Journal of International Economics 60 (2003) 3–34
www.elsevier.com/locate/econbase

Putting the 'New Open Economy Macroeconomics' to a test

Paul R. Bergin*

Department of Economics, University of California, 1 Shields Avenue, Davis, CA 95616, USA

Received 24 January 2001; received in revised form 23 October 2001; accepted 8 December 2001

Abstract

This paper explores one way to extend the New Open Economy Macroeconomics in an empirical direction. Adapting maximum likelihood procedures, it estimates and tests an intertemporal small open economy model with monetary shocks and nominal rigidities. Results offer mixed support for a benchmark model where prices are assumed to be sticky in the currency of the buyer. Price stickiness seems to be an important element, as overall results are poorer for versions of the model in which prices either are flexible or are sticky in the currency of the producer. The benchmark model does a better job explaining some variables than others; in particular, it does a poor job explaining exchange rate movements.

Keywords: New open economy macroeconomics; Empirical model; Maximum likelihood procedures

JEL classification: F32; F41

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

*Tel.: +1-530-752-8398; fax: +1-530-752-9382.
E-mail address: prbergin@ucdavis.edu (P.R. Bergin).

0022-1996/02/$ – see front matter
doi:10.1016/S0022-1996(02)00057-0

based on optimizing agents.[1] Typically, monopolistic competition is incorporated to permit the explicit analysis of price-setting decisions. This literature has tended to focus on shocks to money supply, and demonstrates how such shocks can explain fluctuations in the current account and exchange rate. 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, 2000) argue that assuming prices are sticky in the currency of the buyer (local currency pricing) improves the model's ability to explain exchange rate behavior. On the other hand, Obstfeld and Rogoff (2000) argue in favor of prices sticky in the currency of the seller (producer currency pricing). 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 behind. While earlier generations of inter-temporal international models were evaluated econometrically using present value tests, this approach cannot accommodate the more complex models of the recent generation.[4] Without empirical testing, it is difficult to know which 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.

The present paper explores one approach for addressing these issues. A structural general equilibrium model of a semi-small open economy is estimated by maximum likelihood, and the fit of the model is evaluated by comparing the likelihood to that of an unrestricted counterpart.[5] In addition, alternative versions of the structural model are compared to each other in terms of their fit. The model

[1] See Lane (2001) for a detailed survey of this literature.

[2] To name just a few, Kollmann (2001) 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.

[4] See Sheffrin and Woo, 1990; Ghosh, 1995; Bergin and Sheffrin, 2000, for example.

[5] The estimation methodology used here was developed in Leeper and Sims (1994) and extended in Kim (2000), to estimate closed-economy structural models of monetary policy. The present methodology differs in that it is applied also to an unrestricted counterpart that nests the structural model, so as to permit likelihood ratio tests. The methodology is also extended to consider first differences and to allow correlated shocks. Ireland (1997, 2001) also estimates parameters in a closed economy model by a related maximum likelihood procedure, but utilizes these for different purposes and tests. Ghironi (2000) estimates a New Open Economy model by nonlinear least squares at the single-equation level and by FIML system-wide regressions, but again the tests applied are quite different.

is fit to a data set that includes the nominal exchange rate, the current account, output, money, home and world price levels, and the world real interest rate. Three small open economies are considered: Australia, Canada, and the United Kingdom. The model considers a range of structural shocks in addition to money supply, including shocks to technology, foreign interest rate, foreign demand, and consumer tastes.

Results show mixed support for a benchmark New Open Economy model. A likelihood ratio test does not reject the benchmark theoretical model in comparison with the unrestricted counterpart model for two of three countries considered. Comparisons with a more standard vector autoregression using the Schwarz criterion favor the structural model for all three countries. However, in forecasting individual variables, the structural model does better for some variables than others. The model has some predictive value for the price level and output, but the model cannot beat a random walk in predicting movements in the exchange rate or the current account for any of the three countries. Price rigidities appear to be a useful element in the model, since a version that assumes no such rigidity is rejected for all three countries. Results are ambiguous regarding the importance of wage stickiness. Also, price stickiness of the local currency variety appears to be more useful than the alternative of stickiness in the currency of the producer, as the latter case generates a somewhat lower likelihood value for all three countries.

The next section will present the structural model, and Section 3 will present the estimation methodology. Section 4 will present results and Section 5 will draw some conclusions.

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_t) 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:

$$Y_t = (Y_{Ht}^d)^{\theta}(Y_{Ft}^d)^{1-\theta} \quad (1)$$

[6] It's basic features are based on the model of Kollmann (2001).

where

$$Y^d_{Ht} = \left(\int_0^1 y_{Ht}(i)^{\frac{1}{1+v}} \, di \right)^{1+v} \tag{2}$$

$$Y^d_{Ft} = \left(\int_0^1 y_{Ft}(j)^{\frac{1}{1+v}} \, dj \right)^{1+v} \tag{3}$$

Here Y^d_{Ht} represents an aggregate of the home goods sold in the small open economy, and Y^d_{Ft} 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:

$$\pi_{1t} = \max\left[P_t Y_t - P_{Ht} Y^d_{Ht} - P_{Ft} Y^d_{Ft}\right] \tag{4}$$

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:

$$P_t = (1-\theta)^{\theta-1} \, \theta^{-\theta} P^{\theta}_{Ht} P^{1-\theta}_{Ft} \tag{5}$$

where

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

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

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:

$$Y^d_{Ht} = \theta Y_t (P_t / P_{Ht}) \tag{8}$$

$$Y^d_{Ft} = (1-\theta) \, Y_t (P_t / P_{Ft}) \tag{9}$$

with demands for individual goods:

$$y^d_{Ht}(i) = Y^d_{Ht} (p_{Ht}(i)/P_{Ht})^{-(1+v)/v} \tag{10}$$

$$y^d_{Ft}(j) = Y^d_{Ft} (p_{Ft}(j)/P_{Ft})^{-(1+v)/v} \tag{11}$$

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

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

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

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

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_t^*):

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

where χ_t 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):

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

In addition, home firms produce their goods out of differentiated home labor inputs, indexed by $h \in [0,1]$. Let $l_t(h,i)$ represent the demand for labor input h by producer i. These differentiated labor inputs are aggregated into the total demand for labor by firm i, $L_t(i)$, according to:

$$L_t(i) = \left(\int_0^1 l_t(h,i)^{\frac{1}{1+\eta}} \,\mathrm{d}h \right)^{1+\eta} \tag{16}$$

Let $w_t(h)$ denote the nominal wage of worker h, and let W_t denote the price index for labor inputs. Cost minimization then implies that this index be:

$$W_t = \left(\int_0^1 w_t(h)^{-\frac{1}{\eta}} \,\mathrm{d}h \right)^{-\eta} \tag{17}$$

Given the aggregation function above, labor demand will be:

$$l_t(h,i) = L_t(i) \left(\frac{w_t(h)}{W_t} \right)^{-\frac{1+\eta}{\eta}} \tag{18}$$

