1}, B_{it}\}$ to maximize the expectation of the discounted sum of its utility flows subject to the labour demand that it faces, equation (6), and the budget constraint, equation (10). The first-order conditions for this problem are

$$\frac{z_t c_{it}^{-\frac{1}{\gamma}}}{c_{it}^{\frac{\gamma-1}{\gamma}} + b_t^{1/\gamma}\left(M_{it}/p_t\right)^{\frac{\gamma-1}{\gamma}}} = \lambda_t; \tag{11}$$

$$\frac{z_t b_t^{1/\gamma}\left(M_{it}/p_t\right)^{-\frac{1}{\gamma}}}{c_{it}^{\frac{\gamma-1}{\gamma}} + b_t^{1/\gamma}\left(M_{it}/p_t\right)^{\frac{\gamma-1}{\gamma}}} = \lambda_t - \beta E_t\left(\frac{p_t\lambda_{t+1}}{p_{t+1}}\right); \tag{12}$$

$$\frac{\eta}{1-h_{it}} = \lambda_t\frac{W_{it}}{p_t} - \psi_t; \tag{13}$$

$$\begin{aligned}\theta_h\frac{\psi_t}{\lambda_t}\left(\frac{W_{it}}{W_t}\right)^{-\theta_h-1}\frac{p_t h_t}{W_t h_{it}} &= 1 - \frac{\phi_w}{h_{it}}\left(\frac{W_{it}}{W_{it-1}} - \pi\right)\frac{W_{it}}{W_{it-1}} \\ &+ \frac{\beta\phi_w}{h_{it}}E_t\left[\left(\frac{W_{it+1}}{W_{it}} - \pi\right)\left(\frac{W_{it+1}}{W_{it}}\right)^2\frac{p_t}{p_{t+1}}\frac{\lambda_{t+1}}{\lambda_t}\right];\end{aligned} \tag{14}$$

$$\begin{aligned}\beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left(\frac{R_{kt+1}}{p_{t+1}} + 1 - \delta + \phi_k\left(\frac{k_{it+2}}{k_{it+1}} - 1\right)\frac{k_{it+2}}{k_{it+1}}\right)\right] \\ = 1 + \phi_k\left(\frac{k_{it+1}}{k_{it}} - 1\right);\end{aligned} \tag{15}$$

$$\frac{1}{R_t} = \beta E_t\left[\frac{p_t\lambda_{t+1}}{p_{t+1}\lambda_t}\right]; \tag{16}$$

where ψ_t and λ_t are the Lagrangian multipliers associated with the labour demand and the budget constraint, respectively.

Condition (14) implies that, under the hypothesis of symmetry, the labour demand elasticity, e_{ht}, augmented with the wage-adjustment costs, is[8]

$$e_{ht} = \frac{\lambda_t W_t}{\psi_t p_t}.$$

Thus, the wage markup, q_{wt}, which is the ratio of the real wage to the marginal rate

[8] In fact,

$$e_{ht} = \theta_h\left\{1 - \frac{\phi_w}{h_t}\left(\frac{W_t}{W_{t-1}} - \pi\right)\frac{W_t}{W_{t-1}} + \frac{\beta\phi_w}{h_t}E_t\left[\left(\frac{W_{t+1}}{W_t} - \pi\right)\left(\frac{W_{t+1}}{W_t}\right)^2\frac{p_t}{p_{t+1}}\frac{\lambda_{t+1}}{\lambda_t}\right]\right\}^{-1}.$$

of substitution of consumption for leisure (MRS_t), is derived from condition (13) as[9]

$$q_{wt} = \left(1 - \frac{1}{e_{ht}}\right)^{-1}.$$

With a finite elasticity of substitution (i.e., $e_{ht} < \infty$), the wage markup measures the household's power in the labour market. If nominal wages are perfectly flexible (i.e., $\phi_w = 0$), the wage markup is constant at $\theta_h/(\theta_h - 1)$. In the presence of wage-adjustment costs (i.e., $\phi_w > 0$), however, the exogenous disturbances directly affect the wage markup, which in turn affects the real variables. When log-linearized, conditions (13) and (14) imply that the wage markup measures the discrepancies between actual nominal wages, W_t, and the nominal wages that would prevail in the absence of wage-adjustment costs, W_t^* (see Appendix C).

As Ireland (1997) and Dib (2001) show, combining conditions (11) and (12) yields the following standard money-demand equation:

$$\log\left(\frac{M_{it}}{p_t}\right) \approx \log(c_{it}) - \gamma \log(r_t) + \log(b_t), \tag{17}$$

where $r_t = R_t - 1$ denotes the net nominal interest rate between t and $t+1$, and $-\gamma$ is the interest elasticity of money demand, while b_t is a serially correlated money-demand shock.

2.2 The final-good-producing firm

The final good, y_t, is produced by a perfectly competitive firm using a continuum of intermediate goods, indexed by $j \in (0,1)$. Its technology is

$$y_t \leq \left(\int_0^1 y_{jt}^{\frac{\theta_y - 1}{\theta_y}} dj\right)^{\frac{\theta_y}{\theta_y - 1}}, \qquad \theta_y > 1, \tag{18}$$

[9]With $MRS_t = \frac{u_h}{u_c}$, $q_{wt} = \frac{W_t/p_t}{MRS_t}$.

where y_{jt} denotes the time t input of intermediate good j, and θ_y is the constant elasticity of substitution of intermediate goods.

Given the final-good price, p_t, and the intermediate-good price, p_{jt}, the final-good-producing firm chooses the quantity of intermediate good y_{jt} that maximizes its profits. Profit maximization implies the following demand function:

$$y_{jt} = \left(\frac{p_{jt}}{p_t}\right)^{-\theta_y} y_t, \tag{19}$$

which expresses the demand for good j as a function of its relative price and final output. The final-good price index satisfies

$$p_t = \left(\int_o^1 {p_{jt}}^{1-\theta_y} dj\right)^{\frac{1}{1-\theta_y}}. \tag{20}$$

2.3 The intermediate-good-producing firm

Intermediate-good-producing firm j hires k_{jt} units of capital and h_{jt} units of labour to produce output according to the following constant-returns-to-scale technology:

$$y_{jt} \leq k_{jt}^{\alpha} \left(A_t h_{jt}\right)^{1-\alpha}, \quad \alpha \in (0, 1), \tag{21}$$

where A_t is a technology shock that is common to all intermediate-good-producing firms. The technology shock A_t is assumed to follow the autoregressive process

$$\log A_t = (1 - \rho_A) \log(A) + \rho_A \log(A_{t-1}) + \varepsilon_{At}, \tag{22}$$

where $\rho_A \in (-1, 1)$, and ε_{At} is a serially uncorrelated shock that is normally distributed with mean zero and standard deviation σ_A.

Intermediate goods are imperfectly substitutable for one another in producing the final good, so intermediate-good-producing firm j can set the price p_{jt} that maximizes its profit flows. Furthermore, as in Rotemberg (1982), firm j faces a quadratic cost of adjusting its nominal price across periods. The price-adjustment costs are measured in terms of the final good and given by

$$PAC_{jt} = \frac{\phi_p}{2}\left(\frac{p_{jt}}{\pi p_{jt-1}} - 1\right)^2 y_t, \tag{23}$$

where $\phi_p \geq 0$ is the price-adjustment cost parameter and π is the steady-state value of the inflation rate. In the presence of such price-adjustment costs, the price markup becomes endogenous and the intermediate-good-producing firm's problem is dynamic.

Intermediate-good-producing firm j chooses contingency plans for h_{jt}, k_{jt}, and p_{jt} for all $t \geq 0$, which maximize its expected total profit flows:

$$\max_{\{k_{jt}, h_{jt}, p_{jt}\}} E_0\left[\sum_{t=0}^{\infty} \beta^t \lambda_t D_{jt}/p_t\right], \tag{24}$$

subject to the demand curve it faces, equation (19), and to the production technology, (21), where $\beta^t\lambda_t$ is the firm's discount factor, and the instantaneous profit function is

$$D_{jt} = p_{jt}y_{jt} - R_{kt}k_{jt} - W_t h_{jt} - p_t PAC_{jt}. \tag{25}$$

The first-order conditions for this optimization problem are

$$\alpha \frac{y_{jt}}{k_{jt}}\frac{\xi_t}{\lambda_t} = \frac{R_{kt}}{p_t}; \tag{26}$$

$$(1-\alpha)\frac{y_{jt}}{h_{jt}}\frac{\xi_t}{\lambda_t} = \frac{W_t}{p_t}; \tag{27}$$

$$\begin{aligned}\frac{\xi_t}{\lambda_t} = {} & \frac{\theta_y - 1}{\theta_y} + \frac{\phi_p}{\theta_y}\left(\frac{p_{jt}}{\pi p_{jt-1}} - 1\right)\frac{p_{jt}}{\pi p_{jt-1}}\frac{y_t}{y_{jt}} \\ & - \frac{\beta\phi_p}{\theta_y}E_t\left[\left(\frac{p_{jt+1}}{\pi p_{jt}} - 1\right)\frac{p_{jt+1}}{\pi p_{jt}}\frac{\lambda_{t+1}}{\lambda_t}\frac{y_{t+1}}{y_{jt}}\right];\end{aligned} \tag{28}$$

$$\left(\frac{p_{jt}}{p_t}\right)^{-\theta_y} y_t = k_{jt}^{\alpha}\left(A_t h_{jt}\right)^{1-\alpha}; \tag{29}$$

where $\xi_t > 0$ is the Lagrangian multiplier associated with the technology function.

