The Welfare Implications of Inflation versus Price-Level Targeting in a Two-Sector, Small Open Economy

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Introduction

This paper analyzes the welfare implications of simple monetary policy reaction functions in the context of a New Keynesian, small open economy model with a traded-goods and a non-traded-goods sector and with imperfect competition and staggered prices in the product and labour markets, estimated for the case of Canada. The model belongs to the class of dynamic stochastic general-equilibrium models with explicit microfoundations that constitute the so-called New Open Economy Macroeconomics (NOEM), pioneered by Obstfeld and Rogoff (1995), that has become a substantial literature, the results of which are partly summarized in Lane (2001), among others. Several such models have been estimated for Canada (for example, Ambler, Dib, and Rebei 2003 and Bergin 2003), none of which is in a multisectoral setting.

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In this paper, we have two main objectives. First, we want to characterize the simple, Taylor-type monetary policy reaction function that would deliver higher welfare, given the estimated model.[1] Second, we compare the welfare gain of the welfare-maximizing standard Taylor rule with alternative specifications of the nominal interest rate feedback rule. In particular, we evaluate the welfare gain or loss of using a monetary policy rule that reacts to deviations from target of the price level. If willing to acknowledge that households would like to reduce uncertainty regarding the long-run purchasing power of money, a monetary authority that optimizes social welfare may want to target the price level on top of, or instead of, the inflation rate level. However, many issues arise when a price-level target is introduced, such as the implications for the volatility of the main macro variables, not the least of which is inflation itself (see, for example, Bank of Canada 1998). With an inflation target, the initial increase in the price level after a shock that pushes inflation above its target would not be reversed, so there would be a permanent rise in the price level. In contrast, with a price-level target, a shock that pushed the price level above its target path would initially cause inflation to rise above its long-run average, but as the central bank took action to return the price level to its target path, the inflation rate would have to decline below its long-run average for some time to unwind the effect of the initial positive shock on the price level.

To the best of our knowledge, none of these two issues—i.e., characterizing the welfare-maximizing simple inflation-targeting rule and evaluating the welfare gain of a price-level-targeting monetary policy reaction function—has been explored in the context of a multisector, small open economy NOEM model.[2]

The model economy aims at representing the main features needed for conducting monetary policy analysis in a tractable characterization of the Canadian economy. The main features of our model economy are that (i) there is monopolistic competition and staggered prices in the labour market, as well as in all product markets (domestic non-traded goods, domestic traded goods—for domestic consumption or for exports, and imports); the degree of price rigidity can differ across sectors and with respect to wages; (ii) labour and capital are mobile across sectors and each

1. Throughout the paper, we consider simple reaction functions only. We do not compute the optimal monetary policy; i.e., we do not solve for the instrument value needed to bring inflation to target at each period, given all models' responses to realized shocks, but rather derive the proportional reaction of interest rates to deviations of inflation from target and to the other arguments in the specified Taylor-type rule.

2. Papers by Kollmann (2002) and Smets and Wouters (2002) are recent examples of where the welfare implications of monetary policy are investigated for small open economy NOEM models.

sector has its own technology process; (iii) traded goods are priced to market; and (iv) the systematic behaviour of the monetary policy is represented by the standard Taylor rule, where nominal interest rates respond to deviations of overall inflation from target and to the output gap. The economy is subject to eight shocks: three common domestic shocks (monetary policy shocks, shocks to the money demand, and shocks to the risk premium), two sector-specific technology shocks (to the non-traded-goods sector and to the domestic traded-goods sector), and three foreign shocks (to output, inflation, and the nominal interest rate). The model is estimated using Bayesian techniques for quarterly Canadian data. Our estimates seem reasonable and are compatible with other small open economy estimated models in the NOEM literature for the Canadian case. We find statistically significant heterogeneity in the degree of nominal rigidity across sectoral prices, but wages are the stickiest prices of all.

We evaluate the welfare gains of alternative specifications of a simple monetary policy rule using a second-order approximation of the expected permanent utility in each case compared with that of the estimated rule. We also compare monetary policy rules according to their implications in terms of aggregate fluctuations. In particular, we compute the unconditional volatility they imply for the utility and its arguments, as well as the unconditional volatility they imply for some crucial macro variables, such as output, inflation, and the nominal interest rate. We also compute the long-run variance decomposition under each monetary policy rule, the impulse responses to different shocks, and the prediction for the time series of the inflation deviations with respect to target, in order to gauge the amount of time in which inflation would be out of a certain range, given the monetary policy reaction function and the type of shock.

We find that there would have been some welfare improvement with respect to the estimated rule for the past three decades in Canada had the central bank been slightly more aggressive inflation targeter, i.e., with no reaction to the output gap.

We then compute the welfare implications of moving away from strict inflation targeting to pure price-level targeting. We find that there is no noticeable welfare gain in doing so. A hybrid rule is preferable to strict inflation targeting only when the reaction to price and inflation deviations from target is very low, i.e., when monetary policy is not aggressive and therefore takes longer to bring about price and inflation stabilization, but the welfare gain is still virtually unnoticeable and comes from the lower volatility induced by the mild reaction of the monetary policy.

Still, strict inflation targeting with moderate nominal interest rate smoothing and no output-gap targeting is the simple rule that delivers higher welfare, particularly when the central bank reacts to expected future deviations from target inflation instead of to contemporaneous inflation deviations.

The remainder of the paper is organized as follows. In section 1, we describe the model. In section 2, we describe the estimation method and discuss the parameter estimates. We outline the more relevant quantitative implications of the model in section 3. In section 4, we discuss the optimized parameterization for the monetary policy rule under alternative specifications of inflation-targeting Taylor-type rules. In section 5, we explore the welfare implications of considering price-level and hybrid targeting rules. In section 6, we consider forward-looking monetary policy reaction functions, and we offer conclusions in the final section.

1 The Model

The model embeds three production sectors: the non-traded-goods sector, the traded-goods sector, and the imported-goods sector. All of these types of goods are consumed by local households in different proportions. The economy features sources of nominal friction and real rigidities. The nominal frictions include non-traded price, traded price, imported price, and wage stickiness à la Calvo (1983), with zero inflation at the steady state in addition to money demand by households. The real rigidities originate from monopolistic competition in labour and product markets, capital adjustment costs, and an endogenous risk premium that prevents multiple steady states.[3]

1.1 Households

The i^{th} household chooses consumption, $c_t(i)$, investment, $i_t(i)$, money balances, $M_t(i)$, hours worked, $h_t(i)$, local riskless bonds, $Bd_t(i)$, and foreign bonds, $Bd_t^*(i)$, that maximize the expected utility function; the household sets the wage rate constrained to a Calvo-type nominal rigidity.

The preferences of the i^{th} household are given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(c_t(i) \frac{M_t(i)}{P_t}, h_t(i)\right), \tag{1}$$

where $\beta \in (0, 1)$, E_0 is the conditional expectations operator, M_t denotes nominal money balances held at the end of the period, and P_t is a price index that can be interpreted as the consumer price index (CPI).

3. The model economy is explained in more detail in Ortega and Rebei (2005).

The household's budget constraint is given by:

$$P_t c_t(i) + P_t[i_t(i) + CAC_t(i)] + M_t + \frac{Bd_t(i)}{R_t} + \frac{e_t Bd_t^*(i)}{\kappa_t R_t^*} \leq$$

$$W_t(i)h_t(i) + R_t^k k_t(i) + M_{t-1}(i) + Bd_{t-1}(i) + e_t Bd_{t-1}^*(i)$$

$$+ T_t + D_t\,, \tag{2}$$

where $CAC_t(i)$ is the cost faced each time the household adjusts its stock of capital $k_t(i)$, $i_t(i)$ is the investment, $W_t(i)$ is the nominal wage rate, R_t^k is the nominal interest on rented capital, $Bd_t^*(i)$ and $Bd_t(i)$ are foreign-currency and domestic-currency bonds purchased in t, κ_t is a risk premium that reflects departures from uncovered interest rate parity, and e_t is the nominal exchange rate. Domestic-currency bonds are used by the government to finance its deficit. R_t and R_t^* denote, respectively, the gross nominal domestic and foreign interest rates between t and $t+1$. The household also receives nominal lump-sum transfers from the government, T_t, as well as nominal profits, $D_t = D_t^T + D_t^{NT} + D_t^M$, from domestic producers of traded and non-traded goods and from importers of intermediate goods.

We assume that each household i sells in a monopolistically competitive market their labour supply, $h_t(i)$, to a representative, competitive firm that transforms it into aggregate labour input, h_t, using the following technology:

$$h_t = \left[\int_0^1 h_t(i)^{\frac{\vartheta^h - 1}{\vartheta^h}} di\right]^{\frac{\vartheta^h}{\vartheta^h - 1}}, \tag{3}$$

where $\vartheta^h > 1$ is defined as the constant elasticity of substitution (CES) between differentiated labour skills. The demand for individual labour by the labour aggregator firm is

$$h_t(i) = \left(\frac{W_t(i)}{W_t}\right)^{-\vartheta^h} h_t\,, \tag{4}$$

where W_t is the aggregate wage rate that is related to individual household wages, $W_t(i)$, via the following relationship:

$$W_t = \left[\int_0^1 W_t(i)^{1-\vartheta^h} di\right]^{\frac{1}{1-\vartheta^h}}. \tag{5}$$

Households face a nominal rigidity coming from a Calvo-type contract on wages. When allowed to do so, with probability $(1 - d_h)$ each period, the household chooses the nominal-wage contract, $\tilde{W}_t(i)$, to maximize its utility.[4]

The first-order condition corresponding to the choice of the wage contract is

$$\tilde{w}_t(i) = \frac{\vartheta^h}{\vartheta^h - 1} \frac{E_t \sum_{\tau=0}^{\infty} \beta^\tau d_h^\tau \frac{\eta}{(1 - h_{t+\tau}(i))} h_{t+\tau}(i)}{E_t \sum_{\tau=0}^{\infty} \beta^\tau d_h^\tau \lambda_{t+\tau}(i) h_{t+\tau}(i) \prod_{k=1}^{\tau} \pi_{t+k}^{-1}}, \tag{6}$$

where $\tilde{w}_t$ is the real wage contract, and λ_t is the marginal utility of consumption.

