Putting the “New Open Economy Macroeconomics” to a Test

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Abstract:

This paper offers an initial formal test of the New Open Economy Macroeconomics. It adapts maximum likelihood procedures to estimate and test an intertemporal small open economy model with monetary shocks and sticky prices and wages. Results are surprisingly supportive, in that a likelihood ratio test is unable to reject the theoretical restrictions implied by the model for two of three countries considered. Nominal rigidities appear to be an essential element in this success, since a version that assumes no such rigidities is rejected strongly for all three countries. However, the presence of rigidities is more important for explaining some variables in the data set than others. The methodology is also used to compare some competing versions of the New Open Economy Macroeconomics. First, the assumption of producer currency pricing is rejected, while local currency pricing is not. Second, while flexible prices are important for non-rejection, flexible wages are less so. Finally, a prominent role is found for money supply shocks in driving real as well as nominal exchange rates.

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1. Introduction

Recent years have witnessed a shift in international macroeconomic theory, with the development of a modeling approach that widely has become known as the ”New Open Economy Macroeconomics.” The unifying feature of this literature is the introduction of nominal rigidities into a dynamic general equilibrium model based on optimizing agents.[1] Typically, monopolistic competition is incorporated to permit the explicit analysis of price-setting decisions. This literature focuses on shocks to money supply, and demonstrates how such shocks can explain fluctuations in the current account and exchange rate in the presence of price stickiness. Following the fundamental work of Obstfeld and Rogoff (1995), there has been a proliferation of models extending the theory in varied directions.[2]

There are a number of debates within this literature. One such debate regards the choice of currency in which prices are sticky. Betts and Devereux (1996 and 2000) argue that assuming prices are sticky in the currency of the buyer (local currency pricing) improves the model's ability to match certain moments in exchange rate and consumption data. On the other hand, Obstfeld and Rogoff (2000) argue that prices sticky in the currency of the seller (producer currency pricing) are important for matching behavior of terms of trade data. A second theoretical argument regards whether stickiness is better assumed for prices or for wages. While the literature generally has focused on sticky goods prices, Obstfeld and Rogoff (2000) demonstrate the usefulness of wage stickiness.[3]

Resolution of these theoretical debates is hampered by the fact that while the theoretical literature on New Open Economy Macroeconomics has grown rapidly, the empirical literature has lagged far behind. To date there is no work that formally tests New Open Economy models, or compares one version to another. Earlier generations of intertemporal international models were tested using present value tests (See Sheffrin and Woo 1990, Ghosh 1995, and Bergin and Sheffrin 2000, for example). But this empirical approach cannot accommodate the more complex models of the new generation. Without empirical testing, it is difficult to know which

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[1] See Lane (2000) for a detailed survey of this literature.

[2] To name just a few, Kollmann (1997) considers a semi-small open economy version, Hau (2000) considers a version with nontraded goods, and Obstfeld and Rogoff (1998) and Devereux and Engel (1998) consider a reformulated version that permits a discussion of risk.

[3] Work by Erceg (1997) shows this assumption is important for matching persistence in output data.

of the many versions considered in the literature is preferable. And more generally, it is impossible to say whether the overall approach of the New Open Economy Macroeconomics is sufficiently accurate as a characterization of reality, that it eventually could be used reliably for policy analysis.[4]

The present paper explores an empirical methodology that can address these issues. A structural general equilibrium model of a semi-small open economy is estimated by maximum likelihood and its theoretical restrictions are evaluated by a likelihood ratio test.[5] The model considers a range of structural shocks in additional to money supply, including shocks to technology, interest rate, foreign demand, and consumer tastes. The theoretical model directly implies a set of restrictions, and these are used as a group for identification. By comparing to an analogous reduced form counterpart, a likelihood ratio test can indicate if the data are consistent with the restrictions implied by the theory.

Results are generally supportive of the New Open Economy approach. A likelihood ratio test is unable to reject the theoretical restrictions implied by the benchmark model for two of three countries considered. Nominal rigidities appear to be an essential element in this success, since a version that assumes no such rigidities is rejected strongly for all three countries. However, the presence of rigidities is more important for explaining some variables in the data set than others.

The methodology is also used to compare some competing versions of the New Open Economy Macroeconomics. First, the assumption of producer currency pricing is generally rejected, while local currency pricing is not. Second, while flexible prices are important for non-rejection, flexible wages are less so. Further, the estimated model offers a new perspective on basic questions raised in past empirical studies. In particular, the estimated model implies a prominent role for money supply shocks in driving the real exchange rate and current account.

The next section will present the structural model, and section 3 will present the estima-

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[4] Ghironi (2000) takes steps in this direction by estimating a New Open Economy model by nonlinear least squares at the single-equation level and by FIML system-wide regressions. The present paper differs in that it goes on to test a model and several competing versions, using likelihood ratio tests. It also differs in the particular estimation methodology used.

[5] The estimation methodology used here was developed in Leeper and Sims (1994) and used in Kim (2000) to estimate structural models of monetary policy. The present methodology differs in that it is applied also to an analogous reduced form model to permit likelihood ratio tests.

tion methodology. Section four will present results. Section five will draw some conclusions and make suggestions for future research.

2. The Model

The benchmark model to be tested will be a small open economy model.[6] This is a simpler starting point than the larger, two-country models more widely used in the theoretical literature.

2.1 Demand Specifications

Final goods in this economy (Y) are produced by aggregating over a continuum of intermediate home goods indexed by $i \in [0,1]$ along with aggregating over a continuum of imported foreign goods indexed by $j \in [0,1]$. The aggregation technology for producing final goods is:

$$\begin{aligned} Y_t &= \left(Y_{Ht}^d\right)^{\theta}\left(Y_{Ft}^d\right)^{1-\theta}, \text{ where} && (1) \\ Y_{Ht}^d &= \left(\int_0^1 y_{Ht}(i)^{\frac{1}{1+\upsilon}}\,di\right)^{1+\upsilon} && (2) \\ Y_{Ft}^d &= \left(\int_0^1 y_{Ft}(j)^{\frac{1}{1+\upsilon}}\,dj\right)^{1+\upsilon}. && (3) \end{aligned}$$

Here Y_{Ht}^d represents an aggregate of the home goods sold in the small open economy, and Y_{Ft}^d is an aggregate of the imported foreign goods, where lower case counterparts represent outputs of the individual firms.

Final goods producers behave competitively, maximizing profit each period:

$$\pi_{1t} = \max\ P_tY_t - P_{Ht}Y_{Ht}^d - P_{Ft}Y_{Ft}^d, \tag{4}$$

where P_t is the overall price index of the final good, P_{Ht} is the price index of home goods, and P_{Ft} is the price index of foreign goods, all denominated in the home currency. These may be defined:

$$P_t = (1-\theta)^{\theta-1}\,\theta^{-\theta}P_{Ht}^{\theta}P_{Ft}^{1-\theta}, \text{ where} \tag{5}$$

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[6] It’s basic features are based on the model of Kollmann (1997).

$$P_{Ht} = \left(\int_0^1 p_{Ht}(i)^{-\frac{1}{\upsilon}} di\right)^{-\upsilon} \tag{6}$$

$$P_{Ft} = \left(\int_0^1 p_{ft}(j)^{-\frac{1}{\upsilon}} dj\right)^{-\upsilon}, \tag{7}$$

and where lower case counterparts again represent the prices set by individual firms.

Given the aggregation functions above, demand will be allocated between home and foreign goods according to

$$Y_{Ft}^d = (1-\theta) Y_t (P_t/P_{Ft}) \tag{8}$$

$$Y_{Ht}^d = \theta Y_t (P_t/P_{Ht}) \tag{9}$$

with demands for individual goods:

$$y_{Ht}^d(i) = Y_{Ht}^d (p_{Ht}(i)/P_{Ht})^{-(1+\upsilon)/\upsilon} \tag{10}$$

$$y_{Ft}^d(j) = Y_{Ft}^d (p_{Ft}(j)/P_{Ft})^{-(1+\upsilon)/\upsilon} \tag{11}$$

Foreign demand and prices will be specified in a way analogous to home demand. Let X_t be a quantity index of exports:

$$X_t = \left(\int_0^1 x_t(i)^{\frac{1}{1+\upsilon}} di\right)^{1+\upsilon}, \tag{12}$$

and let P_{Xt} be an index of export prices denominated in foreign currency:

$$P_{Xt} = \left(\int_0^1 p_{Xt}(i)^{-\frac{1}{\upsilon}} di\right)^{-\upsilon}. \tag{13}$$

It will be assumed that foreign demand for the exports of our small economy is negatively related to the ratio of export prices to the price level in the rest of the world (P^*):

$$X_t = \chi (P_{Xt}/P_t^*)^{-(1+\upsilon^*)/\upsilon^*} \tag{14}$$

where χ represents a stochastic shock to overall foreign demand. It is assumed that the export demand function for good i resembles the domestic demand function for that good (10):

$$x_t^d(i) = X_t (p_{Xt}(i)/P_{Xt})^{-(1+\upsilon)/\upsilon}. \tag{15}$$

2.2 Firm Behavior

There are two types of monopolistically competitive intermediates goods suppliers in the small open economy. The first type produces intermediate goods to sell domestically and to export. The second type of firm imports foreign goods to resell in the domestic markets. Both types of firms are owned by domestic households and maximize discounted profits.

