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Putting Up a Good Fight: The Galí-Monacelli Model versus "The Six Major Puzzles in International Macroeconomics"

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Putting Up a Good Fight: The Galí-Monacelli Model versus "The Six Major Puzzles in International Macroeconomics"*

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Abstract

In this paper, the following question is posed: Can the New Keynesian Open Economy Model by Galí and Monacelli (2005b) explain "Six Major Puzzles in International Macroeconomics", as documented in Obstfeld and Rogoff (2000*b*)?
The model features a small open economy with complete markets, Calvo sticky prices and monopolistic competition. As extensions, I explore the effects of an estimated Taylor rule and additional trade costs. After translating the six puzzles into moment conditions for the model, I estimate the five most effective parameters using simulated method of moments (SMM) to fit the moment conditions implied by the data. Given the simplicity of the model, its fit is surprisingly good: among other things, the home bias puzzles can easily be replicated, the exchange rate volatility is formidably increased and the exchange rate correlation pattern is relatively close to realistic values. Trade costs are one important ingredient for this finding.

JEL classification: F41, F42, E52

Keywords: International Macroeconomics, New Keynesian open economy model, trade costs, simulated method of moments (SMM)

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1 Introduction

Nowadays, the New Keynesian dynamic stochastic general equilibrium (DSGE) paradigm is the basis for most open economy macroeconomic models.[1] Since Obstfeld and Rogoff (1995), models with a small set of shocks and frictions are widely used for the analysis of policies, especially monetary policy. The comparative simplicity of these models has two implications. On the one hand, the working mechanisms of these models are easily understood. On the other hand, the connection between these stylized models and real world problems can be easily questioned. Researchers have reacted to this in two ways. First, they have built New Keynesian DSGE models with more shocks and frictions. Adolfson, Laséen, Lindé and Villani (2005) and the IMF's Global Economy Model, as presented in Pesenti (2008) are good examples for this approach, and more are to come. Loosing some of their simplicity and tractability, these papers gain in terms of realism and applicability. Second, researchers have tried to assess the actual quality of the stylized models when confronted with the data, or at least with specific aspects of it. Chari, Kehoe and McGrattan (2002) and Lubik and Schorfheide (2007) are two examples for this approach.

In this paper, this second way is followed. A specific stylized New Keynesian DSGE model is confronted to a specific set of first and second moments of international macroeconomic data. The model used is the one by Galí and Monacelli (2005b). This model is also reprinted in the textbook by Galí (2008) and can be regarded as a prototype of New Keynesian Open Economy Models.[2] The main components of this kind of models are a forward looking Phillips curve, a dynamic IS-curve and Calvo (1983) sticky prices. The open economy assumptions in this model are a small open economy versus the rest of the world, modeled as the limiting case of a two country world with one country infinitely small such that it does not influence the other, producer currency pricing, and complete financial markets. I modify the model in three respects. First, I disregard the multi-country framework, as is done in previous versions of that paper, see Galí and Monacelli (2002), henceforth GM. Second, besides the four monetary policy rules analyzed in Galí and Monacelli (2005b), I include an alternative Taylor rule monetary policy as in Clarida, Galí and Gertler (1998) which is more suitable for estimation issues. Third, I allow for the possibility of costs to trade in goods, following the suggestion by Obstfeld and Rogoff (2000*b*).[3]

Regarding the data, I focus on the "Six Major Puzzles in International Macroeconomics" as presented in Obstfeld and Rogoff (2000*b*), henceforth OR.

[1]Instead of New Keynesian, the labels New Neoclassical Synthesis and – especially for the open economy – New Open Economy Macroeconomics are used interchangeably. A survey on New Open Economy Models can be found in Lane (2001).

[2]McCallum and Nelson (2001, p. 10) call this model a "standard" model that they use as a benchmark with which to compare their own model.

[3]Thus, I am putting Obstfeld and Rogoff's idea to a test "in a much richer framework featuring imperfect competition plus sticky prices". See Obstfeld and Rogoff (2000*b*, pp. 340f.).

These are (1) the home bias in trade puzzle, (2) the high investment-savings correlation, (3) the home bias in equity portfolio puzzle, (4) the low international consumption correlation, (5) the purchasing power parity puzzle and (6) the exchange rate disconnect puzzle. In applying the GM model – extended for trade costs – to the OR puzzles this paper features a second motivation: while Obstfeld and Rogoff only sketch their idea of the effects of trade costs, this paper features a complete DSGE analysis of these effects.

For different sets of parameters, three different procedures are applied in order to "take the model to the data": First, I calibrate those parameters that have agreed-upon values or that are unimportant with respect to the six puzzles. In a next step, I estimate the Taylor rule parameters using generalized method of moments (GMM). Also, I use estimates for the assumed exogenous processes. In this step, I follow Galí and Monacelli (2005b, p. 723) in using data for Canada as "a prototype small open economy". The third and last procedure is simulated method of moments (SMM). This method is used to set the five most important parameters such that the distance between model moments and the data moments from the six puzzles is minimized. The parameters are those for trade costs, degree of openness, Calvo price stickiness, the international elasticity of substitution and relative risk aversion.

I come to the conclusion that the model can easily explain puzzles (1) and (3), thanks to the combination of trade costs and the degree of openness parameter, the "home bias in preferences" parameter mentioned in OR. The investment-savings puzzle is addressed only indirectly by means of a relation between net exports and the real interest rate, where the expected negative correlation is reproduced. The biggest deficiency of the model is that international output correlation is way too low, and the real exchange rate volatility and its correlation pattern is not exactly in line with the data.

Compared to a case without trade costs and without degree of openness parameter, the combination of the two elements leads to better results for all the puzzles. Very high values for the two home bias puzzles (1) and (3) can be replicated. The result of puzzle (2) remains stable, but it is now possible to also address the last three puzzles to some degree. The high exchange rate volatility of the data can be achieved by a combination of a high risk aversion as in Chari, Kehoe and McGrattan (2002), sizeable trade costs and a low degree of openness. The "disconnectedness" of real exchange rate volatility, i.e., the fact that real exchange rates are by far more volatile than any other macroeconomic aggregate – one part of the "disconnect" puzzle – is reproduced relatively well. But the second dimension of the "disconnect" puzzle, i.e., the low correlation between the real exchange rate and all other macroeconomic aggregates, is not explained by the model. Instead, the model features a positive correlation between the real exchange rate and output. The biggest weakness of the model is with respect to the international consumption correlations relative to the international output correlation. Output is by far not enough correlated internationally in the model.

The paper continues as follows. In Section 2, the model is presented. Section 3 briefly sketches the puzzles and the implied moments for the parametrization process. Section 4 explains the parametrization methods and choices. Results are presented in Section 5. Section 6 concludes the paper.

2 Model

2.1 Environment

There are two countries, the home country (H) and the foreign country (the "rest of the world", F). If not indicated differently, the following applies to both of them, whereas foreign variables are denoted by an asterisk. There are infinitely long living households, which experience utility from consumption of home and of foreign goods. Firms produce in monopolistic competition, and governments collect taxes, pay transfers and conduct monetary policy with an interest rate rule. The same applies to the foreign economy, except for the fact that foreign households' consumption of home goods is negligibly small for them. While international financial markets are complete, there is a friction in the goods market: Transportation of goods from one country to another decreases its quantity by the factor κ, which can be understood as "iceberg melting".

2.1.1 Preferences

A representative household decides about its expected infinite labor supply and consumption to maximize its utility, which is assumed to be separable between the two elements consumption C_t and hours of labor N_t:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[U(C_t) - V(N_t) \right] , \tag{1}$$

where U is defined as $U(C_t) \equiv \frac{C_t^{1-\sigma}}{1-\sigma}$ and V as $V(N_t) \equiv \frac{N_t^{1+\varphi}}{1+\varphi}$. The parameters used are discount factor β, constant of relative risk aversion σ and elasticity of labor supply $1/\varphi$. Consumption C_t is composed of

$$C_t = \left[(1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} . \tag{2}$$

$C_{F,t}$ and $C_{H,t}$ are indices related to the consumption of foreign and domestic products, respectively, which are themselves integrals over all firms $i \in [0;1]$:

$$C_{j,t} = \left(\int_0^1 C_{j,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} , \; j \in \{H;F\}, \tag{3}$$

with η being the elasticity of substitution between domestic and foreign goods, and ε the elasticity of substitution between goods of the same country.

2.1.2 Endowment

Each household is endowed with one unit of time per period.

2.1.3 Technology

Each domestic firm $i \in [0;1]$ produces its output $Y_t(i)$ with production technology $Y_t(i) = A_t N_t(i)$, where $\log(A_t) = a_t = \rho_a a_{t-1} + \epsilon_t$ is stochastic productivity. To simplify matters, production in the rest of the world is assumed to evolve exogenously according to $\log(Y_t^*) - \log \bar{Y}^* = y_t^* = \rho_y^* y_{t-1}^* + \epsilon_t^*$.

2.1.4 Information

Households have complete information until and including the current period, and they have rational expectations about future periods. The same applies to firms and governments.

2.2 Competitive Equilibrium

Households work at firms in their own country, pay lump-sum taxes, and trade nominal bonds which include shares in firms of all countries. They have access to a complete set of internationally traded contingent claims. Firms hire labor, produce, and sell their goods at home and abroad under monopolistic competition. They set prices for all markets in domestic currency (producer currency pricing) according to the Calvo (1983) price stickiness. Finally, they receive a wage subsidy τ. Governments receive lump- sum taxes T_t, pay wage subsidies, and are not allowed to accumulate debt. Monetary policy is made by setting the nominal interest rate.