Demand for labor of worker h may be aggregated over producers as follows:

$$l_t(h) = \int_0^1 l_t(h,i)\,\mathrm{d}i \tag{19}$$

and overall labor demand as:

$$L_t = \int_0^1 L_t(i)\,\mathrm{d}i \tag{20}$$

2.2. Firm behavior

There are two types of monopolistically competitive intermediate 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 firm (i) rents capital ($K_t(i)$) at the real rental rate r_t, and hires labor ($L_t(i)$) at the nominal wage rate W_t to produce output of home goods ($z_t(i)$). The firm chooses the price for sale of its good in the home market ($p_{Ht}(i)$) and in the foreign market ($p_{Xt}(i)$) to maximize profits ($\pi_{Ht}(i)$), knowing that its choice of price will determine the level of demands for its good ($y^d_{Ht}(i)$ and $x^d_t(i)$). 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. The size of costs for adjusting both these prices are assumed to depend upon the same 'price adjustment cost parameter,' ψ_P.[7] The problem for these firms may be summarized:

$$\max E_0 \sum_{t=0}^{\infty} \rho_{t,t+n}\,\pi_{Ht}(i) \tag{21}$$

where

$$\begin{aligned}\pi_{Ht}(i) \quad = \quad & p_{Ht}(i)\,y^d_{Ht}(i) + e_t\,p_{Xt}(i)\,x^d_t(i) - P_t r_{t-1} K_{t-1}(i) \\ & - W_t L_t(i) - P_t AC_{Ht}(i) - e_t P_t AC_{Xt}(i)\end{aligned} \tag{22}$$

$$\text{s.t. } AC_{Ht}(i) = \frac{\psi_P}{2}\,\frac{(p_{Ht}(i) - p_{Ht-1}(i))^2}{P_t\,p_{Ht-1}(i)}\,y^d_{Ht}(i) \tag{23}$$

$$AC_{Xt}(i) = \frac{\psi_P}{2}\,\frac{(p_{Xt}(i) - p_{Xt-1}(i))^2}{P_t\,p_{Xt-1}(i)}\,y^d_{Xt}(i) \tag{24}$$

[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.

$$z_t(i) = A_t K_{t-1}(i)^{\alpha} L_t(i)^{1-\alpha} \tag{25}$$

$$z_t(i) = y^d_{Ht}(i) + y^d_{Xt}(i) \tag{26}$$

and subject to the demand functions for $y^d_{Ht}(i)$ and $y^d_{Xt}(i)$ above. Here A_t 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 period $t+n$.

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

$$P_t r_{t-1} K_{t-1}(i) = \frac{\alpha}{1-\alpha} W_t L_t(i) \tag{27}$$

Noting that in equilibrium $p_{Ht}(i) = p_{Ht}$ and $p_{Xt}(i) = p_{Xt}$ for all i, the optimal price setting rules are:

$$E_t\left[\frac{\rho_{t,t+i+1}}{\rho_{t,t+i}} \frac{\psi_P}{2}\left(\frac{p^2_{Ht+1}}{p^2_{Ht}} - 1\right) \frac{y^d_{Ht+1}}{y^d_{Ht}}\right] - \psi_P\left(\frac{p_{Ht}}{p_{Ht-1}} - 1\right) + \frac{1+\nu}{\nu}\left(\frac{P_t r_{t-1}}{p_{Ht} \alpha A_t (L_t(i)/K_{t-1}(i))^{(1-\alpha)}} + \frac{\psi_P}{2} \frac{(p_{Ht} - p_{Ht-1})^2}{p_{Ht} p_{Ht-1}} - 1\right) + 1 = 0 \tag{28}$$

$$E_t\left[\frac{\rho_{t,t+i+1}}{\rho_{t,t+i}} \frac{\psi_P}{2}\left(\frac{p^2_{Xt+1}}{p_{Xt}2} - 1\right) \frac{e_{t+1}}{e_t} \frac{x^d_{t+1}}{x^d_t}\right] - \psi_P\left(\frac{p_{Xt}}{p_{Xt-1}} - 1\right) + \frac{1+\nu}{\nu}\left(\frac{P_t r_{t-1}}{e_t p_{Xt} \alpha A_t (L_t(i)/K_{t-1})^{(1-\alpha)}} + \frac{\psi_P}{2} \frac{(p_{Xt} - p_{Xt-1})^2}{p_{Xt} p_{Xt-1}} - 1\right) + 1 = 0 \tag{29}$$

The importing firms choose the resale price ($p_{ft}(j)$) to maximize their profits. They too are subject to quadratic menu costs, which depend upon the same adjustment cost parameter as the goods prices above, ψ_P. Their problem may be summarized:

$$\max E_0 \sum_{t=0}^{\infty} \rho_{t,t+i} \pi_{Ft}(j) \tag{30}$$

where

$$\pi_{F(j)t} = (p_{Ft}(j) - e_t P^*_t)\, y^d_{Ft}(j) - P_t AC_{Ft}(j) \tag{31}$$

and

$$AC_{Ft}(i) = \frac{\psi_P}{2}\frac{(p_{Ft}(i) - p_{Ft-1}(i))^2}{P_t p_{Ft-1}(i)} y^d_{Ft}(j) \tag{32}$$

and subject to the demand functions for $y^d_{Ft}(i)$ above. Noting that in equilibrium $p_{Ft}(j) = p_{Ft}$ for all j, the optimal pricing rule is:

$$E_t\left[\frac{\rho_{t,t+i+1}}{\rho_{t,t+i}}\frac{\psi_P}{2}\left(\frac{p^2_{Ft+1}}{p^2_{Ft}} - 1\right)\frac{y^d_{Ft+1}}{y^d_{Ft}}\right] - \psi_P\left(\frac{p_{Ft}}{p_{Ft-1}} - 1\right) + \frac{1+\nu}{\nu}\left(e_t\frac{P^*_t}{p_{Ft}} + \frac{\psi_P}{2}\frac{(p_{Ft} - p_{Ft-1})^2}{p_{Ft}p_{Ft-1}} - 1\right) + 1 = 0 \tag{33}$$

2.3. Household behavior

The household/worker h derives utility from consumption ($C_t(h)$), and supplying labor ($L_t(h)$) lowers utility. For simplicity, real money balances ($M_t(h)/P_t$) 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 ($w_t(h_t)$), renting out capital to firms at the real rental rate (r_t), 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 holdings and returns on these bonds may be converted to units of the domestic consumption index by multiplying by $e_t P^*_t/P_t$. Investment ($I_t(h)$) in new capital ($K_t(h)$) involves a quadratic adjustment cost that depends upon the parameter ψ_I, and there is a constant rate of depreciation (δ). Households choose the wage at which they sell their differentiated labor, and there is a cost of changing this wage which depends upon the adjustment cost parameter ψ_W.

