Bank of Canada Banque du Canada

Working Paper 2002-19 / Document de travail 2002-19

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ISSN 1192-5434

Printed in Canada on recycled paper

Bank of Canada Working Paper 2002-19

July 2002

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Acknowledgements

We would like to thank Hamza Malik, Gregory Mankiw, Ricardo Reis, Huntley Schaller, seminar participants at the Bank of Canada, and the participants at the Canadian Economic Association Conference (June 2002), Calgary, Canada.

Abstract

Mankiw and Reis (2001a) have proposed a "sticky-information"-based Phillips curve (SIPC) to address some of the concerns with the "sticky-price"-based new Keynesian Phillips curve. In this paper, we present a methodology for the empirical implementation of the SIPC for closed and open economies. We estimate its key structural parameter—the average duration of information stickiness—for the United States, Canada, and the United Kingdom. The benchmark results (with forecasting horizons of firms of seven to eight quarters) indicate that: (i) the average frequency of information updates is four quarters in the United States, between four and five quarters in Canada, and over seven quarters in the United Kingdom, and (ii) the open-economy estimates for Canada and the United Kingdom are similar to the closed-economy ones. Mankiw and Reis (2001a) assume information stickiness of four quarters to generate inflation dynamics similar to that observed in the U.S. data. We interpret our estimates in terms of the slope of the Phillips curve. Our structural estimates can be used to calibrate dynamic general-equilibrium models for monetary policy analysis that use informational inertia to match the stylized facts on inflation dynamics.

JEL classification: E31
Bank classification: Economic models; Inflation and prices

Résumé

Mankiw et Reis (2001a) ont proposé une courbe de Phillips à rigidité informationnelle pour résoudre certaines des difficultés posées par la courbe de Phillips des nouveaux économistes keynésiens. Dans leur étude, Khan et Zhu présentent une méthodologie d'application empirique de la courbe de Phillips à rigidité informationnelle en économie ouverte et fermée. Ils estiment le principal paramètre structurel de la courbe — la période moyenne de rigidité informationnelle — pour les États-Unis, le Canada et le Royaume-Uni. Les estimations de référence (fondées sur des horizons prévisionnels de sept à huit trimestres dans les entreprises) indiquent que : i) la périodicité moyenne des mises à jour de l'information est de quatre trimestres aux États-Unis, de quatre à cinq trimestres au Canada et de plus de sept trimestres au Royaume-Uni; ii) pour le Canada et le Royaume-Uni, les estimations en économie ouverte se rapprochent de celles en économie fermée. Mankiw et Reis (2001a) font l'hypothèse d'une rigidité informationnelle de quatre trimestres pour produire une dynamique de l'inflation semblable à celle qui ressort des données des États-Unis. Les estimations que Khan et Zhu présentent se rapportent à la pente de la courbe de Phillips. Leurs estimations structurelles peuvent servir à étalonner les modèles dynamiques d'équilibre général appliqués à l'analyse de la politique monétaire qui se fondent sur l'inertie informationnelle pour rendre compte des faits stylisés caractérisant la dynamique de l'inflation.

Classification JEL : E31
Classification de la Banque : Modèles économiques; Inflation et prix

1 Introduction

The stylized facts on inflation dynamics indicate that (i) monetary policy actions require lags of six to eight quarters to have their full impact on inflation, (ii) there is a high serial correlation in inflation, (iii) disinflation policies have contractionary effects, and (iv) monetary policy actions have their maximum effect on cyclical output before they have their maximum effect on inflation. Mankiw and Reis (2001a) (hereafter MR 2001a) have proposed a structural explanation for these stylized facts based on "sticky information." According to their theory, information relevant to firms' pricing decisions diffuses slowly in the economy. Therefore, when choosing prices, firms may not immediately update their old information. This behaviour is rational insofar as there are costs associated with collecting new information.[1] In their model, the specification of inflation dynamics is given by what MR (2001a) describe as "the sticky-information Phillips curve" (SIPC). A key feature of the SIPC specification is that current inflation depends not only on the current output gap but also on the *past* expectations of both current inflation and the growth rate of the current output gap. This feature also makes the empirical estimation of the SIPC parameters difficult. In this paper, we describe a methodology to address this issue.

The general-equilibrium models based on sticky prices yield a completely forward-looking specification for inflation dynamics, called the new Keynesian Phillips curve (NKPC) in the literature.[2] This class of models, which builds on the seminal work of Taylor (1980) and Calvo (1983), generates inertia in the price level but not in the inflation rate. As a result, the NKPC specification

[1] The notion that firms do not update their information as in MR (2001a) is different from the notion that firms do not act on new information. The latter may arise in the presence of constraints on the information-processing capacity of firms. See Woodford (2001) and Sims (2001).

[2] Some prominent contributions to this literature include Fuhrer and Moore (1995), Roberts (1995), Yun (1996), Rotemberg and Woodford (1997), McCallum and Nelson (1999), Galí and Gertler (1999), Sbordone (2002), and Woodford (2002). Excellent expositions are presented in Goodfriend and King (1997, 2001), Clarida, Galí, and Gertler (1999), Galí (2000), Mankiw (2000), and King (2001).

implies that current inflation is determined by the current output gap and *current* expectations of future inflation. Inflation in this model is, therefore, very flexible and responds immediately to monetary policy shocks, and hence does not accord with stylized facts. A further implication of the sticky-price model is that a fully credible disinflationary monetary policy is not contractionary, in contrast to the stylized fact (see Ball 1994). Several modifications of the canonical sticky-price model in the literature overcome these difficulties with various degrees of success, as demonstrated, for example, by Galí and Gertler (1999) and Christiano, Eichenbaum, and Evans (2001). The MR (2001a) model suggests an alternative approach, which replaces the assumption of sticky prices with that of sticky information.

The key structural parameter of the SIPC represents the degree of information stickiness and it influences the inflation dynamics implied by the model. An estimate of this parameter gives the frequency of information updates by firms. Our methodology considers finite forecasting horizons to construct past forecasts (expectations) of current economic conditions. We estimate a set of bivariate vector autoregressions (VARs) iteratively and construct combined dynamic out-of-sample forecasts of inflation and the output gap. Using these forecasts and the data, we use the SIPC to obtain an estimate of the frequency of information updates for the United States, Canada, and the United Kingdom. We derive a small open-economy specification of the SIPC and implement it for Canada and the United Kingdom. Typically, both Canada and the United Kingdom are considered small open economies. We also perform a sensitivity analysis to check the robustness of the estimates.

Our benchmark estimates (forecasting horizons of up to seven or eight quarters) suggest that firms update their information, on average, every four quarters in the United States, between four and five quarters in Canada, and over seven quarters in the United Kingdom. The simulation experiments in MR (2001a) assume a value of four quarters to match the stylized facts. Hence, our estimates for the United States and Canada are close to their assumed value, but those for the United Kingdom are not. The open-economy SIPC specification yields estimates similar to the closed-economy case for both Canada and the United Kingdom.

This paper is organized as follows. Section 2 describes the MR (2001a) model and its extension to a small open economy. In Section 3 we describe the estimation methodology and the data. Section 4 presents the results. In section 5 we interpret the results in terms of the slope of the Phillips curve, suggest the usefulness of our estimates in calibrating dynamic general-equilibrium models with informational inertia for monetary policy analysis, and discuss the caveats to the microfoundations of SIPC. Section 6 concludes.

2 Theory

2.1 The Mankiw-Reis model (closed economy)

In the MR (2001a) model for a closed economy, firms are assumed to operate in a symmetric monopolistically competitive environment. A firm chooses its optimal price in each period, but the information used to compute that optimal price is not necessarily the current one. It is in this sense that the information is "sticky." In other words, unlike the sticky-price model, prices are always changing, but some chosen prices are based on the past or outdated information. Firms form their expectations rationally but, owing to costs associated with updating old information sets or acting on new information, the expectations do not change frequently. Following Calvo's (1983) formulation, the probability that a firm updates its information to the current one in a given quarter is λ, $0 \leq \lambda < 1$. This probability is independent of the history of past updates. The expected time between information updates is therefore $\frac{1}{\lambda}$ quarters. At a macro level, the parameter

λ also represents the fraction of firms that use updated information in their pricing decision. The remaining fraction, $1-\lambda$, of firms use past or outdated information.