2.2.1 Competitive Equilibrium: Households

The budget constraint domestic households are faced with each period t is

$$\int_0^1 [P_{H,t}(i)C_{H,t}(i) + P_{F,t}(i)C_{F,t}(i)]di + E_t\{Q_{t,t+1}D_{t+1}\} \leq D_t + W_t N_t + T_t \ , \quad (4)$$

with $Q_{t,t+1}$ the stochastic discount factor for nominal payoffs, related to the gross return R_t by $E_t(Q_{t,t+1}) = \frac{1}{R_t}$. D_{t+1} is the nominal payoff in period $t+1$ of a portfolio held at the end of period t. This portfolio includes shares in firms, and its payoff is *cum dividend*. As markets are complete, there is a complete set of state-contingent claims, traded internationally. W_t is the nominal wage and T_t a lump-sum transfer or tax. Foreign households similarly face

$$\int_0^1 [P_{H,t}^*(i)C_{H,t}^*(i) + P_{F,t}^*(i)C_{F,t}^*(i)]di + E_t\left[\frac{Q_{t,t+1}D_{t+1}}{\mathcal{E}_{t+1}}\right] \leq \frac{D_t}{\mathcal{E}_t} + W_t^* N_t^* + T_t^* \ , \quad (5)$$

with an asterisk denoting a foreign variable and $\mathscr{E}_t$ the nominal exchange rate, defined as the price of foreign currency in terms of home currency.

Price indices are the result of expenditure minimization for a given level of consumption. This minimization leads to the following outcomes: The consumer price index (CPI) comprises all consumption goods, i.e., domestic and foreign goods, and is given by

$$P_t \equiv [(1-\alpha)P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}]^{\frac{1}{1-\eta}} \ . \tag{6}$$

$P_{H,t}$ and $P_{F,t}$ are the price indices of domestic and foreign goods, respectively, and are given by

$$P_{j,t} \equiv \left(\int_0^1 P_{j,t}(i)^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}} \quad \forall\, j \in \{H, F\} \ . \tag{7}$$

Here, ε measures the elasticity of substitution between firms i within each country. The same equations hold for the rest of the world, with the slight difference that, since the rest of the world's imports from the small open economy are so small, their weighting coefficient α^* is assumed to be negligible. This means that $P_{H,t}^*$, the price index of domestic products in foreign currency, has no influence on the world consumer price index for $\lim_{\alpha^* \to 0}$. This implies $P_{F,t}^* = P_t^*$, where an asterisk denotes the world economy.
The first differences of the logarithms of the price levels are the CPI inflation $\pi_t \equiv \log(P_t) - \log(P_{t-1})$ and the domestic goods (price index) inflation $\pi_{H,t} \equiv \log(P_{H,t}) - \log(P_{H,t-1})$.[4] For the world economy it follows from above that $\pi_{F,t}^* = \pi_t^*$.

2.2.2 Competitive Equilibrium: Firms

A firm's profits are turnover minus total costs, $P_{H,t}(i)Y_t(i) - (1-\tau)W_t N_t(i)$, where the employment subsidy τ lowers the costs of labor. Thus, nominal marginal costs[5] are $MC_t^n = (1-\tau)W_t/A_t$. In the Calvo (1983) staggered price setting scheme, the possibility to reset prices cannot be guaranteed at every period: each period, only the fraction $1-\theta$ of the firms can reset prices.[6] Denoting a newly set price by $\overline{P}_{H,t}(i)$, a representative firm i faces the following maximization problem:[7]

$$\max_{\overline{P}_{H,t}(i)} \sum_{k=0}^{\infty} \theta^k E_t\{Q_{t,t+k}[Y_{t+k}(i)(\overline{P}_{H,t}(i) - MC_{t+k}^n)]\} \ , \tag{8}$$

[4]Throughout the paper small, Latin letters are used to denote that log-linearization around the steady state has taken place. For the inflation rates given in the text, this steady state can be dropped, as it is zero. More on the steady state is provided in Section A.1 in the appendix.

[5]Observe that nominal total costs $TC_t^n(i) = (1-\tau)W_t N_t(i) = (1-\tau)W_t Y_t(i)/A_t$, so that $MC_t^n(i) = \partial TC_t^n(i)/\partial Y_t(i) = (1-\tau)W_t/A_t$.

[6]The assumption is "that each price-setter (or firm) is allowed to change his price whenever a random signal is 'lit up', see Calvo (1983, p. 383).

[7]The maximization problem is derived and explained in Section A.5 in the appendix.

subject to the demand function

$$Y_{t+k}(i) \leq \left(\frac{\overline{P}_{H,t}}{P_{H,t+k}}\right)^{-\varepsilon} (C_{H,t+k} + \frac{1}{1-\kappa} C^*_{H,t+k}) \equiv Y^d_{t+k}(\overline{P}_{H,t}). \tag{9}$$

2.2.3 Competitive Equilibrium: Governments

Domestic fiscal policy is faced with the following budget constraint: $T_t = \int_0^1 \tau W_t N_t(i) di$, with T lump sum taxes and τ an employment subsidy. The fiscal authority acts solely to offset the distortion through monopolistic competition. World fiscal policy symmetric, with variables T^*_t, τ^*, W^*_t, $N^*_t(i)$. Monetary policy in the rest of the world is assumed to follow a Taylor-type rule that fully stabilizes its inflation rate and the output gap. For the small open economy, I deviate from GM, who look at the three different monetary policy regimes domestic inflation targeting (DIT), CPI inflation targeting (CIT) and an exchange rate peg. Instead, to make the model more realistic and to alleviate the model's capability to match empirical data, I follow Clarida et al. (1998) and include a Taylor rule (TR):

$$r_t = \overline{rr}_t + \Phi_\pi \pi_{H,t} + \Phi_y (y_t - \bar{y}_t)\,, \tag{10}$$

where r is a nominal short-term interest rate, $\overline{rr}$ the natural interest rate, π_H the domestic goods inflation rate, and $\bar{y}_t$ the natural level of output.[8]

2.2.4 Competitive Equilibrium: Trade

There are three exchange rates in this model. The nominal exchange rate is the price of foreign currency in terms of home currency. As in OR, I allow for “iceberg"-type costs of trade in the goods market like transportation costs, tariffs etc. These costs affect the economy in such a way that only a fraction $1-\kappa$ of each good exported arrives at the destination market, whereas the other fraction κ “melts away" in the trade process. As markets are competitive internationally, arbitrage considerations force this effect to show up in cross-border price index relations. For the price of foreign goods, this implies:

$$P^*_{F,t} \mathscr{E}_t = (1-\kappa) P_{F,t}, \tag{11}$$

whereas for the price of home goods, these have to sell cheaper abroad:

$$(1-\kappa) P^*_{H,t} \mathscr{E}_t = P_{H,t}\ . \tag{12}$$

Log-linearizing (11) and (12) around the steady state and rearranging results in

$$p_{F,t} = e_t + p^*_{F,t} \tag{13}$$

[8]The expression “natural" is meant to indicate a situation without nominal frictions.

$$p_{H,t} = e_t + p^*_{H,t}, \tag{14}$$

where lower bar letters denote log-deviations of the upper bar letters around steady state, which is described in Section A.1 in the appendix. The terms of trade are the price of foreign goods in terms of home goods. In the small open economy, this might read $\mathscr{S}_t^{\text{soe}} = P_{F,t}/P_{H,t}$, whereas for the world economy this is $\mathscr{S}_t^{\text{world}} = P^*_{F,t}/P^*_{H,t}$. Notice, however, that the terms of trade in the last two equations differ by the constant factor $(1-\kappa)^2$, according to Equations (11) and (12). One could choose either the small open economy's price ratio or the world economy's price ratio for the definition of the terms of trade – or something in between. Following Samuelson (1954), I define intermediate terms of trade:[9]

$$\mathscr{S}_t \equiv (1-\kappa)\frac{P_{F,t}}{P_{H,t}} = \frac{1}{1-\kappa}\frac{P^*_{F,t}}{P^*_{H,t}}. \tag{15}$$

For the log-linear terms of trade,

$$s_t = p_{F,t} - p_{H,t} \ , \tag{16}$$

since $p^*_{F,t} = p^*_t$ as $\lim_{\alpha^* \to 0}$. The real exchange rate is the ratio of the two consumer price indices, measured in domestic currency:

$$\mathscr{Q}_t \equiv \mathscr{E}_t P^*_t / P_t. \tag{17}$$

In terms of log deviations from steady state, the log real exchange rate $q_t \equiv \log(\mathscr{Q}_t) - \log(\overline{\mathscr{Q}})$ is given as follows:

$$q_t = e_t + p^*_t - p_t \ . \tag{18}$$

Because of the producer currency pricing trade costs have no influence on the firms' decisions of price setting. The law of one price obviously holds only in the case of zero trade costs. If domestic goods and foreign goods price indices were equal ($p_{H,t} = p_{F,t}$), α would measure the share of foreign goods' consumption, which could be interpreted as a degree of openness. In this model instead, Section A.1 in the appendix shows that I have a steady state where $\bar{P}_H = (1-\kappa)\bar{P}_F$. The situation around such a steady state can be expressed through log-linearization of (6) as

$$p_t = (1-\alpha')p_{H,t} + \alpha' p_{F,t}, \tag{19}$$

where $\alpha' \equiv \alpha/[\alpha + (1-\alpha)(1-\kappa)^{1-\eta}]$.[10] This equation, derived in Section A.1 in the appendix, can be combined with Equation (16) to obtain the following relationship between domestic CPI and the terms of trade:

$$p_t = p_{H,t} + \alpha' s_t \tag{20}$$

[9]With this "intermediate" definition, I also make sure that the steady state terms of trade are equal to unity, as it is the case in GM. See also Galí and Monacelli (2005b, Appendix A).

[10]Note that $\alpha' = \alpha$ as in GM for $\kappa = 0$.

Replacing $p_{F,t}$ in Equation (16) by Equation (13) and plugging the result in (18) gives rise to a relationship between the domestic CPI, the terms of trade and the real exchange rate:

$$q_t = (1-\alpha')s_t. \tag{21}$$

Nominal net exports are given by

$$P_{H,t}NX_t = P_{H,t}Y_t - P_tC_t. \tag{22}$$

As Section A.3 of the appendix shows, log-linearizing this equation around the steady state results in

$$nx_t = y_t - \frac{PC}{P_HY}(c_t + \alpha' s_t), \tag{23}$$

where the steady state ratio $\frac{PC}{P_HY}$ depends on the parameters α, κ, η and σ and equals unity in the case of zero trade costs.