The optimization problem faced by the household may be expressed:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t(h), \frac{M_t(h)}{P_t}, L_t(h)\right) \tag{34}$$

$$\text{s.t. } \frac{w_t(h)}{P_t} L_t(h) + r_{t-1} K_{t-1}(h) + \int_0^1 (\pi_{Ht}(j) + \pi_{Ft}(j))\, \mathrm{d}j + T_t(h) + \left(\frac{e_t P_t^*}{P_t}\right) R_{t-1} B_{t-1}(h)$$
$$- C_t(h) - I_t(h) - \left(\frac{M_t(h) - M_{t-1}(h)}{P_t}\right) - AC_{It}(h) - AC_{Wt}(h) = \frac{e_t P_t^*}{P_t} (B_t(h) - B_{t-1}(h)) \tag{35}$$

$$AC_{It}(h) = \frac{\psi_I}{2} \frac{(K_t(h) - K_{t-1}(h))^2}{K_{t-1}(h)} \tag{36}$$

$$AC_{Wt}(h) = \frac{\psi_W}{2} \frac{(w_t(h) - w_{t-1}(h))^2}{P_t w_{t-1}(h)} l_t(h) \tag{37}$$

$$l_t(h) = L_t \left(\frac{w_t(h)}{W_t}\right)^{-\frac{1+\eta}{\eta}} \tag{38}$$

$$U_t(h) = \frac{1}{1-\sigma_1} (\tau_{ct} C_t(h))^{1-\sigma_1} + \frac{1}{1-\sigma_2} \left(\tau_{mt} \frac{M_t(h)}{P_t}\right)^{1-\sigma_2} - \frac{\sigma_3}{1+\sigma_3} l_t(h)^{\frac{1+\sigma_3}{\sigma_3}} \tag{39}$$

$$I_t(h) = K_t(h) - (1-\delta) K_{t-1}(h) \tag{40}$$

where $\sigma_i > 0$, $\sigma_i \neq 1$, for $i = 1 \ldots 3$, $\psi_I \geq 0$.

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

$$\frac{e_t P_t^*}{P_t} U'_{Ct}(h) = \beta(1 + R_t) E_t\left[\frac{e_{t+1} P_{t+1}^*}{P_{t+1}} U'_{Ct+1}(h)\right] \tag{41}$$

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.

$$P_t \frac{U'_{Mt}(h)}{U'_{Ct}(h)} = 1 - \left(\frac{1}{1+R_t}\right) E_t\left[\frac{P_t}{P_{t+1}}\right] \tag{42}$$

Third, noting that in equilibrium $w_t(h) = W_t$ for all h, the optimal wage-setting equation is:

$$E_t\left[\frac{\beta U'_{c,t+1}}{U'_{c,t}}\frac{\psi_W}{2}\left(\frac{W^2_{t+1}}{W^2_t}-1\right)\frac{L_{t+1}}{L_t}\frac{P_t}{P_{t+1}}\right]-\psi_W\left(\frac{W_t}{W_{t-1}}-1\right)$$
$$+\frac{1+\eta}{\eta}\left(\frac{L_t^{\sigma_3}C_t^{\sigma_1}\tau_t^{-\sigma_1}}{W_t/P_t}+\frac{\psi_W}{2}\frac{(W_t-W_{t-1})^2}{W_tW_{t-1}}-1\right)+1=0 \quad (43)$$

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

$$(1+R_t)\left(1+\frac{\psi_I(K_t(h)-K_{t-1}(h))}{K_{t-1}(h)}\right)=r_t+(1-\delta)$$
$$+\frac{\Psi_I}{2}E_t\left(\frac{K^2_{t+1}(h)-K^2_t(h)}{K^2_t(h)}\right) \quad (44)$$

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

$$\int_0^1 T_t(h)\,\mathrm{d}h+G=\frac{1}{P_t}(M_t-M_{t-1}) \quad (45)$$

and the money market clearing condition is:

$$M_t=\int_0^1 M_t(h)\,\mathrm{d}h \quad (46)$$

The resource constraint for final goods is:

$$Y_t=\int_0^1(C_t(h)+I_t(h)+AC_{It}(h)+AC_{Wt}(h))\,\mathrm{d}h+G+\int_0^1 AC_{Xt}(i)\,\mathrm{d}i$$
$$+\int_0^1 AC_{Ft}(j)\,\mathrm{d}j \quad (47)$$

The current account may be computed as:

$$CA_t = \frac{e_t P_t^*}{P_t} \int_0^1 (B_t(h) - B_{t-1}(h))\, \mathrm{d}h \tag{48}$$

and the real exchange rate as:

$$q_t = \frac{e_t P_t^*}{P_t} \tag{49}$$

The stochastic shocks in the model are specified to follow:

$$\begin{aligned}
(R_t - \overline{R}) &= \rho_R(R_{t-1} - \overline{R}) + \varepsilon_{Rt} \\
(\log P_t^* - \log P_{t-1}^*) &= \rho_{P*}(\log P_{t-1}^* - \log P_{t-2}^*) + \varepsilon_{P*t} \\
(\log \chi_t - \log \overline{\chi}) &= \rho_x(\log \chi_{t-1} - \log \overline{\chi}) + \varepsilon_{xt} \\
(\log A_t - \log \overline{A}) &= \rho_A(\log A_{t-1} - \log \overline{A}) + \varepsilon_{At} \\
(\log \tau_{ct} - \log \overline{\tau_c}) &= \rho_c(\log \tau_{ct-1} - \log \overline{\tau_c}) + \varepsilon_{ct} \\
(\log \tau_{mt} - \log \overline{\tau_m}) &= \rho_m(\log \tau_{mt-1} - \log \overline{\tau_m}) + \varepsilon_{mt} \\
(\log M_t - \log M_{t-1}) &= \rho_M(\log M_{t-1} - \log M_{t-2}) + \varepsilon_{Mt}
\end{aligned} \tag{50}$$

$$[\varepsilon_{Rt}, \varepsilon_{P*t}, \varepsilon_{xt}, \varepsilon_{At}, \varepsilon_{ct}, \varepsilon_{mt}, \varepsilon_{Mt}]' \sim N(0, \Sigma_1)$$

Note that the shocks may be correlated with each other. This was found to be important in improving the fit of the theoretical model and allow it to compete with the unrestricted counterpart, which likewise allows the shocks to be correlated. Recall that the theoretical restrictions to be tested all relate to the autoregressive coefficients of the model. Furthermore, this assumption is arguably well suited to a small open economy, where several of the variables are taken to be determined outside the model.[8] Furthermore, the fact that the shocks to money growth may be correlated with the other shocks may be 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. Note also that since the data to which the model is fit are detrended, this is consistent with the fact that the shock processes above do not try to explain exogenous trends in series like money supply.

The model will be analyzed in a form log-linearized around a deterministic steady state. Equilibrium for this economy includes sequences for 16 endogenous variables: consumption (C), labor (L), home goods production (Z), capital stock (K), bond position (B), home price index (P), price of home goods sold at home

[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.