1.2 Firms

1.2.1 The intermediate sectors

There is a continuum of firms indexed by $j \in [0, 1]$ in the non-traded-goods sector. There is monopolistic competition in the market for non-traded goods, which are imperfect substitutes for each other in the production of the composite good y_t^N, produced by a representative competitive firm. Aggregate non-traded output is defined using the Dixit and Stiglitz aggregator function

$$y_t^N = \left(\int_0^1 y_t^N(j)^{\frac{\vartheta^N - 1}{\vartheta^N}} dj\right)^{\frac{\vartheta N}{\vartheta^N - 1}},$$

4. There will thus be a distribution of wages $W_t(i)$ across households at any given time t. We follow Christiano, Eichenbaum, and Evans (2001, 2005) and assume that there exists a state-contingent security that insures the households against variations in households' specific labour income. As a result, the labour component of households' income will be equal to aggregate labour income, and the marginal utility of wealth will be identical across different types of households. This allows us to suppose symmetric equilibrium and proceed with the aggregation.

where ϑ^N is the elasticity of substitution between differentiated non-traded goods. Given the aggregate and individual prices P_t^N and $P_t^N(j)$, respectively, the non-traded final-good-producing firm chooses the production, y_t^N, that maximizes its profits. The first-order condition corresponds to the demand constraint for each intermediary firm j

$$y_t^N(j) = \left(\frac{P_t^N(j)}{P_t^N}\right)^{-\vartheta^N} y_t^N, \tag{7}$$

where the price index for the composite imported goods is given by:

$$P_t^N = \left(\int_0^1 P_t^N(j)^{1-\vartheta^N} dj\right)^{\frac{1}{1-\vartheta^N}}. \tag{8}$$

Each monopolistically competitive firm has a production function given by

$$y_t^N(j) = A_t^N [k_t^N(j)]^{\alpha^N} [h_t^N(j)]^{1-\alpha^N},$$

where A_t^N is the non-traded-goods sector-specific total-factor productivity.

Firms face a nominal rigidity coming from a Calvo-type contract on prices. When allowed to do so, with probability $(1-d_N)$ each period, the producer of non-traded good j sets the price $\tilde{P}_t^N(j)$ to maximize its weighted expected profits. The price contract is the following:

$$\tilde{P}_t^N(j) = \left(\frac{\vartheta^N}{\vartheta^N-1}\right) \frac{E_t \sum_{\iota=0}^{\infty} (\beta d_N)^{\iota} \left(\frac{\lambda_{t+1}}{\lambda_t}\right) \xi_{t+1}(j) y_{t+\iota}^N(j)}{E_t \sum_{\iota=0}^{\infty} (\beta d_N)^{\iota} \left(\frac{\lambda_{t+1}}{\lambda_t}\right) y_{t+1}^N(j) \frac{1}{P_{t+\iota}}}, \tag{9}$$

where $\xi_t(i)$ is the Lagrange multiplier associated with the production function constraint. It measures the real marginal cost of the firm in the non-traded-goods sector.

Domestic firms producing goods in the traded sector must solve a similar problem except that each monopolistically competitive firm k produces two types of goods: $y_t^{Td}(k)$, which will be consumed in the domestic market, and $y_t^X(k)$, which will be exported, for $k \in [0, 1]$.

The production function is as follows:

$$y_t^T(k) = A_t^T[k_t^T(k)]^{\alpha^T}[h_t^T(k)]^{1-\alpha^T},$$

where A_t^T is the traded-goods sector-specific technology.

Each firm chooses $k_t^T(k)$, $h_t^T(k)$, $P_t^{Td}(k)$, and $P_t^X(k)$. We assume complete pricing to market for exports, i.e., $P_t^X(k)$ is labelled in US dollars.[5] In addition, once the firm has the opportunity to update its price (with probability $(1-d_T)$ each period), it will choose simultaneously $\tilde{P}_t^{Td}(k)$, and $\tilde{P}_t^X(k)$ given

$$\tilde{P}_t^{Td}(k) = \left(\frac{\vartheta^T}{\vartheta^T-1}\right)\frac{E_t\sum_{\iota=0}^{\infty}(\beta d_T)^{\iota}\left(\frac{\lambda_{t+\iota}}{\lambda_t}\right)\zeta_{t+\iota}(k)y_{t+\iota}^{Td}(k)}{E_t\sum_{\iota=0}^{\infty}(\beta d_T)^{\iota}\left(\frac{\lambda_{t+\iota}}{\lambda_t}\right)y_{t+1}^{Td}(k)\frac{1}{P_{t+\iota}}} \tag{10}$$

$$\tilde{P}_t^{X}(k) = \left(\frac{\vartheta^T}{\vartheta^T-1}\right)\frac{E_t\sum_{\iota=0}^{\infty}(\beta d_T)^{\iota}\left(\frac{\lambda_{t+\iota}}{\lambda_t}\right)\zeta_{t+\iota}(k)y_{t+\iota}^{X}(k)}{E_t\sum_{\iota=0}^{\infty}(\beta d_T)^{\iota}\left(\frac{\lambda_{t+\iota}}{\lambda_t}\right)e_{t+\iota}y_{t+\iota}^{X}(k)\frac{1}{P_{t+\iota}}}, \tag{11}$$

where $\zeta_{t+\iota}(k)$ is the real marginal cost of the firm in the traded-goods sector.

Similarly, the sector that produces final traded goods has the following aggregate functions:

$$y_t^{Td} = \left(\int_0^1 y_t^{Td}(k)^{\frac{\vartheta^T-1}{\vartheta^T}}dk\right)^{\frac{\vartheta^T}{\vartheta^T-1}} \tag{12}$$

and

5. There is substantial evidence in favour of the pricing-to-market hypothesis in the Canada-US case. Engel and Rogers (1996) use CPI data for US and Canadian cities and find that deviations from the law of one price are much higher for two cities located in different countries than for two equidistant cities in the same country. Also, there is evidence suggesting the prevalence of invoicing in US dollars by foreign firms selling in the US market. Indeed, acccording to the ECU Institute (1995), over 80 per cent of US imports were invoiced in US dollars.

$$y_t^X = \left(\int_0^1 y_t^X(k)^{\frac{\vartheta^T - 1}{\vartheta^T}} dk\right)^{\frac{\vartheta^T}{\vartheta^T - 1}} \tag{13}$$

with

$$y_t^T = y_t^{Td} + y_t^X, \tag{14}$$

where y_t^T is total production in the traded-goods sector, and y_t^{Td} and y_t^X are traded goods, respectively, for domestic and foreign markets.

The price indexes for domestically consumed traded goods and exports are as follows:

$$P_t^{Td} = \left(\int_0^1 P_t^{Td}(k)^{1-\vartheta^T} dk\right)^{\frac{1}{1-\vartheta^T}} \tag{15}$$

$$P_t^X = \left(\int_0^1 P_t^X(k)^{1-\vartheta^T} dk\right)^{\frac{1}{1-\vartheta^T}}. \tag{16}$$

The foreign demand for locally produced goods is as follows:

$$y_t^X = \left(\frac{P_t^X}{P_t^*}\right)^{-\mu} y_t^*, \tag{17}$$

where $\frac{\mu - 1}{\mu}$ captures the elasticity of substitution between the exported goods and foreign-produced goods in the consumption basket of foreign consumers, and y_t^* and P_t^* are, respectively, foreign output and the price index. Both variables are exogenously given.

Finally, there is a continuum of intermediate-good-importing firms indexed by $i \in [0, 1]$. Monopolistic competition takes place in the market for imported intermediate goods, which are imperfect substitutes for each other in the production of the composite imported good, y_t^M, produced by a representative competitive firm. We also assume Calvo-type staggered price setting in the imported goods sector to capture the empirical evidence on incomplete exchange rate pass-through into import prices.[6] Thus, when allowed to do so (with probability $(1-d_M)$ each period), the importer of good i sets the price, $\tilde{P}_t^M(i)$, to maximize its weighted expected profits. Note that the marginal cost of the importing firm is $e_t P_t^*$ [7] and thus its real marginal cost is the real exchange rate

$$s_t \equiv \frac{e_t P_t^*}{P_t}.$$

The first-order condition is:

$$\tilde{P}_t^M(i) = \left(\frac{\vartheta^M}{\vartheta^M - 1}\right) \frac{E_t \sum_{\iota=0}^{\infty} (\beta d_M)^{\iota} \left(\frac{\lambda_{t+\iota}}{\lambda_t}\right) y_{t+\iota}^M(i) e_{t+\iota} P_{t+\iota}^* / P_{t+\iota}}{E_t \sum_{\iota=0}^{\infty} (\beta d_M)^{\iota} \left(\frac{\lambda_{t+\iota}}{\lambda_t}\right) y_{t+\iota}^M(i) / P_{t+\iota}}. \tag{18}$$

As in the other cases, aggregate imported output is defined using the Dixit and Stiglitz aggregator function

$$y_t^M = \left(\int_0^1 y_t^M(i)^{\frac{\vartheta^M - 1}{\vartheta^M}} di \right)^{\frac{\vartheta^M}{\vartheta^M - 1}}$$

and the price index for the aggregated good is

$$P_t^M = \left(\int_0^1 P_t^M(i)^{1-\vartheta^M} di \right)^{\frac{1}{1-\vartheta^M}}. \tag{19}$$

6. Campa and Goldberg (2002) find that they can reject the hypothesis of complete short-run pass-through in 22 of the 25 Organisation for Economic Co-operation and Development countries of their study for the period 1975–99, but they find complete long-run pass-through. Ghosh and Wolf (2001) argue that sticky prices or menu costs are a preferable explanation for imperfect pass-through, since they are compatible with complete long-run pass-through, while that is not the case for explanations based on international product differentiation. The evidence of incomplete exchange rate pass-through in Canada is well documented and seems to conclude that zero pass-through has almost been reached in the recent past. See, for example, Bailliu and Bouakez (2004), Kichian (2001), and Leung (2003).