2.2.5 Competitive Equilibrium: Market Clearing

Since there is no possibility to invest in capital, and as the small open economy is negligible for the rest of the world, the foreign country's goods market is cleared if output supply equals its own consumption:

$$Y_t^* = C_t^*\,. \tag{24}$$

In the small open economy, output is consumed at home or abroad. However, because a fraction κ of the bundle exported "melts away" in the trade process, consumption abroad is only $1-\kappa$ times the domestic bundle intended for export, $C_{H,t}^* = (1-\kappa)(Y_t - C_{H,t})$. Hence, in the small open economy goods market clearing is given by

$$Y_t = C_{H,t} + \frac{1}{1-\kappa}C_{H,t}^*\,. \tag{25}$$

In the labor markets, firms set wages so that their demand of labor is supplied by the domestic agents. The international asset market is cleared as the nominal portfolio is in zero net supply. On the currency market, each countries' central bank supplies the amount of currency that is demanded.

Definition 1. *Given policy rules for R_t, an equilibrium is an allocation* $\{D_t, C_t, (C_{j,t})_{j\in\{H,F\}}, (C_{i,j,t})_{i\in[0,1]}, L_t, Y_t, (Y_{j,t})_{j\in\{H,F\}}, (Y_{i,j,t})_{i\in[0,1]}\}_{t=0}^{\infty}$ *and a price system* $\{W_t, P_t, (P_{j,t})_{j\in\{H,F\}}, (P_{i,j,t})_{i\in[0,1]}\}_{t=0}^{\infty}$*, such that*

1. *given prices, the allocation maximizes the utility of the household,*
2. *given prices and the demand function for $Y_{i,j,t}$, the allocation maximizes the profits of the firms, subject to the Calvo-sticky prices,*
3. *markets clear,*
4. *the policy rule is consistent with allocation and prices.*

2.3 Analysis

2.3.1 Analysis: Households

The expenditures of the representative household are distributed optimally between all firms of a country as well as between home country and the rest of the world in the aggregate. The allocations will be:

$$C_{j,t}(i) = \left(\frac{P_{j,t}(i)}{P_{j,t}}\right)^{-\varepsilon} C_{j,t} \quad \forall j \in \{H, F\} \tag{26}$$

within each country, and for total consumption:

$$C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \quad \text{and} \quad C_{F,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t \ . \tag{27}$$

Maximizing the household's utility function leads to a standard intratemporal equation linking marginal utilities of labor and consumption to the real wage:

$$C_t^{\sigma} N_t^{\varphi} = \frac{W_t}{P_t} \tag{28}$$

and a typical Euler equation:

$$\beta R_t E_t \left(\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\left(\frac{P_t}{P_{t+1}}\right)\right) = 1 \ . \tag{29}$$

Log-linearization yields

$$w_t - p_t = \sigma c_t + \varphi n_t \quad \text{and} \quad c_t = E_t\{c_{t+1}\} - \frac{1}{\sigma}(r_t - E_t\{\pi_{t+1}\}). \tag{30}$$

As shown in the appendix Section A.4, Equation (29) and its world analog[11] can be combined and iterated to get a relation for consumption in both economies:

$$C_t = \vartheta C_t^* \mathcal{Q}_t^{\frac{1}{\sigma}} \ , \tag{31}$$

where the parameter ϑ depends on initial conditions regarding the relative size of the small open economy.[12] In log-deviations and using Equation (21), the last equation becomes

$$c_t = c_t^* + \left(\frac{1-\alpha'}{\sigma}\right) s_t \ . \tag{32}$$

[11] Under complete markets for nominal state contingent securities (see Monacelli, 2005), $\beta R_t E_t[(\frac{C^*_{t+1}}{C^*_t})^{-\sigma}(\frac{P^*_t}{P^*_{t+1}})(\frac{\mathcal{E}_t}{\mathcal{E}_{t+1}})] = 1$ holds.

[12] It is assumed that the initial distribution of wealth fulfills $\vartheta = \frac{\alpha^*}{\alpha}$, i. e. equals the ratio of the two economies' import valuations.

2.3.2 Analysis: Firms

Aggregation of individual firms' production functions and log-linearizing around the steady state yields the (log) supply of output

$$y_t = n_t + a_t \ . \tag{33}$$

In every period, firm i has a probability of $(1-\theta)$ that it is allowed to adjust its price. If this is the case in period t, and as each firm has market power, it sets its new price $\overline{P}_{H,t}$ with a markup over marginal costs so that for the expected duration of that price the present discounted value of its expected earnings is maximized. Given the maximization problem of Equations (8) and (9) and as shown in appendix Section A.5, the log-linear price setting rule is

$$\overline{p}_{H,t} = (1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k E_t\{\widehat{mc}^n_{t+k}\} \ , \tag{34}$$

where $\overline{p}_{H,t}$ is the newly set price in period t and $\widehat{mc}^n_t$ is the log-deviation of nominal marginal costs around the steady state. As appendix Section A.6 shows, the inflation dynamics in the small open economy and in the world economy are given by

$$\pi_{H,t} = \beta E_t\{\pi_{H,t+1}\} + \lambda(\widehat{mc}_t) \quad \text{and} \quad \pi^*_t = \beta E_t\{\pi^*_{t+1}\} + \lambda(\widehat{mc}^*_t) \ , \tag{35}$$

where $\lambda \equiv \frac{(1-\theta)(1-\beta\theta)}{\theta}$.

2.3.3 Analysis: Governments

Both fiscal policy authorities set their employment subsidy to offset monopolistic distortion. For reasons of comparability with GM I rely on their values,[13] i. e. for the small open economy

$$\tau = 1 - \frac{\varepsilon - 1}{(1-\alpha)\varepsilon} \quad \text{and} \quad \tau^* = \frac{1}{\varepsilon} \tag{36}$$

for the world economy, where the α^*-term drops as the degree of openness there is essentially zero.

Monetary policy in the world economy leads to a fully stable world output gap and world inflation rate, so that I can set both variables to zero:
$\tilde{y}^*_t = \pi^*_t = 0$.
This drives the world interest rate to its natural level, so that I get

$$r^*_t = -\sigma(1-\rho^*_a)\frac{1+\varphi}{\sigma+\varphi}a^*_t \ . \tag{37}$$

[13] GM derive these values under the special case in which $\sigma = \eta = 1$ holds. See Galí and Monacelli (2002, pp. 22ff.).

The authority for monetary policy in the small open economy follows the Taylor rule given in Equation (10). Alternatively, I also analyze a strict domestic inflation targeting (DIT) policy, a domestic inflation targeting rule (DITR), a CPI targeting rule (CITR) and an exchange rate peg (PEG).

2.3.4 Analysis: Canonical Representation

The model can be written in four equations, a Phillips curve and a dynamic IS curve for both the small open and the world economy. Denoting a variable's deviation from its natural level that would pertain in a flexible price world by an upper tilde, the equations are:

$$
\begin{aligned}
\pi_{H,t} &= \beta E_t\{\pi_{H,t+1}\} + \Phi_{NKPC}\tilde{y}_t && (38)\\
\pi^*_t &= \beta E_t\{\pi^*_{t+1}\} + \Phi_{NKPC^*}\tilde{y}^*_t && (39)\\
\tilde{y}_t &= E_t\{\tilde{y}_{t+1}\} - \frac{\omega}{\sigma}(r_t - E_t\{\pi_{H,t+1}\} - \overline{rr}'_t) && (40)\\
\tilde{y}^*_t &= E_t\{\tilde{y}^*_{t+1}\} - \frac{1}{\sigma}(r^*_t - E_t\{\pi^*_{t+1}\} - \overline{rr}^*_t)\,, && (41)
\end{aligned}
$$

where $\Phi_{NKPC} \equiv \lambda\left(\frac{\sigma}{\omega} + \varphi\right)$, $\omega \equiv \sigma\eta + (1-\sigma\eta)(1-\alpha')\left(1 - \frac{\alpha}{1-\kappa}\Phi^{-1}_{SS2}\right)$ with α' defined after Equation (19) and Φ_{SS2} after Equation (23), and $\Phi_{NKPC^*} \equiv \lambda(\sigma + \varphi)$. The $\overline{rr}$-terms are the natural expected rates of interest in the small open and the world economy, respectively, which would prevail under completely flexible prices. They are given by

$$
\overline{rr}_t \equiv -\frac{\sigma(1+\varphi)(1-\rho_a)}{\sigma+\omega\varphi}a_t - \varphi\frac{\sigma(1-\omega)}{\sigma+\omega\varphi}E_t\{\Delta y^*_{t+1}\} \qquad (42)
$$

and

$$
\overline{rr}^*_t \equiv -\sigma(1-\rho^*_a)\frac{1+\varphi}{\sigma+\varphi}a^*_t. \qquad (43)
$$

A derivation of these equations is given in appendix Section A.7. Together with rules for monetary policies and the exogenous stochastic processes, the model is complete.

3 Puzzles and Deduced Moments

This section briefly states the six puzzling data observations, as collected by OR. It then focuses on the specific moments of the data that may be used to evaluate the corresponding moments of the model and thereby the model's fit. In choosing these data moments I often allow for a wide range of values. This is the consequence of the existing variability in observation moments across time and countries.

3.1 Home Bias in Trade (Puzzle 1)

In an Arrow-Debreu world of complete international markets without any barriers to trade, an equal amount of products is traded across international and intra-national borders, so that borders do not matter for trade. In reality, we see that there is significantly less trade across international borders, i.e., domestic products are preferred. This is pointed out by e. g. McCallum (1995) for the example of the U.S. versus Canada. McCallum found 22 times less trade across the border than across interstate borders in Canada or in the U.S. In a more careful study, Anderson and van Wincoop (2003) argue that borders reduce trade between industrialized countries by 29 percent or, in the case of U.S. - Canadian trade, by 44 percent.