(P_H), price of imported goods (P_F), export price of home goods (P_X), domestic demand for home goods (Y_H^d), domestic demand for imported goods (Y_F^d), demand for foreign exports (X), wage (W), real rental rate on capital (r), nominal exchange rate (e), final goods demand (Y). These variables are matched by 16 equilibrium conditions: the consumption euler Eq. (41), production function (25), definition of home goods production (26), capital accumulation optimality condition (44), the resource constraint (47), price index definition (5), optimal price setting conditions (28), (29), (33), shares of home and imported goods in domestic final output (8), (9), export demand function (14), optimal wage setting condition (43), capital–labor trade-off in production (27), money demand condition (42), and the household budget constraint (35).

In addition, there are three conditions to define related variables that are of interest in the empirical exercise: one to define the current account (48), define investment (40), and define the real exchange rate (49). There are also the seven stochastic equations in (50) defining the role of shocks for the exogenous variables: R, P^*, X, A, τ_c, τ_m, and M. Because the equations above involve expected future values of prices and wages, four equations are used to define these. Finally, because the equations above involve double lags of capital, interest rate, and money, three equations are created to define these variables in the context of the first-order autoregressive structure. Altogether this amounts to a set of 33 variables and 33 linearized equations. A solution for the model equilibrium is found using the method of Blanchard and Kahn (1980).

3. Empirical methods

3.1. Data

Data from three small open economies will be considered: Australia, Canada, and the United Kingdom. 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. Because the estimation algorithm is computationally very intensive, it is important to limit the list of variables to the most essential. Given that the New Open Economy literature is primarily interested in explaining real and nominal exchange rates as well as the current account, this mandates the first four variables listed above. To capture the potentially important roles of shifts in technology and policy, output and money supply are included. Finally, the world interest rate provides a simple way to capture explanatory factors arising outside the small open economy. All data are seasonally adjusted quarterly series at annual rates for the period 1973:2 to 1996:4, 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 interest rate and the current account are logged. 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. The real interest rate is not logged because it can take negative values.

Output (Y) is measured as national GDP, money (M) by M1, and the domestic price level (P) by the CPI.[9] 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 UK are near their 10% critical values.[10] 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

[9] For the UK, the series quasi money, supplied by IFS, is used.

[10] Results for the Dickey–Fuller test, not shown, are similar.

Table 1
Unit root tests

	Australia	Canada	UK
Phillips–Perron test			
Output			
Levels	−2.4622	−1.3565	−2.1387
Differences	−10.6771**	−5.4435**	−8.5192**
Current account			
Levels	−3.8756*	−2.1228	−2.1297
Differences	−13.6025**	−10.8494**	−12.5137**
Money			
Levels	0.5865	−1.1555	−1.2471
Differences	−8.8466**	−8.0456**	−9.1453**
Exchange rate			
Levels	−2.6189	−2.4922	−2.4559
Differences	−10.6173**	−9.0604**	−7.5132**
Price Level			
Levels	−1.1286	0.4643	−1.3842
Differences	−5.9960**	−5.0791**	−8.7884**
World price level			
Levels	−0.5104	−0.6122	−0.5138
Differences	−5.7204**	−5.8607**	−5.9572**
Interest rate			
Levels	−2.4869	−2.5530	−2.6385
Differences	−12.9088**	−13.1721**	−13.1493**

** Indicates unit root rejected at 1% significance level; * Indicates rejected at 5% level. Tests run with three lags. Range is 1973Q2 to 1996Q4. Critical values: 1% −4.06; 5% −3.46; 10% −3.15.

and Sims (1994) and Kim (2000). This estimation methodology is extended here to accommodate first differences in the data and to allow for correlations among the shocks. The method is also adapted to estimate an analogous unrestricted 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 and solved structural model discussed in the previous section is a set of seven stochastic equations and 26 deterministic equations. By using model equations to substitute out variables, the linearized model can be written in its most compact first-order autoregressive form as 15 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 following form:

$$y_t = Ay_{t-1} + A\varepsilon_t \tag{51}$$

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

where y is a 15-element column vector of variables in percent deviations from steady state; A, which appears twice, is a 15×15 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 7×7 covariance matrix of the disturbances in ε.

The model will be dealt with in first differences. This is done for several 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 (51). 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:

$$y_t^* = Ay_{t-1}^* + A\varepsilon_t - A\varepsilon_{t-1} \tag{52}$$

where

$$y_t^* = y_t - y_{t-1}$$

This stochastic model implies a log likelihood function:

$$L(\Pi) = -0.5 \ln|\Omega| - 0.5x'\Omega^{-1}x \tag{53}$$

where x is the vector of differenced variables to which the model is fit, over all periods and stacked into a single vector. Ω is the theoretical variance–covariance matrix of x. Appendix A 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 Eq. (52) 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 Appendix A.

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 (51) and (52), 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.[11] 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, 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. Appendix A 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

[11] As in the structural model, A is restricted to have roots less than or equal to unity. See Appendix A for details.

(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.[12]

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 and 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.

Convergence here can be time-consuming and dependent on good starting values. Numerical issues such as rounding error can create problems for convergence. Optimization software developed by Christopher Sims is used which is more robust to these difficulties.

4. Results

4.1. Benchmark Model

The results of the estimated benchmark model are reported in Table 2, where an overall evaluation of the model can be read from the log likelihood value. First consider a comparison with the unrestricted counterpart model defined in the previous section. Line 4 of Table 2 indicates that a likelihood ratio test fails to reject the restrictions implied by the structural model relative to this counterpart in two of the three cases, Australia and Canada. For the case of the United Kingdom, the model is rejected at the 5% significance level. The structural model can be compared also with an unrestricted model that is more standard and familiar, a simple first-order vector autoregression (VAR) of the seven data series. However, the structural model is not nested in such a VAR, which rules out a comparison based on a likelihood ratio test.[13] Lines six and seven of Table 2 present a comparison based on the Schwarz criterion, indicating that the structural model

[12] 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.

[13] Firstly, the structural model requires some state variables to enter the equations lagged more than once, and secondly, its estimation does not condition on the initial observations as does standard VAR estimation.