As in Ireland (1997) and Dib (2001), conditions (26) and (27) imply that the price markup, q_{pt}, which measures the ratio of price to marginal cost, is equal to λ_t/ξ_t. Moreover, condition (28) indicates that this price markup responds endogenously to exogenous shocks in the presence of price-adjustment costs. However, q_{pt} is constant at $\theta_y/(\theta_y - 1)$ if the prices are perfectly flexible.

Under the symmetry hypothesis, where all intermediate-good-producing firms are identical, log-linearizing condition (28) yields

$$\log(p_t) - \log(p_{t-1}) - \log(\pi) = \left(\frac{\theta_y - 1}{\phi_p}\right) E_t \sum_{t=0}^{\infty} \beta^s \left[\log(p^*_{t+s}) - \log(p_{t+s})\right], \qquad (30)$$

where p^*_{t+s} is the nominal price that would prevail in the absence of price-adjustment costs.[10] The discounted present value of current and future discrepancies between the desired price, p^*_{t+s}, and the actual price, p_{t+s}, is given by the sum on the right-hand side of (30). As in Calvo (1983), the ratio $(\theta_y - 1)/\phi_p$ represents the fraction of intermediate firms that can change their prices in the current period. Price adjustment becomes more rapid when this fraction increases; that is, when the price-adjustment cost becomes smaller (ϕ_p decreases).[11]

2.4 The monetary authority

Following Ireland (2001a,b), I assume that the Bank conducts monetary policy by managing the short-term nominal interest rate, R_t, in response to changes in output, y_t, inflation, $\pi_t = p_t/p_{t-1}$, and the money-growth rate, $\mu_t = M_t/M_{t-1}$. Thus, the

[10] When log-linearized, condition (28) implies that the price markup q_{pt} measures the discrepancies between p_{t+s} and p^*_{t+s}; equation (30) is derived from this relation.

[11] In Calvo's model, $(\theta_y - 1)/\phi_p$ is interpreted at the individual firm level as the probability that the firm will change its price, and at the aggregate level as the fraction of firms that can adjust their price in any given period. Using a version of Calvo's model of price adjustment, King and Watson (1996) assume that each firm has a probability 0.10 of adjusting its price each quarter. This probability is independent over time for each firm.

monetary policy rule evolves according to:

$$\log(R_t/R) = \rho_y \log(y_t/y) + \rho_\pi \log(\pi_t/\pi) + \rho_\mu \log(\mu_t/\mu) + \varepsilon_{Rt}, \tag{31}$$

where R, μ, y, and π are the steady-state values of R_t, μ_t, y_t, and π_t, respectively, and where ε_{Rt} is a zero-mean, serially uncorrelated monetary policy shock with standard deviation σ_R.

The policy coefficients ρ_μ, ρ_y, and ρ_π are chosen by the Bank. When $\rho_\mu = 0$, $\rho_y > 0$, and $\rho_\pi > 0$, monetary policy follows the Taylor (1993) rule, in which the Bank increases the nominal interest rate in response to deviations of output and inflation from their steady-state values.[12] In this case, a unique equilibrium exists only if ρ_π is greater than 1.[13]

If ρ_μ is different from zero, two interpretations are possible. First, the monetary policy can be described as following a modified Taylor (1993) rule that adjusts the short-term nominal interest rate in response to the money-growth rate as well as output and inflation. The money-growth rate can be interpreted as a proxy for some omitted variables to which monetary policy should respond, such as the exchange rate and financial variables. Therefore, the money supply becomes endogenous and responds systematically, but restrictedly, to exogenous disturbances.[14] Alternatively, as Ireland (2001b) points out, the central bank's monetary policy could be characterized as a combination policy, as Poole (1970) shows, that influences a linear combination of the interest rate and the money-growth rate to achieve a target for inflation.

[12] Under the original Taylor (1993) rule, the money supply freely responds to exogenous disturbances.

[13] If $\rho_\pi > 1$, an increase in the inflation rate of 1 per cent generates an increase in the nominal interest rate of more than 1 per cent, which, in turn, increases the real interest rate.

[14] In contrast, an exogenous monetary policy would keep the money supply growing at a constant rate, so that $\mu_t = \mu$ for all $t \geq 0$.

2.5 Symmetric equilibrium

In a symmetric equilibrium, all households and intermediate-good-producing firms make identical decisions, so that

$$c_{it} = c_t, M_{it} = M_t, h_{it} = h_t, k_{it} = k_t, W_{it} = W_t, B_{it} = B_t, T_{it} = T_t,$$

and

$$p_{jt} = p_t, y_{jt} = y_t, k_{jt} = k_t, h_{jt} = h_t, D_{jt} = D_t,$$

for all $i, j \in (0, 1)$ during each period $t \geq 0$. Furthermore, the market-clearing conditions $M_t = M_{t-1} + T_t$ and $B_t = 0$ must hold for all $t \geq 0$. Let $r_{kt} = R_{kt}/p_t$, $w_t = W_t/p_t$, and $m_t = M_t/p_t$ denote the real rental rate on capital services, the real wage rate, and real balances, respectively. Thus, a non-linear symmetric equilibrium system consists of an allocation $\{y_t, c_t, m_t, h_t, k_t\}_{t=0}^{\infty}$ and a sequence of prices and co-state variables $\{w_t, r_{kt}, R_t, \pi_t, \lambda_t, q_{pt}, q_{wt}\}_{t=0}^{\infty}$ that satisfy the household's first-order conditions (11)–(16), the intermediate-good-producing firm's first-order conditions, (26)–(29), the aggregate resource constraint, the money-supply rule, and the stochastic processes of preference, money demand, technology, and monetary policy shocks, equations (3), (4), (22), and (31) (see Appendix A).

Taking a log-linear approximation of the equilibrium system around steady-state values and using Blanchard and Kahn's (1980) method yields a state-space solution of the form:[15]

$$\widehat{s}_{t+1} = \Phi_1 \widehat{s}_t + \Phi_2 \varepsilon_{t+1}, \tag{32}$$

$$\hat{d}_t = \Phi_3 \widehat{s}_t, \tag{33}$$

[15] For any stationary variable x_t, I define $\hat{x}_t = \log(x_t/x)$ as the deviation of x_t from its steady-state value, x (see Appendix B for the steady-state ratios).

where $\widehat{s}_t$ is a vector of state variables that includes predetermined and exogenous variables; $\hat{d}_t$ is the vector of control variables; and the vector ε_{t+1} contains technology, money demand, monetary policy, and preference shocks.[16] This solution is a restricted vector autoregression (VAR), in that the coefficient matrices, Φ_1, Φ_2, and Φ_3, have elements that depend on the structural parameters of the model that describe the household's preferences, technologies, and the Bank's monetary policy rule.

3 Calibration, Data, and Estimation

As in Dib (2001), five structural parameters of the model are set prior to estimation, because the data used contain little information about them. Parameter η, denoting the weight on leisure in the utility function, is set equal to 1.35, so that households spend roughly 32 per cent of their time in market activities. The share of capital in production, α, and the depreciation rate, δ, are assigned values of 0.33 and 0.025, respectively; these values are commonly used in the literature.[17] Kim (2000) estimates the parameter θ_h, which measures the degree of monopoly power in the labour market, as 12.37 for the U.S. economy. Moreover, Christiano, Eichenbaum, and Evans (2001) set the wage markup equal to 1.05. Since wages likely are more rigid in Canada than in the U.S. economy, θ_h is set equal to 15, implying a gross steady-state wage markup of 1.07.[18] Finally, the parameter that measures monopoly power in intermediate-good markets, θ_y, is set equal to 9, implying a steady-state markup of price over marginal

[16] $\widehat{s}_t = \left(\hat{k}_t, \hat{m}_{t-1}, \hat{w}_{t-1}, \hat{A}_t, \hat{b}_t, \varepsilon_{Rt}, \hat{z}_t\right)'$, $\hat{d}_t = \left(\hat{\lambda}_t, \hat{q}_{pt}, \hat{q}_{wt}, \hat{m}_t, \hat{y}_t, \hat{R}_t, \hat{r}_{kt}, \hat{c}_t, \hat{\pi}_t, \hat{w}_t, \hat{h}_t, \hat{\mu}_t\right)'$, and $\varepsilon_{t+1} = (\varepsilon_{At+1}, \varepsilon_{bt+1}, \varepsilon_{Rt+1}, \varepsilon_{zt+1})'$.

[17] Estimating a standard RBC model for the Canadian economy, Dolar and Moran (2001) find that α is about 0.3. Using this value does not affect the estimates in the current model.