OR propose to use the ratio of domestic consumption expenditure on home goods to domestic consumption expenditure on imported goods as moment for the home bias in trade. They argue that 4.2 is a reasonable value for OECD countries. This implies a home share in consumption of about 80 percent. Clearly, this number depends on the size of the country considered: the smaller the country, the fewer goods are produced domestically, and the lower the number gets. As a starting point, I take values above unity as consistent with a home bias. To rule out too distinct a bias, I set an upper limit of 19, implying a home share in consumption of 95 percent. Hence, my first moment is the steady state ratio

$$\text{P1} = \frac{P_H C_H}{P_F C_F} = \frac{1-\alpha}{\alpha}(1-\kappa)^{1-\eta} \in [1; 19], \tag{44}$$

depending only on home bias parameter α, trade costs κ and international substitution elasticity η, according to Equations (27) and (15), evaluated at the steady state.

3.2 Feldstein-Horioka (Puzzle 2)

If one supposes that capital can move freely across countries and people are free to invest their money wherever they want, one would suspect that rising savings in one economy do not necessarily imply rising investments in the same country. If conditions for investment are temporarily better abroad, the savings should all be directed to foreign countries, leaving investments in the home country constant or reducing them. With this in mind one would expect a low correlation between savings and investment in open economies with free capital movements. Instead, the data shows a high positive correlation: Feldstein and Horioka (1980) found a coefficient of 0.89 for 16 OECD countries between 1960 and 1974. A regression for a 22 OECD country sample between 1982-91 by Obstfeld and Rogoff (1996, p. 162) results in a coefficient of 0.62, while the latest regression by the same authors (Obstfeld and Rogoff, 2000*b*, Table 1) for the 24 OECD countries between 1990-97 yields 0.60. Although there is a decreasing trend, the absolute value of the correlation coefficient is still large.

To evaluate where the model's savings are invested, one has to solve for the country portfolios. Given that I use a log-linear approximation to find the model solution, this is not an easy task, for two reasons, as pointed out by Devereux and Sutherland (2007, p.9): "Firstly, the equilibrium portfolio is indeterminate in a first-order approximation of the model. And secondly, the equilibrium portfolio is indeterminate in the non-stochastic steady state." Recently, researchers have drawn their attention to this problem and have come up with different solution approaches, e.g. Coeurdacier and Gourinchas (2008), Coeurdacier (2009), Devereux and Sutherland (2007) and Engel and Matsumoto (2008).[14] One finding of these papers highlighted in Coeurdacier and Gourinchas (2008) is that in a complete markets model, "the equilibrium equity portfolios are extremely sensitive to the values of preference parameters. Whether the coefficient of relative risk aversion is smaller, bigger than or equal to unity, whether domestic and foreign goods are substitute or complements, equity portfolios can exhibit home, foreign, or no bias. In other words, this class of models predict delivers equity portfolios that are *unstable*." Because of this, and because of comparability between my results and those derived in Obstfeld and Rogoff (2000*b*), in the following I stick to the approach OR take to address this puzzle. They built a stylized model to show that "countries running current account surpluses should have lower real interest rates than countries running deficits."[15] This implies a negative correlation between net exports nx_t and the domestic real interest rate $r_t - \pi_t$. So I take as the second moment

$$\text{P2} = \text{Corr}(nx_t, r_t - \pi_t) \in [-1; 0]. \tag{45}$$

Of course, one may cast doubts on this correlation as adequate translation of the Feldstein-Horioka puzzle, and indeed Jeanne (2000) has raised concerns against this approach. But for the current study, I leave this issue unresolved and take the moment at face value.

3.3 Home Bias in Equity Portfolio (Puzzle 3)

In 2005, Canadians held about 76 percent of their equity wealth in their domestic stock market. However, the Canadian equity market capitalization accounted for less than four percent of the world equity market capitalization. In a world of complete risk diversification, this pronounced home bias is difficult to explain. The average home bias across 20 OECD countries is 70 percent, ranging from 31 percent for the Netherlands to above 90 percent for countries like Japan, Greece or Russia.[16] In my model, there is free and costless trade in a complete set of state-contingent Arrow-Debreu securities. Under complete markets, consumption shares are equal to shares in world wealth. Obstfeld and

[14] A lucid summary of the recent developments is given in Obstfeld (2007).
[15] See Obstfeld and Rogoff (2000*b*, p.358) and Table 3 therein for empirical evidence.
[16] Data from Sercu and Vanpee (2008), as reprinted in Coeurdacier and Gourinchas (2008).

Rogoff (1996, Section 5.3) show that (given zero trade costs) these shares are also equal to portfolio shares. For the special case in which $\sigma = 1/\eta$ holds, the Arrow-Debreu allocation is identical to a world where trade is only in equity shares.[17] In that case one can thus evaluate home bias in equity portfolios directly. For the more general case where $\sigma \neq 1/\eta$, OR show that consumption shares are nonetheless relatively constant over a wide range of parameter combinations and are thus a good approximation to equity portfolio shares.[18] Hence, I follow OR and rely on steady state consumption shares as an indicator for equity portfolio shares. I define the small open economy's steady state home bias equivalently to the portfolio home bias definition given in Coeurdacier and Gourinchas (2008):[19] Home bias is given as one minus the share of foreign equities (consumption) in the small open economy's equity holdings (total consumption), divided by the share of foreign equities (consumption in the rest of the world) in the total market portfolio (overall consumption). By definition the home bias is zero in case the share of domestic equities (consumption) in the small open economy is equal to the share of domestic equities (consumption) in the total world portfolio (consumption). Hence, my third moment is

$$\text{P3} = 1 - \frac{\frac{C_F}{C}}{\frac{C^*}{C+C^*}} = 1 - (1 + \vartheta \Phi_{PHP}^{\frac{1}{\sigma}}) \alpha \Phi_{PFP}^{-\eta} \in [0.32; 0.92]. \tag{46}$$

Notice that I have used Equations (31) and (27) at the steady state to rephrase the equation. One can see that the moment depends on the parameters α, η, κ and α^* only, where the last parameter is assumed to be fixed.

3.4 Low International Consumption Correlation (Puzzle 4)

If risks were pooled internationally, changes in consumption would be perfectly correlated across countries to hedge against country specific risk. However, in the real world this is not the case. Despite the intuitive relative consumption smoothing argument, consumption is even less correlated internationally than is output: compared to the "world" analog, the correlation of consumption growth in the OECD countries lies somewhere between 0.27 for Italy and 0.63 for Germany, with an average of 0.43. At the same time, output growth correlations are nearly always higher, between 0.42 for Japan and 0.70 for Canada and Germany, with an average of 0.52.[20] Backus, Kehoe and Kydland (1995, Tables 1 and 2) report correlations relative to the U.S. instead of a "world"

[17] See OR and Obstfeld and Rogoff (1996, Sections 5.2 and 5.3).

[18] See Obstfeld and Rogoff (2000*b*, pp. 363 and Table 4). Obstfeld (2007) emends an approximation error, which nonetheless does not overturn the general picture.

[19] The last page shows a reprint of the 2007 version of Sercu and Vanpee (2008). The published version avoids the term "home bias".

[20] Obstfeld and Rogoff (1996, p. 291), data from Penn World Tables for the period 1973 to 1993. The "world" analog means 35 benchmark countries.

analog. Hence, they have slightly different numbers, but generally the same findings. Moreover, they find productivity[21] to be internationally less correlated than output. They call this puzzle “the consumption/output/productivity anomaly, or the quantity anomaly".[22] I choose the ratio of consumption to output correlations as my fourth moment, which is between about 0.5 for Italy and about 1 for the U.K.:

$$\text{P4} = \frac{\text{Corr}(c_t, c_t^*)}{\text{Corr}(y_t, y_t^*)} \in [0.5; 1]. \tag{47}$$

3.5 Purchasing Power Parity (Puzzle 5)

Rogoff (1996) phrases the purchasing power parity puzzle question as follows: “How can one reconcile the enormous short-term volatility of real exchange rates with the extremely slow rate at which shocks appear to damp out?"[23] The standard deviation of the real exchange rate typically amounts to about eight percent.[24] The autocorrelation of the real exchange rate $\text{Corr}(q_t, q_{t-1})$ is about 0.83.[25] As this puzzle has two dimensions, I collect two data moments based on Chari et al. (2002):

$$\text{P51} = \quad \text{Std}(q_t) \quad = 7.52 \tag{48}$$

$$\text{P52} = \text{Corr}(q_t, q_{t-1}) = 0.83. \tag{49}$$

3.6 Exchange Rate Disconnect (Puzzle 6)

Another fact concerning the real, but also to the nominal exchange rate is the missing of a strong connection to any other macroeconomic variable. This feature can be examined from two points of view: *a*) a connection could be seen if the high volatility of exchange rates would have an effect on the volatility of some other macroeconomic variable. In this respect, the disconnect shows up in a situation in which, “while exchange rate volatility is ultimately tied to volatility in the fundamental shocks to the economy, the exchange rate can display extremely high volatility without any implications for the volatility of other macroeconomic variables."[26] As Flood and Rose (1995) show, moving

[21] Productivity is measured by the Solow residual z of a standard Cobb-Douglas production function $Y_t = Z_t K_t^{\theta} N_t^{1-\theta}$.

[22] Backus et al. (1995, p. 343).

[23] Rogoff (1996, p. 647).

[24] Chari et al. (2002, Table 2) report 7.52 percent for quarterly, logged, Hodrick-Prescott (HP)-filtered European post-Bretton Woods real exchange rates relative to the U.S. Dollar, Kollmann (2001, p. 254) reports 8.89 percent for an average of Germany, Japan and the U.K. versus the U.S.

[25] Chari et al. (2002, Table 1) report values between 0.77 and 0.86 for quarterly, logged, Hodrick-Prescott (HP)-filtered European post-Bretton Woods data relative to the U.S. Dollar, with an average of 0.83. Kollmann (2001, p. 254) comes to a value of 0.78 for a slightly shorter time span of data for Japan, Germany and the U.K.