Table 2
Benchmark sticky price and wage model

		Australia	Canada	UK
Measures of fit				
Log likelihood value				
Model		2491.73	2629.00	2430.92
Unrestricted		2597.54	2749.26	2556.94
Likelihood ratio		211.60	240.52	252.04
P value*		0.48	0.08	0.03
Standard VAR		2481.84	2640.91	2427.57
Schwarz (model)		2450.40	2587.66	2389.58
Schwarz (VAR)		2406.05	2565.12	2351.78
RMSE: structural model/standard VAR				
Current account		1.13	1.03	1.12
nominal *e*		1.06	1.07	1.06
Real *e*		1.06	1.05	1.09
Output		1.05	1.21	1.08
Price level		0.98	1.18	1.09
RMSE: structural model/random walk				
Current account		1.01	1.01	1.03
Nominal *e*		1.04	1.04	1.04
Real *e*		1.03	1.03	1.06
Output		0.99	0.93	0.98
Price level		0.73	0.59	0.80
Main structural parameter estimates				
Consumption	σ_1	37.084	18.777	24.599
elasticity term		(1.697)	(2.522)	(0.549)
Money demand	σ_2	4.972	3.822	2.523
elasticity term		(0.203)	(0.036)	(0.163)
Labor supply	σ_3	0.0004	0.0008	0.0002
elasticity		(0.0000)	(0.0001)	(0.0000)
Investment	ψ_I	265.418	267.682	439.792
adjustment cost		(77.571)	(47.976)	(60.184)
Price adjustment	ψ_P	189.628	68.129	330.483
cost		(34.284)	(4.243)	(27.529)
Wage adjustment	ψ_w	0.077	0.044	0.064
cost		(0.001)	(0.002)	(0.001)
Demand elasticity	ν	1.087	6.102	0.678
term for goods		(0.079)	(1.027)	(0.017)

Values in parentheses indicate standard errors. * Degrees of freedom = 211.

outperforms the standard VAR for all three countries by this measure.[14] These results together offer some statistical support for the benchmark New Open Economy model.

[14]The Schwarz criterion here is calculated as the log likelihood minus $0.5 \cdot k \cdot \log(n)$, where k is the number of free parameters and n is the number of observations.

Table 2 also reports the root mean squared errors (RMSE) for one-step ahead forecasts for the five endogenous variables to which the model is fit. As in Meese and Rogoff (1983) these RMSE are reported in comparison with those of a random walk model, indicating whether the theory has any predictive content.[15] As an additional comparison, RMSE are also reported relative to the standard VAR. The structural model appears to perform best for the price level and output, where it beats the random walk model for all three countries. The structural model does less well on the current account, where it fails to beat the random walk. A striking feature here is the very poor performance on exchange rates. The structural model fails to come close to the random walk model for any of the three countries for the nominal or real exchange rate. This is despite the fact that the model is able to replicate the degree of volatility observed in the data: the model implies a standard deviation of the nominal and real exchange rates (as ratios to output) equal to 4.80 and 4.24, respectively, compared to 4.24 and 4.10 in the data. While past studies have found that price stickiness in the currency of the buyer can help a model match the moments of the exchange rate, apparently this is not sufficient to match the actual time path of this variable.

The overall conclusion is one of mixed support. By some criteria of fit, the model performs better than one might have expected for such a highly structural model. Furthermore, the model has some ability in forecasting particular variables like the price level and output. But disappointingly, the model does a poor job in explaining key international variables, especially exchange rates. This last conclusion should perhaps not come as a surprise, given the poor performance of structural macroeconomic models on this count documented by Meese and Rogoff (1983) and other researchers.

Table 2 also reports key parameter values implied by the estimation, which are mostly reasonable and statistically significant. For all three countries the intertemporal elasticity ($1/\sigma_1$) appears to be very small (below 0.1). While these values are smaller than typically are assumed in calibration studies, Hall (1988) and others have found 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 near to zero.[16] The investment adjustment cost is sizeable. For Australia, for example, a value of $\Psi_I = 265.4$ indicates that if Australia raises investment expenditure 1% above its steady state level, approximately 13.3% of this extra investment expenditure goes toward paying the adjustment cost. The adjustment

[15] Unlike Meese and Rogoff (1983), the forecasts here are in sample.

[16] As a check, the model was re-estimated for Australia under the restriction that the labor supply elasticity takes the more usual value of unity. The maximum likelihood value in this case is 2478.00, much lower than for the benchmark model, and the restriction is rejected even at the 1% significance level.

cost for prices is also sizeable. For Australia, the value of $\psi_P = 189.6$ implies that after a shock to money supply, the aggregate price level moves about 9% of the way toward its long run level each quarter, so that it has a half-life of 7.9 quarters. The adjustment cost for wages is much lower than that estimated for prices.

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.

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, they will be orthogonalized here to make the decomposition easier to interpret. Since the structural model provided sufficient theoretical restrictions to identify the shocks without the need to assume orthogonality, 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, similarly to what is common with nonstructural VARs. The ordering of shocks 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.[17]

Table 3 reports the results of variance decompositions for Australia. Results for the other two countries are very similar. Regarding the current account, it appears that money supply shocks account for only a small fraction of the forecast error variance.[18] But in all three countries, the largest share of current account fluctuation is attributed to taste shocks.[19] 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

[17]The estimated correlations between the shocks identified in the model are generally quite low (almost all under 0.10), so that experiments with reordering shocks had only minor impacts on the variance decompositions. An exception are taste shocks and foreign demand shocks, which are highly correlated. As a result, it is difficult to distinguish their separate effects, and the ordering of these two variables makes a large difference in variance decompositions.

[18]The role of money supply in current account movements is somewhat larger for Canada than for the other two countries, ranging between 20 and 30%. In related work, Lane (1999) finds using structural VAR techniques that monetary shocks account for between 10 and 50% of current account fluctuations.

[19]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.

Table 3
Variance decompositions benchmark model: Australia

	Period	Shocks						
		Interest rate	Foreign price	Foreign demand	Technology	Tastes	Money demand	Money supply
Current account	1	0.011	0.002	0.064	0.014	0.879	0.007	0.024
	2	0.011	0.001	0.036	0.010	0.913	0.006	0.023
	3	0.012	0.001	0.028	0.007	0.926	0.006	0.021
	4	0.014	0.001	0.023	0.006	0.932	0.005	0.020
	5	0.016	0.001	0.020	0.008	0.934	0.005	0.018
	10	0.027	0.001	0.012	0.035	0.910	0.003	0.012
	20	0.050	0.003	0.006	0.093	0.840	0.002	0.007
Nominal *e*	1	0.000	0.026	0.001	0.035	0.005	0.260	0.673
	2	0.000	0.042	0.002	0.026	0.018	0.246	0.666
	3	0.000	0.057	0.004	0.019	0.037	0.232	0.651
	4	0.000	0.072	0.008	0.014	0.062	0.216	0.629
	5	0.000	0.084	0.011	0.012	0.091	0.199	0.602
	10	0.000	0.112	0.033	0.027	0.261	0.123	0.445
	20	0.002	0.087	0.063	0.088	0.496	0.045	0.220
Real *e*	1	0.000	0.005	0.017	0.034	0.001	0.268	0.674
	2	0.000	0.006	0.016	0.029	0.005	0.263	0.681
	3	0.000	0.007	0.015	0.024	0.012	0.258	0.684
	4	0.000	0.008	0.013	0.021	0.022	0.252	0.684
	5	0.000	0.009	0.012	0.018	0.034	0.246	0.681
	10	0.002	0.010	0.008	0.017	0.125	0.208	0.630
	20	0.002	0.007	0.011	0.055	0.324	0.138	0.463
Output	1	0.002	0.041	0.014	0.942	0.001	0.000	0.000
	2	0.003	0.044	0.011	0.941	0.001	0.000	0.000
	3	0.003	0.046	0.009	0.940	0.002	0.000	0.000
	4	0.002	0.048	0.007	0.939	0.004	0.000	0.001
	5	0.002	0.049	0.006	0.936	0.006	0.000	0.001
	10	0.008	0.051	0.008	0.905	0.024	0.000	0.004
	20	0.033	0.044	0.034	0.781	0.099	0.000	0.009

does not account for a large share of output variations, although the estimate here is even lower than that found in other studies.