7. For convenience, we assume that the price in foreign currency of all imported intermediate goods is P_t^*, which is also equal to the foreign price level.

1.3 The final-goods sectors

The final domestically consumed good, y_t^d, is produced by a competitive firm that uses non-traded goods, y_t^N, and domestically consumed traded goods, y_t^{Td}, as inputs subject to the following CES technology

$$y_t^d = \left[n^{\frac{1}{\phi}} (y_t^N)^{\frac{\phi - 1}{\phi}} + (1 - n)^{\frac{1}{\phi}} (y_t^{Td})^{\frac{\phi - 1}{\phi}} \right]^{\frac{\phi}{\phi - 1}}, \tag{20}$$

where $n > 0$ is the share of non-traded goods in the domestic goods basket at the steady state, and $\phi > 0$ is the elasticity of substitution between non-traded and non-exported traded goods. Profit maximization entails

$$y_t^N(n) = n \left(\frac{P_t^N}{P_t^d} \right)^{-\phi} y_t^d \tag{21}$$

and

$$y_t^{Td} = (1 - n) \left(\frac{P_t^{Td}}{P_t^d} \right)^{-\phi} y_t^d. \tag{22}$$

Furthermore, the domestic final-good price, P_t^d, is given by

$$P_t^d = [n(P_t^N)^{1 - \phi} + (1 - n)(P_t^{TD})^{1 - \phi}]^{1/(1 - \phi)}. \tag{23}$$

Finally, we aggregate domestic and imported goods using a CES function, as follows

$$z_t = \left[m^{\frac{1}{\nu}} (y_t^d)^{\frac{\nu - 1}{\nu}} + (1 - m)^{\frac{1}{\nu}} (y_t^M)^{\frac{\nu - 1}{\nu}} \right]^{\frac{\nu}{\nu - 1}}, \tag{24}$$

where $m > 0$ is the share of domestic goods in the final-goods basket at the steady state; and $\nu > 0$ is the elasticity of substitution between domestic and imported goods. The first-order conditions are

$$y_t^d = m \left(\frac{P_t^d}{P_t} \right)^{-\nu} z_t \tag{25}$$

and

$$y_t^M = (1-m)\left(\frac{P_t^M}{P_t}\right)^{\upsilon} z_t. \tag{26}$$

The final-good price, P_t, which corresponds to the CPI, is given by

$$P_t = [m(P_t^d)^{1-\nu} + (1-m)(P_t^M)^{1-\nu}]^{1/(1-\nu)}. \tag{27}$$

Aggregate output is used for consumption, investment, and for covering the cost of adjusting capital

$$z_t = c_t + i_t(1 + CAC_t). \tag{28}$$

The gross domestic product is $y_t = z_t + y_t^X - y_t^M$.

1.4 The government

The government budget constraint is given by

$$T_t + Bd_{t-1} = M_t - M_{t-1} + \frac{Bd_t}{R_t}. \tag{29}$$

We consider a simple decision rule for the nominal interest rate, such as the standard Taylor rule,

$$\begin{aligned}\log(R_t/R) &= \rho_R \log(R_{t-1}/R) + \rho_\pi \log(\pi_t/\pi) \\ &\quad + \rho_y \log(y_t/y) + \varepsilon_{Rt},\end{aligned} \tag{30}$$

where R, π, and y are the steady-state values of the gross nominal interest rate, CPI inflation, and real gross domestic output, and where ε_{Rt} is a zero-mean, serially uncorrelated monetary policy shock.

2 Calibration

We calibrate the structural parameters of the model using the posterior medians of the estimation in Ortega and Rebei (2005). They estimate the same model using Bayesian techniques that update prior distributions for the deep parameters of the model, which are defined according to a reasonable calibration, with the actual data. The estimation is done using recursive simulation methods, in particular, the Metropolis-Hastings algorithm, which has been applied to estimate similar dynamic stochastic general-equilibrium models in the literature, such as Smets and Wouters (2003).

The model has eight shock processes: three common domestic shocks—monetary policy shocks, ε_{Rt}, shocks to the money demand, ε_{bt}, and shocks to the risk premium, $\varepsilon_{\kappa t}$; two sector-specific technology shocks—to the non-traded sector, $\varepsilon_{A^N t}$, and to the traded one, $\varepsilon_{A^{Td} t}$; and three foreign shocks—output, $\varepsilon_{y^* t}$, inflation, $\varepsilon_{\pi^* t}$, and the nominal interest rate, $\varepsilon_{R^* t}$. To identify them in the estimation process, we need to use the same number of actual series. Ortega and Rebei (2005) choose them to be as informative as possible. HP-filtered and seasonally adjusted quarterly series are used for Canada for the period 1972Q1–2003Q4. The series are real exchange rate (against the US dollar), real output, nominal interest rate on three-month T-bills, real M2 per capita (deflated with the CPI), CPI inflation, US real output per capita, US CPI inflation, and nominal US interest rate on three-month T-bills.

Table 1 shows the prior distributions imposed for the deep parameters of the model, as well as the median and 90 per cent confidence interval for the posterior distributions.

It is important to note that all three sectors—domestic traded goods, imports, and non-traded goods—were given the same degree of nominal rigidity in the a priori distributions, in the form of an average prior probability of not changing prices of 0.67, which corresponds to changing prices every three quarters, on average. But the prior of equal nominal rigidity across sectors did not hold, consistent with the findings of Bils and Klenow (2004), who document a high degree of heterogeneity in the frequency of price changes across retail goods and services. Significant heterogeneity was found in the degree of price stickiness across sectors, since import prices were more flexible (with posterior median duration for prices of two quarters) and non-traded prices were stickier (posterior median of almost three quarters). The prices of domestic traded goods were estimated to have a posterior median duration of two and one-half quarters. Table 1 shows that the 90 per cent posterior confidence interval for d_M does not even overlap with those for d_N and d_T. As with virtually any study that examines wage and price rigidities, the highest nominal stickiness is found for wages, with an estimated posterior duration of five quarters.

It is also worth noting that the posterior estimates of the Taylor rule almost halve the prior degree of interest rate smoothing (posterior median $\rho_R = 0.46$), somewhat reduce the reaction to deviations of inflation from target to $\rho_\pi = 1.19$, and find a significant but low reaction to the output gap, with a posterior median coefficient of $\rho_y = 0.3$. The historical estimated Taylor rule, therefore, is an inflation-targeting rule with moderate concern for output stabilization and with some sluggishness in the monetary policy instrument.

Table 1
Parameter estimation results

	Parameter distribution				
	Prior			Posterior	
Parameter	Type	Mean	Standard error	Median	90 per cent interval
ρ_{AN}	Beta	0.85	0.1	0.7976	[0.7419, 0.8404]
ρ_{AT}	Beta	0.85	0.1	0.5850	[0.5018, 0.6746]
ρ_b	Beta	0.85	0.1	0.8128	[0.7359, 0.8712]
ρ_{R^*}	Beta	0.8	0.1	0.7175	[0.6672, 0.7913]
ρ_{y^*}	Beta	0.85	0.1	0.7486	[0.6419, 0.8470]
ρ_{π^*}	Beta	0.8	0.1	0.5330	[0.4515, 0.6044]
ρ_κ	Beta	0.8	0.1	0.6289	[0.5698, 0.6727]
σ_{AN}	Inv. gamma	1.5	2	6.1442	[5.8442, 6.5318]
σ_{AT}	Inv. gamma	1.5	2	1.5003	[1.3487, 1.6095]
σ_R	Inv. gamma	1.5	2	0.9983	[0.9187, 1.1228]
σ_b	Inv. gamma	1.5	2	12.3049	[12.1777, 12.4786]
σ_{R^*}	Inv. gamma	1.5	2	0.8421	[0.7618, 0.9330]
σ_{y^*}	Inv. gamma	1.5	2	1.1208	[1.0466, 1.2398]
σ_{π^*}	Inv. gamma	1.5	2	0.4429	[0.4017, 0.5006]
σ_κ	Inv. gamma	1.5	2	0.9846	[0.8981, 1.1067]
d_M	Beta	0.67	0.05	0.5101	[0.4453, 0.5585]
d_N	Beta	0.67	0.05	0.6243	[0.5790, 0.6604]
d_T	Beta	0.67	0.05	0.5951	[0.5622, 0.6296]
d_h	Beta	0.67	0.05	0.8027	[0.7519, 0.8453]
m	Beta	0.6	0.05	0.5447	[0.5130, 0.5845]
n	Beta	0.5	0.05	0.5355	[0.4825, 0.5967]
μ	Gamma	1.2	0.2	1.2496	[1.1320, 1.3439]
ν	Gamma	1.2	0.2	0.7140	[0.5915, 0.8440]
ϕ	Gamma	1.2	0.2	2.2653	[2.1644, 2.3529]
φ	Normal	–0.02	0.005	–0.0238	[–0.0307, –0.0166]
χ	Gamma	20	5	10.1331	[10.0299, 10.6912]
b	Gamma	0.4	0.1	0.2715	[0.1643, 0.4142]
ρ_R	Beta	0.8	0.1	0.4612	[0.4077, 0.5082]
ρ_π	Gamma	1.5	0.2	1.1888	[1.0624, 1.3432]
ρ_y	Normal	0.2	0.1	0.3142	[0.2570, 0.3937]
α_N	Beta	0.34	0.05	0.1982	[0.1570, 0.2453]
α_T	Beta	0.36	0.05	0.4764	[0.4457, 0.4964]

Note: Inv. gamma—inverted gamma.