[26] Devereux and Engel (2002, p. 4).

from floating to fixed exchange rates or into the other direction does not influence the volatility of other macroeconomic variables. b) The disconnect is also a question of correlations between the exchange rate and other variables such as output or prices. Kollmann (2001, p. 254) reports correlations with domestic GDP between -0.21 and 0.15 for Japanese, German and U.K. post-Bretton Woods data, on average -0.07 for the nominal and -0.01 for the real exchange rate. As for the previous puzzle, I select two moments: first, the standard deviation of the real U.S. $ exchange rate relative to that of real GDP, which is 4.36 percent, according to Chari et al. (2002).[27] Second, the contemporaneous correlation between the real U.S. $ exchange rate and real GDP, which Chari et al. (2002) report to be 0.08.[28]

$$P61 = \quad \text{Std}(q_t)/\text{Std}(y_t) \quad = 4.36 \tag{50}$$

$$P62 = \quad \text{Corr}(q_t, y_t) \quad = 0.08. \tag{51}$$

While puzzles 1 and 3 follow immediately from the model's steady state, the remaining moments are obtained from simulations of the model. I average the moments of 500 simulations of 100 periods length.

4 Parametrization

For the specification of parameter values I will make use of three different procedures. In a first step, I use calibration to obtain values for those parameters that have (a) agreed upon values in the literature and (b) no significant effect on the model outcome with respect to the six puzzles. In a second step, I identify a set of parameter values via estimation.This procedure is applied to parameters that have a close relationship to observable data, like exogenous processes and the Taylor rule. The third step is choosing the remaining parameter values to minimize the distance between simulated moments from the model and the moments implied by the “six puzzles". This procedure is applied in Jermann (1998) to “maximize the model's ability to match a set of moments of interest"[29]. A textbook treatment under the label *Simulated Method of Moments Estimation* (SMM) is given in Canova (2007, Section 5.5.2).

I use data for Canada versus the U.S. for two reasons. First, because of its relative size and proximity to the U.S., Canada is “a prototype small open economy".[30] Not only is Canada a relatively small country, it also trades mainly with the U.S.[31] so that the assumption of the U.S. as the rest of the world seems especially plausible. Second, Galí and Monacelli (2005b) use Canadian data for

[27] See Table 5 in Chari et al. (2002). Kollmann (2001, Table 1) reports $\frac{8.89}{1.52} = 5.85$ percent.

[28] See Table 6 in Chari et al. (2002). Kollmann (2001, Table 1) reports -0.01.

[29] Jermann (1998, p. 264).

[30] Galí and Monacelli (2005b, p. 723).

[31] According to `en.wikipedia.org`, about 80 percent of Canadian exports go to and about two thirds of Canadian imports come from the U.S.

their numerical analysis. So it seems fair to stick to the same data when putting the model to test. The dataset used for the analysis is the one built by Chari, Kehoe and McGrattan (2002), added by central bank short term interest rates obtained from IFS. It contains quarterly macroeconomic data for Canada and the U.S. from 1973:1 till 2000:1, obtained from the IMF's IFS and the OECD.[32] The data are seasonally adjusted, in logs, and HP-filtered. The series contain real GDP, consumption, net exports, CPI price level, PPI price level, nominal and real exchange rate, terms of trade and employment. Series for technology are obtained by use of Equation (33) and its world analog.[33]

4.1 Calibrated Parameter Values

Results for the first procedure (calibration) are given in column two of Table 1. Mostly, the values were chosen in accordance with those of the GM model. The (quarterly) discount factor β is set to 0.987 according to Cooley and Prescott (1995, p. 21). The net steady state markup μ of roughly 20 percent over marginal costs is consistent with the findings of Rotemberg and Woodford (1995, pp. 260-261) as well as Schmitt-Grohé and Uribe (2004, p. 11). With μ fixed I have already set the elasticity of substitution between different firms within a country ε to be six, through $\mu = \log(\varepsilon) - \log(\varepsilon - 1)$ from Section A.7 in the appendix. The labor supply elasticity $1/\varphi$ is fixed at $1/\varphi = 1/3$, like in GM. Benigno (2004) proposes a value of 0.67, whereas Blanchard and Fischer (1989) report a low value between 0 and 0.45.[34] Yun (1996) calibrates his model with $1/\varphi = 1/4$. I also tested values between zero and unity and found that the model's performance is not affected. Finally, the degree of openness parameter for the world economy α^* has to be fixed close to zero to maintain the small open economy assumption.

4.2 Estimated Parameter Values

The second procedure was applied for the Taylor rule (TR). Again, results are given in Table 1, columns three and four. For t estimation of the Taylor rule for Canada I follow the example of Clarida et al. (1998) and use the generalized method of moments (GMM). Instruments are eight lags of inflation, output gap and interest rate ($R^2 = 0.82$, standard errors in parentheses).

$$r_t = \underset{(0.02)}{0.90} * r_{t-1} + (1 - 0.9) * (\underset{(0.15)}{2.20} * \pi_{t+1} + \underset{(0.83)}{2.43} * (y_t - \bar{y}_t)) + \varepsilon_t^M \ . \quad (52)$$

For the estimation of the stochastic processes I rely on Galí and Monacelli (2005b). They assume AR(1) processes for log Canadian labor productivity

[32]The original dataset contains data 17 OECD countries and a longer sample period for most series, which allows for an extended analysis in future work.

[33]This results in the standard correlation pattern given e.g. in Uhlig (2003).

[34]See Blanchard and Fischer (1989), Chapters 7 and 8, especially pp. 338-342 and 388.

and log U.S. GDP and obtain

$$a_t = \underset{(0.06)}{0.66} a_{t-1} + \epsilon_t, \quad \text{Std}(\epsilon) = 0.0071 \tag{53}$$

$$y_t^* = \underset{(0.04)}{0.86} y_{t-1}^* + \epsilon_t^*, \quad \text{Std}(\epsilon^*) = 0.0078 \tag{54}$$

with a correlation between the two shocks of 0.3. Standard errors are given in parentheses. It is clear that the international correlation of productivity shocks will have an influence on the puzzle outcomes. Especially the international consumption correlation and the real exchange rate correlation would be significantly affected if I took this parameter as free in my minimization procedure laid out below. Nonetheless, I abstain from making use of this opportunity as I regard this parameter to be given by the data.

4.3 Simulated Method of Moments Parameter Values

Applying the third procedure, I single out five parameters that mainly influence the model's features relative to the six puzzles or, in the case of price stickiness, are key to this class of models. These are the international substitution elasticity η, the constant of relative risk aversion σ, the small open economy's openness parameter α, the Calvo price stickiness parameter for both economies $\theta = \theta^*$ and the trade costs parameter κ. Let Θ_1 be the vector of these five model parameters: $\Theta_1 = [\eta, \sigma, \alpha, \theta, \kappa]'$. I choose Θ_1 in order to minimize

$$\mathfrak{J} = [\Theta_2 - f(\Theta_1)]' \Omega [\Theta_2 - f(\Theta_1)], \tag{55}$$

where $\Theta_2 = [P1, P2, P3, P4, P51, P52, P61, P62]'$ is the vector of moments to be matched, given by equations (44) to (51). $f(\Theta_1)$ is a 8×1 vector which contains the corresponding moments generated by the model. The weighting matrix Ω is chosen as a diagonal matrix with the inverse of each data mean as the diagonal elements. Since many of the data moments are given in target ranges, the expression $\Theta_2 - f(\Theta_1)$ is not trivial. Following Uhlig (2004), I allow for these ranges by combining maximum and minimum functions:

$$\Theta_2 - f(\Theta_1) = \begin{bmatrix} \min(19 - f(\Theta_1)_1, 0) + \max(1 - f(\Theta_1)_1, 0) \\ \min(0 - f(\Theta_1)_2, 0) + \max(-1 - f(\Theta_1)_2, 0) \\ \min(0.92 - f(\Theta_1)_3, 0) + \max(0.32 - f(\Theta_1)_3, 0) \\ \min(1 - f(\Theta_1)_4, 0) + \max(0.5 - f(\Theta_1)_4, 0) \\ 7.52 - f(\Theta_1)_5 \\ 0.83 - f(\Theta_1)_6 \\ 4.36 - f(\Theta_1)_7 \\ 0.08 - f(\Theta_1)_8 \end{bmatrix}. \tag{56}$$

For the minimization process, the model solution has to be calculated. This is done using standard techniques, as explained in Uhlig (1999). To minimize the criterion function $\mathfrak{I}$, I furthermore need to set starting values and boundaries to the parameters in Θ_1.

The elasticity of substitution between domestic and foreign goods η typically takes values between unity, as in Galí and Monacelli (2005b) and something as high as 20, as Obstfeld and Rogoff (2000*b*) say. In between lie $\eta = 1.5$ as in Backus et al. (1995, pp. 346-347.) and the OR benchmark of $\eta = 6$. The higher the substitutability between domestic and foreign goods, the bigger the home biases get. But there is a theoretical qualification to this. The elasticity of substitution between different domestic goods ε is set to six, in order to allow for a steady state markup of 20 percent above marginal costs. It seems unrealistic that substitutability is much higher internationally than intranationally. Engel (2000) raises exactly this question at the end of his comment on the "Six Puzzles"; he proposes the intranational elasticity to be twice as high as the international. I follow his suggestion and restrict η to be between 1 and 12. As a a starting value, I set $\eta = 3$.

The risk aversion parameter σ, also the inverse of the intertemporal rate of substitution, is difficult to determine: GM and Yun (1996) use $\sigma = 1$, implying log utility of consumption. Erceg, Henderson and Levine (2000, p. 299) use 1.5 for σ, Cochrane calls values between one and two standard,[35] Chari, Kehoe and McGrattan (2002) choose a high value of $\sigma = 5$ and argue that this is needed to obtain volatile exchange rates. Like GM, I use $\sigma = 1$ as my starting value and allow it to be between 0.2 and as much as 10, which is also the upper bound in Anderson and van Wincoop (2004).

The degree of openness parameter α should be between zero and unity, where one half implies no home bias and more than one half is a bias towards foreign goods. GM choose $\alpha = 0.4$ as their baseline value to match the import to GDP ratio for Canada. I follow them with my starting value and set the boundaries to zero and 0.9, where the upper boundary implies a bias towards foreign goods. This might be especially reasonable for very small countries which produce only a restricted subset of all goods.