The optimal (symmetric, log-linearized) price p_t^o of any firm in a given period is

$$p_t^o = p_t + \alpha y_t, \tag{2.1}$$

where y_t is the output gap and p_t is the aggregate price level. The parameter α implies that if the output gap is positive, a firm's optimal (or desired) price, p_t^o, will be higher relative to the aggregate price, p_t. This parameter depends on the detailed structure of the economy (for instance, the preference, technology, and the market structure parameters). We clarify this point further in section 2.2.

The sticky-information assumption implies that a firm that uses j-period old information sets the price

$$x_t^j = E_{t-j}[p_t^o]. \tag{2.2}$$

The formulation in (2.2) resembles Fischer's (1977) model of wage contracts.[3] The aggregate price level in period t is the average of the prices of all existing firms

$$\begin{aligned} p_t &= \lambda p_t^o + \lambda(1-\lambda)E_{t-1}[p_t^o] + \lambda(1-\lambda)^2 E_{t-2}[p_t^o] \\ &\quad +... + \lambda(1-\lambda)^j E_{t-j}[p_t^o] + ...\infty \\ &= \lambda \sum_{j=0}^{\infty}(1-\lambda)^j x_t^j. \end{aligned} \tag{2.3}$$

Combining (2.1), (2.2), and (2.3), we can derive the SIPC[4]

$$\pi_t = \frac{\lambda\alpha}{1-\lambda} y_t + \lambda \sum_{j=0}^{\infty}(1-\lambda)^j E_{t-1-j}\left[\pi_t + \alpha \Delta y_t\right], \quad \Delta y_t = y_t - y_{t-1}, \tag{2.4}$$

where Δy_t is the growth rate of the output gap. According to (2.4), current inflation is determined by the current output gap, and past expectations of current inflation and the growth rate of the

[3] Devereux and Yetman (2001) use a similar formulation to study the effect of monetary shocks.

[4] Appendix A presents the complete derivation.

current output gap. The structural parameter λ represents the *degree of information stickiness* at a given point in time. As λ rises, more and more firms use updated information when choosing prices, thereby implying a smaller degree of information stickiness. Therefore, from (2.4), inflation becomes more sensitive to the current output gap and less sensitive to the past expectations of current inflation and the growth rate of the current output gap. The parameter α in (2.4) captures the sensitivity of the optimal relative price to the current output gap. It can be interpreted as the *degree of real rigidity*, as discussed by Ball and Romer (1990). As MR (2001a) point out, firms who update their information set in a given period realize that other firms are not updating their information, and this in turn limits the size of their price adjustment when α takes a small value. Woodford (2002) explains the structural components of α and the conditions under which it implies strategic complementarity ($\alpha < 1$) and strategic substitutability ($\alpha > 1$) in the pricing decisions of firms. The calibrated value of $\alpha = 0.1$ as in MR (2001a), therefore, implicitly assumes strategic complementarity.

2.2 A small open-economy SIPC specification

In this section, we present a small open-economy specification of the SIPC based on Galí and Monacelli (2000).[5] We relax their assumption of common-factor markets and instead assume specific-factor markets, as in Woodford (2002). This modification is necessary to obtain strategic complementarity in firms' pricing decisions implicit in the MR (2001a) model. Relative to the closed-economy model, the additional parameters in the open-economy case are the degree of openness of the economy, δ, and the elasticity of substitution between domestic and foreign goods, η. Moreover, the underlying structural parameters, elasticity of intertemporal substitution in consumption (σ^{-1}), elasticity of substitution in labour hours (ϕ^{-1}), returns to labour in the production

[5] Appendix A presents the details.

technology (a), and elasticity of demand (ϵ), which are implicit in the closed-economy case, take an explicit role.

In contrast to (2.1), the optimal symmetric price for domestic output in the small open-economy model is

$$p^o_{H,t} = p_{H,t} + \left(\frac{\omega}{1+\omega\epsilon} + \frac{\sigma}{(1+\omega\epsilon)\omega^*}\right) y_t + \left(\frac{\sigma}{1+\omega\epsilon} - \frac{\sigma}{(1+\omega\epsilon)\omega^*}\right) y^*_t, \tag{2.5}$$

where ω represents the elasticity of the firm's marginal cost with respect to its own output. It depends on the details of the structure of the economy. In our derivation, $\omega \equiv \frac{\phi}{a} + \frac{1}{a} - 1$.[6] The other parameter, ω^*, depends on the two additional parameters in the open-economy model, η and δ. Specifically, $\omega^* \equiv 1 + \delta(\sigma\eta - 1)(2 - \delta)$.[7] The optimal price is influenced by the aggregate domestic price level ($p_{H,t}$), domestic output gap (y_t), and world output gap (y^*_t). The marginal cost of producing domestic output depends on both domestic and world output gaps; hence, the optimal price is influenced by these variables. There are two sources of real rigidity in the small open-economy model. First, the real rigidity relates to the responsiveness of the domestic price to the domestic output gap. This is given by the term $\alpha_1 \equiv \left(\frac{\omega}{1+\omega\epsilon} + \frac{\sigma}{(1+\omega\epsilon)\omega^*}\right)$. Second, the real rigidity relates to the responsiveness of the domestic price to the world output gap. This is given by the term $\alpha_2 \equiv \left(\frac{\sigma}{1+\omega\epsilon} - \frac{\sigma}{(1+\omega\epsilon)\omega^*}\right)$. Note that $\alpha_1 + \alpha_2 = \alpha \equiv \frac{\sigma+\omega}{1+\omega\epsilon}$. Therefore, the overall real rigidity in the small open economy is the same as that in the closed economy. However, since $\alpha_1 < \alpha$, there is relatively more real rigidity with respect to the domestic output gap in the open-economy case.

The open-economy SIPC, in terms of domestic inflation, $\pi_{H,t}$, is

$$\pi_{H,t} = \frac{\lambda}{1-\lambda}\alpha_1 y_t + \frac{\lambda}{1-\lambda}\alpha_2 y^*_t + \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-1-j}\left[\pi_{H,t} + \alpha_1 \Delta y_t + \alpha_2 \Delta y^*_t\right]. \tag{2.6}$$

[6]In our empirical implementation, we directly calibrate ω, which allows us to not use any specific values for ϕ and a.

[7]See Appendix A for the derivation.

According to (2.6), domestic inflation is determined by the current domestic and world output gaps, and by past expectations of their respective current growth rates.[8]

3 Estimation Methodology and Data

From an empirical implementation viewpoint, the SIPC specifications in (2.4) and (2.6) reveal two important facts. First, the SIPC involves past expectations of current economic conditions. In the closed-economy case, these economic conditions are the inflation rate and output-gap growth. In the open-economy case, the economic conditions are the inflation rate, the growth rate of the domestic output gap, and the growth rate of the world output gap. These expectations from past periods are the data for the current time period, t, and are required for the estimation. Second, the time index, j, goes into the infinite past. This implies very long forecasting horizons for some firms. Given the limited data, a truncation point, $j^{\max}$, is necessary to set the forecasting horizons of the firms.

3.1 Forecasting and estimation procedure

We consider a VAR-based methodology to construct out-of-sample forecasts of inflation (π_t), the output gap (y_t), and the world output gap (Y_t^*). Following Stock and Watson (2001), for each of these variables, we estimate a bivariate VAR using a set, X_t, of financial and non-financial variables. Table 1a lists these variables for the United States, Canada, and the United Kingdom. The table also indicates whether the level/logarithm/growth rate of a particular variable is used. For each country, we iteratively estimate the following bivariate VAR:

$$\begin{bmatrix} Z_t \\ X_t \end{bmatrix} = \mu + \beta(L) \begin{bmatrix} Z_t \\ X_t \end{bmatrix} + \epsilon_t, \qquad (3.1)$$

[8] See Appendix A for the derivation.

where $Z_t \in \{\pi_t, y_t, y_t^*\}$ and $\beta(L)$ is a lag polynomial. The lags of the variables for each country are selected on the basis of the forecasting performance. In particular, we choose the lags that give the smallest root-mean-square forecasting errors (RMSFE). We follow Stock and Watson (2001) to obtain combined forecasts by taking the average of the forecasts from each bivariate VAR. To assess the forecasting performance of (3.1), we compare the combined forecast errors from (3.1) with those from a simple autoregressive model, $Z_t = \mu + \beta(L)Z_t + \epsilon_t$ (with the same number of lags as in (3.1)). Tables 1b and 1c list the RMSFE of the average forecasts from (3.1) relative to those from the autoregressive model. A value of less than 1 indicates that the combined forecasts from (3.1) are better than the autoregressive model. For the inflation rate and output-gap growth, the combined forecasts are clearly better than the autoregressive forecasts.