3 Quantitative Implications of the Model

This section discusses the dynamics of the estimated model in terms of the variance decomposition of its main endogenous variables and in terms of their impulse responses to the shocks contemplated in the model. We discuss only the responses to the three shocks that are found to be more important in explaining the variability of consumption (the main determinant of utility and hence welfare), inflation, and output. These are the technology shock in the non-traded-goods sector, the monetary policy shock, and the foreign monetary policy shock.

3.1 Variance decomposition

Table 2 shows the decomposition of the long-run variance of the main endogenous variables of the model into the contribution of each of the eight shocks.

The business cycle volatility of the output in each production sector, traded and non-traded, is explained mainly by its corresponding sector-specific technology shock, but there is a substantial role for the monetary policy shocks as well, the domestic policy shocks on domestic traded production, and foreign shocks on exports and imports. Aggregate inflation is found to be better explained by technology shocks (through their impact on the non-traded inflation) and by foreign interest rate and risk-premium shocks (through the impact of both on imports inflation) than by monetary policy shocks in the past three decades. Final spending, i.e., consumption and investment, are explained mainly by the non-traded-goods technology shock, which is one of the shocks with higher estimated volatility, although the steady-state share of the non-traded-goods sector in final good is only one-third. Hours worked are substantially explained by technology shocks in the two sectors, but are also clearly affected by monetary policy shocks. Finally, the volatility of the real exchange rate is explained by shocks to technology, foreign monetary policy, and the risk premium.

3.2 Responses to a foreign shock under the estimated monetary policy rule

The lines termed “historical” in Figure 2 represent the responses in terms of percentage deviations with respect to the steady state to a one-period increase of 100 basis points in the monetary policy instrument of the foreign economy, the United States.

The uncovered interest rate parity yields a nominal and real impact depreciation of the Canadian dollar (2 per cent posterior median depreciation on the impact of the real exchange rate, s_t). The real depreciation causes a direct rise in the marginal cost of the importing firms and is therefore translated into higher import prices and fewer imports, y_t^M. It is important to note, however, that as a result of the estimated sluggishness of import prices, the exchange rate pass-through is not complete and imports inflation rises by only 50 basis points.

Table 2
Variance decomposition historical Taylor rule

Variable	A_t^N	A_t^T	R_t	b_t	R_t^*	y_t^*	π_t^*	w_t^*
y_t	14.60	24.46	34.63	0.01	9.31	9.66	0.47	6.83
	[11.61, 17.72]	[21.50, 27.43]	[32.24, 38.42]	[0.00, 0.01]	[6.52, 12.68]	[8.135, 11.57]	[0.36, 0.58]	[4.75, 8.90]
y_t^N	93.00	1.02	1.69	0.00	2.48	0.05	0.01	1.70
	[91.65, 94.74]	[0.85, 1.30]	[1.22, 2.35]	[0.00, 0.00]	[1.77, 3.32]	[0.035, 0.09]	[0.00, 0.02]	[1.11, 2.38]
y_t^T	20.37	28.58	28.75	0.00	6.98	9.75	0.41	5.12
	[14.54, 28.94]	[24.27, 32.40]	[25.39, 32.07]	[0.00, 0.01]	[4.67, 9.48]	[8.171, 11.37]	[0.30, 0.51]	[3.56, 6.70]
y_t^x	38.17	3.91	2.21	0.00	26.00	12.29	0.11	17.27
	[30.25, 47.77]	[3.03, 4.80]	[1.64, 2.95]	[0.00, 0.00]	[19.04, 34.87]	[9.690, 16.49]	[0.03, 0.23]	[13.07, 21.82]
y_t^m	16.79	0.22	8.80	0.00	41.06	4.85	0.39	27.85
	[9.94, 24.49]	[0.13, 0.37]	[5.71, 12.56]	[0.00, 0.00]	[30.21, 50.40]	[2.972, 7.03]	[0.23, 0.58]	[21.46, 33.28]
c_t	52.15	0.36	8.45	0.04	21.67	2.42	0.15	14.70
	[42.82, 60.85]	[0.28, 0.47]	[6.53, 11.12]	[0.03, 0.06]	[15.24, 30.10]	[1.650, 3.40]	[0.07, 0.23]	[10.45, 19.54]
h_t	17.53	27.23	25.63	0.01	13.00	6.83	0.35	9.37
	[12.55, 24.91]	[21.59, 30.41]	[22.92, 29.47]	[0.01, 0.02]	[9.51, 17.28]	[5.508, 8.46]	[0.24, 0.43]	[6.58, 12.01]
h_t^N	43.23	9.33	15.24	0.01	18.51	0.69	0.18	12.76
	[38.96, 48.19]	[7.97, 11.04]	[11.55, 19.87]	[0.00, 0.01]	[13.52, 23.55]	[0.367, 1.17]	[0.10, 0.26]	[9.80, 16.60]
h_t^T	30.98	25.32	20.04	0.01	9.30	7.28	0.29	6.74
	[24.51, 41.80]	[20.03, 28.82]	[16.91, 23.10]	[0.00, 0.01]	[6.77, 12.22]	[5.769, 8.97]	[0.19, 0.37]	[4.68, 8.77]
i_t	44.76	0.31	8.78	0.00	26.72	1.14	0.20	18.05
	[34.68, 52.82]	[0.22, 0.46]	[6.45, 11.67]	[0.00, 0.00]	[18.98, 36.07]	[0.773, 1.59]	[0.10, 0.31]	[12.92, 23.42]
s_t	51.13	0.49	3.84	0.00	21.95	2.92	0.83	18.80
	[45.58, 57.00]	[0.38, 0.64]	[3.04, 4.80]	[0.00, 0.00]	[18.22, 26.48]	[2.220, 3.88]	[0.64, 0.98]	[16.16, 21.83]
π_t	27.40	13.29	7.66	0.00	27.15	2.24	0.83	21.40
	[21.67, 34.18]	[11.70, 15.02]	[6.27, 9.75]	[0.00, 0.00]	[22.28, 33.24]	[1.461, 3.30]	[0.61, 1.07]	[17.38, 25.19]
π_t^N	98.05	0.29	0.11	0.00	0.90	0.10	0.01	0.51
	[97.09, 98.95]	[0.18, 0.39]	[0.07, 0.14]	[0.00, 0.00]	[0.39, 1.51]	[0.056, 0.17]	[0.00, 0.02]	[0.22, 0.87]

(cont'd)

Table 2 (cont'd)
Variance decomposition historical Taylor rule

Variable	A_t^N	A_t^T	R_t	b_t	R_t^*	y_t^*	π_t^*	w_t^*
π_t^{Td}	14.49	60.50	4.94	0.00	11.07	2.00	0.19	6.78
	[11.75, 17.36]	[55.31, 67.17]	[4.11, 6.31]	[0.00, 0.00]	[6.40, 16.60]	[1.339, 2.77]	[0.11, 0.25]	[4.20, 9.49]
π_t^m	19.34	3.90	6.05	0.00	36.23	3.33	1.25	29.86
	[15.02, 23.34]	[3.17, 4.54]	[4.77, 7.70]	[0.00, 0.00]	[30.88, 41.38]	[2.429, 4.63]	[1.00, 1.52]	[26.00, 33.51]
π_t^x	13.12	11.57	0.94	0.00	31.57	4.58	12.86	25.32
	[10.23, 16.58]	[9.58, 13.94]	[0.73, 1.23]	[0.00, 0.00]	[26.33, 37.17]	[3.503, 5.94]	[11.14, 14.45]	[22.18, 28.69]
R_t	26.18	3.25	27.18	0.00	24.52	0.25	0.39	18.20
	[21.26, 30.10]	[2.82, 3.75]	[21.58, 34.16]	[0.00, 0.00]	[17.75, 32.11]	[0.126, 0.46]	[0.24, 0.54]	[13.32, 22.76]

Exports benefit from the depreciation. Because exports are priced in the foreign currency, but traded-sector firms maximize their profits in Canadian dollars, the depreciation by itself increases the benefits from the portion of the production that is exported. As a result, producers in the traded-goods sector lower export prices and increase their exports on impact.

The increase of imports inflation makes aggregate inflation rise, which causes a monetary policy contraction. That, in turn, decreases demand (c_t and i_t) that further reduces imports demand but also decreases demand of non-traded and of traded goods produced domestically. The monetary policy contraction also helps undo the initial depreciation.

3.3 Responses to a sectoral shock under the estimated monetary policy rule

The lines termed “historical” in Figure 1 represent the responses to a positive one-period technology shock of 1 per cent in the non-traded-goods sector.

Increased production in the non-traded-goods sector[8] causes demand to rise throughout the economy and therefore causes output to increase in the traded-goods and imports sectors as well.

Prices in the non-traded-goods sector fall on impact, leading to a mild drop in overall inflation, which in turn causes an expansionary reaction of the monetary policy that feeds into a further increase of demand and causes nominal and real depreciation on impact.