[18] The presence of unions is more important in Canada than in the United States.

cost equal to 12.5 per cent, which matches the values usually used in similar studies.[19]

Except for the wage- and price-adjustment cost parameters (ϕ_w and ϕ_p), the choices of θ_h and θ_y do not affect the estimated values of the model's remaining parameters. Moreover, the degrees of nominal rigidity associated with wage and price stickiness are not affected as long as the ratios $(\theta_h - 1)/\phi_w$ and $(\theta_y - 1)/\phi_p$ remain constant.[20]

The non-calibrated parameters are estimated using Hansen and Sargent's (1998) method: a Kalman filter is applied to a model's state-space form to generate series of innovations, which are then used to evaluate the likelihood function for the sample. Because the solution (32) and (33) is a state-space econometric model, driven by four innovations in ε_t, the underlying structural parameters embedded in Φ_1, Φ_2, and Φ_3 can be estimated by a maximum-likelihood procedure using data for four series, particularly c_t, π_t, R_t, and m_t (see also Hamilton 1994, chapter 13).[21]

Using quarterly Canadian data that run from 1981Q3 through 2000Q4, I estimate three versions of the model. The first is a sticky-price (SP) model where nominal wages are flexible ($\phi_w = 0$). The second is a sticky-wage (SW) model with flexible prices ($\phi_p = 0$). The third has both sticky prices and sticky wages (SPSW model), in which ϕ_p and ϕ_w are greater than zero.

Consumption is measured by real personal spending on non-durable goods and services. The inflation rate is measured by changes in the GDP deflator, while the

[19]Conversely, Rotemberg and Woodford (1995), Ireland (1997), and Dib (2001) set θ_y equal to 6. The choice of θ_y affects the estimated value of ϕ_p only proportionally.

[20]The model's structural parameters were also estimated with $\theta_h = 21$ and $\theta_y = 6$; I find that the estimated values of ϕ_w and ϕ_p change proportionally with the choices of θ_h and θ_y, so the ratios $(\theta_h - 1)/\phi_w$ and $(\theta_y - 1)/\phi_p$ remain constant. The estimates of the other parameters, however, are not affected by the choice of θ_h and θ_y.

[21]The vector of structural parameters to estimate is

$$(\phi_p, \phi_w, \phi_k, \gamma, \beta, b, \rho_b, \sigma_b, A, \rho_A, \sigma_A, \pi, \rho_\mu, \rho_y, \rho_\pi, \sigma_R, \rho_z, \sigma_z)'.$$

short-term nominal interest rate is measured by the rate on three-month treasury bills.[22] Real balances are measured by dividing the M2 money stock by the GDP implicit price deflator. The series for consumption and real balances are expressed in per capita terms using the civilian population aged 15 and over. The model implies that all variables are stationary and fluctuate around a constant mean. Thus, before estimating the model, the data are rendered stationary by regressing the logarithm of each variable on a constant and a time trend.[23]

4 Empirical Results

This section discusses the estimated parameter values, displays the impulse-response functions to exogenous shocks, and reports the forecast-error variance decomposition of detrended output and inflation implied by the three estimated models. Table 1 displays the maximum-likelihood estimates of the SP, SW, and SPSW models' structural parameters with their standard errors.[24] First, the estimates of parameters describing the price- and wage-adjustment costs, ϕ_p and ϕ_w, are reported and their implications are discussed. The estimated value of ϕ_p is 16.86 in the SP model, where ϕ_w is set equal to 0. These values imply that, in any given period, only 47.45 per cent of the intermediate-good-producing firms can adjust their price in the SP model.[25] Thus, on

[22]Because, in the data, the overnight rate is highly correlated with the rate on three-month treasury bills, following the previous studies I use the second as a measure of the short-term nominal interest rate in this economy.

[23]In the data, the m_t growth rate is much larger in the pre-1992 period than in the post-1992 period, so I introduced a break point into the linear trend at 1991Q4.

[24]I have tested the SP and SW models against the SPSW model. At the 5 per cent significance level, the likelihood-ratio test, which has a chi-squared distribution with one degree of freedom, rejects the hypothesis that $\phi_w = 0$ in the SP model, but it does not reject the hypothesis that $\phi_p = 0$ in the SW model.

[25]When $\theta_y = 6$, the estimate of ϕ_p is equal to 10.52 in the SP model, and to 2.53 in the SPSW model. Thus, the ratio $(\theta_y - 1)/\phi_p$ remains constant in the two models. Furthermore, with $\theta_y = 6$, Dib (2001) estimates a value for ϕ_p equal to 14.36 in the model with price- and capital-adjustment

average, prices remain unadjusted for 2.10 quarters in the SP model. The estimate of ϕ_p, however, is only 4.01 in the SPSW model that combines price- and wage-adjustment costs. This finding indicates that prices are almost flexible in the presence of wage stickiness. Christiano, Eichenbaum, and Evans (2001) find a similar result. The estimates of ϕ_w are 22.60 and 24.88 in the SW and SPSW models, respectively. These estimates are slightly imprecise, with high standard errors. The estimated values imply that, in any period, 18.75 per cent of nominal wages can be adjusted in the SW model, whereas the percentage is about 17 per cent in the SPSW model.[26] This result means that the average duration of wage stickiness in the SW and SPSW models is roughly 5.33 and 5.67 quarters, respectively.[27]

The estimates of the capital-adjustment cost parameter, ϕ_k, are 8.52, 7.18, and 5.76 in the SP, SW, and SPSW models, respectively. These values produce an average cost of adjusting capital of about 1.5 per cent of quarterly investment.[28]

The discount parameter, β, is estimated at 0.98 in the three models; the estimate of the gross quarterly steady-state inflation rate, π, is 1.028.[29] The parameter b, which determines the steady-state ratio of real balances to consumption, is estimated at 0.24. The estimate of γ, the constant elasticity of substitution between real consumption and real balances, is 0.40 and 0.43 in the SP and SW models, respectively; it is about 0.47 in the SPSW model. The estimates of ρ_A are relatively small, but have high standard

costs and with money growth used as the monetary policy instrument.

[26]When $\theta_h = 21$, the estimates of ϕ_w are 32.21 in the SW model and 34.64 in the SPSW model. Therefore, the ratio $(\theta_h - 1)/\phi_w$ remains almost constant compared with the standard estimations.

[27]In the estimated version of the Christiano, Eichenbaum, and Evans (2001) model with staggered prices and wages, the average duration of price and wage contracts is roughly 2 and 3 quarters, respectively.

[28]The estimated value for ϕ_k in Ireland (2001b) is 32.13 and 17.41 in his sticky-price and flexible-price models for the post-1979 period for the U.S. economy.

[29]The estimated steady-state values for π and R depend on the detrending method. Alternative methods will be investigated in future research.

errors; they are 0.63 and 0.76 in the SP and SW models, respectively. The estimates of ρ_b are close to 0.99, revealing that money-demand shocks are highly persistent, whereas the estimates of ρ_z are around 0.93.[30] On the other hand, the estimates of σ_A, σ_b, and σ_z indicate that these exogenous shocks are quite volatile.

The estimates of the monetary policy parameters are all statistically different from zero. The estimates of ρ_π, the coefficient that measures the response of monetary policy to inflation deviations, are significant, with estimated values of 0.67, 0.62, and 0.60 in the SP, SW, and SPSW models, respectively. In contrast, the estimates for ρ_y, the coefficient measuring the response of monetary policy to output deviations, are close to 0.08 in the SP and SPSW models, and estimated at 0.085 in the SPSW model. The coefficient measuring the response of monetary policy to the deviations of money growth from its steady-state level, ρ_μ, is substantial and statistically significant; it is estimated at 0.37, 0.42, and 0.44 in the SP, SW, and SPSW models, respectively. The estimates of σ_R, which are close to 0.006, indicate that monetary policy shocks are quite volatile. Thus, this finding supports the hypothesis that, since 1981, the Bank has managed the short-term nominal interest rates in response to the deviations of inflation, output, and money growth. Similarly, the Bank could be described as having used a policy that influences short-term nominal interest rates and money growth to achieve its objectives.

Figures 2 to 5 display the impulse responses of detrended output, the short-term nominal interest rate, inflation, and money growth to a 1 per cent shock to monetary policy, money demand, technology, and preferences using the estimated SP, SW, and SPSW models. These impulse responses are generated from the state-space forms in

[30] I have also estimated the models with ρ_b fixed at 0.93. The only parameters affected by this constraint are γ and b, which are estimated in the constrained models to be about 0.24 and 0.42, respectively. The remaining parameters are affected only marginally.

(32) and (33), and each response is expressed as the percentage deviation of a variable from its steady-state level.

Figure 2 plots the different impulse responses to a 1 per cent positive monetary policy shock; i.e., $\varepsilon_{Rt} = 0.01$. This shock represents an exogenous tightening of monetary policy. Detrended output, inflation, and money growth fall sharply on impact, and the first two variables remain below their steady-state levels for several quarters after the shock. This merely reflects the slow adjustment of prices and nominal wages to their steady-state levels in response to the shock. Furthermore, because the estimated degree of nominal rigidity is higher in the SW and SPSW models, nominal wages decrease by a lesser amount in response to the policy shock. Thus, the return of detrended output to its steady-state level in these models is slower and more persistent than in the SP model.[31]

Nevertheless, the nominal short-term interest rate responds sharply but positively to this shock, and its positive response persists for at least five quarters, above its steady-state level, after the shock. As Ireland (2001a) shows, persistent movements in detrended output, inflation, and money growth, the variables on the right-hand side of the monetary policy rule (31), generate persistence in the nominal interest rate response, even without the smoothing terms that Clarida, Galì, and Gertler (2000) and Ireland (2000) include in their specifications. More importantly, endogenous money helps to create a liquidity effect in the estimated models: an instantaneous increase in the short-term nominal interest rate is accompanied by a decrease in money growth. Therefore, a recession, such as that of 1990–91, could be the result of a tightening in monetary policy that increases the short-term nominal interest rate and decreases the money stock, as occurred in 1989 (see Figure 1).