We construct a matrix of average forecasts, F_Z, for π_t, y_t, and y_t^*, respectively. This matrix is

$$F_Z = \begin{bmatrix} E_{t_1-1}[Z_{t_1}] & . & . & E_{t_1-j-1}[Z_{t_1}] & . & E_{t_1-j^{\max}-1}[Z_{t_1}] \\ E_{t_2-1}[Z_{t_2}] & . & . & E_{t_2-j-1}[Z_{t_2}] & . & E_{t_2-j^{\max}-1}[Z_{t_2}] \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ E_{t_T-1}[Z_T] & . & . & E_{t_T-j-1}[Z_T] & . & E_{t_T-j^{\max}-1}[Z_{t_T}] \end{bmatrix}_{T \quad X \quad (j^{\max}+1)} . \qquad (3.2)$$

The information set Ω_{t_k-j-1} for each forecast $E_{t_k-j-1}[\ .\ |\Omega_{t_k-j-1}]$ contains all the $(t_k - j - 1)$-period variables, and the forecasts of the interim periods. To generate each column of F_Z, we estimate the forecasting bivariate VARs iteratively over the period $\{T_0, ..., (t_k - j - 1)\}$, where $j = 0, 1, 2, .., j^{\max}$, $t_k \in \{t_1 = 1980 : 1, t_2 = 1980 : 2, t_3 = 1980 : 3, ..., t_T = 2000 : 4\}$, and T_0 is the initial period. The first column of the matrix F_Z represents one-quarter-ahead average forecasts. The last columns represent the $j^{\max} + 1$-quarter-ahead average forecasts. From F_Z we obtain the expected growth rates of the y_t and y_t^*.[9]

[9]We iteratively estimate the VARs based on historical data available for the entire period. It is likely that firms forecasting the output gap or the inflation rate one or more quarters ahead will use data available

We use the forecasts F_Z and $\{\pi_t, y_t\}_{t_1}^{t_T}$ to estimate the degree of information stickiness, conditional upon the degree of real rigidity, for the closed-economy SIPC, (2.4), by non-linear least squares. Similarly, we estimate the open-economy SIPC, equation (2.6), for Canada and the United Kingdom using the forecasts F_Z and $\{\pi_t, y_t, y_t^*\}_{t_1}^{t_T}$ conditional upon the open-economy parameters δ and η, and the degree of real rigidity.

Finally, we check the robustness of the estimates to (i) the degree of real rigidity, (ii) the detrending method (the Hodrick-Prescott (H-P) filter output gap versus the quadratic detrended (QD) output gap), (iii) the measures of inflation (consumer price index (CPI), core inflation (Core), and the GDP deflator (GDP def.)), and (iv) the forecasting horizon, $j^{\max}$. We consider the values $j^{\max} \in \{4, 5, 6, 7, 11\}$, which imply forecasting horizons of 5, 6, 7, 8, and 12 quarters, respectively.[10]

We use data for the United States over the period 1969Q1 to 2000Q4, for Canada over the period 1968Q1 to 2000Q4, and for the United Kingdom over the period 1975Q1 to 2000Q4. Appendix B gives a complete description of the variables and the data sources.

4 Results

We examine the sign and statistical significance of the key parameter, λ, in the SIPC. We test the null hypothesis, H_0: $\lambda = 1$ (no information stickiness), against the alternative, H_1: $\lambda < 1$.

4.1 Estimates of the closed-economy SIPC

As stated above, the empirical implementation of the SIPC requires a forecasting horizon (truncation point), $j^{\max}$. There is no obvious way to choose this truncation point. A short forecasting

to them up until that period. In this sense, one would require a detailed real-time dataset to generate the forecasts for each forecasting horizon. This exercise is beyond the scope of this paper.

[10]For the United States, core inflation is the change in total CPI minus food and energy prices. For Canada, core inflation is the change in total CPI minus food and energy prices, and the effect of changes in indirect taxes. For the United Kingdom, core inflation is the change in the total retail price index (RPI) less mortgage interest payments. It is denoted RPIX.

horizon of two or three quarters would induce a bias in the distribution of firms that update their information relative to the theoretical distribution. On the other hand, a long forecasting horizon will give large forecast errors, which tend to bias down the estimates of λ. Given these concerns, we present the estimates for a range of forecasting horizons.

4.1.1 United States

Table 2 lists the results for the United States. The estimates of λ are conditional upon the value of α. Following MR (2001a) and Woodford (2002), we consider two values for α: 0.10 and 0.15.[11] As discussed in section 2, these values imply strategic complementarity in pricing decisions implicit in the MR (2001a) model. The sign of estimated λ is consistent with the SIPC framework outlined in section 2. We reject the null hypothesis of "no information stickiness" at the 99 per cent level of confidence for all the cases considered.[12]

For each forecasting horizon, the point estimates of λ are marginally sensitive to the two values of α, and the two measures of the output gap. The point estimates are slightly larger when $\alpha = 0.1$ than when $\alpha = 0.15$. The estimates are relatively more sensitive to the different measures of inflation. In general, they are smaller for the GDP deflator relative to the core CPI. The estimates decline in magnitude with a rise in the forecasting horizon.[13]

Given the trade-off in the choice of the appropriate truncation point, we consider seven to eight quarters as our benchmark forecasting horizons.[14] When the forecasting horizon is seven quarters,

[11]We estimated λ and α jointly; however, the point estimates of α were sensitive to the measure of inflation and were statistically insignificant. The corresponding estimates of λ were qualitatively similar to those reported here. This finding is likely owing to the fact that α is a reduced-form parameter that depends on the details of the structure of the economy (for instance, the preference, technology, and the market structure parameters) and is therefore imprecisely estimated. The results for the jointly estimated α and λ parameters are available upon request.

[12]The standard errors are corrected using White's (1980) method.

[13]Measurement errors associated with a long forecasting horizon can induce a downward bias in the estimates of λ.

[14]Our benchmark forecasting horizons of seven to eight quarters are slightly longer than that of the Survey of Professional Forecasters, which uses a six-quarter forecasting horizon (see Croushore 1993).

the average estimate of λ (averaged across the three measures of inflation) implies information updates of just under four quarters. For instance, when $\alpha = 0.1$ with the QD output gap, the average estimate of λ is $(0.257{+}0.287{+}0.267)/3 = 0.270$. The average duration between information updates is, therefore, $1/0.270 = 3.7$ quarters. Similarly, when the forecasting horizon is eight quarters, the average estimate of λ implies information updates of just over four quarters. For instance, when $\alpha = 0.10$ with the QD output gap, the average estimate of λ is $(0.234 + 0.264 + 0.241)/3 = 0.246$. The average time between information updates is, therefore, $1/0.246 = 4.06$ quarters. These estimates suggest that, for plausible forecasting horizons, firms in the United States appear to update their information, on average, every four quarters. In other words, approximately 25 per cent of firms base their decisions on current information in a given quarter.