However, money supply shocks are assigned a more important role when it comes to 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 40–60% in the long run. The large role for money in driving the real exchange rate probably results from the estimate of a substantial 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. Rogers (1999) found between 19 and 60%. Faust and Rogers (2000) found estimates ranging from the single digits to around 50% using a structural VAR that considered a wide range of identification 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. Figs. 1 and 2 show the impulse responses to a 1% shock to the money supply growth rate for Australia. To make interpretation easier, the variables are plotted in percent deviations from the initial steady state rather than in first differences. 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 4 reports results for a model in which there is no price or wage stickiness, so the two stickiness parameters ψ_P and Ψ_W are set to zero. The likelihood values are much lower than for the reduced form counterpart, and a likelihood ratio test rejects the model for all three countries. The model without stickiness may also be compared to the benchmark model with stickiness from

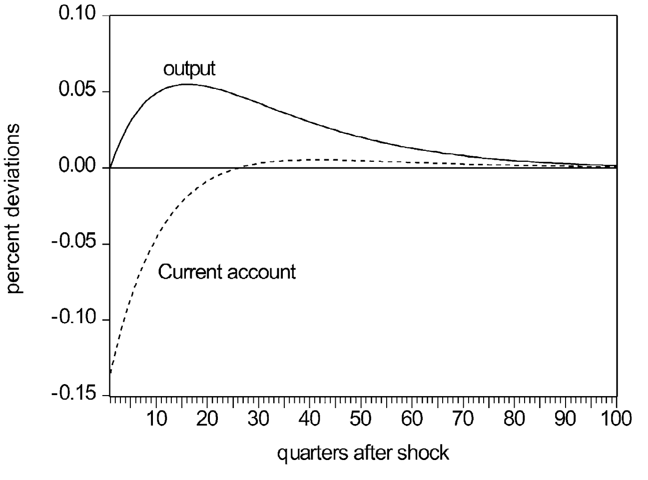

Fig. 1. Impulse responses: monetary shock (Australia).

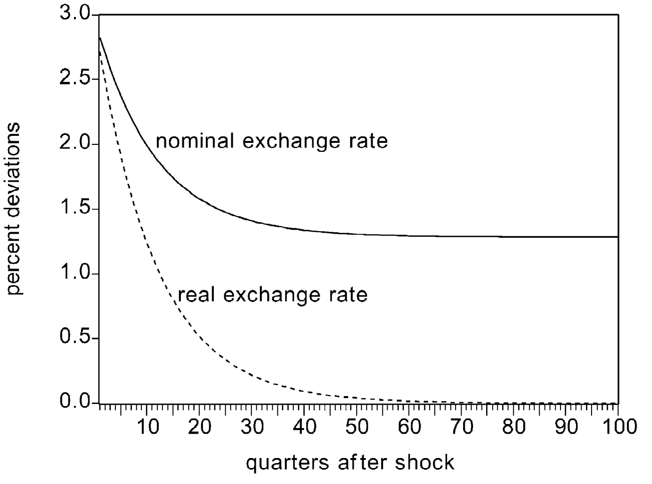

Fig. 2. Impulse responses: monetary shock (Australia).

Table 2, since it can be regarded as a restricted version of the benchmark model with two additional restrictions imposed ($\psi_P = \psi_W = 0$). Table 4 reports a likelihood ratio test comparing these two structural models, which specifically rejects the two restrictions of no stickiness. Finally, the Schwarz criterion for all three countries is well below that of the benchmark model.

These rejections are informative, first because they indicate the likelihood ratio 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 overall success found above for the New Open Economy approach. However, the root mean squared errors 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 for Australia and Canada, indicating that stickiness is present and important for understanding how prices move in response to shocks. Regarding output, the residuals are uniformly larger 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.

The current account residuals are similar under the two cases, indicating that nominal rigidities may not be important for understanding fluctuations in the current account. Finally, the model without nominal rigidities does better explaining the nominal exchange rate than did the benchmark model with rigidities,

Table 4
Flexible price and wage model

		Australia	Canada	UK
Measures of fit				
Log likelihood value				
Model		2468.41	2610.67	2395.71
Unrestricted		2597.54	2749.26	2556.94
Likelihood ratio		258.26	277.18	322.45
P value*		0.02	0.00	0.00
Comparison with benchmark model (Table 2)				
Likelihood ratio		46.65	36.66	70.41
P value**		0.00	0.00	0.00
Schwarz (model)		2429.04	2571.30	2356.34
RMSE: structural model/VAR				
Current account		1.15	1.08	1.10
Nominal *e*		1.02	1.03	1.04
Real *e*		1.03	1.02	1.04
Output		1.12	1.30	1.46
Price level		1.10	1.36	1.05
RMSE: structural model/random walk				
Current account		1.02	1.05	1.01
Nominal *e*		1.00	1.01	1.01
Real *e*		1.00	1.00	1.01
Output		1.06	1.01	1.33
Price level		0.82	0.68	0.77
Main structural parameter estimates				
Consumption	σ_1	30.728	9.545	24.149
elasticity term		(1.079)	(0.297)	(0.560)
Money demand	σ_2	18.651	14.637	4.548
elasticity term		(0.587)	(0.524)	(0.050)
Labor supply	σ_3	0.0007	0.0005	0.0002
elasticity		(0.0000)	(0.0000)	(0.0000)
Investment	ψ_I	465.508	1238.452	106.457
adjustment cost		(8.336)	(290.598)	(3.664)
Demand elasticity	ν	1.117	1.680	1.369
term for goods		(0.037)	(0.140)	(0.035)

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

reflecting the poor performance of the benchmark model described in the previous section.