Growth in demand increases imports as well as imports inflation, which helps to quickly undo the fall of aggregate inflation.

As before, the depreciation increases the profits of the exported production in the traded sector, but the demand for exports does not rise (foreign output being exogenous). Thus, maximization of the profit in the traded-goods sector makes firms lower export prices fixed in US dollars (pricing to market) and increase exports.

8. As is well known in the literature, sticky prices prevent the 1 per cent increase in total-factor productivity to be fully transformed into a 1 per cent increase in y_t^{NT}. Since capital is predetermined, the only way to generate that lower output increase is by reducing hours worked on impact, which is observed in Figure 1. h_t^{NT} falls on impact but increases after four quarters.

3.4 Responses to a common domestic shock under the estimated monetary policy rule

The lines termed “historical” in Figure 3 represent the responses to a temporary monetary policy contraction. The nominal interest rate shock increases by 100 basis points for one period. On impact, the monetary policy instrument rises by less than 1 per cent because of the immediate fall in inflation and because of the presence of significant interest rate smoothing. In fact, nominal interest rates rise by only one-half of the 1 per cent shock. Inflation falls on impact owing to an immediate decrease in demand and consequently in activity in every sector—traded goods, non-traded goods, and imports.

The monetary policy contraction causes a nominal and real impact appreciation of the Canadian dollar. Since export prices are being set in US dollars, the appreciation reduces exporters’ profits and export prices consequently rise, which causes a drop in exports.

4 Simple Inflation-Targeting Rules

In this section, we search for the parameterization of feedback Taylor-type interest rate rules, similar to equation (30), that maximize household welfare given our estimated model. We evaluate the welfare gain they represent with respect to the estimated monetary policy reaction function (or “historical rule” in the tables), as well as their implications in terms of aggregate fluctuations.

The welfare implications are shown in Table 3. Table 4 reports another dimension for comparing alternative monetary policy reaction functions: the unconditional volatility they imply for the utility and its arguments, as well as for several crucial macro variables, i.e., output, inflation, and the nominal interest rate. We also compute the long-run variance decomposition (Table 5) and the impulse responses to different shocks (in Figures 1, 2, and 3) for various monetary policy rule specifications.

The search for the welfare-maximizing feedback monetary policy rules is set out as follows. We maximize the unconditional expectation of lifetime