The domestic producing firms rent capital (K) at the real rental rate r, and hire labor (L) at the nominal wage rate W. These firms choose the price for sale of their good in the home market ($p_{Ht}\left(i\right)$) and in the foreign market ($p_{Xt}\left(i\right)$) to maximize profits ($\pi_{Ht}(i)$), knowing their choice of price will determine the level of demands for their good ($y_{Ht}^{d}\left(i\right)$ and $x_{t}^{d}\left(i\right)$). Markets are assumed to be segmented, and the foreign sale price is in terms of the foreign (world) currency. The nominal exchange rate (e_t) is the home currency price of one unit of the world currency. It is assumed that it is costly to reset prices because of quadratic menu costs.[7] The problem for these firms may be summarized:

$$\begin{aligned}
& \max \quad E_0 \sum_{t=0}^{\infty} \rho_{t,t+n} \pi_{Ht}\left(i\right) && (16)\\
\text{where} \quad \pi_{Ht}(i) &= p_{Ht}\left(i\right) y_{Ht}^{d}\left(i\right) + e_t p_{Xt}\left(i\right) x_t^{d}\left(i\right) - P_t r_{t-1} K_{t-1}\left(i\right) && (17)\\
& \quad -W_t L_t\left(i\right) - AC_{Ht}\left(i\right) - e_t AC_{Xt}\left(i\right) && (18)\\
\text{s.t.} \quad AC_{Ht}\left(i\right) &= \frac{\psi_H}{2} \frac{\left(p_{Ht}\left(i\right) - p_{Ht-1}\left(i\right)\right)^2}{p_{Ht-1}\left(i\right)} y_{Ht}^{d}\left(i\right) && (19)\\
AC_{Xt}\left(i\right) &= \frac{\psi_X}{2} \frac{\left(p_{Xt}\left(i\right) - p_{Xt-1}\left(i\right)\right)^2}{p_{Xt-1}\left(i\right)} y_{Xt}^{d}\left(i\right) && (20)\\
y_{Ht}^{d}\left(i\right) + y_{Xt}^{d}\left(i\right) &= A_t K_{t-1}\left(i\right)^{\alpha} L_t\left(i\right)^{1-\alpha} && (21)
\end{aligned}$$

and subject to the demand functions for $y_{Ht}^{d}\left(i\right)$ and $y_{Xt}^{d}\left(i\right)$ above. Here A represents technology common to all production firms in the country, and it is subject to shocks. Lastly, $\rho_{t,t+n}$ is the pricing kernel used to value random date $t+n$ payoffs. Since firms are assumed to be owned by the representative household, it is assumed that firms value future payoffs according to the household's intertemporal marginal rate of substitution in consumption, so $\rho_{t,t+n}{=}\beta^n U'_{C,t+n}/U'_{C,t}$, where $U'_{C,t+n}$ is the household's marginal utility of consumption in pe-

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[7] It has been demonstrated in Rotemberg (1982) that menu costs of this type, although simple to specify and work with, generate price dynamics identical to those of Calvo random price staggering.

riod $t+i$.

This problem implies an optimal trade-off between capital and labor inputs that depend on the relative cost of each:

$$P_t r_{t-1} K_{t-1}(i) = \frac{\alpha}{1-\alpha} W_t L_t(i) \tag{22}$$

The optimal price setting rules are:

$$\begin{array}{l} E_t\left[\frac{\rho_{t,t+i+1}}{\rho_{t,t+i}}\frac{\psi_H}{2}\left(\frac{p_{Ht+1}(i)}{p_{Ht}(i)}-1\right)^2\frac{y^d_{Ht+1}}{y^d_{Ht}}\right]-\psi_H\left(\frac{p_{Ht}(i)}{p_{Ht-1}(i)}-1\right)+ \\ +\frac{1+\nu}{\nu}\left(\frac{P_t r_{t-1}}{p_{Ht}(i)\alpha A_t(L_t(i)/K_{t-1}(i))^{(1-\alpha)}}-1\right)+1=0 \end{array} \tag{23}$$

$$\begin{array}{l} E_t\left[\frac{\rho_{t,t+i+1}}{\rho_{t,t+i}}\frac{\psi_X}{2}\left(\frac{p_{Xt+1}(i)}{p_{Xt}(i)}-1\right)^2\frac{e_{t+1}}{e_t}\frac{x^d_{t+1}}{x^d_t}\right]-\psi_X\left(\frac{p_{Xt}(i)}{p_{Xt-1}(i)}-1\right)+ \\ +\frac{1+\nu}{\nu}\left(\frac{P_t r_{t-1}}{e_t p_{Xt}(i)\alpha A_t(L_t(i)/K_{t-1}(i))^{(1-\alpha)}}-1\right)+1=0 \end{array} \tag{24}$$

The importing firms choose the resale price ($p_{ft}(j)$) to maximize their profits, where they too are subject to quadratic menu costs. Their problem may be summarized:

$$\max\ E_0 \sum_{t=0}^{\infty} \rho_{t,t+i} \pi_{Ft}(j) \tag{25}$$

$$\text{where } \pi_{Fjt} = \left(p_{Ft}(j) - e_t P^*_t\right) y^d_{Ft}(j) - AC_{Ft}(j) \tag{26}$$

$$\text{and } AC_{Ft}(i) = \frac{\psi_H}{2}\frac{\left(p_{Ft}(i)-p_{Ft-1}(i)\right)^2}{p_{Ft-1}(i)} y^d_{Ft}(j), \tag{27}$$

and subject to the demand functions for $y^d_{Ft}(i)$ above. The optimal pricing rule is:

$$\begin{array}{l} E_t\left[\frac{\rho_{t,t+i+1}}{\rho_{t,t+i}}\frac{\psi_F}{2}\left(\frac{p_{ft+1}(i)}{p_{Ft}(i)}-1\right)^2\frac{y^d_{Ft+1}}{y^d_{Ft}}\right]-\psi_F\left(\frac{p_{Ft}(i)}{p_{Ft-1}(i)}-1\right)+ \\ +\frac{1+\nu}{\nu}\left(e_t\frac{P^*_t}{p_{Ft}(i)}-1\right)+1=0 \end{array} \tag{28}$$

2.3 Household Behavior

The household derives utility from consumption (C), and supplying labor (L) lowers utility. For simplicity, real money balances (M/P) are also introduced in the utility function, where P is the overall price level. The household discounts future utility at the rate of time preference β. Preferences are additively separable in these three arguments, and preferences for consumption and money demand are subject to preference shocks. The taste shock for consumption is of a type considered by Stockman and Tesar (1995), in which a rise in τ_C lowers the marginal utility of consumption. The money demand shock is modeled analogously.

Households derive income by selling their labor at the nominal wage rate (W), renting capital to firms at the real rental rate (r), receiving real profits from the two types of firms (π_1 and π_2), and from government transfers (T). In addition to money, households can hold a noncontingent real bond (B), measured in terms of the foreign (world) consumption index. This pays an interest rate (R) in terms of the foreign consumption index, which is subject to exogenous shocks. The nominal exchange rate is e and the foreign price level is P^*, so the real exchange rate (eP^*/P) may be used to convert bond holdings to units of the domestic consumption index. Investment (I) in new capital (K) involves a quadratic adjustment cost, and there is a constant rate of depreciation (δ).

The optimization problem faced by the household may be expressed:

$$\max\ E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, \frac{M_t}{P_t}, L_t) \tag{29}$$

$$\text{s.t. } CA_t = \frac{e_t P_t^*}{P_t}\left(B_t - B_{t-1}\right) \tag{30}$$

$$\text{where } CA_t \equiv \frac{W_t}{P_t} L_t + r_{t-1} K_{t-1} + \int \pi_{Ht} + \int \pi_{Ft} + T_t + \left(\frac{e_t P_t^*}{P_t}\right) R_{t-1} B_{t-1} \tag{31}$$

$$-C_t - I_t - \left(\frac{M_t}{P_t} - \frac{M_{t-1}}{P_t}\right) \tag{32}$$

$$U(C_t, L_t) = \frac{1}{1-\sigma_1}\left(\tau_{ct} C_t\right)^{1-\sigma_1} + \frac{1}{1-\sigma_2}\left(\tau_{mt}\frac{M_t}{P_t}\right)^{1-\sigma_2} - \frac{\sigma_3}{1+\sigma_3} L_t^{\frac{1+\sigma_3}{\sigma_3}} \tag{33}$$

$$I_t = K_t - \left(1 - \delta_{t-1}\right) K_{t-1} + \frac{\psi_I}{2}\frac{\left(K_t - K_{t-1}\right)^2}{K_{t-1}}, \tag{34}$$

$$\text{where } \sigma_i > 0,\ \ \sigma_i \neq 1,\ \text{for } i = 1...3,\ \ \psi_I \geq 0. \tag{35}$$

Note that the budget constraint here defines the current account (CA_t).