[31] Real wages respond countercyclically in the SW and SPSW models, where nominal wages are sticky, while they respond procyclically in the SP model, where nominal wages are perfectly flexible.

Figure 3 shows the impulse responses to a positive 1 per cent money-demand shock; i.e., $\varepsilon_{bt} = 0.01$. This shock exogenously increases the money demand of households. In the three estimated models, the impact of this shock is highly persistent, because the estimates of the money-demand shock's autocorrelation coefficient, ρ_b, are close to one. Nevertheless, the impact of this shock is systematically very small. In fact, output decreases sharply but modestly before slowly returning to its steady-state level. On the other hand, inflation modestly responds to this shock, but then jumps slightly above its steady-state level two quarters after and is highly persistent thereafter.

The nominal short-term interest rate and money growth respond positively to the money-demand shock. These responses are highly persistent, particularly in the SP and SW models. As expected, the positive money-demand shock increases real balances held by households, so that, with endogenous money, the money supply adjusts to equate money demand. More importantly, the Bank increases, modestly but persistently, the short-term nominal interest rate to respond positively to money growth, as suggested by the monetary policy rule, (31). By doing so, real balances held by households eventually decrease and inflation returns to its initial level. This result matches Poole's (1970) classic analysis, in which the monetary policy authority changes the short-term nominal interest rate to react to exogenous demand-side disturbances.

Figure 4 shows the effects of a 1 per cent positive technology shock, $\varepsilon_{At} = 0.01$, in the three estimated models. Because the estimates of the technology autocorrelation coefficient, ρ_A, are relatively small, the impact of this shock on the real and nominal variables is not persistent. Therefore, in response to a positive technology shock, detrended output jumps up instantaneously before returning gradually but relatively quickly to its steady-state level. On the other hand, the nominal interest rate and inflation fall below their steady-state levels. Money growth responds positively to the shock before falling below its steady-state level after two quarters. The negative nominal interest rate response is very persistent and associated with the decrease in money growth.

Responding to the technology shock, inflation falls sharply before returning to its steady-state level. But the deflationary pressure, brought about by the positive technology shock, calls for a transitory increase in money growth and for a modest but sustained easing of monetary policy. This mechanism helps to accelerate and magnify the increase in output, which peaks above its steady-state level several quarters after the shock in the SP and SPSW models. Therefore, the Bank's response helps the economy to adjust to supply-side disturbances, as it would in the absence of nominal rigidities.

Figure 5 shows the impulse responses to a 1 per cent positive preference shock, $\varepsilon_{zt} = 0.01$; this is an exogenous shock to the household's marginal utility of consumption and real balances. In equilibrium, this shock acts like a disturbance that looks like the IS shock in traditional Keynesian analysis, as shown by McCallum and Nelson (1999). Hence, in response to this shock, detrended output, the nominal interest rate, inflation, and money growth jump immediately above their steady-state levels before returning gradually to those levels. Because the estimate of the preference autocorrelation coefficient is higher in the SP model, the computed impulse responses show more persistence. To control the impact of preference shocks on output and inflation, the Bank increases modestly but persistently the short-term nominal interest rate.

By actively managing the short-run nominal interest rate in response to changes in inflation, output, and money growth, monetary policy allows the economy to respond more efficiently to exogenous demand- and supply-side disturbances. Ireland (2000) finds a similar result for the U.S. economy.

To compare the performance of the economy under the estimated policy to its hypothetical performance under an alternative monetary policy specified by the original Taylor (1993) rule, I introduce the impulse response of output, the nominal interest rate, inflation, and money growth to a 1 per cent positive monetary policy, money demand, and technology shocks.[32] In the alternative monetary policy rule, the Bank makes no attempt to respond to money-growth deviations. Therefore, the money supply freely responds to the state of the economy, but the Bank responds aggressively to output and inflation changes. As Figure 6 shows, under the alternative monetary policy rule, the policy shock produces large nominal effects: the nominal interest rate rises and the money growth falls substantially, compared with their responses under the estimated monetary policy rule. The negative inflation response lasts only one quarter, however, before becoming positive in the second quarter. Thus, by responding to or manipulating money-growth deviations (and by setting ρ_y and ρ_π based on Canadian data), as in the estimated monetary policy, the Bank has been less successful in reducing the variation of inflation. Thus, the Bank has not followed as aggressive a monetary policy as the original Taylor rule.

Nevertheless, Figure 7, which displays the impulse response to a 1 per cent positive money-demand shock, shows that the Bank can more substantially reduce the negative effects of money-demand shocks on output, the nominal interest rate, and inflation by following the original Taylor rule. As the money-supply response is restricted under the estimated monetary policy, money-demand shocks can still substantially affect the aggregate output and nominal interest rate; however, this is not the case when the money supply freely responds. As expected from Poole's (1970) analysis, to completely

[32]The coefficient ρ_μ is fixed equal to 0, and ρ_π and ρ_y are set equal to 1.5 and 0.5, as in Taylor (1993). The remaining parameters are set equal to their values calibrated or estimated in the SPSW model.

isolate the economy from the negative effects of money-demand shocks, the Bank should aggressively adjust the money supply.[33]

Figure 8 shows that, following the original Taylor rule, the Bank responds aggressively to technology shocks by increasing the short-term nominal interest rate and allowing money growth to rise sharply. Despite this strong response, the Bank is unable to reduce output and inflation volatiliy. Surprisingly, under the estimated monetary policy rule, which is less aggressive, the Bank has better success in reducing output and inflation volatility. Similarly, the Bank responds less aggressively to preference shocks under the estimated monetary policy.

Tables 2 and 3 decompose, for the three estimated models, the forecast-error variance of detrended output and inflation owing to policy, technology, money demand, and preference shocks for various horizons. Table 2 decomposes the forecast-error variance of detrended output. As Panel A shows, the SP model implies that all of the shocks explain a substantial fraction of the output fluctuations in the short term. Surprisingly, technology shocks account for only about 15 per cent of output volatility. Furthermore, Panels B and C, for the SW and SPSW models, verify that, while technology, policy, and money-demand shocks are important sources of output fluctuations in the short term, preference shocks contribute most to the variance of output in the long term. At the one-quarter-ahead horizon, monetary policy shocks account for about 21 and 26 per cent of the forecast-error variance of detrended output in the SW and SPSW models, respectively. Nevertheless, up to the one-year-ahead horizon, money-demand shocks account for between 7 and 11 per cent of the output forecast-error variance.

Table 3 decomposes the forecast-error variance of inflation. Panels A and B, for the

[33] Alternatively, under an exogenous monetary policy that keeps the money supply growing at a constant rate, $\mu_t = \mu$, the effects of money-demand shocks on output, the nominal interest rate, and inflation are much greater than those under the estimated policy.

SP and SW models, show that policy shocks contribute most to the observed variation in the inflation rate, even in the medium term. The fraction of the total variance explained by these shocks is about 50 per cent at the one-quarter-ahead horizon. This fraction decreases to 34 per cent at the four-quarters-ahead horizon in both models. Even though money-demand shocks contribute little to inflation variation in the short term, the fraction attributed to these shocks significantly increases in the long term. Technology shocks still explain a substantial fraction of inflation variation at the short and long horizons. On the other hand, Panel C shows that the SPSW model, which combines price and wage stickiness, predicts that both monetary policy and technology shocks are the important factors that determine the movements in the inflation rate in the short term, even though money-demand shocks account for over 80 per cent of the inflation variation in the long run and preference shocks modestly contribute to the inflation variations in the short and long terms.[34] The large amount of output variation owing to money-demand shocks primarily results from their high degree of persistence relative to technology shocks. This contrasts with results found in other studies.

5 Conclusion

The Bank of Canada follows a monetary policy that actively manages short-term nominal interest rates to control inflation. Under this policy, the money supply is endogenous. Instead of Taylor's (1993) rule, the Bank is assumed to adjust short-term nominal interest rates to respond not only to the deviations of output and inflation from their steady-state levels, but also to those of money growth. To evaluate this policy, a dynamic, stochastic, general-equilibrium model with nominal and real rigidities has been

[34]When I set ρ_A, the autocorrelation coefficient of technology shock, equal to 0.95, technology and policy shocks explain, at a one-quarter-ahead horizon, 87 and 11 per cent of the inflation variance, respectively; however, these fractions decrease as the horizon increases.

developed and estimated. To compare the implications of price and wage stickiness, three versions of the DSGE model were estimated and simulated: sticky-price, sticky-wage, and combined sticky-price and sticky-wage models. The structural parameters were estimated using a maximum-likelihood procedure with a Kalman filter applied to the state-space forms. The estimates reveal that either price or wage rigidities are key nominal frictions to account for real monetary policy effects. Furthermore, the estimates of the monetary policy rule coefficients indicate that, since 1981, Canadian policy has responded actively to changes in inflation and money growth, but modestly to output deviations. Similarly, one can consider that the Bank has used a policy that influences the short-term nominal interest rate and money growth to control inflation.

More importantly, the results suggest that, by a small increase in the short-term nominal interest rate and in money growth, monetary policy has been able to reduce the negative effects of money-demand shocks on real economic activity. Furthermore, monetary policy has accommodated positive technology shocks by persistently reducing the short-term nominal interest rate. As a positive technology shock produces temporary deflationary pressures, the Bank responds to these pressures with a modest but persistent reduction in short-term nominal interest rates. To reduce the inflationary pressures implied by positive demand-side (preferences) shocks, the Bank modestly, but persistently, increases the short-term nominal interest rate and temporarily decreases the money growth. Nevertheless, the Bank's responses to different shocks, under the estimated policy, are less aggressive than those under the original Taylor (1993) rule.