Figure 1
Non-tradables technology shock

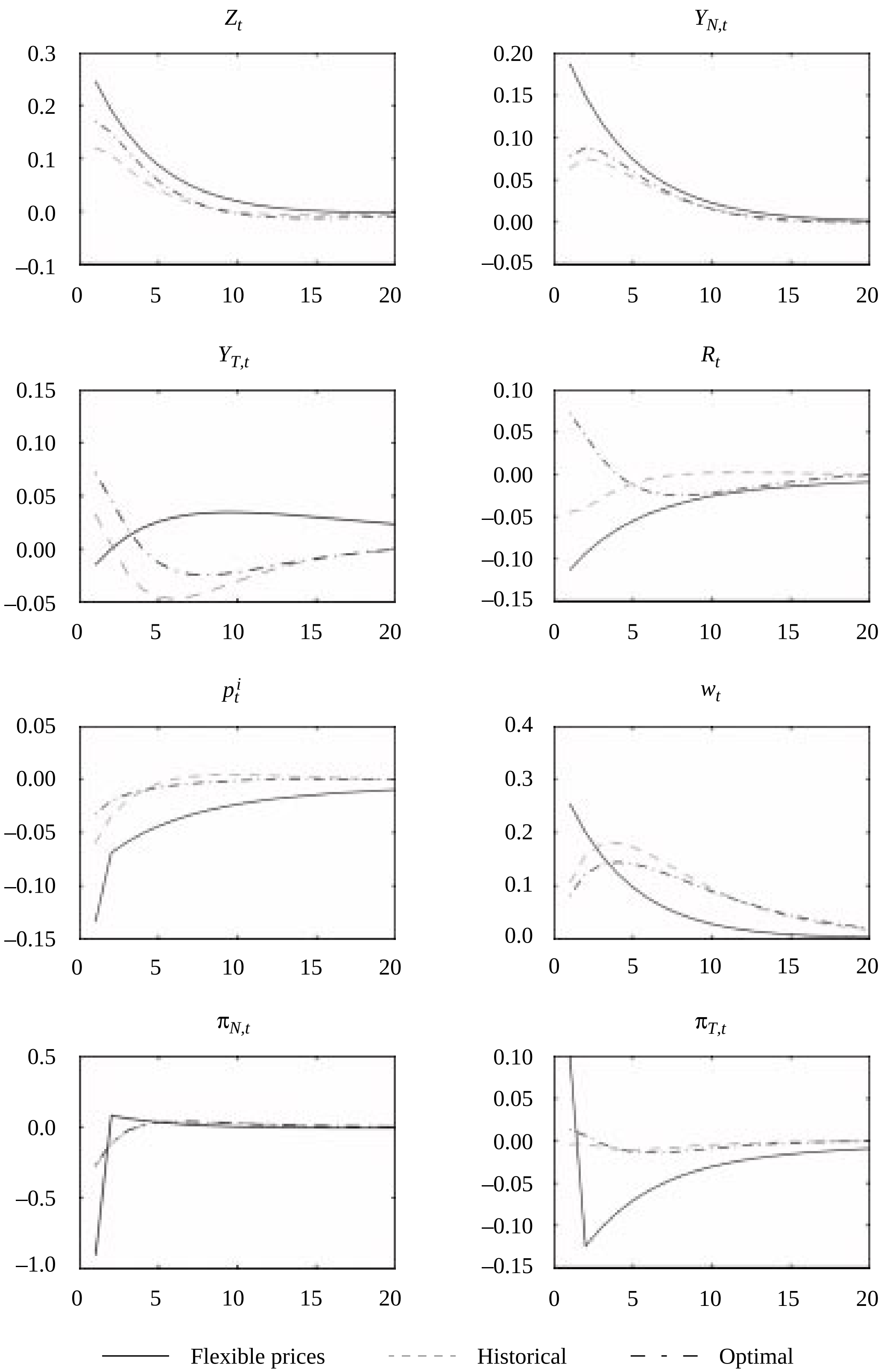

Figure 2
Foreign nominal interest rate shock

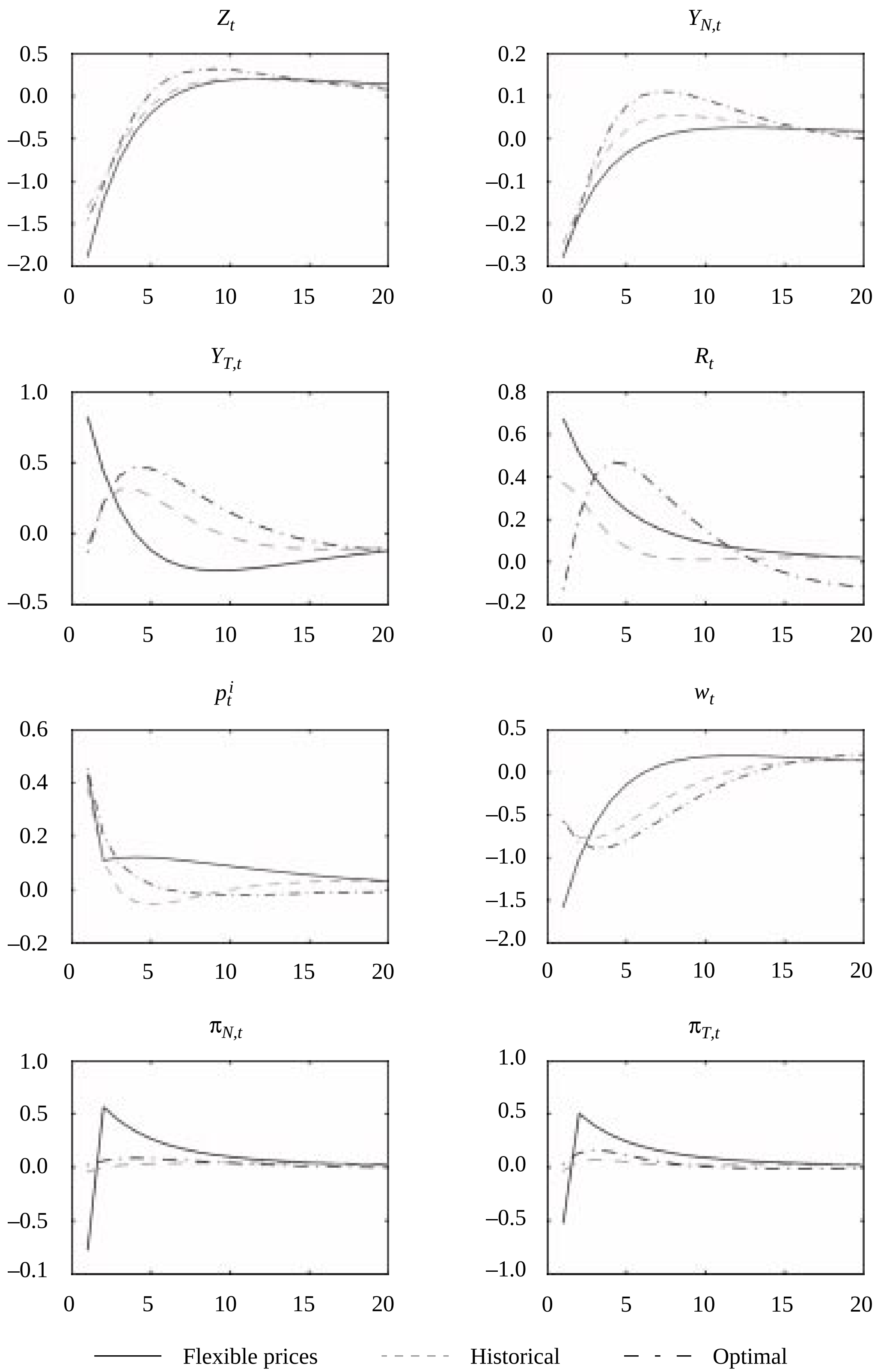

Figure 3
Local nominal interest rate shock

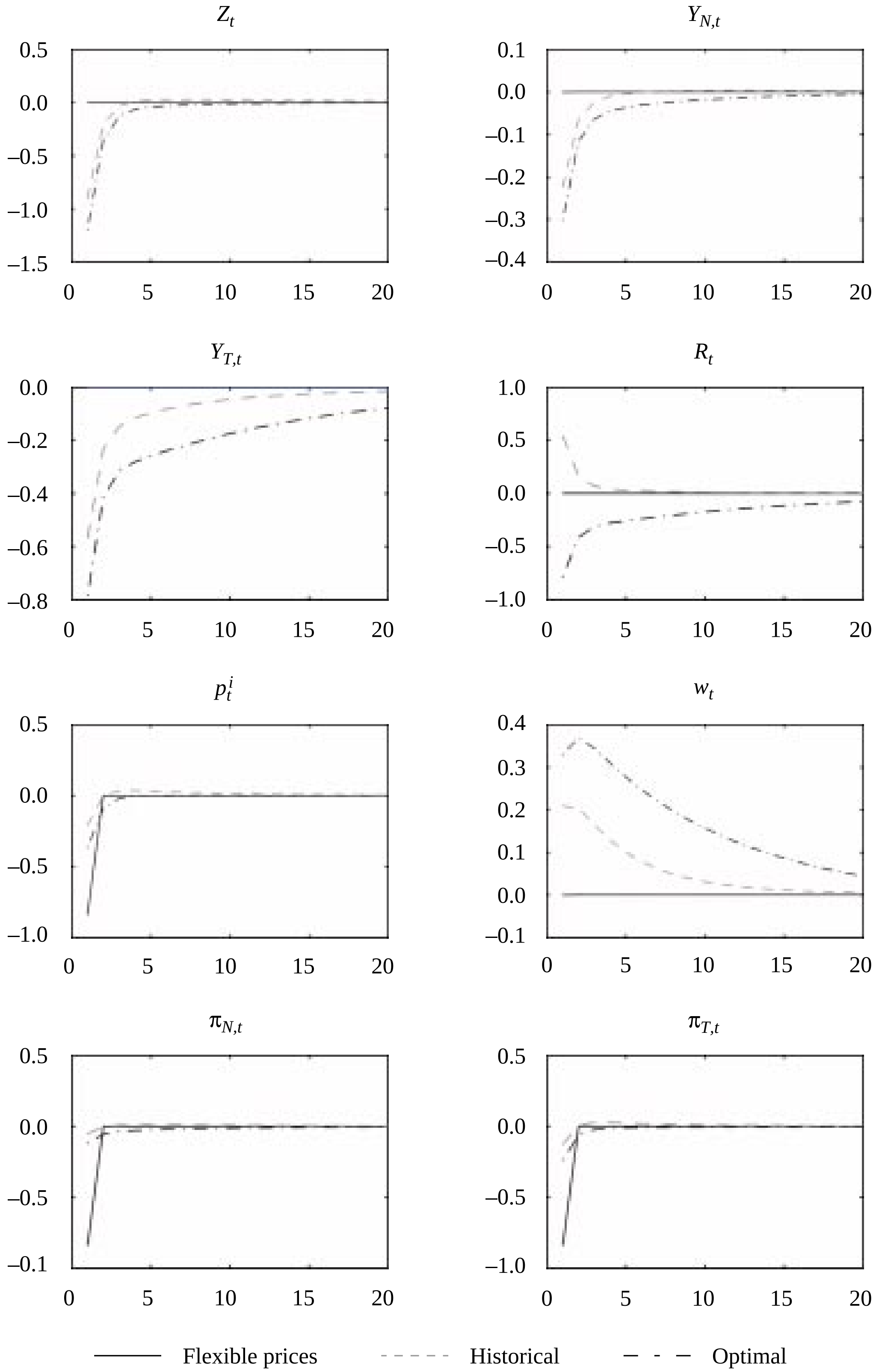

Table 3
Welfare implications of alternative monetary policy rules

Interest rate rules	Average c_t	Average m_t	Average h_t	Average u_t	Welfare gain	1st-level effect	2nd-level effect
Historical rule $\hat{R}_t = 0.46\hat{R}_{t-1} + 1.19\hat{\pi}_t + 0.31\hat{y}_t$	0.5337	0.2497	0.3005	–0.7929	0.0000	0.0000	0.0000
CPI inflation targeting $\hat{R}_t = 0.46\hat{R}_{t-1} + 1.20\hat{\pi}_t$	0.5345	0.2558	0.3013	–0.7921	0.0799	0.1112	–0.0311
Future CPI inflation targeting $\hat{R}_t = 0.46\hat{R}_{t-1} + 1.20\hat{\pi}_{t+1}$	0.5349	0.2572	0.3018	–0.7918	0.1136	0.1549	–0.0410
CPI inflation stabilization $\hat{R}_t = 0.46\hat{R}_{t-1} + \infty\hat{\pi}_t$	0.5345	0.2618	0.3008	–0.7921	0.0847	0.1606	–0.0755
Output-gap stabilization $\hat{R}_t = 0.46\hat{R}_{t-1} + \infty\hat{y}_t$	0.5333	0.2462	0.3001	–0.7933	–0.0415	–0.0551	0.0136
CPI level targeting $\hat{R}_t = 0.46\hat{R} + 0.20\hat{P}_t$	0.5345	0.2500	0.3012	–0.7921	0.0834	0.0952	–0.0117

Note: The welfare gain is expressed as a permanent percentage increase of consumption compared with the historical consumption mean.

utility[9] of households over the parameters of the Taylor rule. This implies:

$$\max_{\rho_\pi, \rho_y} E\{u(c_t, m_t, h_t)\}.$$

We measure the welfare gain associated with a particular monetary policy in terms of its compensating variation. That is, we calculate the percentage of lifetime consumption that should be added to that obtained under the estimated Taylor rule in order to give households the same unconditional expected utility as under the scenario for the new monetary policy rule:

$$E\{u(c_t(1 + \mathit{welfare\ gain}), m_t, h_t)\} = E\{u(\tilde{c}_t, \tilde{m}_t, \tilde{h}_t)\},$$

where variables without tildes are obtained under the estimated rule described before, and variables with tildes are under the optimized Taylor rule. Based on the results found in Kim and Kim (2003) and subsequent literature, we compute the long-run average utility by means of a second-order approximation around the steady-state utility. In particular, we follow the approach of Schmitt-Grohé and Uribe (2004a).

$$E(u(\tilde{c}_t, \tilde{m}_t, \tilde{h}_t)) = u(c, m, h) + u'E(\hat{\tilde{c}}_t, \hat{\tilde{m}}_t, \hat{\tilde{h}}_t) + \frac{1}{2}E(\hat{\tilde{c}}_t, \hat{\tilde{m}}_t, \hat{\tilde{h}}_t)'u''(\hat{\tilde{c}}_t, \hat{\tilde{m}}_t, \hat{\tilde{h}}_t),$$

where u' and u'' are the first and second derivatives, respectively, of the utility function with respect to its arguments, evaluated at their deterministic steady-state values; variables with hats measure deviations from their levels in the deterministic steady state. The compensating variation in consumption can therefore be decomposed into a first-level effect and a second-level or stabilization effect, i.e., into the welfare gains of the new parameterization of the monetary policy owing to the effect of monetary policy on the average levels of consumption, real balances, and leisure, as well as its effect on their volatilities. The first-level effect is defined as:

9. Schmitt-Grohé and Uribe (2004b) adopt the conditional welfare optimization in their framework and they consider the non-stochastic steady state as an initial state of the economy. By computing the unconditional long-run utility, we do not consider the effect of the initial state. Transition costs are crucially dependent on that initial state, especially if the real state of the economy is never at the deterministic level. In addition, Schmitt-Grohé and Uribe show that the optimal rule is robust to these definitions of welfare, but that the welfare improvement could be different in the sense that it is higher in the case of unconditional welfare given that no short-term transition costs are incurred.

$$E\{u(c_t(1 + 1st\text{-}level\ effect), m_t, h_t)\} = u(c, m, h) + u'E(\hat{\tilde{c}}_t, \hat{\tilde{m}}_t, \hat{\tilde{h}}_t),$$

and the second-level effect as:

$$E\{u(c_t(1 + 2nd\text{-}level\ effect), m_t, h_t)\} = u(c, m, h) + \frac{1}{2}E(\hat{\tilde{c}}_t, \hat{\tilde{m}}_t, \hat{\tilde{h}}_t)' u''(\hat{\tilde{c}}_t, \hat{\tilde{m}}_t, \hat{\tilde{h}}_t).$$

The overall effect in all cases is such that, approximately, $(1 + welfare\ gain) \approx (1 + 1st\text{-}level\ effect)(1 + 2nd\text{-}level\ effect)$. Table 3 reports the welfare gains, together with the unconditional long-run average values of the arguments of the utility function as well as that of the log utility itself.