The household problem implies the following optimality conditions. First, households will smooth consumption across time periods according to:

$$U'_{Ct} = \beta\left(1 + R_t\right) E_t\left[U'_{Ct+1}\right]. \tag{36}$$

Households prefer expected marginal utilities to be constant across time periods, unless a rate of return on saving exceeding their time preference induces them to lower consumption today relative to the future. Second, household money demand will depend on consumption and the interest rate.

$$P_t \frac{U'_{Mt}}{U'_{Ct}} = 1 - \left(\frac{1}{1+R_t}\right) E_t \left[\frac{P_t}{P_{t+1}}\right]. \tag{37}$$

Third, they supply labor to the point that the marginal disutility of labor equals its marginal product:

$$\frac{U'_{Lt}}{U'_{Ct}} = (1-\alpha) A_t \left(\frac{K_{t-1}}{L_t}\right)^{\alpha}. \tag{38}$$

Finally, capital accumulation is set to equate the costs and expected benefits:

$$(1+R_t)\left(1+\frac{\psi_I (K_t - K_{t-1})}{K_{t-1}}\right) = r_t + (1-\delta) + \frac{\Psi_I}{2} E_t \left(\frac{K_{t+1}^2 - K_t^2}{K_t^2}\right). \tag{39}$$

The cost, on the left side, is the gross return if the funds instead had been used to purchase bonds; and the benefits on the right include the return from rental of the capital plus the resale value after depreciation, and the fact that a larger capital stock lowers the expected adjustment cost of further accumulation in the subsequent period.

2.4 Equilibrium

The resource constraint for final goods is

$$Y_t = C_t + I_t + G + \int_0^1 AC_{It}(i)\, di + \int_0^1 AC_{Xt}(i)\, di + \int_0^1 AC_{Ft}(j)\, dj \tag{40}$$

The government uses final goods for a fixed amount of government purchases. It also chooses a money supply, which it distributes by transfers to households. The government budget constraint is

$$T_t - G = \frac{1}{P_t}(M_t - M_{t-1}). \tag{41}$$

The stochastic shocks in the model are specified to follow:

$$
\begin{aligned}
\left(\log R_t - \log \overline{R}\right) &= \rho_R \left(\log R_{t-1} - \log \overline{R}\right) + \varepsilon_{Rt} \\
\left(\log P_t^* - \log P_{t-1}^*\right) &= \rho_{P^*} \left(\log P_{t-1}^* - \log P_{t-2}^*\right) + \varepsilon_{P^*t} \\
\left(\log \chi_t - \log \overline{\chi}\right) &= \rho_x \left(\log \chi_{t-1} - \log \overline{\chi}\right) + \varepsilon_{xt} \\
\left(\log A_t - \log \overline{A}\right) &= \rho_A \left(\log A_{t-1} - \log \overline{A}\right) + \varepsilon_{At} \\
\left(\log \tau_{ct} - \log \overline{\tau_c}\right) &= \rho_c \left(\log \tau_{ct-1} - \log \overline{\tau_c}\right) + \varepsilon_{ct} \\
\left(\log \tau_{mt} - \log \overline{\tau}_m\right) &= \rho_m \left(\log \tau_{mt-1} - \log \overline{\tau_m}\right) + \varepsilon_{mt} \\
\left(\log M_t - \log M_{t-1}\right) &= \rho_M \left(\log M_{t-1} - \log M_{t-2}\right) + \varepsilon_{Mt}
\end{aligned}
\tag{42}
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$$
\left[\varepsilon_{Rt}, , \varepsilon_{P^*t}, \varepsilon_{xt}, \varepsilon_{At}, \varepsilon_{ct}, \varepsilon_{mdt}, \varepsilon_{Mt}\right]' \,\tilde{}\, N\left(0, \Sigma_1\right),
$$

Note that the shocks may be correlated with each other. Since the model will be tested against a reduced form counterpart which permits shocks to be correlated, it is sensible to permit the model to do likewise. Recall that the theoretical restrictions to be tested all relate to the autoregressive coefficients of the model. Further, the fact that the shocks to money growth may be correlated with the other shocks is useful in that it allows us to approximate a money growth rule in which policy makers can respond to economic conditions. Although there are no explicit fiscal shocks, the shock to foreign demand specified here could in principle be viewed as representing a wide variety of exogenous shocks to demand.[8] Note also that since the data to which the model is fit is detrended, this is consistent with the fact that the shock processes above do not try to explain exogenous trends in series like money supply.

Equilibrium for this economy is a collection of 38 sequences satisfying a set of 38 equilibrium conditions given above, including the seven stochastic equations defined in (42). The model will be analyzed in a form log-linearized around a deterministic steady state. A solution for the model equilibrium is found using the method of Blanchard and Kahn (1980).

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[8] Given that the small open economy model does not explain foreign production, there is no global technology shock here of the type emphasized in Glick and Rogoff (1995). However, correlated shocks to the domestic technology term (A) and the world real interest rate (R) may in practice reflect supply shocks that are global in nature.

3. Empirical Methods

3.1 Data

The model will be fit to seven series: the current account, nominal exchange rate, domestic price index, foreign price index, output, money supply, and world real interest rate. All data are seasonally adjusted quarterly series at annual rates for the period 1973:1 to 1997:3, obtained from International Financial Statistics. Quantities are deflated to real terms using the GDP deflator and put in per-capita terms. Series other than the current account are logged, so that they may be expressed as log deviations from steady state as required by the log-linearized model above. Because the steady state value of the current account in the theoretical model is necessarily zero, this variable cannot be expressed in the model in a form that represents deviations from steady state in log form. Instead the current account is scaled by taking it as a ratio to the mean level of output.

Output (y) is measured as national GDP, money (M) by M1, and the domestic price level (P) by the CPI. A measure of the world real interest rate (r) is computed following the method of Barro and Sala i Martin (1990). I collected short-term nominal interest rates, T-bill rates or the equivalent, on the G-7 economies. Short-term interest rates are used because I wish to adjust for inflation expectations, which are much more reliably forecast over a short-time horizon. Inflation in each country is measured using that country's consumer price index, and expected inflation is forecast using a six-quarter autoregression. The nominal interest rate in each country then is adjusted by inflation expectations to compute an ex-ante real interest rate. The aggregate real interest rate is an average over the G-7 countries, excluding the domestic country under consideration. The time-varying weights used in this average are based on each country's share of real GDP in the total.

A measure of the foreign price index is computed in a similar manner to the interest rate. The national CPIs of the G-7 economies, excluding the domestic country under consideration, are averaged using the same GDP weighting scheme. Similarly, the nominal exchange rate is the average of the relative price of the domestic currency to a weighted average of the currencies of the remaining G-7 countries. Given that the data set includes measures of domestic and foreign CPIs as well as the nominal exchange rate, the data set thereby implicitly contains data on the real exchange rate.

As a preliminary step, the data series are tested for unit roots. Table 1 shows the results. The seven series appear to be nonstationary in levels but stationary in first differences. Using the Phillips-Perron test, the presence of a unit root cannot be rejected for any of the data series used here for any of the countries, with one exception. Nonstationarity is rejected only for the current account in Australia. However, it may be worth noting that the statistics for the current account data in Canada and the U.K. are near their 10% critical values.[9] As will be explained below, this data will be used in the form of log differences that are demeaned. This follows the standard practice in the related present value test literature. (See Bergin and Sheffrin, 2000 for a discussion.)

3.2 Econometric Methods

The econometric methodology estimates the linear approximation to the structural model, adapting a maximum likelihood algorithm developed in Leeper and Sims (1994) and extended in Kim (2000). This estimation methodology is then applied also to an analogous reduced form model, and the two models are compared on the basis of their likelihood values. Because the linearized structural model is a nested version of the unrestricted model, where the only difference is a set of theoretical restrictions imposed, a likelihood ratio test can be used as a test of these theoretical restrictions.