Our average estimated values of λ for these cases lie on either side of MR's (2001a) assumed value of 0.25 for λ in their simulation experiments. They show that, for this value, the dynamic response of inflation in the sticky-information model, relative to a sticky-price model, can account for the observed stylized facts. Interestingly, using very different methodologies and data than ours, both Carroll (2001) and Mankiw and Reis (2001b) estimate a value of 0.25 for λ that is close to the estimates we present in this paper.[15]

4.1.2 Canada

Table 3 lists the closed-economy results for Canada. The estimated information stickiness is similar to that for the United States for all forecasting horizons. The null hypothesis of "no information stickiness" is rejected for Canada at the 99 per cent confidence level. The qualitative pattern of

[15] In an earlier version, we considered a Bayesian VAR to generate the forecast matrix F_Z. The estimates of λ using that approach were qualitatively similar. The advantage of Bayesian VARs, in the present context, is their slightly better out-of-sample forecasting performance relative to the traditional VARs, as documented in the VAR literature. To maintain a consistent methodology for both forecasting and estimation stages, we present the results based on the forecasts from traditional VARs.

the point estimates is similar to that for the United States. The point estimates of λ, however, are smaller when the GDP deflator is used to measure inflation than when the CPI is used to measure inflation. For a forecasting horizon of seven quarters, the average (across three measures of inflation) duration of information updates is approximately four quarters. For instance, when $\alpha = 0.1$ with the QD output gap, the average estimate of λ is $(0.286 + 0.261 + 0.207)/3 = 0.251$. This value implies an average time between information updates of 3.98 quarters. In the same case, when the forecasting horizon is eight quarters, the average estimate of λ is $(0.263+0.230+0.187)/3 = 0.226$. This value implies an average time between information updates of 4.42 quarters. Thus, for the benchmark forecasting horizons, we find information updates of between four and five quarters, which suggests that approximately 20 to 25 per cent of firms use current information in a given quarter.

4.1.3 United Kingdom

Table 4 lists the closed-economy results for the United Kingdom. The null hypothesis is rejected at the 99 per cent confidence level. The point estimates decline with the rise in the forecasting horizons, as for the United States and Canada. The estimates are similar across the two degrees of real rigidity. For a forecasting horizon of seven quarters, the average (across three measures of inflation) frequency of information updates is slightly over seven quarters. For instance, when $\alpha = 0.1$ with the QD output gap, the average estimate of λ is $(0.128 + 0.119 + 0.141)/3 = 0.13$. This value implies an average time between information updates of 7.7 quarters. In the same case, when the forecasting horizon is eight quarters, the average estimate of λ is $(0.109 + 0.101 + 0.120)/3 = 0.11$. This value implies an average time between information updates of approximately nine quarters. These estimates are higher than the corresponding estimates for the United States and Canada. In other words, for plausible forecasting horizons, approximately 10 to 13 per cent of the firms base their pricing decisions on the current information in a given quarter.

4.2 Estimates of the small open-economy SIPC for Canada and the United Kingdom

In this section, we report the estimates of the open-economy SIPC, equation (2.6), for Canada and the United Kingdom. Following Galí and Monacelli (2000), we assume that the elasticity of substitution between home and foreign goods is $\eta = 1.5$. The degree of openness for Canada, δ_{can}, is 0.3 and for the United Kingdom, δ_{uk}, it is 0.4. In the model, the degree of openness is the share of imported-goods consumption in total domestic consumption.[16] This value represents the average ratio of nominal imported consumption to nominal total consumption over the period 1980 to 2000 for Canada and the United Kingdom, respectively. We assume standard values (see Woodford 2002): $\sigma = 1$ (log-utility), $\omega = 1.25$, and $\epsilon = 10$. In our estimation, we use the GDP deflator to measure domestic inflation and the U.S. output gap as a proxy for the world output gap, y_t^*.[17]

Table 5 lists the results for Canada and the United Kingdom. For the benchmark forecasting horizon of seven quarters, the estimate of λ is approximately 0.20 for Canada and 0.14 for the United Kingdom. These values imply an average frequency of information updates of five quarters and seven quarters, respectively. Therefore, the estimates obtained in the open-economy case are very similar to those for the closed-economy specifications. The goodness-of-fit measure, $\bar{R}^2$, indicates that the best fit occurs when the forecasting horizon is five quarters. For this horizon, the frequency of information updates for Canada is a little under four quarters, and for the United Kingdom it

[16] An alternative definition of openness commonly used in the literature is the ratio of imports plus exports to GDP. This definition differs from the one we use.

[17] The ratio (imports into Canada from the United States + Canadian exports to the United States)/(total Canadian imports + total Canadian exports) is 0.775 over the period 1980 to 2000. This ratio motivates the use of the U.S. output gap as a proxy for the world output gap.

is approximately five quarters.[18]

5 Discussion

5.1 The slope of the SIPC

Typically, from a policy perspective, descriptions of Phillips curves focus on the slope coefficient (the coefficient on the current output gap) representing the short-run output-inflation relationship, with expectations terms playing the role of shift variables. What do the estimates described in section 4 imply about the slope of the SIPC? For the closed-economy SIPC, the slope is given by the term $\frac{\lambda\alpha}{1-\lambda}$. This term is the coefficient of the current output gap in equation (2.4). For the open-economy SIPC, the slope is given by the corresponding coefficient, $\frac{\lambda}{1-\lambda}\alpha_1$, where $\alpha_1 = \left(\frac{\omega}{1+\omega\epsilon} + \frac{\sigma}{(1+\omega\epsilon)\omega^*}\right)$. Tables 6 and 7 give the implied slopes of the SIPC for the closed- and open-economy specifications, respectively. We find that a 1 per cent (or 100 basis points) rise in the domestic demand pressures (as captured by the current output gap) leads to a direct rise in inflation of 3 to 5 basis points in the United States, 2 to 4 basis points in Canada, and between 2 to 3 basis points in the United Kingdom. For the open-economy case the conclusion is similar. We find that the same degree of demand pressure leads to an approximately 4 basis-points rise in inflation in Canada, and a 3 basis-points rise in inflation in the United Kingdom. Although, theoretically speaking, the slope of the closed-economy SIPC is steeper than the slope of the open-economy SIPC, because $\alpha_1 < \alpha$, the difference is empirically too small to distinguish between the two cases. For the calibrated parameters, $\alpha = 0.166$, α_1 is 0.152 for Canada, and 0.151 for the United Kingdom.

[18]The fit of the SIPC for the open economy is not as good as that for the closed economy. One reason for this result is that we are using forecasts of an additional variable (the U.S. output gap) in the estimation, thereby imparting an additional forecast error.

5.2 Calibrating structural models with sticky information

Using the methodology outlined in section 3 and the aggregate macroeconomic data, we empirically implement the SIPC and provide a range of estimates for its key structural parameter: the frequency of information updates. This exercise is similar in spirit to the work of Galí and Gertler (1999), who estimate a key structural parameter of the NKPC — the frequency of price adjustment — using aggregate macroeconomic data. The benchmark estimates for the United States and Canada are similar to the values that MR (2001a) assume to generate the stylized features of inflation dynamics. Whether the implications of the sticky information extend to a fully specified dynamic general-equilibrium model, in which monetary policy is described by a more realistic interest rate rule, is an open question.[19] The range of estimates we present can be useful in calibrating this class of models for monetary analysis.

5.3 Theoretical issues

In addition to the empirical implementation issues discussed in section 3, there are some theoretical issues with the assumption of sticky information. The prices chosen are optimal conditional upon the old information set. In any period, each firm faces an identical probability of acquiring complete information (i.e., all shocks to aggregate demand that have occurred, including the most recent one). In this sense, there is a discontinuous jump in the information set of firms. When this occurs, the firm learns completely and instantaneously about the demand conditions and determines the optimal price. The learning process is itself discontinuous, and the same for all kinds of shock (Woodford 2001). This parallels the assumption of exogenous frequency of price adjustments made in time-dependent sticky-price models. Future modifications of the MR (2001a) model that eliminate the stark discontinuity in the information set update and the learning process would

[19]The monetary policy in the MR (2001a) model is described by a simple money-growth-rate rule.

clearly add more realism to the model. It would then be possible to determine whether the frequency of information updates itself varies over the business cycle.[20] Woodford (2001) presents a "noisy information" model in which firms continuously receive information about the aggregate demand, but it is mixed with noise. In this noisy information model, firms charge prices based on their subjective estimates of the aggregate demand, and their estimates of others' estimate of aggregate demand, and so on. Uncertainty associated with these higher-order expectations makes the firms' subjective perceptions evolve slowly. Therefore, they may choose to not act on new information. Sims (2001) develops the notion of "rational inattention" under the assumption of constraints on information-processing capacities of firms. In the noisy information model, the rate of learning could potentially vary, depending upon the source of the shock. These are interesting issues to investigate in future work that develops quantitative models with informational inertia for monetary policy analysis.