In what follows, we limit our attention to the Taylor-type rules that guarantee the existence of a unique and stable equilibrium in the neighbourhood of the deterministic steady state. We also restrict our search to monetary policy reactions to price and output deviations from target; we do this by keeping the degree of nominal interest rate smoothing unchanged and equal to the posterior median of the estimated value, i.e., $\rho_R = 0.46$.[10]

Our reference interest rate feedback rule is the estimated one where, on top of the moderate nominal interest rate smoothing, the monetary authority has targeted inflation but not very aggressively (the posterior median estimate for the reaction to deviations of the aggregate CPI inflation from target is

10. Several reasons motivate the choice of fixing ρ_R. One is that without interest rate smoothing there would be indeterminacy for values of the coefficient on inflation smaller than one. By keeping ρ_R at its estimated value, we can compute the welfare gains of a wider range of values for ρ_π, including those smaller than one.

Another important reason is that because the optimized rule would aim at maximizing inflation stabilization rather than instrument smoothing, the welfare-maximizing value of ρ_R is very likely going to be zero. Indeed, Schmitt-Grohé and Uribe (2004b) find that the optimal degree of interest rate smoothing for Taylor rules in the Christiano, Eichenbaum, and Evans (2001) model is zero. However, they also look for, as we do, the parameterization of the Taylor rule that delivers higher utility for degrees of interest rate smoothing closer to the observed ones. Keeping our frame of analysis of alternative monetary policy reaction functions close to the observed features of monetary policy as it is implemented in practice constitutes a further reason for keeping ρ_R fixed as well as for remaining with simple Taylor rules. A final reason is that maximizing welfare over several parameters is computationally expensive.

slightly above 1, $\rho_\pi = 1.19$) and there has been a significant though weak response of the monetary policy to the output gap (posterior median of $\rho_y = 0.31$).

4.1 CPI inflation-rate targeting

Here we consider the case where the central bank targets the same variables as in the historical rule, i.e., aggregate CPI inflation and the output gap. The welfare-maximizing Taylor rule implies a very similar level of aggressiveness with respect to inflation deviations from target to that of the estimated historical rule, $\rho_\pi = 1.20$, but, unlike the historical case, there is no response to the output gap, $\rho_y = 0$.

The historical rule entails a welfare cost of 0.08 per cent of the lifetime consumption associated with the optimized CPI inflation-targeting rule (see second row in Table 3). Most of the welfare improvement of choosing $\rho_\pi = 1.20$ and $\rho_y = 0$ rather than the estimated parameters comes from the first-level effect or improvement in long-run average utility, which amounts to a 0.11 per cent increase in lifetime consumption. This welfare-maximizing monetary policy reaction function implies slightly higher volatility in the utility arguments (see second row of Table 4), which is captured by a negative second-order effect, as well as in output, while it only marginally improves inflation stabilization.

As Table 4 shows, not only consumption and the other arguments in the utility function show higher volatility; so do output and the monetary policy instrument. Instead, inflation remains with similar levels of volatility. Table 5 shows the medians of the long-run variance decomposition of model variables under this new monetary policy rule. It does not differ much from that in Table 2. However, it is worth noting that consumption variability is better explained by domestic shocks, including the monetary policy shock, and less by foreign shocks than under the historical rule. Inflation variability owes much more to monetary policy shocks than under the historical rule, but the explanatory power of foreign shocks has not substantially decreased. In general, monetary policy shocks are more responsible for aggregate variability under this optimized strict inflation-targeting rule than under the historical one.

In terms of the responses to shocks, the impulse responses obtained replacing the historical rule with this new optimized CPI inflation-targeting rule are quite similar. The median responses are displayed in Figures 1 to 3

Table 4
Aggregate volatility induced by alternative monetary policy regimes

Interest rate rules	σ_c	σ_m	σ_h	σ_u	σ_y	σ_π	σ_R
Historical rule $\hat{R}_t = 0.46\hat{R}_{t-1} + 1.19\hat{\pi}_t + 0.31\hat{y}_t$	0.0133	0.0552	0.0112	0.0226	0.0173	0.0077	0.0098
CPI inflation targeting $\hat{R}_t = 0.46\hat{R}_{t-1} + 1.20\hat{\pi}_t$	0.0163	0.0596	0.0128	0.0301	0.0301	0.0076	0.0126
Future CPI inflation targeting $\hat{R}_t = 0.46\hat{R}_{t-1} + 1.20\hat{\pi}_{t+1}$	0.0158	0.0595	0.0205	0.0277	0.0440	0.0140	0.0128
CPI inflation stabilization $\hat{R}_t = 0.46\hat{R}_{t-1} + \infty\hat{\pi}_t$	0.0212	0.0624	0.0114	0.0357	0.0345	0.0007	0.0137
Output-gap stabilization $\hat{R}_t = 0.46\hat{R}_{t-1} + \infty\hat{y}_t$	0.0120	0.0525	0.0115	0.0245	0.0097	0.0084	0.0077
CPI level targeting $\hat{R}_t = 0.46\hat{R}_{t-1} + 0.20\hat{P}_t$	0.0150	0.0564	0.0102	0.0276	0.0268	0.0065	0.0108

Note: σ denotes the unconditional standard deviation for the listed variables.

Table 5
Variance decomposition, optimized CPI inflation-targeting rule

Variable	A_t^N	A_t^T	R_t	b_t	R_t^*	y_t^*	π_t^*	w_t
y_t	15.19	33.73	31.40	0.01	7.05	6.97	0.50	5.14
y_t^N	90.56	0.17	3.71	0.00	3.17	0.25	0.05	2.08
y_t^T	10.27	40.69	30.68	0.01	5.91	7.56	0.50	4.37
y_t^x	37.49	9.77	9.25	0.01	19.77	10.94	0.25	12.53
y_t^m	22.12	1.07	12.86	0.01	36.44	3.36	0.71	23.44
c_t	54.83	1.29	11.91	0.03	18.02	1.93	0.30	11.69
h_t	15.50	6.23	40.48	0.03	16.60	8.82	0.69	11.64
h_t^N	32.52	0.79	27.97	0.02	21.57	2.41	0.42	14.29
h_t^T	26.46	8.23	34.15	0.02	12.59	9.03	0.61	8.92
i_t	48.94	1.74	13.23	0.00	21.06	1.19	0.39	13.45
s_t	57.85	0.64	9.06	0.00	16.19	0.65	0.71	14.89
π_t	22.25	2.48	25.56	0.00	26.44	0.12	0.71	22.44
π_t^N	97.76	0.06	0.60	0.00	0.93	0.05	0.01	0.58
π_t^{Td}	15.97	45.91	13.56	0.00	13.09	2.67	0.28	8.52
π_t^m	29.52	0.35	16.47	0.00	27.75	0.24	1.03	24.64
π_t^x	16.25	18.61	2.87	0.00	25.16	1.87	14.65	20.60
R_t	29.29	1.93	22.15	0.00	26.02	0.18	0.55	19.89

(under optimal inflation-targeting rule), together with those that would have been obtained in the case of flexible prices and wages.[11]

5 Price-Level Targeting

As stated in the introduction, many issues arise when a price-level target is introduced, such as the implications for the price level and responses of inflation to shocks, as well as for the volatility of the main macro variables, not the least of which is inflation itself.

Starting with Wicksell (1907), numerous authors have considered aggregate price-level stability the main goal of central banks, and this is reflected in the mandates of many central banks. How to achieve price stability has more often been interpreted as targeting at an explicit inflation rate or range than at a specific price-level path. Still, some recent research has shown that there can be substantial gains in including a specific price-level target in the monetary policy reaction function. In the above-mentioned Bank of Canada (1998) publication, Coulombe (1998) shows that there is a clear information

11. However, we keep the rest of the estimated parameters of Table 1, including those referring to the monetary policy reaction function. Suppressing the latter would mean not being able to solve the model.

gain under an explicit price-level-targeting regime: the price level itself conveys useful information about future inflation, because past shocks to prices must be reversed in the future. Under strict inflation targeting, however, where all shocks to the price level are permanent, the price level reveals no useful information. In Bank of Canada (1998), Black, Macklem, and Rose (1998) show that, when comparing simple monetary policy rules in a calibrated small open economy one-good model of the Canadian economy, and provided the price-level target is credible and that private sector expectations of inflation adjust accordingly, the economy performs better with a price-level target than with an inflation target, in the sense that the variability of both inflation and output are lower with the price-level target. These potential benefits of price-level targeting are not without risks, however. How to communicate such policy is a challenge. It could be difficult to justify why, following an increase in inflation above its long-run average, inflation had to be reduced below this long-run average for some time to drive the price level back to its target. Also, that reduction in inflation after the monetary policy takes action can lead to sharper initial declines in economic activity than under a strict inflation-targeting regime.

Giannoni (2000) argues that simple price-level-targeting rules,[12] while as simple as standard inflation-targeting Taylor rules, have received considerably less attention in recent studies of monetary policy. It is widely believed that such rules would result in greater variability of inflation (and, under nominal rigidity, of the output gap), since the policy-maker would respond to an inflationary shock by generating a deflation in subsequent periods. Studies such as Lebow, Roberts, and Stockton (1992) and Haldane and Salmon (1995) support this conventional view. However, Giannoni shows that when agents are forward looking and the monetary authority credibly commits to a price-level-targeting rule, such a Wicksellian rule yields lower variability of inflation and of nominal interest rates. Agents' expectation of a future deflation after an inflationary shock dampens the initial increase in inflation, lowers the variability of inflation, and causes welfare to rise. Williams (1999) confirms this result using the FRB/US model.