The linearized structural model discussed in section (2.1) is a set of seven stochastic equations and 31 deterministic equations. By using model equations to substitute out variables, the linearized model can be written in its most compact autoregressive form as fifteen equations involving the seven variables on which we have data, as well as eight other variables. (These additional eight variables are those that appear in lagged form in the equations above, so they cannot be substituted out and still retain the first-order autoregressive form of the model.) Seven of these equations are stochastic and eight deterministic. This model system can be arranged in the form:

$$y_t = Ay_{t-1} + A\varepsilon_t \tag{43}$$

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[9] Results for the Dickey-Fuller test, not shown, are similar.

$$\varepsilon_t \tilde{} N(0, \Sigma) \quad \Sigma = \begin{bmatrix} \Sigma_2 & 0 \\ 0 & 0 \end{bmatrix}$$

where y is a 15-element column vector of variables in percent deviations from steady state; A, which appears twice, is a 15x15 matrix, where each cell is a non-linear function of the structural parameters; ε is a column vector, where the first seven elements are functions of the seven structural disturbances and the remaining eight elements are zeros; and Σ_2 is the 7x7 covariance matrix of the disturbances in ε.

The model will be dealt with in first differences. This is done for three reasons. The first is that the unit root tests discussed in the previous section cannot in general reject a unit root for the data series used here. A second and equally important reason for using first differences is that the structural model implies the presence of a unit root in the linearized system (43). Given that asset markets are assumed to be incomplete, a wide range of transitory shocks will cause domestic households to borrow abroad as they smooth their consumption. This has a permanent effect on the wealth allocation between the small open economy and the rest of the world, and hence also on the endogenous variables which depend on this wealth allocation. This unit root implies that the methods used for estimation here cannot be applied to these variables in levels, because the variance-covariance matrix is not defined for these variables. A third reason is that I hope to relate my results to the preceding papers in the literature, especially Ahmed et. al. (1993), which worked with the data in first differences. In addition, the differenced data will be demeaned, to remove a linear trend. This is the common practice in the present value tests of intertemporal models, such as Sheffrin and Woo (1990) and Bergin and Sheffrin (2000).

The model system may be rewritten in terms of first differences as follows:

$$y_t^* = Ay_{t-1}^* + A\varepsilon_t - A\varepsilon_{t-1} \tag{44}$$

$$where \quad y_t^* = y_t - y_{t-1}$$

This stochastic model implies a log likelihood function:

$$L(\Pi) = -.5 \ln |\Omega| - .5x'\Omega^{-1}x \tag{45}$$

where x is the vector of differenced variables over all periods stacked into a single vector, and Ω is the theoretical variance-covariance matrix of x. The appendix discusses the details of how Ω is computed as a function of the matrices A and Σ_2. But note that each cell in A is a nonlinear function of the structural parameters from the theoretical model. An algorithm is used to search for values of these structural parameters and for the elements of the symmetric positive-definite covariance matrix Σ_2, which will maximize the likelihood function.

Note that taking first differences should not introduce the classic problem of ”overdifferencing” here. The fact that differencing may introduce a moving average term is taken into consideration in equation (44) and hence the computation of Ω and the likelihood function, so a misspecified model is not being estimated. It is true that the presence of a unit moving average root may mean the moving average is not invertible, so that an approximate likelihood conditional on the initial observations may not be a good approximation to the true unconditional likelihood. In part for this reason, the true likelihood is used here, unconditional on the initial observations. Again details are in the appendix.

The estimated model will be compared to an entirely analogous reduced form model. Like the structural model, the reduced form counterpart also takes the from of (43) and (44), and it involves the same differenced variables. However, the estimation algorithm treats the cells of the matrix A as distinct parameters, rather than as functions of underlying structural parameters. For the covariance matrix, Σ_2, the estimation algorithm is permitted to choose any symmetric positive semidefinite matrix, exactly as with the structural model. The structural model then is a nested version of the reduced form model, with an extra set of restrictions specifying the elements of the A matrix as functions of a common set of structural parameters, and shocks defined to have structural interpretations.

Estimating the reduced form model amounts to searching over values for the cells of A and Σ_2 to maximize the likelihood function, computed in exactly the same way as for the structural model using the unconditional likelihood[10]. Because the reduced form estimation is unhindered by theoretical restrictions, it is certain to generate a higher likelihood value than the restricted model. A likelihood ratio offers a way to compare the two likelihood values,

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[10] As in the structural model, A is restricted to have roots greater than or equal to unity. See the appendix for details.

adjusting for the number of restrictions, which will equal the number of cells in A and the lower triangular portion of Σ_2, minus the number of structural parameters that are free to be chosen by the estimation algorithm. The paper also reports approximate standard errors for the parameter estimates and residuals from a one-step ahead forecast. The appendix describes how these are computed.

A few parameters will not be estimated here, but instead are pinned down ahead of time. This is because the data set omits the relevant series for these parameters, like capital and investment, or because the data set in first differences is not very relevant for parameters pertaining to steady states. As a result, these parameters are pinned down at values common in the Real Business Cycle literature. In particular, the capital share in production (α) is set at 0.40, the depreciation rate (δ) is set at 0.10, the share of home intermediate goods in the home final goods aggregate (θ) is set at 0.80, and the discount factor (β) is set at 0.96.[11]

Some regions of the parameter space do not imply a well defined equilibrium within the model. These regions can be precluded by imposing boundaries on the parameters by functional transformations. For example the variances of shocks, the intertemporal elasticity are restricted to be positive. The depreciation rate and discount factor must be restricted between zero and unity: Autoregressive coefficients on shock processes are also restricted to be greater than zero and less than unity. Finally, the covariances between shocks must be restricted so that the implied correlations lie between -1 and 1.

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[11] It is widely understood that when some parameters in a model are calibrated exogenously and some estimated, the estimation should be viewed as conditional on the choice of calibration values. In principal, these calibrated values could be regarded as part of the specification of the particular model that is being tested here, akin to the choice of functional forms. (The choice of a Cobb-Douglas form for the production function implies an elasticity of substitution equal to 1.0.) Future work using this methodology could extend the method to a larger data set, to permit all the structural parameters in the model to be estimated. However, increasing the dimension of the estimation job has the disadvantage of increasing the time for convergence, which already is very long.

4. Results

4.1 Benchmark Model

The results of the estimated benchmark model are reported in Table 2. For Australia and Canada, the structural model performs surprisingly well. A likelihood ratio test indicates the structural model cannot be rejected for these two countries. Only for the United Kingdom is the structural model rejected at the 5% significance level, and it may be worth noting that even this cannot be rejected at the 1% significance level. These results offer some of the first formal statistical support for the New Open Economy macroeconomics. The table also reports the root mean squared errors for one step ahead forecasts, as a way of gauging the model's success for individual variables. These residuals are uniformly higher for the structural model, which is not surprising given that the unrestricted model has 211 more free parameters to use in forming its predictions. What is surprising is that the residuals from the structural model in many cases are fairly close to that of the unrestricted model. This appears to be more true for the current account than for the exchange rate. This too is not surprising, given the history of models having difficulty explaining volatile exchange rate movements.

The table also reports parameter values implied by the estimation, which are generally reasonable and statistically significant. For all three countries the intertemporal elasticity ($1/\sigma_1$) appears to be quite small (below 0.2). Hall (1988) and others have found very similar results in econometric studies of the intertemporal elasticity. A low elasticity indicates that households are strongly committed to smoothing their consumption across time, and are not willing to adjust consumption in response to the interest rate. The estimate of the labor supply elasticity (σ_3) is very near to zero. The investment adjustment cost is sizeable but reasonable. For Australia, for example, a value of $\Psi_I =$111.9 indicates that if Australia raises investment expenditure 1% above its steady state level, approximately 5.6% of this extra investment expenditure goes toward paying the adjustment cost. The adjustment cost for prices is sizeable, indicating a fair degree of price rigidity. For Australia, the value of $\Psi_H =$114.7 implies that after a shock to money supply, the aggregate price level moves about 11 percent of the way toward its long run level each quarter, so that it has a half-life of 5.9 quarters. The adjustment cost for wages is much lower than that estimated for prices, and approximately equals zero.

Since there are 35 parameters characterizing the variances, covariances, and persistences of the shocks, these are not reported in the table. But all appear to be reasonable, and the large majority of variances and persistence parameters are statistically different from zero and unity. (The latter are reported in a final supplementary table.)

Variance decompositions can be used to infer the role of monetary shocks in driving exchange rates and the current account. Given that the shocks are all correlated with each other, the shocks must be orthogonalized for forecast errors to be attributed to them separately. While the theory in the structural model could have been used to identify structural shocks separately, it was decided to allow the shocks to be correlated to permit a more fair comparison between the structural and unrestricted models. So now a simple Cholesky decomposition will be used to orthogonalize the shocks, as is common with nonstructural VARs. The ordering of variables will be as follows: world interest rate, world price level, world demand for home-country exports, home technology shocks, home tastes shocks, home model demand shocks, and home money supply shocks. World shocks are ordered first to reflect the fact they should be exogenous to events within the home small open economy. Money supply shocks are listed last to reflect the possibility that home monetary authorities might respond to other shocks in setting monetary policy.