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 5 summarizes results for two restricted versions of the model: the top portion shows a version in which

Table 5
Flexible prices or wages

	Australia	Canada	UK
Sticky price, flexible wage			
Log likelihood value			
Model	2491.11	2624.18	2429.70
Unrestricted	2597.54	2749.26	2556.94
Likelihood ratio	212.86	250.16	254.47
P value*	0.47	0.04	0.02
Comparison with benchmark model (Table 2)			
Likelihood ratio	1.26	9.63	2.43
P value**	0.26	0.00	0.12
Sticky wage, flexible price			
Log likelihood value			
Model	2471.01	2618.00	2399.38
Unrestricted	2597.54	2749.26	2556.94
Likelihood ratio	253.05	262.51	315.10
P value*	0.03	0.01	0.00
Comparison with benchmark model (table2)			
Likelihood ratio	41.45	21.99	63.06
P value**	0.00	0.00	0.00

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

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. For all three countries we can reject the single restriction that prices are flexible. But the single restriction that wages are flexible is rejected strongly only for one country. While the results are mixed, it appears that price stickiness is generally more important to the model's fit here. It is quite possible that the estimate of the wage adjustment cost parameter is influenced by the exclusion of labor market data from the data set. Future work should consider this extension. Nevertheless, the fact that the estimation algorithm had the ability to choose any value of wage stickiness but failed to raise the likelihood value, indicates this was not found to be a particularly useful means in this model of explaining the variables that are in the data set, notably output, current account, and the 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, 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, 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). Furthermore, the profits of home exporting firms must be redefined in problem (22) as:

$$\pi_H(i)_t = p_{Ht}(i)\, y^d_{Ht}(i) + p_{Xt}(i)\, x^d_t(i) - P_t r_{t-1} K_{t-1}(i) - W_t L_t(i) - P_t AC_{Ht}(i) - P_t AC_{Xt}(i) \qquad (54)$$

so the optimal price setting rule for exports (29) is replaced by:

$$E_t\left[\frac{\rho_{t,t+i+1}}{\rho_{t,t+i}}\frac{\psi_P}{2}\left(\frac{p^2_{Xt+1}}{p^2_{Xt}}-1\right)\frac{x^d_{t+1}}{x^d_t}\right] - \psi_P\left(\frac{p_{Xt}(i)}{p_{Xt-1}(i)}-1\right) + \frac{1+\nu}{\nu}\left(\frac{P_t r_{t-1}}{p_{Xt}(i)\,\alpha A_t (L_t(i)/K_{t-1}(i))^{(1-\alpha)}} + \frac{\psi_P}{2}\frac{(p_{Xt}-p_{Xt-1})^2}{p_{Xt}p_{Xt-1}} - 1\right) + 1 = 0 \qquad (55)$$

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 $e_t P_{Ft}$ in the home demand for imported goods (9) and also the home consumer price index (5). The profits of home importing firms in problem (31) must be redefined:

$$\pi_F(j)_t = (e_t p_{Ft}(j) - e_t P^*_t)\, y^d_{Ft}(j) - e_t P_t AC_{Ft}(j) \qquad (56)$$

so the optimal price setting rule (33) is replaced by:

$$E_t\left[\frac{\rho_{t,t+i+1}}{\rho_{t,t+i}}\frac{\psi_P}{2}\left(\frac{p_{Ft+1}(i)}{p_{Ft}(i)}-1\right)^2\frac{y^d_{Ft+1}}{y^d_{Ft}}\frac{e_{t+1}}{e_t}\right] - \psi_P\left(\frac{p_{Ft}(i)}{p_{Ft-1}(i)}-1\right) + \frac{1+\nu}{\nu}\left(\frac{P^*_t}{p_{Ft}(i)}-1\right) + 1 = 0 \qquad (57)$$

Results of estimating this model are found in Table 6. 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 6 indicates that the producer currency pricing model is rejected for two of the three countries, Canada and the United Kingdom. Even while the model is not rejected for Australia, the P value is 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 generally supportive of the recent trend in the New Open Economy

Table 6
Producer currency pricing model

		Australia	Canada	UK
Measures of fit				
Log likelihood value				
Model		2483.87	2619.66	2428.08
Unrestricted		2597.54	2749.26	2556.94
Likelihood ratio		227.33	259.20	257.71
P value*		0.21	0.01	0.02
Regular VAR		2481.84	2640.91	2427.57
Schwarz (model)		2442.53	2578.32	2386.74
Schwarz (VAR)		2406.05	2565.12	2351.78
RMSE: structural model/VAR				
Current account		1.14	1.02	1.10
Nominal *e*		1.02	1.04	1.04
Real *e*		1.03	1.02	1.04
Output		1.13	1.29	1.19
Price level		1.01	1.34	1.09
RMSE: structural model/random walk				
Current account		1.01	0.99	1.02
Nominal *e*		1.00	1.01	1.01
Real *e*		1.00	1.00	1.01
Output		1.06	1.00	1.09
Price level		0.75	0.67	0.80
Main structural parameter estimates				
Consumption	σ_1	49.268	12.766	48.136
elasticity term		(3.069)	(1.206)	(0.235)
Money demand	σ_2	23.723	99.886	17.268
elasticity term		(1.489)	(11.924)	(0.497)
Labor supply	σ_3	0.0011	0.0002	0.0010
elasticity		(0.0000)	(0.0000)	(0.0000)
Investment	ψ_I	380.750	16473.796	736.221
adjustment cost		(108.253)	(3650.108)	(39.363)
Price adjustment	ψ_P	46.728	7.704	39.722
cost		(0.249)	(0.689)	(0.496)
Wage adjustment	ψ_w	0.041	0.046	0.099
cost		(0.000)	(0.000)	(0.000)
Demand elasticity	ν	0.179	0.097	0.138
term for goods		(0.005)	(0.014)	(0.002)

*Degrees of freedom = 211.

Macroeconomics to assume local currency pricing rather than producer currency pricing.

Looking at the forecast residuals, the PCP model does uniformly less well than the LCP benchmark model for forecasting output and the price level. For the current account, the producer and local currency pricing models are fairly similar.

For the exchange rate, the PCP model does better, but it still fails to beat the random walk.

Overall, the results further support the conclusions drawn previously. The local currency pricing benchmark model performs fairly well overall and for particular variables like price level and output. On these counts the benchmark model also outperforms alternative structural models, like flexible prices and prices sticky in the currency of the producer. But the benchmark model performs poorly in terms of explaining exchange rates, relative to reduced form comparison models as well as against alternative structural models.

5. Conclusion

This paper has explored one promising approach for giving the New Open Economy Macroeconomics an empirical dimension. 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 results showed some mixed support for a benchmark model. In comparison with an unrestricted counterpart model, the restrictions of the structural model were not rejected in two of three countries. The structural model fared even better in comparison with a more standard vector autoregression, where the Schwarz criterion favored the structural model for all three countries. However, the model's performance was poorer in terms of forecasting individual variables. While the model has some predictive value for the price level and output, the model cannot beat a random walk in predicting movements in the exchange rate or the current account for any of the three countries.

Price rigidities appear to be a useful element in the model, since a version that assumes no such rigidity is rejected for all three countries. 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.

Acknowledgements

I would like to thank seminar participants at University of California–Berkeley, University of Munich, Institute for Advanced Studies in Vienna, the Federal Reserve Bank of San Francisco, and conference participants at the University of Wisconsin. I acknowledge financial support from the Economics Program of the National Science Foundation.