6 Conclusion

The theoretical SIPC developed by MR (2001a) provides an alternative framework to explain the stylized facts on inflation dynamics. We have described a methodology for the empirical implementation of the SIPC using data from the United States, Canada, and the United Kingdom. We extended the model and derived a specification of the SIPC for a small open economy, and presented estimates for Canada and the United Kingdom. We estimated the key parameter — the degree of information stickiness — for closed- and open-economy specifications. Under plausible forecasting horizons of seven to eight quarters, the average estimated interval between pricing decisions based

[20] Caplin and Spulber (1987) theoretically showed that state-dependent pricing in the presence of menu costs implies perfect aggregate price flexibility (i.e., monetary neutrality at the aggregate level). Whether this result holds for the sticky-information model with state-dependent frequency of information updates is an open question.

on new information is four quarters in the United States, between four and five quarters for Canada, and over seven quarters for the United Kingdom. The open-economy estimates of SIPC for both Canada and the United Kingdom are similar to the closed-economy estimates. We interpret our results in terms of the slope of the Phillips curve. Our results can be used to calibrate dynamic general-equilibrium models for monetary policy analysis that use informational constraints as a source of inertia.

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Table 1a: Variables used in Forecasting

	Inflation	Output gap
United States	Short-term rate (level)	Short-term rate (level)
	Dividend yield (ln)	Dividend yield (ln)
	Term spread* (level)	Term spread*(level)
	Unemployment rate (level)	Stock market index (growth)
	Capacity utilization (level)	Capacity utilization (level)
	Output gap (ln)	Output gap (ln)
Canada	Short-term rate (level)	Short-term rate (level)
	Dividend yield (ln)	Dividend yield (ln)
	Term spread* (level)	Term spread* (level)
	Stock market index (growth)	Stock market index (growth)
	Capacity utilization (level)	Capacity utilization (level)
	Output gap (ln)	Output gap (ln)
United Kingdom	Short-term rate (level)	Short-term rate (level)
	Capacity utilization (level)	Capacity utilization (level)
	Output gap (ln)	Output gap (ln)
	Unemployment rate (level)	Unemployment rate (level)

*Term spread = Long-term minus short-term interest rates.

Table 1b: Relative RMSFE: Inflation Rate

	Forecast horizon	United States	Canada	United Kingdom
Lags* →		2	4	2
CPI	2Q	0.873	1.003	0.967
	4Q	0.866	0.925	0.954
	6Q	0.834	0.867	0.964
	8Q	0.863	0.891	0.971
Lags* →		2	4	2
Core	2Q	0.797	0.937	1.044
	4Q	0.773	0.879	1.017
	6Q	0.742	0.879	1.057
	8Q	0.782	0.888	1.066
Lags* →		4	4	2
GDP def.	2Q	0.922	1.036	0.973
	4Q	0.817	0.984	0.969
	6Q	0.761	0.927	0.978
	8Q	0.745	0.958	0.993

* Number of lags used in forecasting. Q = quarters.

Table 1c: Relative RMSFE: Output-Gap Growth

	Forecast horizon	United States	Canada	United Kingdom
Lags* →		2	4	2
QD	2Q	0.837	0.798	0.952
	4Q	0.821	0.802	0.958
	6Q	0.826	0.796	0.948
	8Q	0.834	0.787	0.966
Lags* →		2	4	2
H-P	2Q	0.862	0.853	0.962
	4Q	0.856	0.864	0.972
	6Q	0.866	0.841	0.961
	8Q	0.878	0.823	0.983

* Number of lags used in forecasting. Q = quarters.

Table 2: Estimates of the SIPC: United States

		$\alpha = 0.1$				$\alpha = 0.15$			
		H-P *output gap*		QD *output gap*		H-P *output gap*		QD *output gap*	
F.H.	Inflation	λ	$\bar{R}^2$	λ	$\bar{R}^2$	λ	$\bar{R}^2$	λ	$\bar{R}^2$
5Q	CPI	0.335***	0.660	0.325***	0.624	0.324***	0.651	0.302***	0.577
		(0.048)		(0.050)		(0.045)		(0.045)	
	Core	0.374***	0.737	0.351***	0.672	0.360***	0.729	0.323***	0.607
		(0.058)		(0.056)		(0.051)		(0.048)	
	GDP Def.	0.354***	0.793	0.330***	0.714	0.333***	0.767	0.299***	0.621
		(0.038)		(0.039)		(0.033)		(0.036)	
6Q	CPI	0.288***	0.659	0.287***	0.636	0.281***	0.653	0.270***	0.604
		(0.045)		(0.048)		(0.042)		(0.044)	
	Core	0.327***	0.739	0.315***	0.695	0.319***	0.736	0.293***	0.648
		(0.057)		(0.057)		(0.051)		(0.049)	
	GDP Def.	0.309***	0.799	0.296***	0.745	0.294***	0.781	0.271***	0.677
		(0.035)		(0.038)		(0.032)		(0.034)	
7Q	CPI	0.253***	0.651	0.257***	0.635	0.250***	0.646	0.245***	0.612
		(0.042)		(0.047)		(0.040)		(0.043)	
	Core	0.292***	0.735	0.287***	0.702	0.286***	0.733	0.268***	0.667
		(0.056)		(0.059)		(0.051)		(0.050)	
	GDP Def.	0.271***	0.801	0.267***	0.762	0.261***	0.788	0.247***	0.711
		(0.032)		(0.036)		(0.030)		(0.032)	
8Q	CPI	0.227***	0.636	0.234***	0.626	0.224***	0.632	0.225***	0.607
		(0.040)		(0.046)		(0.039)		(0.043)	
	Core	0.265***	0.727	0.264***	0.702	0.261***	0.726	0.249***	0.674
		(0.055)		(0.060)		(0.052)		(0.052)	
	GDP Def.	0.239***	0.800	0.241***	0.771	0.233***	0.790	0.226***	0.731
		(0.029)		(0.033)		(0.027)		(0.030)	
12Q	CPI	0.156***	0.577	0.169***	0.574	0.156***	0.573	0.167***	0.565
		(0.031)		(0.039)		(0.031)		(0.039)	
	Core	0.197***	0.689	0.221***	0.678	0.198***	0.688	0.199***	0.664
		(0.051)		(0.079)		(0.051)		(0.058)	
	GDP Def.	0.156***	0.783	0.163***	0.770	0.154***	0.777	0.160***	0.751
		(0.019)		(0.023)		(0.019)		(0.023)	

F.H. = Forecasting horizon. Q = quarters. $H_0 : \lambda = 1$ versus $H_1 : \lambda < 1$. *** indicates statistically *less* than 1 at the 1 per cent significance level. Standard error in brackets.

Table 3: Estimates of the SIPC: Canada

		$\alpha = 0.1$				$\alpha = 0.15$			
		H-P *output gap*		QD *output gap*		H-P *output gap*		QD *output gap*	
F.H.	Inflation	λ	$\bar{R}^2$	λ	$\bar{R}^2$	λ	$\bar{R}^2$	λ	$\bar{R}^2$
5Q	CPI	0.393***	0.685	0.352***	0.682	0.364***	0.674	0.317***	0.653
		(0.048)		(0.035)		(0.039)		(0.030)	
	Core	0.356***	0.822	0.319***	0.781	0.333***	0.798	0.288***	0.720
		(0.039)		(0.031)		(0.033)		(0.027)	
	GDP Def.	0.291***	0.546	0.283***	0.549	0.280***	0.532	0.263***	0.524
		(0.041)		(0.038)		(0.038)		(0.034)	
6Q	CPI	0.342***	0.683	0.317***	0.688	0.322***	0.676	0.287***	0.668
		(0.049)		(0.036)		(0.040)		(0.030)	
	Core	0.311***	0.824	0.284***	0.797	0.294***	0.806	0.259***	0.752
		(0.038)		(0.031)		(0.033)		(0.026)	
	GDP Def.	0.246***	0.549	0.244***	0.556	0.239***	0.538	0.231***	0.540
		(0.036)		(0.035)		(0.034)		(0.031)	
7Q	CPI	0.300***	0.678	0.286***	0.686	0.286***	0.672	0.261***	0.673
		(0.047)		(0.037)		(0.040)		(0.030)	
	Core	0.273***	0.821	0.255***	0.803	0.261***	0.808	0.234***	0.768
		(0.036)		(0.030)		(0.032)		(0.026)	
	GDP Def.	0.212***	0.545	0.213***	0.555	0.207***	0.536	0.204***	0.544
		(0.032)		(0.031)		(0.030)		(0.029)	
8Q	CPI	0.267***	0.669	0.263***	0.680	0.257***	0.664	0.240***	0.670
		(0.046)		(0.037)		(0.040)		(0.030)	
	Core	0.243***	0.816	0.230***	0.803	0.233***	0.805	0.213***	0.776
		(0.033)		(0.029)		(0.030)		(0.025)	
	GDP Def.	0.185***	0.535	0.187***	0.546	0.181***	0.527	0.181***	0.538
		(0.028)		(0.029)		(0.027)		(0.027)	
12Q	CPI	0.167***	0.627	0.167***	0.627	0.167***	0.622	0.178***	0.633
		(0.031)		(0.031)		(0.030)		(0.030)	
	Core	0.158***	0.777	0.156***	0.774	0.155***	0.770	0.150***	0.760
		(0.023)		(0.023)		(0.022)		(0.021)	
	GDP Def.	0.114***	0.490	0.116***	0.500	0.113***	0.484	0.115***	0.497
		(0.018)		(0.018)		(0.018)		(0.018)	