Tables 3-5 report the results of variance decompositions. Regarding the current account, it appears that money supply shocks account for only a small fraction of the forecast error variance in this variable in Australia and the United Kingdom (around 4 percent at most). The role of monetary shocks is somewhat larger for Canada, accounting for 20 to 30 percent.[12] But in all three countries, the largest share of current account fluctuation is attributed to taste shocks.[13] Regarding output, almost no role is attributed by the model to money supply shocks, with the large share attributed to technology shocks. It is also a fairly common finding in VAR studies that money does not account for a large share of output variations, although the estimate here is even lower than that found in other studies.

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[12] Lane (1999) finds using structural VAR techniques that monetary shocks account for between 10 and 50 percent of current account fluctuations.

[13] As found in Nason and Rogers (2000), models with consumption behavior rooted in the permanent income hypothesis have difficulty explaining observed current account dynamics. Taste shocks provide a way to get away from this type of consumption behavior.

However, money supply shocks are found here to play an important role when it comes to the exchange rates. Regarding the nominal exchange rate, money supply shocks account for 60-70% of the forecast error in the short run, and for 20-40% in the longer run. Regarding the real exchange rate, money accounts for a similar degree in the short run, and for 50-60% in the long run. The large role for money in driving the real exchange rate probably results from the estimate of a large degree of price stickiness. This result is comparable but somewhat larger than that found in past studies. Eichenbaum and Evans (1995) found variance decompositions between 18% and 43% using standard VAR techniques. Faust and Rogers (2000) found estimates ranging from the single digits to around 50% using a structural VAR that considered a wide range of identifcation assumptions. Ahmed et al (1993) found almost no role for monetary shocks in a structural VAR using long-run identification restrictions.

Finally, impulse responses can confirm that the model implies a reasonable story for the effects of money shocks. Figures 1 and 2 show the impulse responses to a 1% shock to the money supply growth rate for Australia. The model implies a hump shaped response to output, as is often observed in non-structural VAR studies. It is encouraging that a theoretical model can reproduce this feature. Note also how the real exchange rate moves gradually to its new long run equilibrium. The impulse responses for other countries are very similar.

4.2 Price and Wage Flexibility

Next the model will be used to examine the importance of assuming nominal rigidities. Table 6 reports results for a model in which there is no price or wage stickiness, so the two stickiness parameters Ψ_H and Ψ_W are set to zero. The likelihood values are much lower than for the reduced form counterpart, and a likelihood ratio test strongly rejects the model for all three countries. The model without stickiness may also be compared to the benchmark model with stickiness from Table 2, since it can be regarded as a restricted version of the benchmark model with two additional restrictions imposed ($\Psi_H = \Psi_W = 0$). Table 6 reports a likelihood ratio test comparing these two structural models, which specifically rejects the two restrictions of no stickiness.

These rejections are informative, first because they indicate the testing methodology here is sensitive enough to discriminate between models. In addition, these rejections offer evidence that nominal rigidities are an essential element of the success found above for the New Open Economy approach. However, the forecast error variances reported in the table indicate nominal rigidities are more important for understanding some variables than others. First, the residuals for price level data are larger for the model without rigidities, indicating that stickiness is present and important for understanding how prices move in response to shocks. The residuals are also larger for output in the case without rigidities. This is surprising, because one may recall that the variance decomposition discussed above indicated that output fluctuations were driven mainly by technology shocks rather than monetary shocks. This offers evidence that stickiness also has important implications for the effects of real as well as nominal shocks. This is entirely plausible, for example, if a rise in technology raising output also raises money demand; firms may wish to lower their prices, but they are unable to do so under the assumption of stickiness.

The current account residuals are almost the same under the two cases, indicting that nominal rigidities may not be important for understanding fluctuations in the current account. This is consistent with the conclusion from variance decompositions above, that monetary shocks contribute little to current account fluctuations. Apparently the nominal rigidities have less effect on the taste shocks driving the current account, than they did on the technology shocks driving output.

More surprising is the fact that the model without nominal rigidities does better explaining the nominal exchange rate than the benchmark model with rigidities. This evidence does not support the claims of theoretical models that pricing to market can amplify exchange rate movements in a way that helps explain this highly volatile variable. The same conclusion applies to a lesser degree for the real exchange rate. The better prediction of the nominal exchange rate is naturally reflected in the prediction for the real exchange rate, but the fact that the model with rigidities does better predicting the price level component of the real exchange rate erases some of this gap.

Now consider the roles of sticky prices and wages separately. This comparison is interesting in that while sticky prices were standard in the early New Open Economy Macro literature, recent additions have proposed sticky wages instead. Some theoretical work argues that sticky wages are important for generating persistence in the real effects of monetary shocks. Table 7 summarizes results for two restricted versions of the model: the top portion shows a version in which goods prices are sticky but wages are flexible, and the bottom portion shows a version in which goods prices are flexible but wages are sticky. We can reject the single restriction that prices are flexible, but not the single restriction that wages are flexible. This suggests that price stickiness is more important than wage stickiness to the benchmark model's overall success. It is possible that this result is influenced by the fact that the model is not estimated using labor market data, such as wages or employment. Future work could consider this extension. In any case, the result indicates that the modeling of wage stickiness here is not a particularly useful means of explaining the behavior of the variables that are in the data set: output, current account, and the real exchange rate.

4.3 Producer Currency Pricing

A prominent argument in the theoretical literature is whether prices should be regarded as sticky in the currency of the producer or the buyer. The assumption in most of the New Open Economy Macroeconomics has been producer currency pricing. However, Engel (1993 and 1999) has presented significant evidence of local currency pricing for a wide range of goods, and this has been incorporated in theoretical models by Betts and Devereux (1996 and 2000) and Devereux and Engel (1998). The benchmark model above followed this recent literature by assuming local currency pricing, but now a version of the model will be tested that makes the more traditional assumption of producer currency pricing.

First, if the price set for exported home goods, P_{Xt}, is understood to be denominated in the home currency, the expression P_{Xt} must be replaced with P_{Xt}/e_t in the equation describing foreign demand for these home goods (14). Further, the profits of home exporting firms must be redefined in problem (17) as:

$$\begin{aligned} \pi_{Hit} &= p_{Ht}(i)\,y_{Ht}^{d}(i) + p_{Xt}(i)\,x_{t}^{d}(i) - P_t r_{t-1} K_{t-1}(i) \\ &\quad - W_t L_t(i) - AC_{Ht}(i) - AC_{Xt}(i)\,, \end{aligned} \tag{46}$$

so the optimal price setting rule for exports (24) is replaced by:

$$\begin{gathered}E_t\left[\frac{\rho_{t,t+i+1}}{\rho_{t,t+i}}\frac{\psi_X}{2}\left(\frac{p_{Xt+1}(i)}{p_{Xt}(i)}-1\right)^2\frac{x_{t+1}^d}{x_t^d}\right]-\psi_X\left(\frac{p_{Xt}(i)}{p_{Xt-1}(i)}-1\right)+\\+\frac{1+\nu}{\nu}\left(\frac{P_t r_{t-1}}{p_{Xt}(i)\alpha A_t(L_t(i)/K_{t-1}(i))^{(1-\alpha)}}-1\right)+1=0.\end{gathered}\tag{47}$$

Similarly, if the price of imported goods, P_{Ft}, is understood to be denominated in the foreign currency, the expression P_{Ft} must be replaced with e_tP_{Ft} in the home demand for imported goods (8) and also the home consumer price index (5). The profits of home importing firms in problem (26) must be redefined:

$$\pi_{Fjt}=\left(e_t p_{Ft}\left(j\right)-e_t P_t^*\right)y_{Ft}^d\left(j\right)-e_t AC_{Ft}\left(j\right),\tag{48}$$

so the optimal price setting rule (28) is replaced by:

$$\begin{gathered}E_t\left[\frac{\rho_{t,t+i+1}}{\rho_{t,t+i}}\frac{\psi_F}{2}\left(\frac{p_{ft+1}(i)}{p_{Ft}(i)}-1\right)^2\frac{y_{Ft+1}^d}{y_{Ft}^d}\frac{e_{t+1}}{e_t}\right]-\psi_F\left(\frac{p_{Ft}(i)}{p_{Ft-1}(i)}-1\right)+\\+\frac{1+\nu}{\nu}\left(\frac{P_t^*}{p_{Ft}(i)}-1\right)+1=0.\end{gathered}\tag{49}$$

Results of estimating this model are found in Table 8. While this model cannot be cast as a nested version of the benchmark model with local currency pricing, it still is a nested version of the same unrestricted model used to test this benchmark. Table 8 indicates that the producer currency pricing model is strongly rejected for two of the three countries, Canada and the United Kingdom. Even while the model cannot be rejected for Australia at a typical significance level, the p-value is much lower than in the benchmark case. Given that the local currency pricing model was not rejected for two of the three countries, this is taken as general support for the recent trend in the New Open Economy Macroeconomics to assume local currency pricing rather than producer currency pricing.