Appendix A

The estimation strategy applied here is drawn from that developed in Leeper and Sims (1994), although it differs in its handling of first differences, in allowing correlated shocks, and in the fact it is applied also to an unrestricted counterpart model. Given the autoregressive moving average model in (52), the contemporaneous covariances matrix, $R_{y*}(0)$, can be written as follows:

$$\begin{aligned} R_{y*}(0) &\equiv E[y_t^* y_t^{*\prime}] \\ &= A\Sigma A' + \sum_{i=0}^{\infty} [BD^i(D-I)\, B^{-1}]\, A\Sigma A' [BD^i(D-I)\, B^{-1}]' \end{aligned} \tag{58}$$

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

$$R_{y*}(0) = A\Sigma A' + B[K]B' \tag{59}$$

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

$$K_{ij} = \begin{cases} \dfrac{(1-d_i)(1-d_j)\, M_{ij}}{1-d_i d_j} & \text{for} \quad d_i \neq 1 \quad \text{or} \quad d_j \neq 1 \\ 0 & \text{for} \quad d_i = 1 \quad \text{and} \quad d_j = 1 \end{cases} \tag{60}$$

where

$$M = B^{-1} A\Sigma A' B^{-1\prime} \tag{61}$$

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

$$\lim_{d_i \to 1, d_j \to 1} \frac{(1-d_i)(1-d_j)\, M_{ij}}{1-d_i d_j} = 0 \tag{62}$$

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

$$R_{y*}(1) = E[y_t^* y_{t-1}^{*\prime}] = A \qquad R_{y*}(0) - A\Sigma A' \tag{63}$$

and over lags greater than one:

$$R_{y*}(k) = E[y_t^* y_{t-k}^{*\prime}] = A^{k-1} \qquad R_{y*}(1) \text{ for } k > 1 \tag{64}$$

The full covariance matrix, Ω, can be constructed by assembling the blocks for various lags.[20] 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 Ω for the observed variables in vector x then is constructed by selecting only those elements of the full covariance matrix that pertain to these variables. The covariance matrix is a key component in computing the log-likelihood to be maximized:

$$L(\Pi) = -0.5 \ln|\Omega| - 0.5x'\Omega^{-1}x \tag{65}$$

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 $\bar{A}$. 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 Eq. (52), 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 delta method is used to adjust these error variances for the parameter transformations discussed above, used to impose boundaries on the parameter estimates.[21] 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:

---

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

[21] 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.

$$v = \varpi^{-1} y^{*} \tag{66}$$

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

$$v_t^{*} = \left(\varpi^{-1}\right)_{tt}^{-1} v_t \tag{67}$$

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

References

Ahmed, S., Ickes, B., Wang, P., Yoo, B.S., 1993. International business cycles. American Economic Review 83, 335–339.

Barro, R.J., Sala i Martin, X., 1990. World real interest rates. In: Blanchard, O.J., Fischer, S. (Eds.), NBER Macroeconomics Annual. MIT Press, Cambridge, MA, pp. 15–61.

Bergin, P.R., Sheffrin, S., 2000. Interest rates, exchange rates, and present value models of the current account. Economic Journal 110, 535–558.

Betts, C., Devereux, M.B., 1996. The exchange rate in a model of pricing-to-market. European Economic Review 40, 1007–1021.

Betts, C., Devereux, M.B., 2000. Exchange rate dynamics in a model of pricing-to-market. Journal of International Economics 50, 215–244.

Blanchard, O., Kahn, C., 1980. The solution of linear difference models under rational expectations. Econometrica 48, 1305–1311.

Devereux, M.B., Engel, C., 1998. Fixed vs. Floating Exchange Rates: How Price Setting Affects the Optimal Choice of Exchange-rate Regime. NBER Working Paper no. 6867.

Eichenbaum, M., Evans, C.L., 1995. Some empirical evidence on the effects of shocks to monetary policy on exchange rates. Quarterly Journal of Economics 110, 975–1009.

Engel, C., 1993. Real exchange rates and relative prices: an empirical investigation. Journal of Monetary Economics 32, 35–50.

Engel, C., 1999. Accounting for U.S. real exchange rate changes. Journal of Political Economy 107, 507–538.

Erceg, C.J., 1997. Nominal Wage Rigidities and the Propagation of Monetary Disturbances. Board of Governers of the Federal Reserve System Working Paper.

Faust, J., Rogers, J.H., 2000. Monetary Policy's Role in Exchange Rate Behavior. Board of Governors of the Federal Reserve System Working Paper.

Ghironi, F., 2000. Towards A New Open Economy Macroeconometrics. Boston College Working Paper.

Ghosh, A.R., 1995. International capital mobility among the major industrialised countries: too little or too much? Economic Journal 105, 107–128.

Glick, R., Rogoff, K., 1995. Global versus country-specific productivity shocks and the current account. Journal of Monetary Economics 35, 159–192.

Hall, R.E., 1988. Intertemporal substitution in consumption. Journal of Political Economy 96, 339–357.

Hau, H., 2000. Exchange rate determination: the role of factor price rigidities and nontradables. Journal of International Economics 50, 421–447.

Ireland, P., 1997. A small, structural, quarterly model for monetary policy evaluation. Carnegie–Rochester Conference Series on Public Policy 47, 83–108.

Ireland, P., 2001. Sticky-price models of the business cycle: specification and stability. Journal of Monetary Economics 47, 3–18.

Kim, J., 2000. Constructing and estimating a realistic optimizing model of monetary policy. Journal of Monetary Economics 45, 329–359.
Kollmann, R., 2001. The exchange rate in a dynamic-optimizing current account model with nominal rigidities: A quantitative investigation. Journal of International Economics (in press).
Lane, P.R., 1999. Money Shocks and the Current Account. Trinity College Dublin Working Paper.
Lane, P.R., 2001. The new open economy macroeconomics: a survey. Journal of International Economics 54, 235–266.
Leeper, E., Sims, C., 1994. Toward a modern macroeconomic model usable for policy analysis. NBER Macroeconomic Annual 1994, 81–118.
Meese, R.A., Rogoff, K., 1983. Empirical exchange rate models of the seventies: Do they fit out of sample? Journal of International Economics 14, 3–24.
Nason, J.M., Rogers, J.H., 2000. The Present Value Model of the Current Account Has Been Rejected: Round Up the Usual Suspects. Mimeo. University of British Columbia.
Obstfeld, M., Rogoff, K., 1995. Exchange rate dynamics redux. Journal of Political Economy 103, 624–660.
Obstfeld, M., Rogoff, K., 1998. Risk and Exchange Rates. NBER Working Paper No. 6694.
Obstfeld, M., Rogoff, K., 2000. New directions for stochastic open economy models. Journal of International Economics 20, 117–153.
Rogers, J.H., 1999. Monetary shocks and real exchange rates. Journal of International Economics 49, 269–288.
Rotemberg, J., 1982. Monopolistic price adjustment and aggregate output. Review of Economic Studies 49, 517–531.
Sheffrin, S., Woo, W.T., 1990. Present value tests of an intertemporal model of the current account. Journal of International Economics 29, 237–253.
Stockman, A.C., Tesar, L.L., 1995. Tastes and technology in a two-country model of the business cycle: explaining international comovements. American Economic Review 85, 168–185.