F.H. = Forecasting horizon. Q = quarters. $H_0 : \lambda = 1$ versus $H_1 : \lambda < 1$. *** indicates statistically *less* than 1 at the 1 per cent significance level. Standard error in brackets.

Table 4: **Estimates of the SIPC: United Kingdom (closed economy)**

		$\alpha = 0.1$				$\alpha = 0.15$			
		H-P *output gap*		QD *output gap*		H-P *output gap*		QD *output gap*	
F.H.	Inflation	λ	$\bar{R}^2$	λ	$\bar{R}^2$	λ	$\bar{R}^2$	λ	$\bar{R}^2$
5Q	RPI	0.185***	0.703	0.187***	0.704	0.186***	0.704	0.188***	0.706
		(0.027)		(0.027)		(0.027)		(0.028)	
	RPIX	0.172***	0.674	0.174***	0.675	0.172***	0.674	0.174***	0.675
		(0.026)		(0.026)		(0.024)		(0.020)	
	GDP def.	0.207***	0.838	0.208***	0.840	0.206***	0.839	0.207***	0.837
		(0.021)		(0.021)		(0.021)		(0.021)	
6Q	RPI	0.151***	0.700	0.152***	0.701	0.152***	0.700	0.153***	0.702
		(0.022)		(0.023)		(0.022)		(0.023)	
	RPIX	0.141***	0.672	0.142***	0.673	0.141***	0.672	0.142***	0.673
		(0.021)		(0.023)		(0.021)		(0.021)	
	GDP def.	0.168***	0.835	0.169***	0.835	0.168***	0.833	0.169***	0.834
		(0.018)		(0.018)		(0.018)		(0.018)	
7Q	RPI	0.127***	0.697	0.128***	0.698	0.127***	0.697	0.128***	0.699
		(0.019)		(0.019)		(0.019)		(0.019)	
	RPIX	0.118***	0.670	0.119***	0.671	0.118***	0.670	0.119***	0.671
		(0.018)		(0.019)		(0.018)		(0.018)	
	GDP def.	0.140***	0.832	0.141***	0.834	0.140***	0.830	0.141***	0.832
		(0.015)		(0.015)		(0.016)		(0.016)	
8Q	RPI	0.109***	0.696	0.109***	0.697	0.109***	0.696	0.110***	0.698
		(0.016)		(0.016)		(0.016)		(0.016)	
	RPIX	0.101***	0.671	0.101***	0.672	0.101***	0.671	0.102***	0.672
		(0.015)		(0.015)		(0.015)		(0.015)	
	GDP def.	0.119***	0.828	0.120***	0.828	0.120***	0.826	0.119***	0.828
		(0.013)		(0.013)		(0.013)		(0.013)	
12Q	RPI	0.067***	0.688	0.067***	0.688	0.067***	0.687	0.068***	0.689
		(0.010)		(0.010)		(0.010)		(0.010)	
	RPIX	0.062***	0.664	0.063***	0.665	0.062***	0.664	0.063***	0.664
		(0.009)		(0.010)		(0.009)		(0.009)	
	GDP def.	0.070***	0.816	0.071***	0.817	0.069***	0.815	0.070***	0.816
		(0.008)		(0.008)		(0.008)		(0.008)	

F.H. = Forecasting horizon. Q = quarters. $H_0 : \lambda = 1$ versus $H_1 : \lambda < 1$. *** indicates statistically *less* than 1 at the 1 per cent significance level. Standard error in brackets.

Table 5: Estimates of the Open-Economy SIPC

		Canada ($\alpha_1 = 0.152,\ \alpha_2 = 0.015$)				**United Kingdom** ($\alpha_1 = 0.151,\ \alpha_2 = 0.018$)			
		H-P *output gap*		QD *output gap*		H-P *output gap*		QD *output gap*	
F.H.	Inflation	λ	$\bar{R}^2$	λ	$\bar{R}^2$	λ	$\bar{R}^2$	λ	$\bar{R}^2$
5Q	GDP def.	0.276***	0.509	0.258***	0.500	0.206***	0.560	0.207***	0.555
		(0.038)		(0.034)		(0.021)		(0.022)	
6Q	GDP def.	0.237***	0.507	0.228***	0.509	0.167***	0.551	0.168***	0.548
		(0.035)		(0.032)		(0.021)		(0.022)	
7Q	GDP def.	0.206***	0.498	0.202***	0.505	0.139***	0.543	0.140***	0.540
		(0.032)		(0.032)		(0.015)		(0.015)	
8Q	GDP def.	0.181***	0.481	0.180***	0.493	0.118***	0.533	0.119***	0.530
		(0.029)		(0.028)		(0.013)		(0.013)	
12Q	GDP def.	0.116***	0.403	0.118***	0.416	0.070***	0.503	0.071***	0.502
		(0.020)		(0.020)		(0.008)		(0.008)	

F.H. = Forecasting horizon. Q = quarters. $H_0 : \lambda = 1$ versus $H_1 : \lambda < 1$. *** indicates statistically *less* than 1 at the 1 per cent significance level. Standard error in brackets. Degree of openness $\delta_{can} = 0.3$ and $\delta_{uk} = 0.4$.

Table 6: Slope of the Closed-Economy SIPC

		Slope	
Country	λ	$\alpha = 0.1$	$\alpha = 0.15$
United States	0.25	0.03	0.05
Canada	0.20	0.03	0.05
United Kingdom	0.13	0.02	0.03

Table 7: Slope of the Open-Economy SIPC

		Slope
Canada	λ	$\alpha_1 = 0.152$
	0.20	0.04
United Kingdom		$\alpha_1 = 0.151$
	0.14	0.03

Appendix A: Derivation of the SIPC

A.1 The SIPC for a closed economy

We present an explicit derivation of the MR (2001a) model. Assume that a representative consumer has preferences

$$U(C_t, H_t(i)) = \frac{C_t^{1-\sigma}}{1-\sigma} - \int_0^1 \frac{H_t(i)^{1+\phi}}{1+\phi}, \tag{A.1}$$

where C_t is an aggregate consumption good, and $H_t(i)$ is the specialized ith type of labour input supplied by the representative household (that is, a factor-specific market instead of a common labour market). As Woodford (2002) explains, the assumption of a factor-specific market is important to generate strategic complementarity in the pricing decisions of firms. This assumption is implicit in the MR (2001a) framework. The parameter σ^{-1} is the intertemporal elasticity of substitution, and ϕ^{-1} is the elasticity of labour supply. Utility maximization subject to the standard budget constraint yields the atemporal consumption-leisure trade-off

$$\frac{H_t(i)^{\phi}}{C_t^{-\sigma}} = \frac{W_t(i)}{P_t}, \tag{A.2}$$

where P_t is the price of a unit of the aggregate consumption good C_t, and $W_t(i)$ is the wage for labour type i.