However, the forecast error variances offer a more nuanced conclusion. It is true that the benchmark model has lower residuals for output. But the two models perform equally well in predicting the movements in the current account and price level. Further, the producer currency pricing model does better than the benchmark model for real and nominal exchange rates for all three countries. In fact, in the case of Australia, the theoretical model with producer currency pricing not only has lower residuals than the benchmark model, but it actually beats the reduced form, unrestricted model! While the producer currency pricing model performs less well overall than the local currency pricing counterpart, if one is interested in understanding exchange rates in particular, the former model appears to have an advantage.

5. Conclusion

This paper has offered a formal statistical test of the New Open Economy Macroeconomics. It has adapted maximum likelihood procedures to estimate and test an intertemporal small open economy model with monetary shocks and sticky prices and wages. The theoretical benchmark economy did surprising well, in that it was not rejected for two of the countries considered. The assumption of nominal rigidities appeared to be an essential element in the model, since a version that assumed there were no such rigidities was rejected soundly for all three countries. However, the presence of rigidities was more important for explaining some variables in the data set than others. In particular, the benchmark model with rigidities performed better for price level and output data, but the rigidities did not seem to help in explaining fluctuations in the current account or exchange rate data.

The methodology also tested a version of the model in which prices were assumed to be sticky in the currency of the seller rather than the buyer. Overall, this model performed less well than the benchmark model in terms of likelihood ratios. This offers some evidence in favor of the assumption of local currency pricing, which is a current debate in the theoretical literature. However, forecast error variances indicate that the producer currency pricing alternative, while performing less well overall, is a better model for explaining nominal and real exchange rates in particular.

The estimated models also indicated a prominent role for monetary shocks in driving fluctuations in the real and nominal exchange rates. This was not the case for the current account or output level.

These results indicate that the empirical methodology developed here has promise as a means of distinguishing between competing open economy models, and permitting an empirical counterpart to the rapidly growing theoretical literature in this area. Future work should consider a wider range of theoretical models in this literature, and should test them against a wider range of data.

6. Appendix

The estimation strategy applied here is drawn from that developed in Leeper and Sims (1994), although it differs somewhat in its handling of first differences, and the fact it is applied also to a reduced form model. Given the autoregressive moving average model in (44), the contemporaneous covariances matrix, $R_{y^*}(0)$, can be written as follows :

$$R_{y^*}(0) \equiv E\left[y_t^* y_t^{*\prime}\right] = A\Sigma A' + \sum_{i=0}^{\infty} \left[BD^i\left(D-I\right)B^{-1}\right] A\Sigma A' \left[BD^i\left(D-I\right)B^{-1}\right]' \quad (50)$$

where D is the diagonal matrix of eigenvalues and B the matrix of eigen vectors of A. $R_{y^*}(0)$ can then be computed:

$$R_{y^*}(0) = A\Sigma A' + B\left[K\right]B' \quad (51)$$

where the typical element (i, j) of K is

$$K_{ij} = \begin{matrix} \frac{(1-d_i)(1-d_j)M_{ij}}{1-d_i d_j} & for\ d_i \neq 1\ or\ d_j \neq 1 \\ 0 & for\ d_i = 1\ and\ d_j = 1 \end{matrix}, \quad (52)$$

where

$$M = B^{-1}A\Sigma A' B^{-1\prime}. \quad (53)$$

and where d_i is the ith diagonal element of the matrix D. It is easily verified that

$$\lim_{d_i \to 1, d_j \to 1} \frac{(1-d_i)(1-d_j)M_{ij}}{1-d_i d_j} = 0. \quad (54)$$

Once $R_{y^*}(0)$ is computed, the covariances across one lag $R_{y^*}(1)$ may be found:

$$R_{y^*}(1) = E\left[y_t^* y_{t-1}^{*\prime}\right] = A\ R_{y^*}(0) - A\Sigma A' \quad (55)$$

and over lags greater than one:

$$R_{y^*}(k) = E\left[y_t^* y_{t-k}^{*\prime}\right] = A^{k-1}\ R_{y^*}(1)\ for\ k > 1 \quad (56)$$

The full covariance matrix, Ω, can be constructed by assembling the blocks for various lags.[14] To reduce numerical problems associated with rounding error, lags of only up to 15 periods are currently used, with covariances assumed to be zero over lags greater than 15 periods. The covariance matrix is a key component in computing the log-likelihood to be maximized:

$$L(\Pi) = -.5 \ln |\Omega| - .5 x' \Omega^{-1} x \tag{57}$$

Note that the likelihood is computed unconditionally on the initial observations.

One difficulty is that some regions of the parameter space are not defined within the model. These regions can be precluded by imposing boundaries on the parameters by functional transformations. For example the following variables are restricted to be positive: the variances of shocks, the preference parameters $\sigma_1 - \sigma_3$, and $\overline{A}$. The autoregressive coefficients for shocks must be restricted between the values of 0 and 1. Finally, the covariances between shocks must be restricted so that the implied correlations lie between -1 and 1.

The reduced form model used for comparison may also be expressed in the form of equation (44), and it is estimated in precisely the same manner as the structural model. A likelihood function is computed in the same way as above, as a function of the autoregressive matrix A and the covariance matrix of shocks Σ_2. As with the structural model, this likelihood function is computed unconditionally on the initial observations, and the same search algorithm is used to maximize it. The elements of the matrix Σ_2 for the reduced form model is subject to the identical boundaries as applied to its counterpart in the structural model. In addition, to ensure that the covariance matrix is positive definite, the autoregressive matrix A is required to have roots less than unity in absolute value. This is accomplished by dealing with A in its Jordan decomposition. The free parameters are the roots of the A matrix and all but the last element of each eigen vector.

Optimization is conducted using an algorithm developed by Christopher Sims which is robust to discontinuities. (This algorithm, csminwel.m is available from Christopher Sims as a Matlab .m file.)

A measure of precision can be obtained by looking at the inverse of the Hessian matrix, the diagonal elements of which approximate parameter estimation error variances. The

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[14] An alternative means of computing the likelihood would be to use the Kalman filter.

delta method is used to adjust these error variances for the parameter transformations discussed above, used to impose boundaries on the parameter estimates.[15] In addition, a measure of the fit of the model can be obtained by computing residuals from one-step ahead forecasts. Standardized residuals may be computed:

$$v = \varpi^{-1} y^{*} \tag{58}$$

where ϖ is the cholesky decomposition of the overall covariance matrix. Unstandardized residuals may be computed on a period-by-period basis as:

$$v_t^{*} = \left(\varpi^{-1}\right)_{tt}^{-1} v_t \tag{59}$$

where $\left(w^{-1}\right)_{tt}$ is the t-th diagonal block of the inverse of ϖ.

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[15] In particular, the standard error of the transformed parameter estimate is computed as the standard error of the untransformed estimate multiplied by the derivative of the functional transformation.

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Table 1: Unit Root Tests

	Australia	Canada	U. K.
Phillips-Perron Test:			
Output			
Levels	-2.9255	-1.4851	-2.2406
Differences	-10.7003**	-5.6376**	-8.9216**
Current account			
Levels	-4.1727**	-3.0092	-2.9781
Differences	-8.7610**	-14.0856	-12.2992**
Money			
Levels	-2.2016	-1.5092	-1.3184
Differences	-8.5262**	-9.1036**	-9.9532**
Exchange rate			
Levels	-1.2333	-1.5312	-2.2678
Differences	-8.5994**	-7.1376**	-7.7573**
Price Level			
Levels	-0.8559	-0.1277	-2.3168
Differences	-8.5865**	-5.1524**	-7.4869**
World price level			
Levels	-0.5638	-0.5636	-0.5638
Differences	-10.1960**	-10.1960**	-10.1960**
Interest rate			
Levels	-0.5598	-0.5596	-0.5597
Differences	-10.1952**	-10.1952**	-10.1953**

** indicates unit root rejected at 1% significance level; * indicates rejected at 5% level. Tests run with 3 lags. Range is 1973Q1 to 1997Q3. Critical values:1% -4.06; 5% -3.46; 10% -3.16.