More recently, and closer to our approach, Batini and Yates (2003) also challenge the established view that price-level targeting entails lower price-level variance at the expense of higher inflation and output variance. They investigate monetary policy regimes that combine price-level and inflation

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12. In those rules, the nominal interest rate deviates from a constant in response to the output gap and to deviations of the price level from a prespecified path of constant inflation. Giannoni (2000) follows Woodford (1998, 2003) in referring to such rules as "Wicksellian." Wicksell (1907) argued that "price stability" could be obtained by allowing the interest rate to respond positively to fluctuations in the price level.

targeting in a variety of models and conclude that the relative merits of each regime depend on several modelling and policy assumptions, and do so in a non-monotonic fashion when moving from one regime to another.

In this section, we conduct the same calculations of welfare gains and implied macroeconomic volatility as before, but we consider a different type of monetary policy reaction function, i.e., where the central bank is concerned with returning the price level to its target path as well as or instead of bringing inflation to target.[13]

We follow Batini and Yates (2003) and encompass price-level and inflation targeting using the following specification of the monetary policy reaction function:

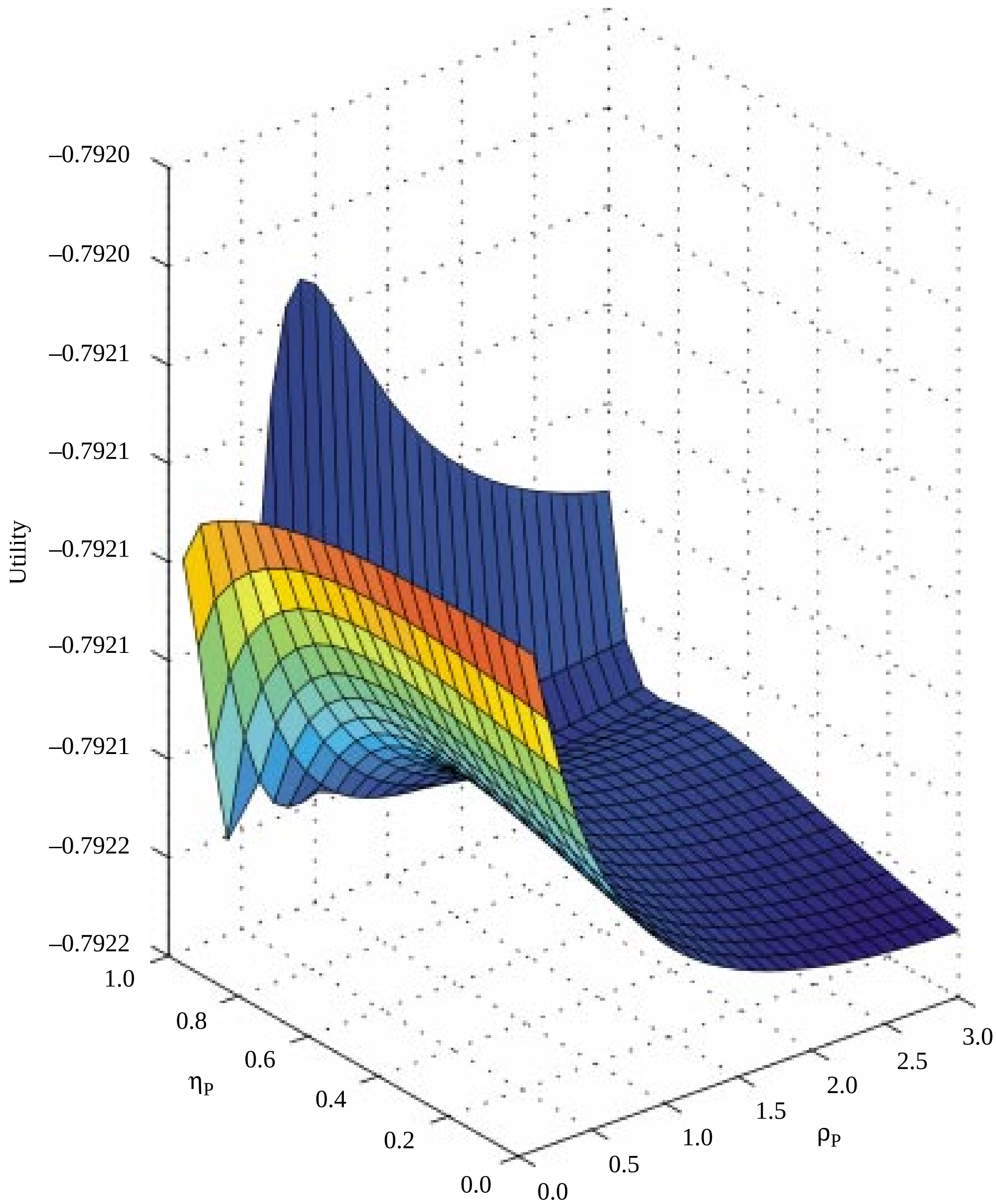
$$\log(R_t/R) = \rho_R \log(R_{t-1}/R) + \rho_P[\log(P_t/\bar{P}_t) - \eta_P \log(P_{t-1}/\bar{P}_{t-1})] + \rho_y \log(y_t/y),$$

where $\bar{P}_t$ is the target or steady-state value for the price level at period t, compatible with the established inflation target. Note that for $\eta_P = 1$, we have exactly the case of the Taylor rule defined for the inflation rate, while $\eta_P = 0$ means pure price-level targeting. For $0 < \eta_P < 1$, the rule is a hybrid one where the central bank is concerned about reaching the inflation target rate but also about the evolution of prices on the way to the inflation target. As before, we keep $\rho_R = 0.46$ and $\rho_y = 0$ fixed while jointly optimizing over $0 \le \eta_P \le 1$ and over ρ_P.

Figure 4 shows the utility surface of this optimization exercise, while further welfare implications and the implied volatility are shown in the last row of Tables 3 and 4. Two results emerge from this exercise. First, it is almost impossible to establish a clear ranking of combinations of parameters in this case; the long-run utility level (the vertical axis in Figure 4) associated with the depicted parameter surface is virtually the same. Pure approximation errors embedded in our procedure could be behind the plotted differences. Second, for the central bank to give a non-zero weight to the deviations of the price level from its target path, i.e., for $\eta_P < 1$, the monetary policy reaction to price and inflation deviations from target has to be very low, $\rho_P = 0.2$. In that case, welfare is maximized for the hybrid rule with $\eta_P = 0.25$, i.e., where 25 per cent of the price-stability concern of the monetary authority takes the form of inflation targeting and the rest is pure

13. We have computed the simulated impulse responses of the main macro variables after all shocks in the economy and find very similar reactions under pure inflation targeting as under pure price-level targeting for the same degree of price stabilization (same ρ_P coefficient).

Figure 4
Inflation versus price-level targeting



price-level targeting. Still, the welfare gain is almost unnoticeable and comes from the lower volatility induced (smaller negative second-level effect) by the mild reaction of the monetary policy.

It is interesting that gains from an explicit price-level target come only with low policy reactions, causing a far longer time to bring about price and inflation stabilization than in strict inflation-targeting regimes. This result is in line with the findings of Smets (2003).

6 Targeting Future Price Developments

To conclude these optimization exercises for simple monetary policy rules, we explore the impact of targeting expected future deviations of the inflation rate or the price level rather than targeting contemporaneous deviations. In their analysis of price-level versus inflation targeting under different model specifications, policy rules, and loss functions of the central bank, Batini and Yates (2003) find that the more forward looking the model, the less noticeable the difference between the reaction functions of inflation and price-level targeting.

We find two main results: (i) the welfare-maximizing parameter set is the same as when the central bank is not forward looking, i.e., $\rho_{\pi}^{+1} = 1.2$, $\rho_{\pi}^{+1}w = 0$, and $\rho_{\pi}^{+1} = 0$; and (ii) the welfare attained with a forward-looking monetary policy rule is noticeably higher. Row 3 of Table 3 shows that the welfare gain now is 0.11 per cent of the lifetime consumption versus 0.08 per cent when optimizing a contemporary monetary policy rule. And this welfare gain comes with increased output and inflation volatility but with lower volatility in household utility (see row 3 in Table 4).

Of all of the possible specifications explored in this paper, the one that achieves a higher welfare given the estimated model for the Canadian economy without causing substantial excess macroeconomic volatility is a strict inflation-targeting rule where the central bank reacts to the next period's expected deviation from the inflation target and does not target the output gap but allows for a moderate degree of nominal interest rate smoothing.

Conclusion

We analyze welfare-improving monetary policy reaction functions in the context of a New Keynesian small open economy model with a traded-goods sector and a non-traded-goods sector and with sticky prices and wages. We estimate the model for the case of Canada and use it to evaluate the welfare gains of alternative specifications of the feedback nominal interest rate rule.

The model is estimated using Bayesian techniques for quarterly Canadian data. We find statistically significant heterogeneity in the degree of price rigidity across sectors. We explore what would have been the optimal parameterization of a Taylor rule such as the estimated one, where the central bank targets aggregate inflation. We find welfare gains in responding slightly more aggressively to aggregate inflation deviations from target than has been the case in the past three decades, and in not responding to the output gap, as opposed to what the Bank of Canada has done.

We then consider recent literature that has questioned the optimality of aiming at a stable inflation rate instead of a stable price level in a world where households would prefer to reduce uncertainty about the long-run purchasing value of money. We look for the welfare-maximizing specification of an interest rate reaction function that targets a combination of price-level and inflation targets or just one of the two. We find no clear welfare gain in moving towards price-level targeting, unless the monetary policy is willing to accept very long horizons for prices and inflation to get back to target.

We find that higher welfare, without inducing excess macroeconomic volatility, is achieved with a strict inflation-targeting rule, where the central bank reacts to next period's expected deviation from the inflation target and does not target the output gap but allows for a moderate degree of nominal interest rate smoothing.

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