Firms are assumed to operate in a monopolistically competitive output market, as in Blanchard and Kiyotaki (1987). Each firm faces a demand

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} Y_t \tag{A.3}$$

for its product, where Y_t is the aggregate output level and ϵ is the constant elasticity of demand. The firm produces output using a technology $Y_t(i) = H_t(i)^a$, $0 < a \leq 1$. For a given level of demand, the labour requirement for a firm is

$$H_t(i) = Y_t(i)^{\frac{1}{a}}. \tag{A.4}$$

The total costs for the firm (there are no fixed costs) are $W_t(i)Y_t(i)^{\frac{1}{a}}$. Therefore, the nominal marginal cost, $MC_t^n(i)$,

$$MC_t^n(i) = W_t(i)\frac{1}{a}Y_t(i)^{\frac{1}{a}-1}, \tag{A.5}$$

and the real marginal cost, $MC_t^r(i) \equiv \frac{MC_t^n(i)}{P_t}$, is

$$MC_t^r(i) = \frac{W_t(i)}{P_t}Y_t(i)^{\frac{1}{a}-1}. \tag{A.6}$$

Substituting $\frac{W_t(i)}{P_t}$ from (A.2), and imposing the closed-economy aggregate constraint, $Y_t = C_t$ in (A.6), we get

$$MC_t^r(i) = Y_t(i)^{\omega} Y_t^{\sigma} a^{-1}, \tag{A.7}$$

where $\omega \equiv \frac{\phi}{a} + \frac{1}{a} - 1$.

Profit maximization implies a markup-pricing rule such that the optimal relative price of a firm, $P_t^o(i)$, is a markup over its real marginal cost. That is,

$$\frac{P_t^o(i))}{P_t} = \mu MC_t^r(i), \tag{A.8}$$

where μ is the constant markup.

Log-linearization of (A.7), (A.8), and (A.3) around the no-shock and zero-inflation steady-state, where $Y_t(i) = \bar{Y}$, $MC_t(i)^r = \overline{MC}$, $P_t(i) = P_t = 1$, yields

$$mc_t(i) = \omega y_t(i) + \sigma y_t, \tag{A.9}$$

where $mc_t(i) = \log MC_t^r(i)$ - $\log\overline{MC}$, $y_t = \log Y_t$ - $\log\bar{Y}$, $p_t(i) = \log P_t(i)$, $p_t = \log P_t$.

$$p_t^o(i) = p_t + mc_t(i). \tag{A.10}$$

$$y_t(i) = -\epsilon(p_t^o(i) - p_t) + y_t. \tag{A.11}$$

Substituting (A.9) and (A.11) in (A.10), we get

$$p_t^o = p_t + \alpha y_t, \tag{A.12}$$

where $\alpha = \frac{\sigma+\omega}{1+\omega\epsilon}$.

From (A.12), if the output gap is positive, a firm's optimal (or desired) price, p_t^o, will be higher than the aggregate price, p_t. The sticky-information assumption in MR (2001a) implies that a firm that uses j-period old information sets the price

$$x_t^j = E_{t-j} p_t^o. \tag{A.13}$$

The aggregate price level in period t is the average of the prices of all existing firms:

$$p_t = \lambda \sum_{j=0}^{\infty} (1-\lambda)^j x_t^j, \tag{A.14}$$

where λ is the fraction of firms that use the updated information to compute the optimal price, and $1-\lambda$ is the fraction of firms that use past information, in any period, to compute the optimal price.

Combining (A.12), (A.13), and (A.14) to get the equation for the aggregate price level,

$$p_t = \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j}[p_t + \alpha y_t]. \tag{A.15}$$

Taking out the first term in (A.15) and redefining the summation index,

$$p_t = \lambda(p_t + \alpha y_t) + \lambda \sum_{j=0}^{\infty} (1-\lambda)^{j+1} E_{t-1-j}[p_t + \alpha y_t]. \tag{A.16}$$

The period $t-1$ price level is

$$p_{t-1} = \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-1-j}[p_{t-1} + \alpha y_{t-1}]. \tag{A.17}$$

Subtracting (A.17) from (A.16), we get

$$\pi_t = \lambda(p_t + \alpha y_t) + \lambda \sum_{j=0}^{\infty} (1-\lambda)^{j+1} E_{t-1-j}[p_t + \alpha y_t] - \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-1-j}[p_{t-1} + \alpha y_{t-1}]. \quad \text{(A.18)}$$

Rearranging (A.18) by subtracting (s), and adding (a) terms

$$\begin{aligned}\pi_t = \lambda(p_t + \alpha y_t) + \lambda((1-\lambda)E_{t-1}[p_t + \alpha y_t] - \underbrace{(1-\lambda)E_{t-1}[p_{t-1} + \alpha y_{t-1}]}_{s} + \underbrace{(1-\lambda)E_{t-1}[p_{t-1} + \alpha y_{t-1}]}_{a} \\ +(1-\lambda)^2 E_{t-2}[p_t + \alpha y_t] - \underbrace{(1-\lambda)^2 E_{t-2}[p_{t-1} + \alpha y_{t-1}]}_{s} + \underbrace{(1-\lambda)^2 E_{t-2}[p_{t-1} + \alpha y_{t-1}]}_{a} \\ (1-\lambda)^3 E_{t-3}[p_t + \alpha y_t] - \underbrace{(1-\lambda)^3 E_{t-3}[p_{t-1} + \alpha y_{t-1}]}_{s} + \underbrace{(1-\lambda)^3 E_{t-3}[p_{t-1} + \alpha y_{t-1}]}_{a} + ...) \\ -\lambda(E_{t-1}[p_{t-1} + \alpha y_{t-1}] + (1-\lambda)E_{t-2}[p_{t-1} + \alpha y_{t-1}] + ...).\end{aligned} \quad \text{(A.19)}$$

Collecting terms in (A.19), we get

$$\pi_t = \lambda(p_t + \alpha y_t) + \lambda \sum_{j=0}^{\infty} (1-\lambda)^{j+1} E_{t-1-j}[\pi_t + \alpha \Delta y_t] - \lambda^2 \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-1-j}[p_{t-1} + \alpha y_{t-1}], \quad \Delta y_t = y_t - y_{t-1}. \quad \text{(A.20)}$$

Using (A.17) in (A.20), we get

$$\pi_t = \lambda(p_t + \alpha y_t) + \lambda \sum_{j=0}^{\infty} (1-\lambda)^{j+1} E_{t-1-j}[\pi_t + \alpha \Delta y_t] - \lambda p_{t-1}, \quad \text{(A.21)}$$

where $p_{t-1} = \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-1-j}[p_{t-1} + \alpha y_{t-1}]$.

Further simplification yields

$$\pi_t = \lambda \pi_t + \lambda \alpha y_t + \lambda \sum_{j=0}^{\infty} (1-\lambda)^{j+1} E_{t-1-j}[\pi_t + \alpha \Delta y_t], \quad \text{(A.22)}$$

which gives the SIPC

$$\pi_t = \frac{\lambda \alpha}{1-\lambda} y_t + \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-1-j}[\pi_t + \alpha \Delta y_t]. \quad \text{(A.23)}$$

A.2 The SIPC for a small open economy

This section draws on Galí and Monacelli (2000). We relax their assumption of common-factor markets and assume, as above, specific-factor markets. The implication of this assumption is consistent with the calibration of the real rigidity parameter, α, in MR (2001a). Here, we describe only the part of the model that pertains to the derivation of marginal cost. Clearly, $Y_t \neq C_t$ in the open-economy case. Instead, C_t now represents a composite consumption index, $C_t = [(1-\delta)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \delta^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}}]^{\frac{\eta}{\eta-1}}$, and the corresponding consumption-based CPI is $P_t = [(1-\delta)P_{H,t}^{1-\eta} + \delta P_{F,t}^{1-\eta}]^{\frac{1}{1-\eta}}$. The purchasing-power-parity (PPP) holds: $P_{F,t} = E_t P^*_{F,t}$.[21] $C_{H,t}$ and $C_{F,t}$ are

[21] * indicates foreign variables.