Table 2: Benchmark Sticky Price and Wage Model

		Australia	Canada	U.K.
Measures of Fit:				
log likelihood value:				
model		2320.357	2477.447	2267.321
reduced form		2419.269	2585.629	2397.733
likelihood ratio		197.826	216.364	260.823
p-value*		0.733	0.385	0.011
RMSE - structural model:				
current account		0.0130	0.0087	0.0103
nominal ϵ		0.0542	0.0380	0.0458
real e		0.0513	0.0384	0.0469
output		0.0119	0.0083	0.0094
price level		0.0089	0.0048	0.0133
RMSE - reduced form model:				
current account		0.0115	0.0082	0.0087
nominal ϵ		0.0521	0.0354	0.0366
reale e		0.0499	0.0361	0.0381
output		0.0110	0.0064	0.0079
price level		0.0076	0.0042	0.0113
Structural Parameter Estimates:				
cons. elast term	σ_1	54.144	5.308	17.444
		(4.494)	(1.924)	(0.359)
money elast term	σ_2	5.016	2.777	1.395
		(0.173)	(1.367)	(0.019)
labor elasticity	σ_3	0.00116	0.00023	0.00022
		(0.00030)	(0.00005)	(0.00000)
Invest adjust cost	ψ_I	111.938	705.876	462.820
		(48.773)	(272.523)	(9.056)
Price adjust cost	ψ_P	114.671	154.620	259.847
		(15.438)	(31.337)	(3.294)
Wage adjust cost	ψ_w	0.006	0.035	0.067
		(0.000)	(0.011)	(0.001)
demand elast - goods	ν	0.966	1.441	0.680
		(0.102)	(0.263)	(0.006)

*Degrees of freedom = 211.

Table 3: Variance Decompositions

Benchmark model

Australia

	Period	Shocks						
		interest rate	foreign price	foreign demand	tecnology	tastes	money demand	money supply
Current Account	1	0.0022	0.0006	0.0716	0.0050	0.8598	0.0151	0.0457
	2	0.0028	0.0010	0.0424	0.0073	0.8915	0.0132	0.0419
	3	0.0024	0.0013	0.0311	0.0083	0.9077	0.0115	0.0377
	4	0.0020	0.0016	0.0249	0.0090	0.9188	0.0100	0.0339
	5	0.0016	0.0018	0.0208	0.0094	0.9270	0.0088	0.0306
	10	0.0016	0.0028	0.0117	0.0106	0.9481	0.0053	0.0198
	20	0.0056	0.0043	0.0112	0.0116	0.9519	0.0033	0.0122
nominal e	1	0.0159	0.0338	0.0025	0.0282	0.0005	0.2741	0.6450
	2	0.0140	0.0551	0.0013	0.0371	0.0027	0.2544	0.6354
	3	0.0120	0.0770	0.0013	0.0469	0.0104	0.2365	0.6158
	4	0.0101	0.0979	0.0023	0.0575	0.0231	0.2187	0.5905
	5	0.0084	0.1167	0.0043	0.0683	0.0399	0.2011	0.5614
	10	0.0044	0.1705	0.0224	0.1184	0.1553	0.1241	0.4049
	20	0.0108	0.1646	0.0577	0.1735	0.3487	0.0458	0.1988
real e	1	0.0097	0.0082	0.0395	0.0147	0.0046	0.2814	0.6418
	2	0.0085	0.0105	0.0387	0.0175	0.0027	0.2725	0.6495
	3	0.0074	0.0128	0.0372	0.0208	0.0024	0.2668	0.6526
	4	0.0066	0.0150	0.0356	0.0243	0.0037	0.2617	0.6531
	5	0.0059	0.0171	0.0340	0.0281	0.0067	0.2568	0.6515
	10	0.0049	0.0254	0.0271	0.0486	0.0429	0.2303	0.6207
	20	0.0108	0.0316	0.0226	0.0818	0.1579	0.1808	0.5145
output	1	0.0378	0.0346	0.0738	0.8491	0.0047	0.0000	0.0000
	2	0.0307	0.0379	0.0404	0.8848	0.0058	0.0001	0.0003
	3	0.0225	0.0400	0.0302	0.8991	0.0073	0.0002	0.0008
	4	0.0169	0.0413	0.0260	0.9050	0.0090	0.0003	0.0014
	5	0.0145	0.0420	0.0243	0.9057	0.0109	0.0005	0.0021
	10	0.0406	0.0403	0.0272	0.8639	0.0218	0.0009	0.0053
	20	0.1619	0.0304	0.0385	0.7199	0.0420	0.0007	0.0066

Table 4: Variance Decompositions

Benchmark model

Canada

	Period	Shocks						
		interest rate	foreign price	foreign demand	tecnology	tastes	money demand	money supply
Current Account	1	0.0021	0.0006	0.0019	0.0002	0.6640	0.0373	0.2939
	2	0.0039	0.0003	0.0059	0.0001	0.6811	0.0344	0.2742
	3	0.0063	0.0004	0.0107	0.0002	0.6953	0.0318	0.2553
	4	0.0090	0.0008	0.0167	0.0003	0.7065	0.0294	0.2373
	5	0.0119	0.0011	0.0237	0.0004	0.7152	0.0272	0.2204
	10	0.0263	0.0024	0.0669	0.0016	0.7312	0.0186	0.1530
	20	0.0466	0.0021	0.1556	0.0043	0.7007	0.0096	0.0812
nominal e	1	0.0006	0.0272	0.1464	0.0220	0.0988	0.0658	0.6391
	2	0.0012	0.0516	0.1318	0.0210	0.0895	0.0641	0.6408
	3	0.0020	0.0778	0.1177	0.0199	0.0806	0.0624	0.6395
	4	0.0034	0.1038	0.1047	0.0188	0.0722	0.0606	0.6366
	5	0.0053	0.1284	0.0928	0.0177	0.0645	0.0588	0.6326
	10	0.0245	0.2208	0.0528	0.0129	0.0374	0.0495	0.6020
	20	0.1011	0.2749	0.0618	0.0066	0.0366	0.0314	0.4876
real e	1	0.0009	0.0015	0.2474	0.0144	0.0991	0.0606	0.5761
	2	0.0014	0.0023	0.2439	0.0139	0.0953	0.0602	0.5830
	3	0.0021	0.0032	0.2397	0.0134	0.0916	0.0601	0.5899
	4	0.0030	0.0041	0.2353	0.0130	0.0881	0.0599	0.5967
	5	0.0041	0.0049	0.2308	0.0126	0.0847	0.0598	0.6031
	10	0.0130	0.0079	0.2090	0.0108	0.0705	0.0590	0.6299
	20	0.0449	0.0101	0.1777	0.0091	0.0606	0.0552	0.6424
output	1	0.0993	0.0277	0.0056	0.8674	0.0001	0.0000	0.0000
	2	0.0753	0.0293	0.0172	0.8782	0.0001	0.0000	0.0000
	3	0.0578	0.0306	0.0201	0.8915	0.0001	0.0000	0.0000
	4	0.0449	0.0316	0.0212	0.9021	0.0001	0.0000	0.0001
	5	0.0366	0.0324	0.0216	0.9092	0.0001	0.0000	0.0001
	10	0.0557	0.0327	0.0195	0.8915	0.0001	0.0000	0.0004
	20	0.2546	0.0255	0.0120	0.7071	0.0001	0.0000	0.0007

Table 5: Variance Decompositions

Benchmark model

United Kingdom

	Period	Shocks						
		interest rate	foreign price	foreign demand	tecnology	tastes	money demand	money supply
Current Account	1	0.0167	0.0000	0.1032	0.0071	0.8370	0.0053	0.0308
	2	0.0223	0.0006	0.0589	0.0075	0.8755	0.0051	0.0302
	3	0.0262	0.0010	0.0428	0.0069	0.8896	0.0048	0.0288
	4	0.0296	0.0012	0.0337	0.0062	0.8975	0.0044	0.0273
	5	0.0329	0.0015	0.0276	0.0056	0.9024	0.0041	0.0258
	10	0.0480	0.0024	0.0162	0.0033	0.9073	0.0030	0.0198
	20	0.0710	0.0031	0.0305	0.0027	0.8781	0.0018	0.0128
nominal e	1	0.0033	0.0814	0.0305	0.0183	0.0085	0.1610	0.6971
	2	0.0021	0.1048	0.0209	0.0164	0.0046	0.1549	0.6963
	3	0.0014	0.1249	0.0144	0.0146	0.0037	0.1488	0.6921
	4	0.0014	0.1412	0.0110	0.0129	0.0058	0.1425	0.6852
	5	0.0021	0.1537	0.0106	0.0114	0.0108	0.1359	0.6755
	10	0.0172	0.1698	0.0462	0.0058	0.0696	0.1007	0.5908
	20	0.0680	0.1097	0.1837	0.0036	0.2268	0.0443	0.3639
real e	1	0.0053	0.0444	0.1979	0.0132	0.0142	0.1398	0.5854
	2	0.0043	0.0471	0.1928	0.0125	0.0112	0.1387	0.5933
	3	0.0035	0.0494	0.1866	0.0120	0.0089	0.1383	0.6014
	4	0.0028	0.0512	0.1803	0.0114	0.0072	0.1378	0.6092
	5	0.0024	0.0527	0.1740	0.0109	0.0063	0.1373	0.6164
	10	0.0046	0.0561	0.1446	0.0087	0.0132	0.1327	0.6401
	20	0.0271	0.0508	0.1123	0.0070	0.0808	0.1131	0.6089
output	1	0.0023	0.0363	0.0124	0.9489	0.0001	0.0000	0.0000
	2	0.0020	0.0381	0.0535	0.9061	0.0003	0.0000	0.0000
	3	0.0052	0.0377	0.0571	0.8991	0.0007	0.0000	0.0001
	4	0.0118	0.0369	0.0554	0.8943	0.0013	0.0000	0.0003
	5	0.0214	0.0360	0.0521	0.8880	0.0021	0.0000	0.0005
	10	0.1074	0.0304	0.0329	0.8193	0.0083	0.0000	0.0016
	20	0.3439	0.0190	0.0224	0.5865	0.0250	0.0001	0.0031