This paper has focused on the historical monetary policy rule that the Bank has followed since 1981. The choice of an optimal monetary policy rule is left for future work. Moreover, since Canada is a small open economy, the effects of foreign economic disturbances on its domestic economy should be considered. Future work will extend this framework to develop and estimate an optimizing DSGE model for a small open economy.

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Table 1:
Maximum-likelihood estimates and standard errors: 1981Q3 to 2000Q4

	SP model		SW model		SPSW model	
Parameters	Est.	Std. er.	Est.	Std. er.	Est.	Std. er.
ϕ_p	16.861	11.271	-	-	4.008	4.6709
ϕ_w	-	-	22.597	17.275	24.884	18.737
ϕ_k	8.5824	10.648	7.1826	4.8855	5.7651	4.8626
A	2446.7	29.514	2451.5	29.551	2454.8	28.242
ρ_A	0.6284	0.1206	0.7637	0.0780	0.6243	0.1280
σ_A	0.0071	0.0033	0.0043	0.0008	0.0069	0.0024
β	0.9805	0.0007	0.9804	0.0007	0.9803	0.0007
γ	0.4048	0.1567	0.4346	0.1831	0.4699	0.2354
b	0.2585	0.1229	0.2359	0.1311	0.2094	0.1494
ρ_b	0.9984	0.0127	0.9950	0.0136	0.9963	0.0103
σ_b	0.0247	0.0069	0.0259	0.0081	0.0276	0.0105
π	1.0285	0.0024	1.0287	0.0025	1.0286	0.0026
ρ_μ	0.3686	0.0885	0.4165	0.0971	0.4426	0.0856
ρ_y	0.0720	0.0248	0.0850	0.0291	0.0806	0.0279
ρ_π	0.6717	0.0832	0.6242	0.0954	0.6006	0.0845
σ_R	0.0061	0.0007	0.0064	0.0007	0.0063	0.0007
ρ_z	0.9392	0.0154	0.9375	0.0144	0.9381	0.0152
σ_z	0.0153	0.0015	0.0160	0.0017	0.0155	0.0016
LL	-1470.6		-1467.5		-1466.1	

Table 2:
Forecast-error variance decomposition of detrended output

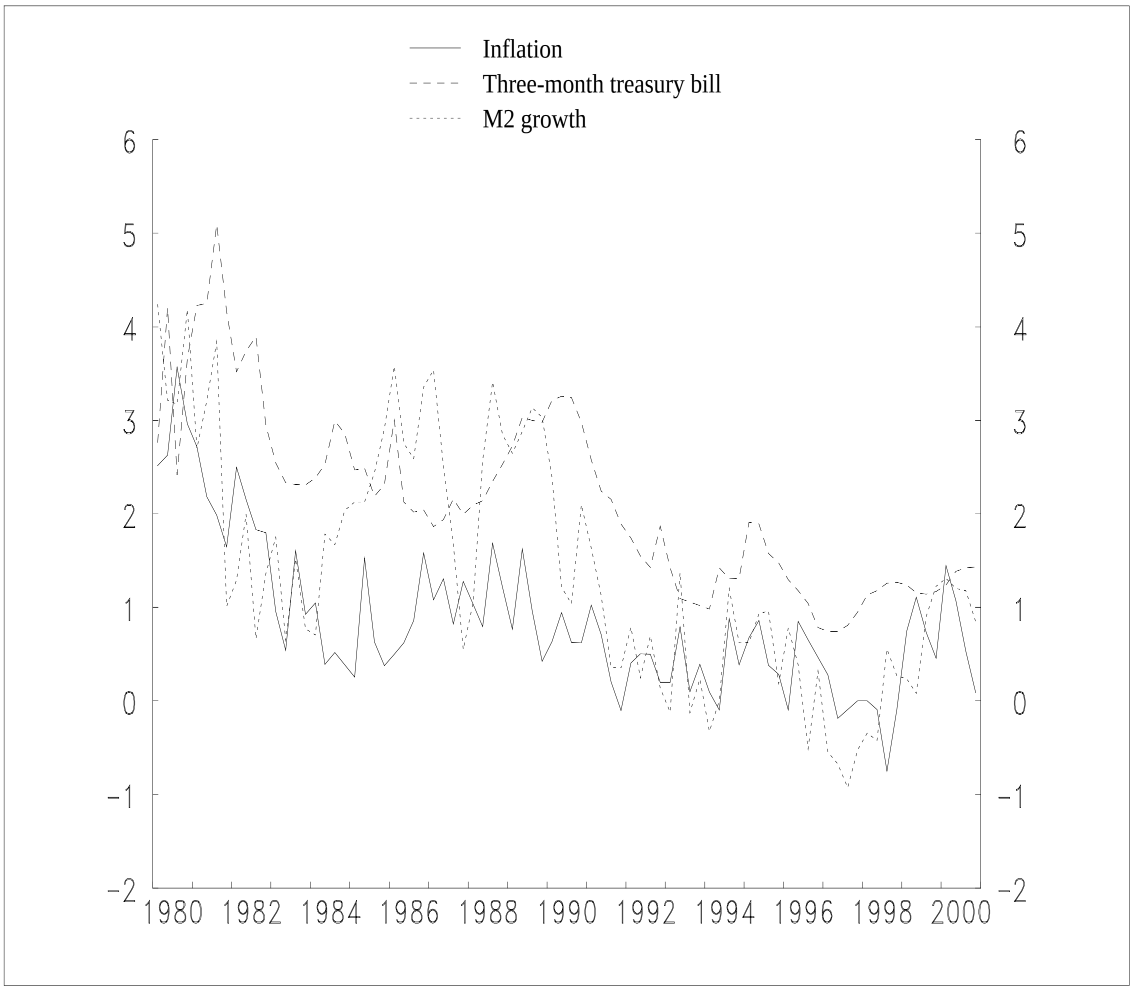
		Percentage owing to:			
Quarters	Variance	Policy	Technology	Money demand	Preference
		A. The SP model			
1	0.000057	17.36	15.496	9.226	57.93
2	0.000098	10.96	18.47	7.17	63.40
3	0.000130	8.34	17.98	6.29	67.38
4	0.000156	6.97	16.66	5.91	70.46
5	0.000177	6.13	15.33	5.75	72.78
10	0.000248	4.39	11.47	6.17	77.96
50	0.000355	3.09	8.16	17.54	71.20
		B. The SW model			
1	0.000041	21.67	26.37	9.69	42.75
2	0.000073	16.09	23.30	8.52	52.08
3	0.000101	12.66	20.61	7.70	59.02
4	0.000126	10.49	18.44	7.17	63.88
5	0.000147	9.08	16.74	6.83	67.34
10	0.000218	6.18	12.35	6.62	74.84
50	0.000309	4.41	9.00	15.11	71.46
		C. The SPSW model			
1	0.000065	26.38	28.38	16.15	29.07
2	0.000104	20.30	29.40	13.69	36.56
3	0.000132	16.96	27.018	12.37	43.64
4	0.000155	14.78	24.35	11.51	49.35
5	0.000175	13.24	22.11	10.90	53.74
10	0.00024	9.69	16.36	9.84	64.10
50	0.00033	7.12	12.06	17.24	63.57

Table 3:
Forecast-error variance decomposition of inflation

		Percentage owing to:			
Quarters	Variance	Policy	Technology	Money demand	Preference
		A. The SP model			
1	0.000022	59.32	38.59	0.84	1.25
2	0.000026	53.56	33.77	10.42	2.23
3	0.000030	46.61	29.28	21.16	2.95
4	0.000035	40.80	25.63	30.14	3.42
5	0.000039	36.21	22.75	37.31	3.73
10	0.000061	23.17	14.57	58.00	4.25
50	0.000229	6.22	3.95	87.52	2.30
		B.The SW model			
1	0.000025	50.18	43.06	0.33	6.42
2	0.000029	43.92	37.28	13.13	5.66
3	0.000033	38.56	32.67	23.57	5.20
4	0.000038	34.17	28.96	31.94	4.92
5	0.000042	30.60	25.96	38.67	4.74
10	0.000064	20.12	17.14	58.47	4.25
50	0.000211	6.20	5.32	86.19	2.29
		C. The SPSW model			
1	0.000023	38.33	56.22	0.03	5.42
2	0.000026	36.20	50.19	8.28	5.32
3	0.000029	32.21	44.63	18.12	5.03
4	0.000033	28.69	39.80	26.69	4.81
5	0.000036	25.78	35.77	33.78	4.67
10	0.000055	17.01	23.60	55.15	4.22
50	0.000186	5.08	7.06	85.75	2.09

Figure 1:

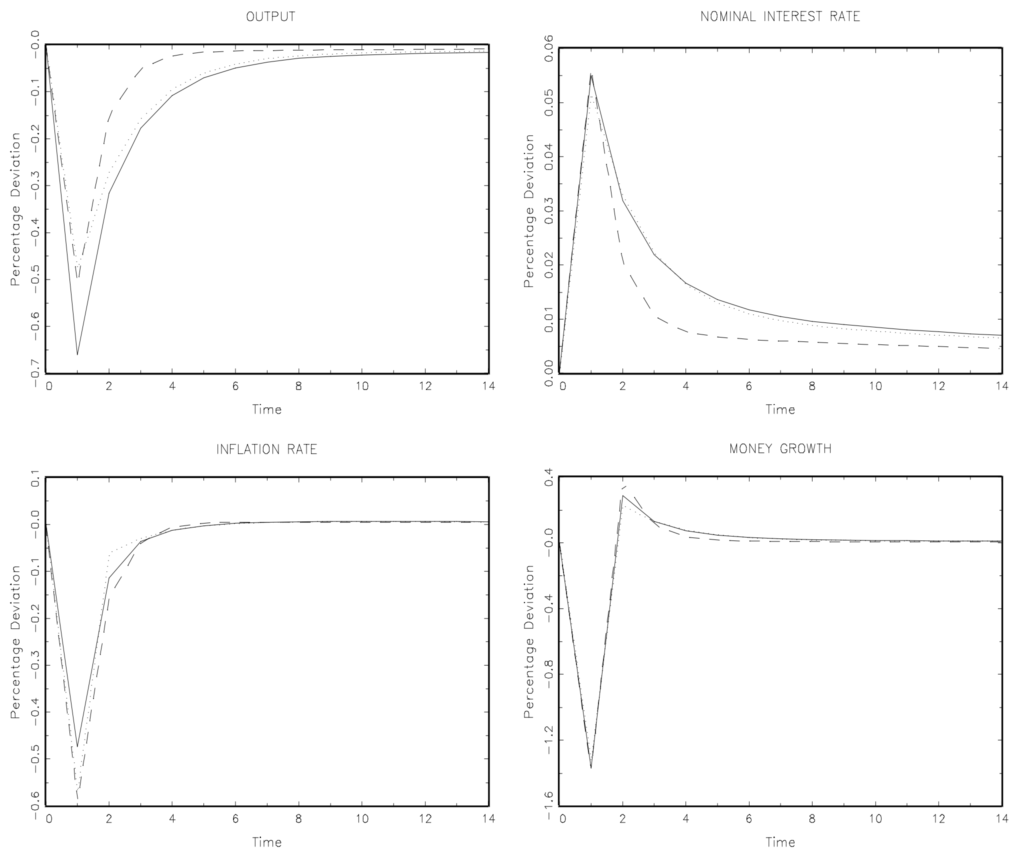
Inflation, nominal interest, and money growth in Canada



Inflation rate (solid line), three-month treasury-bill rate (dashed line), and M2 growth rate (dotted line).

Figure 2:

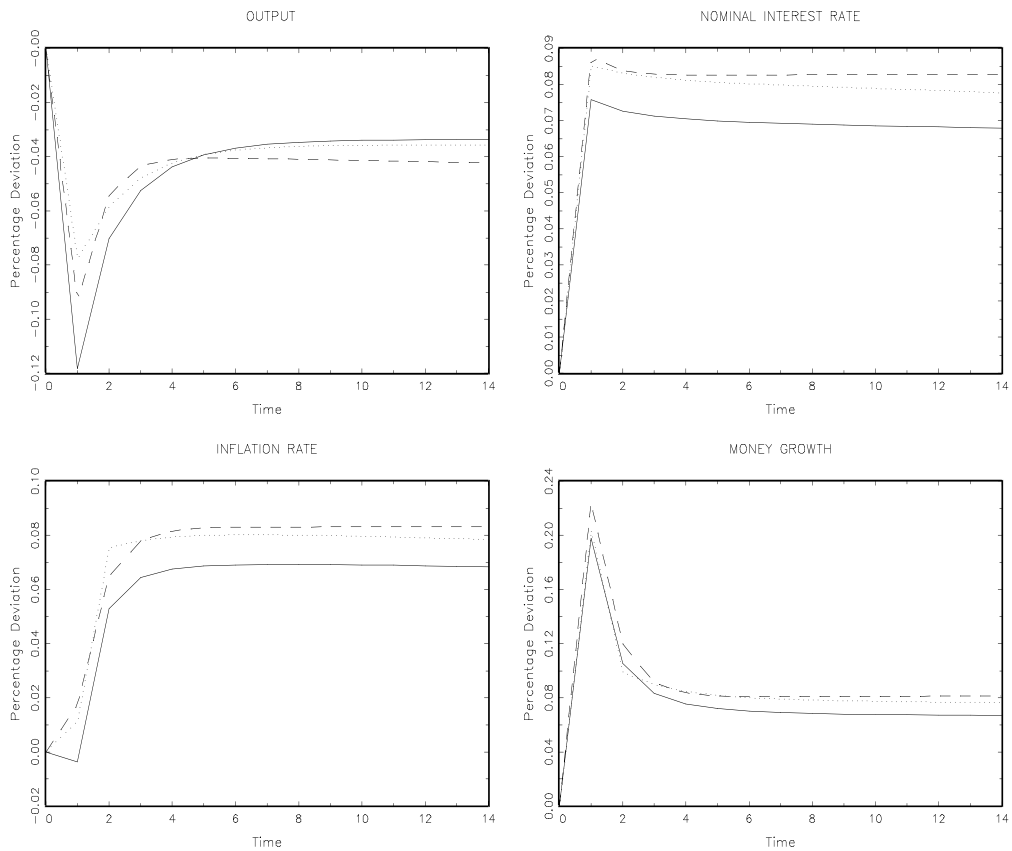
The effects of monetary policy shocks in the three estimated models



The impulse responses are computed for the SP model (dashed line), the SW model (dotted line), and the SPSW model (solid line).

Figure 3:

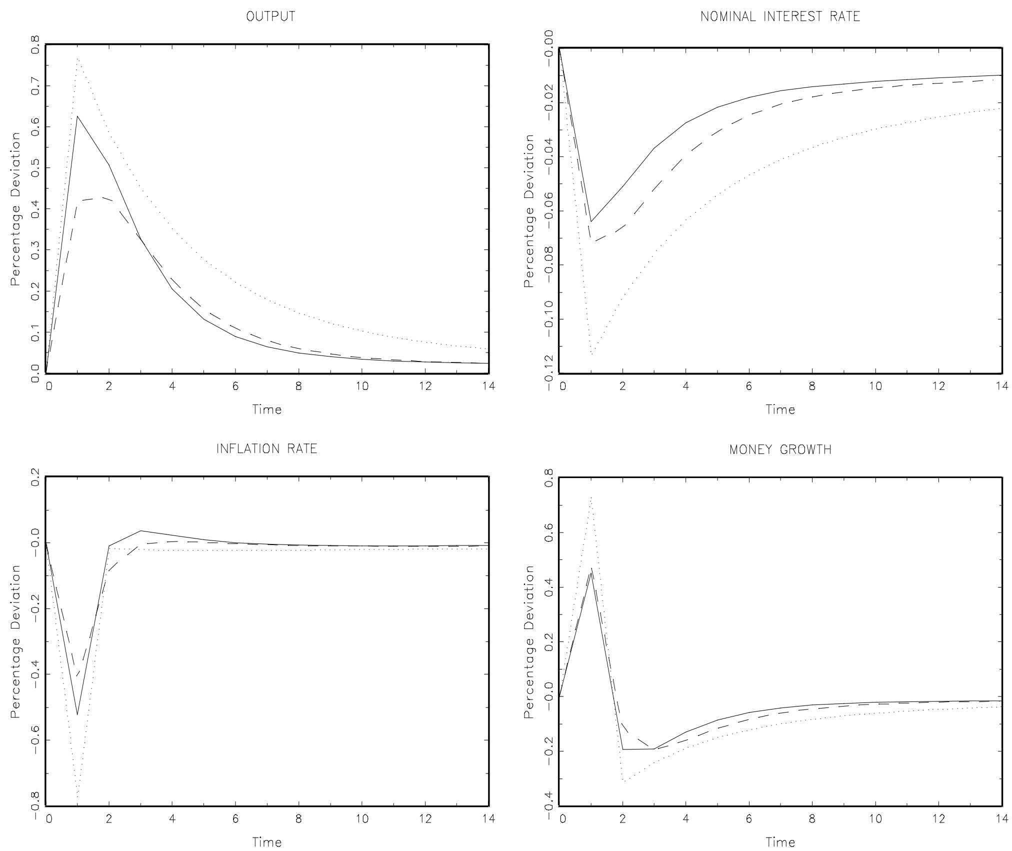
The effects of money-demand shocks in the three estimated models



The impulse responses are computed for the SP model (dashed line), the SW model (dotted line), and the SPSW model (solid line).