The Calvo sticky price parameter $\theta = \theta^*$, assumed to be identical across countries, is typically set to 0.75, implying an average price duration of four quarters, $\frac{1}{1-\theta} = 4$. This is also my starting value. In the SMM estimation, I choose θ from the interval $[0.0, 0.9]$, implying price changes between every quarter and every 10th quarter.

Finally, the trade costs' starting value is set to 25 percent, the value OR choose as their "baseline". Midrigan (2007) chooses a distribution of trade costs that replicates moments of certain export shares. He comes up with trade costs between 2 percent and 48 percent, with a mean of 20 percent. Relative to the sources reported in OR, 20 or 25 percent are high, but taking into account that about a half of total output is nontraded, the number might become

[35] Cochrane (1997, p. 15). The asset pricing literature yields for even higher values to explain the equity premium puzzle.

more reasonable. Anderson and van Wincoop (2004) report a 170 percent tax equivalent of trade costs. This number breaks down into 21 percent transportation costs, 44 precent border related trade barriers, and 55 percent retail and wholesale distribution costs. Of course, “iceberg” trade costs cannot be bigger than unity, as unit trade costs lead to autarky of the two then closed economies. Given the degree of uncertainty about this parameter, I hardly restrict the SMM estimation using the interval $[0.0; 0.9]$.

Boundaries and starting values for the parameters in Θ_1 are given in columns four and two of Table 1. The resulting estimates are given in column five of the same table.

Table 1: Benchmark Parameter Values

Parameter	Calibration	Estimation	SMM Range	SMM	Explanation
Preferences					
β	0.987	–	–	–	Discount factor
η	3.00	–	$[1.0; 12]$	1.0	Elasticity of substitution between domestic and foreign goods
ε	6.00	–	–		Elasticity of substitution among goods within each category
σ	1.00	–	$[0.2; 10]$	3.15	Constant of relative risk aversion
φ	3.00	–	–	–	Inverse of labor supply elasticity
α	0.40	–	$[0.0; 0.9]$	0.05	Degree of openness of the small open economy
α^*	0.001	–	–	–	Degree of openness of the world economy
Technology					
$\theta = \theta^*$	0.75	–	$[0.0; 0.9]$	0.78	Percentage of firms that cannot (re)set prices in period t
μ	0.182	–	–	–	Log of the gross steady state markup
κ	0.25	–	$[0.0; 0.9]$	0.39	Trade costs
Monetary Policy					
ρ^{TR}	–	0.90 (0.02)	–	–	Degree of interest rate smoothing
β^{TR}	–	2.20 (0.15)	–	–	Coefficient on next period inflation
γ^{TR}	–	2.43 (0.83)	–	–	Coefficient on output gap
Processes					
σ_{ϵ}	–	0.0071(–)	–	–	Standard deviation of domestic productivity shock
σ_{ϵ^*}	–	0.0078(–)	–	–	Standard deviation of world GDP shock
ρ_a	–	0.66 (0.06)	–	–	Autocorrelation of domestic productivity AR(1) process
ρ_y^*	–	0.86 (0.04)	–	–	Autocorrelation of world GDP AR(1) process
ρ_{a,y^*}	–	0.30 (–)	–	–	Cross-correlation of productivity shocks

Notes: Column 2 includes calibrated values as well as the starting values for the SMM estimation, column 3 has standard errors in parentheses, column 4 shows the allowed values for the simulated method of moments estimation and column 5 gives the SMM estimates.

5 Results

As the title of this paper might suggest, the results of this model are not too bad. Table 2 reports how the thus parameterized model performs against the six puzzles.

Table 2: Baseline Results for the Taylor Rule Model

Criterion	Moment	Value	Lower	Data	Upper
Puzzle 1	$P_H C_H/(P_F C_F)$	19.36	1		19
Puzzle 2	$\text{Corr}(nx_t, r_t - \pi_t)$	-0.48	-1		0
Puzzle 3	$1 - \frac{C_F/C}{C^*/(C+C^*)}$	0.97	0.32		0.92
Puzzle 4	$\text{Corr}(c_t, c_t^*)/\text{Corr}(y_t, y_t^*)$	2.83	0.5		1
Puzzle 51	$\text{Std}(q_t)$	1.97		7.52	
Puzzle 52	$\text{Corr}(q_t, q_{t-1})$	0.61		0.83	
Puzzle 61	$\text{Std}(q_t)/\text{Std}(y_t)$	3.13		4.36	
Puzzle 62	$\text{Corr}(q_t, y_t)$	0.63		0.08	

Notes: The baseline results use the parametrization given in Table 1. In particular, $\kappa = 0.39$, $\theta = 0.78$, $\alpha = 0.05$, $\eta = 1$ and $\sigma = 3.15$. “Data" refers to the target ranges or values discussed in Section 3.

We see that with sizeable trade costs of close to 40 percent and a small degree of openness parameter, implying a steady state import share of only five percent, the model is able to replicate strong home biases in consumption and in equity portfolio. These biases are slightly above what is observed for typical small OECD countries, but not by much. Puzzle 2 in its translated form is nicely replicated: The correlation between net exports and the real interest rate is right in the range of what OR estimated for OECD countries. A high relative risk aversion of more than three, low international substitutability and a small degree of openness lead to volatile real exchange rates. This is in accordance with the argument in Hau (2002) that less open economies experience a higher exchange rate volatility. Compared to the model results with calibrated parameter values, the number for real exchange rate volatility is extraordinarily big: Nonetheless, the volatility is not as big as in the data, both per se and relative to GDP volatility. With respect to the correlation pattern of the real exchange rate the findings are mixed: The autocorrelation of the real exchange rate is a bit low in the model, the correlation with GDP is too big. The perhaps worst outcome concerns the consumption correlation puzzle. The ratio of correlations is 2.83, which is way above the expected value of less than one. This ratio is the result of an international output correlation of only 0.14, whereas the international correlation of consumption is 0.47. Though the data does not provide a very clear pattern, this combination is not realistic.

5.1 Do Trade Costs Improve the Model's Fit?

The original model of GM does not include trade costs. On the other hand, OR argue that "the effects of home bias in preferences [...] can be isomorphic to the effects of trade costs".[36] So a natural question is whether or not a model with zero trade costs or a model with no home bias can fare equally well. Results to this are reported in Table 3.

Table 3: Comparison of Results:
Trade Costs and Degree of Home Bias Parameter in the Trade Costs Model

Criterion	Data	Baseline	$\kappa = 0$	$\alpha = .5$	κ=0, α=.5	$\kappa = .9999$
κ	–	0.39	0	0.26	0	0.9999
θ	–	0.78	0.75	0.75	0.75	0.71
α	–	0.05	0.40	0.5	0.5	0.56
η	–	1.00	3.00	3.00	3.00	1.30
σ	–	3.15	1.00	1.00	1.00	0.73
Puzzle 1	$[1; 19]$	19.36	1.50	1.84	1.00	13.45
Puzzle 2	$[-1; 0]$	-0.48	-0.57	-0.43	-0.33	-0.10
Puzzle 3	$[.32; .92]$	0.97	0.60	0.70	0.50	1.00
Puzzle 4	$[0.5; 1]$	2.83	9.13	9.55	10.58	1.14
Puzzle 51	7.52	1.97	0.33	0.34	0.25	0.81
Puzzle 52	0.83	0.61	0.62	0.62	0.62	0.62
Puzzle 61	4.36	3.13	0.37	0.39	0.28	0.97
Puzzle 62	0.08	0.63	0.63	0.63	0.64	0.48
min $\mathfrak{J}$	–	36.10	134.09	140.76	161.49	56.71

As column three of this table shows, the zero trade costs model does not leave out a lot in terms of the correlation between net exports and the real interest rate and in terms of the correlation pattern of real exchange rates. Also, the home bias puzzles can be addressed without relying on trade costs. But the volatility of the real exchange rate is significantly smaller in a model without trade costs. This is an aspect in favor of OR's idea. But notice that the estimation process did not deviate from the parameters' starting values, which may indicate some estimation deficiency. Column four of Table 3 shows the case without the home bias in preferences or degree of openness parameter, i.e. $\alpha = 0.5$. The result here is very much comparable to the one obtained in a model without trade costs. Hence, the isomorphic effects of the two parameters are shown here. The case of excluding both trade costs and openness parameter is depicted in column five. Here, exchange rate volatility is espe-

[36]See OR, p. 348.

cially difficult to obtain. As the comparison shows, the combination of trade costs and openness parameter can do a lot in this respect. Finally, the last column shows the estimation outcome if trade costs are fixed to a prohibitively high number $\kappa = 0.9999$, implying that virtually nothing of an exported good arrives at the destination market. This was done just for theoretical considerations. In this case, there is an offsetting foreign bias in consumption, as well as high intertemporal substitutability. While relative consumption correlation ($P4$) is decreased significantly, the outcome on the real exchange rate volatility dimension ($P51$ and $P61$) is worse than in the baseline model.

5.2 Alternative Monetary Policy Rules

In this section, I briefly check whether or not the previous results hinge on the estimated monetary policy rule. My deviations from this rule are along the suggestions in Galí and Monacelli (2005b). In particular, I investigate four different monetary policies:

1. Strict domestic inflation targeting (DIT), which GM show to be optimal from a welfare perspective under certain parameter restrictions. This rule can be written as follows:

$$r_t = \overline{rr}_t + \Phi_\pi \pi_{H,t} + \Phi_y \tilde{y}_t, \tag{57}$$

   where the last two summands are only added to circumvent indeterminacy, as explained in Galí and Monacelli (2005b).

2. A domestic inflation targeting rule (DITR), which relates the domestic short-term nominal interest rate only to the domestic inflation rate,

$$r_t = \Phi_\pi \pi_{H,t}. \tag{58}$$

3. A CPI inflation targeting rule (CITR), as given by

$$r_t = \Phi_\pi \pi_t. \tag{59}$$

4. And finally an exchange rate peg (PEG) that fixes the domestic nominal interest rate to its world analog,

$$r_t = r_t^*. \tag{60}$$

Estimation results for these alternative monetary policy rules are given in Table 4. We see that despite the differences in the level of abstraction, and despite the differences in the estimated parameter values, there are no substantial differences in terms of the model fit. As expected, the model fit measured by the value of the minimization problem $\mathfrak{J}$ is best for the estimated Taylor rule (TR), but it is nearly as good for strict domestic inflation targeting (DIT).