Table 6: Flexible Price and Wage model

		Australia	Canada	U.K.
Measures of Fit:				
log likelihood value:				
model		2284.373	2452.305	2256.050
reduced form		2419.269	2585.629	2397.733
likelihood ratio		269.792	266.647	283.365
p-value*		0.005	0.007	0.001
comparison with benchmark model (table 2):				
likelihood ratio		71.967	50.283	22.542
p-value**		0.000	0.000	0.000
RMSE - structural model:				
current account		0.0129	0.0086	0.0105
nominal ϵ		0.0518	0.0367	0.0439
real e		0.0496	0.0373	0.0449
output		0.0138	0.0087	0.0100
price level		0.0119	0.0063	0.0140
Structural Parameter Estimates:				
cons. elast term	σ_1	245.535	3.381	6.921
		(171.558)	(0.167)	(0.505)
money elast term	σ_2	16678.881	8.872	5.632
		(2752.066)	(0.420)	(0.180)
labor elasticity	σ_3	0.00093	0.00023	0.00020
		(0.00083)	(0.00000)	(0.00000)
Invest adjust cost	ψ_I	123456.717	1723.571	527.304
		(124154.819)	(330.331)	(4.161)
demand elast - goods	ν	0.003	0.711	0.945
		(0.001)	(0.054)	(0.120)

*Degrees of freedom = 213; **Degrees of freedom = 2.
Standard errors in parentheses.

Table 7: Flexible Prices or Wages

	Australia	Canada	U.K.
Sticky Price, Flexible Wage			
log likelihood value:			
model	2320.3289	2477.4098	2265.0191
unrestricted	2419.269	2585.629	2397.733
likelihood ratio	197.8809	216.4378	265.4269
p-value*	0.7482	0.4027	0.0074
comparison with benchmark model (table2)			
likelihood ratio	0.0552	0.0736	4.6043
p-value**	0.8142	0.7862	0.0319
RMSE - model:			
current account	0.0130	0.0086	0.0100
nominal e	0.0516	0.0360	0.0438
real e	0.0498	0.0373	0.0446
output	0.0122	0.0095	0.0102
price	0.0119	0.0091	0.0172
Sticky Wage, Flexible Price			
log likelihood value			
model	2284.651	2455.225	2260.677
unrestricted	2419.269	2585.629	2397.733
likelihood ratio	269.237	260.808	274.112
p-value*	0.005	0.013	0.003
comparison with benchmark model (table2)			
likelihood ratic	71.412	44.443	13.289
p-value**	0.000	0.000	0.000
RMSE - model:			
current account	0.0129	0.0086	0.0103
nominal e	0.0519	0.0367	0.0440
real e	0.0497	0.0373	0.0449
output	0.0137	0.0086	0.0098
price	0.0119	0.0064	0.0138

* degrees of freedom = 212; ** degrees of freedom = 1.

Table 8: Producer Currency Pricing Model

		Australia	Canada	U.K.
Measures of Fit:				
log likelihood value:				
model		2302.333	2452.715	2260.667
reduced form		2419.269	2585.629	2397.733
likelihood ratio		233.873	265.828	274.131
p-value*		0.134	0.006	0.002
RMSE - structural model:				
current account		0.0131	0.0087	0.0103
nominal ϵ		0.0514	0.0367	0.0441
real e		0.0498	0.0373	0.0451
output		0.0136	0.0086	0.0097
price level		0.0091	0.0064	0.0138
RMSE - reduced form model:				
current account		0.0115	0.0082	0.0087
nominal ϵ		0.0521	0.0354	0.0366
reale e		0.0499	0.0361	0.0381
output		0.0110	0.0064	0.0079
price level		0.0076	0.0042	0.0113
Structural Parameter Estimates:				
cons. elast term	σ_1	55.454	2.544	9.163
		(7.165)	(0.004)	(0.455)
money elast term	σ_2	43.281	12.303	7.109
		(2.339)	(0.309)	(0.313)
labor elasticity	σ_3	0.00142	0.00013	0.00015
		(0.00002)	(0.00000)	(0.00000)
Invest adjust cost	ψ_I	40112.578	896.542	1548.270
		(4161.319)	(59.775)	(333.561)
Price adjust cost	ψ_P	17.106	9.346	19.883
		(--)**	(0.294)	(4.857)
Wage adjust cost	ψ_w	0.005	0.027	0.073
		(0.000)	(0.000)	(0.003)
demand elast - goods	ν	0.109	0.325	0.420
		(0.006)	(0.012)	(0.048)

*Degrees of freedom = 211.

Supplementary table 1: Additional parameters from benchmark Mode

	Australia	Canada	U.K.
Autoregressive Parameters for Shocks:			
money supply growth rate	0.131	0.020	0.029
	(0.003)	(0.000)	(0.001)
interest rate	0.998	1.000	0.998
	(0.000)	(0.000)	(0.000)
foreign price	0.752	0.744	0.718
	(0.009)	(0.009)	(0.010)
technology	0.998	0.987	0.962
	(0.000)	(0.000)	(0.001)
taste	0.979	0.996	0.985
	(0.004)	(0.001)	(0.003)
government purchases	0.968	0.981	0.974
	(0.008)	(0.005)	(0.006)
money demand	0.984	0.994	0.992
	(0.003)	(0.001)	(0.002)
Shock Variances:			
money supply	0.00483	0.00462	0.00494
	(0.00060)	(0.00057)	(0.00061)
interest rate	0.00003	0.00003	0.00003
	(0.00000)	(0.00000)	(0.00000)
foreign price	0.00015	0.00007	0.00010
	(0.00001)	(0.00001)	(0.00001)
technology	0.00379	0.06336	0.01399
	(0.00045)	(0.00752)	(0.00166)
taste	0.00493	0.00130	0.02074
	(0.00046)	(0.00012)	(0.00195)
government purchases	0.10877	0.22144	0.63439
	(0.02221)	(0.04521)	(0.12954)
money demand	0.05429	0.54333	0.13762
	(0.04019)	(0.03739)	(0.04003)

Figure 1: Impulse Responses
Monetary Shock, Australia

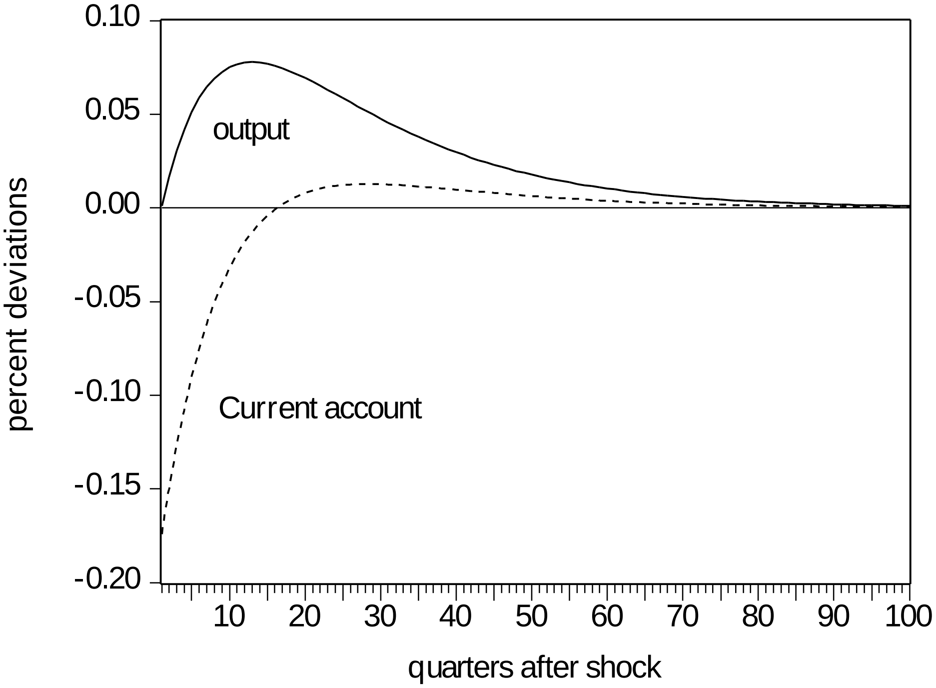

Figure 2: Impulse Responses
Monetary Shock, Australia