consumption indexes for domestic and foreign consumption, respectively. $P_{H,t}$ and $P_{F,t}$ are price indexes, in domestic currency units, for domestic output (the consumption-based GDP deflator) and the foreign output. η is the elasticity of substitution between domestic and foreign goods, δ is the index of openness (the share of imported goods in domestic consumption), and E_t is the nominal exchange rate (domestic currency price of foreign currency). Domestic inflation is $\pi_{H,t} \equiv \log(P_{H,t+1}) - \log(P_{H,t})$, CPI inflation is $\pi_t \equiv \log(P_{t+1}) - \log(P_t)$, and the terms of trade are $S_t = \frac{P_{F,t}}{P_{H,t}}$. The log-linearized relationship between CPI inflation and domestic inflation is $\pi_t = \pi_{H,t} + \delta \Delta s_t$. The real exchange rate is $Q_t = \frac{E_t P_t^*}{P_t}$ (assuming $P_t^* = P_{F,t}^*$). The log-linearized relationship between the real exchange rate and the terms of trade is $q_t = (1-\delta)s_t$. Therefore, $\pi_t = \pi_{H,t} + \frac{\delta}{1-\delta}\Delta q_t$. Some of the important details of the Galí and Monacelli (2000) model that are relevant here are: (i) PPP holds, (ii) there is perfect international risk-sharing, ($c_t = c_t^* + \frac{1}{\sigma}q_t$), (iii) world consumption is equal to world output with negligible imports from the domestic economy (i.e., $y_t^* = c_t^*$), (iv) the equilibrium relationship between the domestic output gap and the world output gap is $y_t = y_t^* + \frac{\omega}{\sigma(1-\delta)}q_t$, and (v) domestic production is $y_t(i) = ah_t(i)$:

$$Y_t(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\epsilon} Y_t, \tag{A.24}$$

and the log-linearization gives

$$y_t(i) = -\epsilon(p_{H,t}(i) - p_{H,t}) + y_t \tag{A.25}$$

$$MC_t^r(i) = \frac{W_t(i)}{p_{H,t}^r P_t} Y_t(i)^{\frac{1}{a}-1}, \tag{A.26}$$

where $p_{H,t}^r \equiv \frac{P_{H,t}}{P_t}$:

$$MC_t^r(i) = \frac{C_t^\sigma H_t(i)^\phi}{p_{H,t}^r} Y_t(i)^{\frac{1}{a}-1}. \tag{A.27}$$

After substituting for $H_t(i)$, we get

$$MC_t^r(i) = \frac{C_t^\sigma Y_t(i)^\omega}{p_{H,t}^r}. \tag{A.28}$$

Linearization yields

$$mc_t(i) = \sigma c_t + \omega y_t(i) - p_{H,t}^r. \tag{A.29}$$

From Galí and Monacelli (2000), we have (i) $c_t = c_t^* + \frac{1-\delta}{\sigma}s_t$, (ii) $c_t^* = y_t^*$, where y_t^* is the world output gap, (iii) $y_t = y_t^* + \frac{\omega^*}{\sigma}s_t$, and (iv) $p_{H,t}^r = -\delta s_t$, where $\omega^* = 1 + \delta(\eta\sigma - 1)(2-\delta)$. After substitutions, we get

$$mc_t(i) = \sigma c_t + [-\epsilon p_{H,t}(i) + \epsilon pH, t + y_t] + \delta s_t. \tag{A.30}$$

The pricing rule is

$$\frac{P_{H,t}(i)}{P_{H,t}} = \mu MC_t^r(i). \tag{A.31}$$

Linearization gives

$$p_{H,t}(i) = p_{H,t} + mc_t(i). \tag{A.32}$$

Substituting for $mc_t(i)$ from (A.29), we get

$$p_{H,t}(i) = p_{H,t} + \sigma c_t - \omega\epsilon p_{H,t}(i) + \omega\epsilon p_{H,t} + \omega y_t + \delta s_t. \tag{A.33}$$

Using the relationships $c_t = c_t^* + \frac{1-\delta}{\sigma} s_t$ and $c_t^* = y_t^*$, we get

$$p_{H,t}(i) = p_{H,t} + \omega y_t + \sigma y_t^* + s_t. \tag{A.34}$$

Using the relationship $y_t = y_t^* + \frac{\omega^*}{\sigma} s_t$, we can substitute for s_t, where $s_t = \frac{\sigma}{\omega^*}(y_t - y_t^*)$, and imposing symmetry, we get the optimal equilibrium price:

$$p_{H,t}^o = p_{H,t} + \left(\frac{\omega}{1+\omega\epsilon} + \frac{\sigma}{(1+\omega\epsilon)\omega^*}\right) y_t + \left(\frac{\sigma}{1+\omega\epsilon} - \frac{\sigma}{(1+\omega\epsilon)\omega^*}\right) y_t^*. \tag{A.35}$$

Note that, since $\omega^* = 1 + \delta(\eta\sigma - 1)(2-\delta)$, if $\delta = 0$ and $\omega^* = 1$, foreign output is not consumed domestically. Therefore, y_t^* does not influence domestic inflation and we get the closed-economy specification (A.12). Following steps (A.13) to (A.23), we derive the small open-economy SIPC in terms of domestic inflation $\pi_{H,t}$:

$$\pi_{H,t} = \frac{\lambda}{1-\lambda}\left(\frac{\omega}{1+\omega\epsilon} + \frac{\sigma}{(1+\omega\epsilon)\omega^*}\right) y_t + \frac{\lambda}{1-\lambda}\left(\frac{\sigma}{1+\omega\epsilon} - \frac{\sigma}{(1+\omega\epsilon)\omega^*}\right) y_t^* +$$
$$\lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-1-j}\left[\pi_{H,t} + \left(\frac{\omega}{1+\omega\epsilon} + \frac{\sigma}{(1+\omega\epsilon)\omega^*}\right)\Delta y_t + \left(\frac{\sigma}{1+\omega\epsilon} - \frac{\sigma}{(1+\omega\epsilon)\omega^*}\right)\Delta y_t^*\right], \tag{A.36}$$

where y_t^* is the growth rate of the world output gap.

Appendix B: Description of the Variables and the Data Sources

All data are of a quarterly frequency and are seasonally adjusted. Monthly series were converted to quarterly series.

B.1 Definitions

1. Price inflation (π_t) is $100(\ln P_t - \ln P_{t-1})$, where the price index, P_t, refers to the total CPI, core CPI, and total GDP deflator.
2. Output gap (y_t) is the deviation of the natural logarithm of total real GDP, $\ln Y_t$, from its quadratic or H-P filter trend.
3. Short-term interest rate is the federal funds rate (U.S.), 3-month treasury bill rate (Canada), and 3-month bank rate (U.K.).
4. Long-term interest rate is the 10-year government bond rate (U.S.), and 5- to 10-year government bond rate (Canada).
5. Term spread is the difference between the long- and short-term interest rates.
6. Dividend yield is the S&P 500 stock dividend yield (U.S.) and Toronto Stock Exchange (TSX) stock dividend yield (Canada).
7. Stock price index is the S&P 500 stock price index (U.S.) and TSX stock price index (Canada).

B.2 United States: 1969Q2 to 2000Q4

The data for the United States are from the Bank of Canada's databases.
Total CPI = $CUSA0$, total CPI excluding food and energy = $CUSA0L1E$, nominal GDP = GDP, real GDP = $GDP96c$, GDP deflator = $GDP/GDP96c$, capacity utilization rate = $UCAPFRBM$, short-term interest rate = $CP90D$, long-term interest rate = $BOND10$, stock dividend yield = $B4226$, stock price index = $B4291$, unemployment rate = $M.RUC$.

B.3 Canada: 1968Q4 to 2000Q4

The data for Canada are from the Bank of Canada's databases.
Total CPI = $B820600$, core = total CPI - food & energy - indirect taxes = $B820655$, total GDP deflator (expenditures approach) = $D15612$, total real GDP = $I56001$, labour productivity = $I602502$, capacity utilization = $D883644$, short-term interest rate = $B14006$, long-term interest rate = $B14011$, stock dividend yield = $B4254$, stock price index = $B4237$, unemployment rate = $D980745$.

B.4 United Kingdom: 1972Q1 to 2000Q4

The data for the United Kingdom are from the Bank of England's database.[22] Total CPI ≡ retail price index (RPI), real GDP (Y), nominal GDP (Y_n), GDP deflator ($P = \frac{Y_n}{Y}$), capacity utilization (CU), short-term interest rate (R), unemployment rate (U), stock dividend yield (D).

[22]We thank Colin Ellis and Alison Schomberg for assistance with the U.K. data.

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