Figure 4:

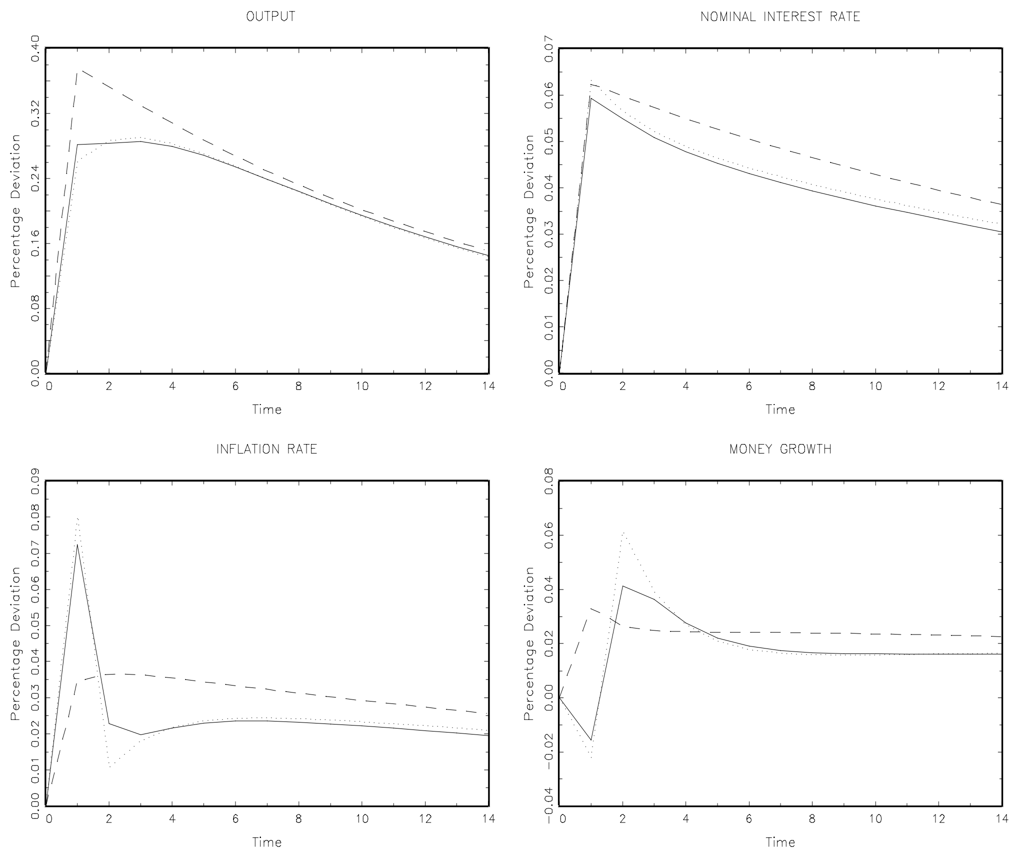
The effects of technology shocks in the three estimated models



The impulse responses are computed for the SP model (dashed line), the SW model (dotted line), and the SPSW model (solid line).

Figure 5:

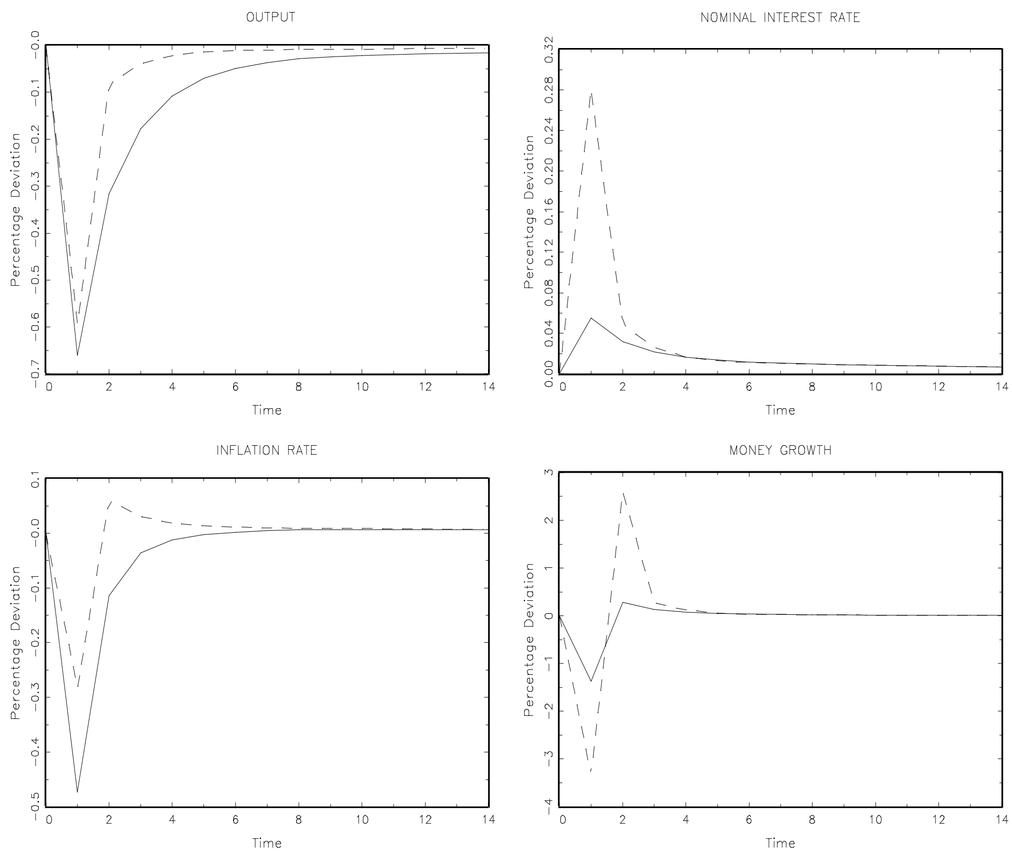
The effects of preference shocks in the three estimated models



The impulse responses are computed for the SP model (dashed line), the SW model (dotted line), and the SPSW model (solid line).

Figure 6:

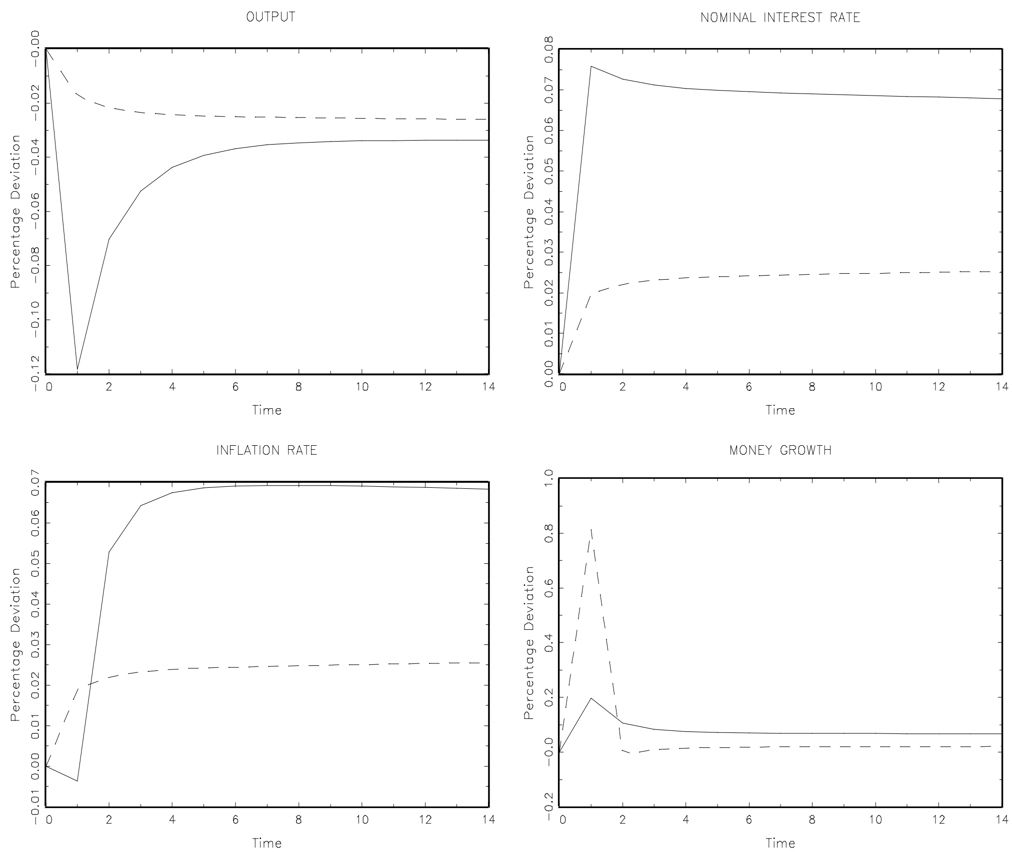
The effects of monetary policy shocks, in the SPSW model, under estimated and alternative policies



The impulse responses are computed for the SPSW model under the estimated monetary policy (solid line) and the original Taylor rule (dashed line).