Table 4: Comparison of Results for Different Monetary Policy Rules

Criterion	TR	DIT	DITR	CITR	PEG
κ	0.39	0.42	0.48	0.90	0.41
θ	0.78	0.90	0.38	0.90	0.87
α	0.05	0.05	0.05	0.06	0.05
η	1.00	1.00	1.00	1.10	1.03
σ	3.15	3.11	1.67	1.14	1.62
Puzzle 1	19.36	19.37	19.13	19.05	19.06
Puzzle 2	-0.48	-0.65	-0.81	-0.75	0.46
Puzzle 3	0.97	0.97	0.97	0.99	0.97
Puzzle 4	2.83	2.85	1.59	1.65	1.56
Puzzle 51	1.97	1.96	1.47	1.11	1.44
Puzzle 52	0.61	0.61	0.61	0.61	0.61
Puzzle 61	3.13	3.09	1.88	1.27	1.84
Puzzle 62	0.63	0.63	0.56	0.56	0.56
Minimization $\mathfrak{J}$	36.10	36.43	43.44	51.33	43.93

5.3 Results for the GM Baseline Model

We have seen that a carefully estimated model with trade costs performs very well in the cross-validation of the puzzling data. But what about the original GM model? What if their "special case" calibration and their then optimal DIT policy is used? In that case, $\sigma = \eta = 1$, $\theta = 0.75$, $\alpha = 0.4$ and, of course, $\kappa = 0$. All other parameters are virtually the same as here. The result of this endeavor is presented in Table 5. For comparison reasons, I also add column three of Table 2, containing the moments of my TR parameter estimation. What we see from this is that the original GM model does very well compared to the estimated TR model. Its only comparative weakness is the very low exchange rate volatility.

6 Conclusion

Can the Galí and Monacelli (2005b) model replicate the six major puzzles in international macroeconomics, as collected by Obstfeld and Rogoff (2000*b*)? At first glance, this seems to be a challenging endeavor: This model is highly stylized, with complete financial markets, no capital, and a minimum of shocks and frictions. Nonetheless, some insight might be obtained. This textbook model

Table 5: Comparison of the TR Model with the GM DIT Model

Criterion	Data	TR	GM DIT
Puzzle 1	$[1; 19]$	19.36	1.50
Puzzle 2	$[-1; 0]$	-0.48	-0.63
Puzzle 3	$[.32; .92]$	0.97	0.60
Puzzle 4	$[0.5; 1]$	2.83	2.74
Puzzle 51	7.52	1.97	0.65
Puzzle 52	0.83	0.61	0.62
Puzzle 61	4.36	3.13	0.82
Puzzle 62	0.08	0.63	0.48

Notes: The GM DIT model is calibrated as suggested in GM, especially $\sigma = \eta = 1$, $\theta = 0.75$, $\alpha = 0.4$, and $\kappa = 0$. The TR model is parameterized as given in Table 1.

is widely used in academics and at central banks. It forms the way economists think about monetary policy in open economies. If the model deviates essentially from reality along the six puzzles, its usefulness should be doubted. So I have put up the fight between a stylized model and the rich and puzzling data. And it turns out to be a good one: Given the simplicity of the model, it performs quite well. This result holds true even for the case of a very stylized, close to optimal monetary policy in the small open economy.

Against expectance, the combination of two rather isomorphic ingredients – trade costs and a home bias in preferences – helps a lot to bring the model close to the data. So OR's assumption that trade costs do help in resolving the six puzzles proves true.

There are three big deficiencies for the model: First, the international correlation pattern of output and consumption, termed as quantity anomaly by Backus et al. (1995), is not met in any of the model specifications considered. All parameter combinations investigated result in a situation where international consumption correlation is higher than international output correlation. Given the simplicity of the model stochastics, this might simply be an artefact of the assumed productivity correlation. Indeed, changing the latter results in an improvement along this dimension. However, since this correlation is inherent in the data, its influence on the model accuracy will be neglected here. The second deficiency is the volatility of the real exchange rate, which still remains too low compared to the data. Nonetheless, compared to the original GM calibration, my baseline choice of parameter implies a strong increase in the real exchange rate volatility. For further increases, the literature has shown that pricing-to-market arrangements may help a lot, but this is left for future research. The third and last deficiency is the high correlation between real exchange rate and output, which is seen in all specifications of the model. As a remedy for this, one should again think about a richer set of stochastic elements in the model. Another promising topic is the inclusion of a more realistic fiscal policy instead of the production subsidy assumed so far.

If these deficiencies are important for a specific research question, one should not rely on the stylized New Keynesian small open economy model examined in this paper. Instead, one should look for a more elaborated model. In case these deficiencies are of minor importance, I have shown in Section 5.3 that even the textbook GM model is doing reasonably well against the six puzzles.

A Technical Appendix

A.1 Steady State

For the derivation of the nonstochastic perfect foresight steady state, I assume without loss of generality that steady state domestic technology $A = 1$. For notational simplicity, I omit a variable's time subscript to denote its steady state. In the steady state, prices are flexible and markups are constant. In connection with firms' pricing derived in Section A.5, this implies

$$MC = \frac{MC^n}{P_H} = \frac{(1-\tau)W}{P_H} = \frac{\varepsilon - 1}{\varepsilon}. \tag{61}$$

Plugging this result in the household's intratemporal first-order condition gives

$$C^\sigma N^\varphi = \frac{W}{P} \tag{62}$$

$$\Leftrightarrow \quad C^\sigma Y^\varphi = \frac{\varepsilon - 1}{\varepsilon} \frac{1}{1-\tau} \frac{P_H}{P}, \tag{63}$$

where the latter equation used the steady state relationship $Y = AN = N$. From the risk sharing condition (31) we obtain

$$C = \vartheta Y^* \mathscr{Q}^{\frac{1}{\sigma}}, \tag{64}$$

using $C^* = Y^*$. Replacing C in (62) by equation (64) leads to

$$Y = \left(\frac{\frac{\varepsilon-1}{\varepsilon} \frac{P_H}{P}}{(1-\tau)(\vartheta Y^*)^\sigma \mathscr{Q}} \right)^{\frac{1}{\varphi}} \tag{65}$$

$$= \left(\frac{1 - \frac{1}{\varepsilon}}{1-\tau} \right)^{\frac{1}{\varphi}} \mathscr{S}^{-\frac{1}{\varphi}} (\vartheta Y^*)^{-\frac{\sigma}{\varphi}}, \tag{66}$$

where the second line replaced the price ratio and the real exchange rate by the terms of trade, along

$$\mathscr{Q} = \frac{\mathscr{E}P^*}{P} = \mathscr{S}\frac{P_H}{P}, \quad \text{as} \quad \mathscr{S} = \frac{(1-\kappa)P_F}{P_H} = \frac{\mathscr{E}P_F^*}{P_H} = \frac{\mathscr{E}P^*}{P_H}, \tag{67}$$

see Equations (11), (12), (15) and (17).

Furthermore, transforming the market clearing condition (25) gives rise to a second equation linking domestic output to foreign output and the terms of trade:

$$
\begin{aligned}
Y &= C_H + \frac{1}{1-\kappa} C_H^* && (68) \\
&= (1-\alpha)\left(\frac{P_H}{P}\right)^{-\eta} C + \frac{\alpha^*}{1-\kappa}\left(\frac{P_H}{\mathscr{E}P^*}\right)^{-\eta} C^* && (69) \\
&= (1-\alpha)\left(\frac{P_H}{P}\right)^{-\eta} C + \frac{\alpha^*}{1-\kappa}\mathscr{S}^{\eta} Y^* && (70) \\
&= \left[(1-\alpha)\left(\frac{P_H}{P}\right)^{\frac{1}{\sigma}-\eta}\mathscr{S}^{\frac{1}{\sigma}} + \frac{\alpha}{1-\kappa}\mathscr{S}^{\eta}\right]\vartheta Y^*, && (71)
\end{aligned}
$$

where α^* is replaced by $\alpha\vartheta$, where $\vartheta = \frac{C_0}{C_0^*}$ denotes initial conditions of the model. Equations (66) and (71) together determine the terms of trade and domestic output as functions of world output. The unique solution for the terms of trade is given by $\mathscr{S} = \frac{(1-\kappa)P_F}{P_H} = 1$. This result can be used to simplify the CPI Equation (6)

$$
\begin{aligned}
\bar{P}^{1-\eta} &= (1-\alpha)\bar{P}_H^{1-\eta} + \alpha\bar{P}_F^{1-\eta} && (72) \\
&= [1-\alpha+\alpha(1-\kappa)^{\eta-1}]\bar{P}_H^{1-\eta} && (73) \\
&= [\alpha+(1-\alpha)(1-\kappa)^{1-\eta}]\bar{P}_F^{1-\eta} && (74)
\end{aligned}
$$

and to solve it for the steady state ratios:

$$
\begin{aligned}
\frac{P_H}{P} &= \left[1-\alpha+\alpha(1-\kappa)^{\eta-1}\right]^{\frac{1}{\eta-1}} \equiv \Phi_{PHP} && (75) \\
\frac{P_F}{P} &= \left[\alpha+(1-\alpha)(1-\kappa)^{1-\eta}\right]^{\frac{1}{\eta-1}} \equiv \Phi_{PFP}. && (76)
\end{aligned}
$$

Notice that these ratios are equal to unity if trade costs are zero, $\kappa = 0$, or if the substitution elasticity is $\eta = 1$. With this in mind, Equations (66) and (71) simplify to

$$
Y = \left(\frac{1-\frac{1}{\varepsilon}}{1-\tau}\right)^{\frac{1}{\varphi}} (\vartheta Y^*)^{-\frac{\sigma}{\varphi}} = \Phi_{SS1}(\vartheta Y^*)^{-\frac{\sigma}{\varphi}} \quad (77)
$$

and

$$
Y = \left[(1-\alpha)\Phi_{PHP}^{\frac{1}{\sigma}-\eta} + \frac{\alpha}{1-\kappa}\right]\vartheta Y^* = \Phi_{SS2}\vartheta Y^*. \quad (78)
$$

The solution to this system is given by

$$
Y^* = \frac{1}{\vartheta}\left(\frac{\Phi_{SS1}}{\Phi_{SS2}^{\varphi}}\right)^{\frac{1}{1+\sigma}} \quad (79)
$$

and

$$
Y = \Phi_{SS2}\vartheta Y^*. \quad (80)
$$

Some remarks are in order. First, in the case of zero trade costs, $\Phi_{SS2} = 1$ and $Y = \vartheta Y^*$, as in GM. For positive trade costs (and $\eta > 1$), the relative size of domestic output increases, as $\Phi_{SS2} > 1$. Trade costs decrease the demand for imports and increase domestic production. As the small open economy is by definition more open, this effect is more pronounced for the small open economy. Hence, the size effect on the output ratio Y/Y^*.