Figure 7:

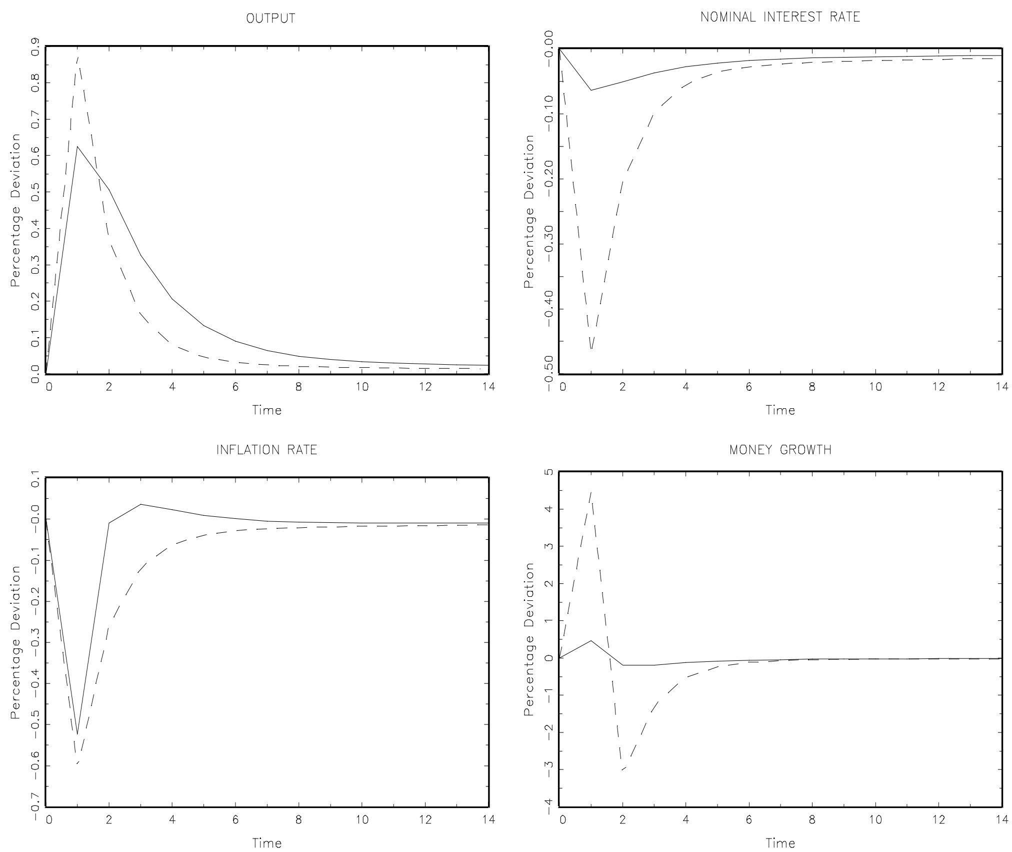
The effects of money-demand shocks, in the SPSW model, under estimated and alternative policies



The impulse responses are computed for the SPSW model under the estimated monetary policy (solid line) and the original Taylor rule (dashed line).

Figure 8:

The effects of technology shocks, in the SPSW model, under estimated and alternative policies



The impulse responses are computed for the SPSW model under the estimated monetary policy (solid line) and the original Taylor rule (dashed line).

Appendix A: The Symmetric Equilibrium

$$\frac{z_t c_t^{-\frac{1}{\gamma}}}{c_t^{\frac{\gamma-1}{\gamma}} + b_t^{1/\gamma} m_t^{\frac{\gamma-1}{\gamma}}} = \lambda_t; \tag{34}$$

$$\frac{z_t b_t^{1/\gamma} m_t^{-\frac{1}{\gamma}}}{c_t^{\frac{\gamma-1}{\gamma}} + b_t^{1/\gamma} m_t^{\frac{\gamma-1}{\gamma}}} = \lambda_t - \beta E_t \left(\frac{\lambda_{t+1}}{\pi_{t+1}} \right); \tag{35}$$

$$\frac{\eta}{1-h_t} = \frac{\lambda_t w_t}{q_{wt}}; \tag{36}$$

$$\begin{aligned} q_{wt}^{-1} = {} & \frac{\theta_h - 1}{\theta_h} + \frac{\phi_w}{\theta_h h_t} \left(\frac{\pi_t w_t}{w_{t-1}} - \pi \right) \frac{\pi_t w_t}{w_{t-1}} \\ & - \frac{\beta \phi_w}{\theta_h h_t} E_t \left[\left(\frac{\pi_{t+1} w_{t+1}}{w_t} - \pi \right) \left(\frac{w_{t+1}}{w_t} \right)^2 \frac{\pi_{t+1} \lambda_{t+1}}{\lambda_t} \right]; \end{aligned} \tag{37}$$

$$\begin{aligned} & \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \left(r_{kt+1} + 1 - \delta + \phi_k \left(\frac{k_{t+2}}{k_{t+1}} - 1 \right) \frac{k_{t+2}}{k_{t+1}} \right) \right] \\ & \quad = 1 + \phi_k \left(\frac{k_{t+1}}{k_t} - 1 \right); \end{aligned} \tag{38}$$

$$\frac{1}{R_t} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{p_t}{p_{t+1}} \right] \tag{39}$$

$$y_t = k_t^{\alpha} (A_t h_t^{1-\alpha}); \tag{40}$$

$$\frac{\alpha y_t}{k_t} = q_{pt} r_t; \tag{41}$$

$$\frac{(1-\alpha) y_t}{h_t} = q_{pt} w_t; \tag{42}$$

$$q_{pt}^{-1} = \frac{\theta_y - 1}{\theta_y} - 1 + \frac{\phi_p}{\theta_y} \left(\frac{\pi_t}{\pi} - 1 \right) \frac{\pi_t}{\pi} - \frac{\beta \phi_p}{\theta_y} E_t \left[\left(\frac{\pi_{t+1}}{\pi} - 1 \right) \frac{\pi_{t+1}}{\pi} \frac{\lambda_{t+1}}{\lambda_t} \frac{y_{t+1}}{y_t} \right]; \tag{43}$$

$$y_t = c_t + k_{t+1} - (1-\delta) k_t + CAC_t + CAP_t; \tag{44}$$

$$\mu_t = \frac{m_t \pi_t}{m_{t-1}}; \tag{45}$$

$$\log(A_t) = (1-\rho_A) \log(A) + \rho_A \log(A_{t-1}) + \varepsilon_{At}; \tag{46}$$

$$\log(b_t) = (1-\rho_b) \log(b) + \rho_b \log(b_{t-1}) + \varepsilon_{bt}; \tag{47}$$

$$\log(R_t/R) = \rho_y \log(y_t/y) + \ rho_{\pi} \log(\pi_t/\pi) + \rho_{\mu} \log(\mu_t/\mu) + \varepsilon_{Rt}; \tag{48}$$

$$\log(z_t) = \rho_z \log(z_{t-1}) + \varepsilon_{zt}. \tag{49}$$

Appendix B: The Steady-State Equilibrium

$$\mu = \pi; \tag{50}$$

$$R = \frac{\pi}{\beta}; \tag{51}$$

$$r_k = \frac{1}{\beta} - 1 + \delta; \tag{52}$$

$$q_{pt} = \frac{\theta_y}{\theta_y - 1}; \tag{53}$$

$$q_{wt} = \frac{\theta_h}{\theta_h - 1}; \tag{54}$$

$$\lambda c = \left[1 + b^{1/\gamma}\left(\frac{b^{1/\gamma}\mu}{\mu - \beta}\right)^{\gamma-1}\right]^{-1}; \tag{55}$$

$$\lambda m = \lambda c \left(\frac{b^{1/\gamma}\mu}{\mu - \beta}\right)^{\gamma}; \tag{56}$$

$$\frac{k}{y} = \frac{\alpha}{r_k q_p}; \tag{57}$$

$$\frac{c}{y} = 1 - \delta\left(\frac{k}{y}\right); \tag{58}$$

$$wh\lambda = \frac{(1-\alpha)}{q_p}\frac{(\lambda c)}{(c/y)}; \tag{59}$$

$$h = \frac{wh\lambda}{\eta q_w + wh\lambda}; \tag{60}$$

$$y = hA\left(\frac{k}{y}\right)^{\frac{\alpha}{1-\alpha}}. \tag{61}$$

Appendix C: Nominal Wage Discrepancies

Log-linearizing equation (37), in Appendix A, around the steady-state values of the variables, will give

$$\beta(\hat{w}_{t+1} - \hat{w}_t + \hat{\pi}_{t+1}) - \hat{w}_t + \hat{w}_{t-1} - \hat{\pi}_t = \frac{\theta_h - 1}{\phi_w}\frac{h}{\pi^2}\hat{q}_{wt}; \tag{62}$$

which implies that

$$(1 - \beta F)(\hat{w}_t - \hat{w}_{t-1} + \hat{\pi}_t) = -\frac{\theta_h - 1}{\phi_w}\frac{h}{\pi^2}\hat{q}_{wt}, \tag{63}$$

where F is a forward operator. Hence,

$$\hat{w}_t - \hat{w}_{t-1} + \hat{\pi}_t = -\frac{\theta_h - 1}{\phi_w}\frac{h}{\pi^2}E_t\sum_{s=0}^{\infty}\beta^s\hat{q}_{wt+s}, \tag{64}$$

because the nominal wage is equal to the wage markup times the labour marginal cost, lmc_t; i.e., $W_t = q_{wt}lmc_t$ in the presence of wage rigidities. Similarly, $W_t^* = q_w lmc_t$, where W_t^* is the nominal wages that would prevail in the absence of wage-adjustment costs and q_w is a constant wage-markup rate. Therefore, the ratio of nominal wages that would prevail in the absence of wage-adjustment costs to nominal wages under wage-adjustment costs is

$$\frac{W_t^*}{W_t} = \frac{q_w}{q_{wt}}. \tag{65}$$

Thus, by taking the log of both sides,

$$\log(W_t^*) - \log(W_t) = -\log(q_{wt}/q_w) = -\hat{q}_{wt}. \tag{66}$$

Therefore, equation (64) becomes

$$\log(W_t) - \log(W_{t-1}) - \log(\pi) = \frac{\theta_h - 1}{\phi_w}\frac{h}{\pi^2}E_t\sum_{s=0}^{\infty}\beta^s\left[\log(W_{t+s}^*) - \log(W_{t+s})\right]. \tag{67}$$

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