Second, for positive trade costs, $\Phi_{PFP} > 1 > \Phi_{PHP}$, i. e., the price index of imports is higher than the average price index, reflecting transport costs.

Third, the steady state real exchange rate $\mathcal{Q} = \Phi_{PHP}\mathcal{S}$ is unity under zero trade costs, but smaller than unity for $\kappa > 0$.

Fourth, inspecting Equation (64), steady state consumption in the small open economy equals domestic output for zero trade costs. For positive trade costs, steady state consumption becomes smaller than steady state output. At first glance, this might seem unreasonable, as it suggests that the small open economy does not spend all its income. However, this is not the case, as "some portion of the traded good dissipates in transit".[37]

Fifth, trade costs also influence steady state net exports. Nominal net exports are given by Equation (22). In steady state, this reads

$$NX = Y - PC/P_H = Y - C/\Phi_{PHP}. \tag{81}$$

As in GM steady state net exports are zero for $\kappa = 0$, but they are negative for positive trade costs, where $\Phi_{PHP} < 1$.

A.2 Log-Linearization of the CPI Equation

I linearly approximate the domestic CPI, as given by Equation (6) around the steady state, where $\bar{P}_H = (1-\kappa)\bar{P}_F$. Rewriting the CPI equation as

$$P_t^{1-\eta} = (1-\alpha)P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}, \tag{82}$$

it is straightforward to log-linearize this equation to get

$$p_t = (1-\alpha)\left(\frac{\bar{P}_H}{\bar{P}}\right)^{1-\eta} p_{H,t} + \alpha\left(\frac{\bar{P}_F}{\bar{P}}\right)^{1-\eta} p_{F,t}, \tag{83}$$

where small letters denote log deviations from the steady state. The constant steady state ratios P_H/P and P_F/P are derived in Section A.1 of the appendix, they are given in Equations (75) and (76). Plugging them in Equation (83) yields

$$\begin{aligned} p_t &= \frac{1-\alpha}{1-\alpha+\alpha(1-\kappa)^{\eta-1}} p_{H,t} + \frac{\alpha}{\alpha+(1-\alpha)(1-\kappa)^{1-\eta}} p_{F,t} \\ &= \left(1 - \frac{\alpha}{\alpha+(1-\alpha)(1-\kappa)^{1-\eta}}\right) p_{H,t} + \frac{\alpha}{\alpha+(1-\alpha)(1-\kappa)^{1-\eta}} p_{F,t} \\ &= (1-\alpha')p_{H,t} + \alpha' p_{F,t}. \end{aligned} \tag{84}$$

[37] See Obstfeld and Rogoff (1996, p. 251).

The last equation is Equation (19) in the text. Notice that the coefficients $1-\alpha'$ and α' sum up to one like $1-\alpha$ and α in GM, they actually coincide with them in the case of zero trade costs $\kappa = 0$. These coefficients show the relative importance of changes in domestic producer prices and import prices for changes in the CPI. In GM, the baseline value $\alpha = 0.4$ implies that import prices affect the CPI by 40 percent. In my baseline calibration with substitution elasticity $\eta = 1.5$ and trade costs $\kappa = 0.25$, this effect is reduced to 36.6 percent as a result of the trade reducing costs. Notice, however, that trade costs only influence the CPI if the international substitution elasticity is non-unitary. Using the same value for this elasticity as for the intranational substitution elasticity, i.e., setting $\eta = \varepsilon = 6$, the effect of imports on the CPI is reduced by more than one half, to 13.7 percent. The higher the substitutability between domestic and foreign goods, the easier it is to replace trade cost affected imports by domestically produced goods. Finally, in the OR baseline of $\eta = 6$, $\kappa = 0.25$ and $\alpha = 0.5$ (no home bias), the effect of imports is again strongly reduced to 19.2 percent.

A.3 Log-Linearization of Net Exports Equation

Nominal net exports are given by

$$P_{H,t}NX_t = P_{H,t}Y_t - P_t C_t. \tag{85}$$

As Section A.1 shows, the steady state implies $NX = Y - PC/P_H = Y - C/\Phi_{PHP}$, which could be zero. Hence, log deviations of net exports around steady state cannot be defined in the usual way. Instead, define

$$nx_t \equiv \frac{NX_t - NX}{Y} \tag{86}$$

to be the percentage deviation of net exports from steady state in terms of domestic steady state GDP. Rewriting Equation (85), we have

$$\begin{aligned}
NX_t &= Y_t - \frac{P_t}{P_{H,t}}C_t && (87)\\
\Leftrightarrow \quad Ynx_t + NX &= Y(1+y_t) - \frac{PC}{P_H}(1+p_t - p_{H,t} + c_t) && (88)\\
\Leftrightarrow \quad nx_t &= y_t - \frac{PC}{P_H Y}(p_t - p_{H,t} + c_t) && (89)\\
&= y_t - \frac{PC}{P_H Y}(c_t + \alpha' s_t), && (90)
\end{aligned}$$

where the last equation, obtained using Equation (20), is Equation (23) in the main text. The steady state ratio $\frac{PC}{P_H Y}$ can be solved for parameters using equations (64), (80) and $\mathcal{Q} = \Phi_{PHP}\mathcal{S}$. One then gets $\frac{PC}{P_H Y} = \Phi_{PHP}^{\frac{1}{\sigma}-1}\Phi_{SS2}^{-1}$. Notice that in the case of zero trade costs, steady state nominal net exports are zero, and hence $P_H Y = PC$, or $\Phi_{PHP} = \Phi_{SS2} = 1$, so that one obtains the GM result

$$nx_t = y_t - c_t - \alpha' s_t.$$

A.4 Derivation of the Risk Sharing Condition Equation

Equating the domestic Euler Equation (29) and its foreign analog given in footnote 11, we have

$$C_t = C_t^* \left(\frac{\mathcal{E}_t P_t^*}{P_t} \right)^{\frac{1}{\sigma}} E_t \left[\frac{C_{t+1}}{C_{t+1}^*} \left(\frac{P_{t+1}}{\mathcal{E}_{t+1} P_{t+1}^*} \right)^{\frac{1}{\sigma}} \right]. \tag{91}$$

Using the definition of the real exchange rate, $\mathcal{Q}_t \equiv \frac{\mathcal{E}_t P_t^*}{P_t}$, this may be rewritten as

$$\frac{C_t}{C_t^* \mathcal{Q}_t^{\frac{1}{\sigma}}} = E_t \left[\frac{C_{t+1}}{C_{t+1}^* \mathcal{Q}_{t+1}^{\frac{1}{\sigma}}} \right]. \tag{92}$$

Iterating this equation backwards and assuming that the period zero real exchange rate is at its steady state, $\mathcal{Q}_t = 1$, and denoting initial conditions $\frac{C_0}{C_0^*} = \vartheta$, we get

$$\frac{C_t}{C_t^* \mathcal{Q}_t^{\frac{1}{\sigma}}} = \vartheta, \tag{93}$$

which, multiplied by the denominator, is Equation (31) in the text.

A.5 Derivation of the Price Setting Rule Equation

A representative firm i faces the following maximization problem:

$$\max_{\overline{P}_{H,t}} \sum_{k=0}^{\infty} \theta^k E_t \{ Q_{t,t+k} [Y_{t+k} (\overline{P}_{H,t} - MC_{t+k}^n)] \} , \tag{94}$$

subject to the demand function. Demand for domestic good i is the sum of demand from the small open economy and the world economy. But as a fraction κ of the good melts away in the trade process, consumption abroad is only $1-\kappa$ of what was meant for export of good i. From the market clearing Equation (25), we obtain for good i

$$C_{H,t}^*(i) = (1-\kappa)[Y_t(i) - C_{H,t}(i)]. \tag{95}$$

Hence, demand can be written as

$$\begin{aligned} Y_t^d(i) &= C_{H,t}(i) + \frac{1}{1-\kappa} C_{H,t}^*(i) && (96) \\ &= \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon} C_{H,t} + \left(\frac{P_{H,t}^*(i)}{P_{H,t}^*}\right)^{-\varepsilon} \frac{1}{1-\kappa} C_{H,t}^* && (97) \\ &= \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon} \left(C_{H,t} + \frac{1}{1-\kappa} C_{H,t}^*\right), && (98) \end{aligned}$$

where I have made use of Equation (26) in the second line and of the nominal exchange rate definition in the third line, where trade costs cancel each other out in the numerator and in the denominator. At date $t+k$, good i production is not bigger than its demand. Replacing the individual price $P_{H,t}(i)$ by the newly set price $\overline{P}_{H,t}$, the constraint to the maximization problem reads

$$Y_{t+k}(i) \leq \left(\frac{\overline{P}_{H,t}}{P_{H,t+k}}\right)^{-\varepsilon} (C_{H,t+k} + \frac{1}{1-\kappa} C_{H,t+k}^*) \equiv Y_{t+k}^d(\overline{P}_{H,t}). \tag{99}$$

Each firm sets the same price in equilibrium, so the index i can be dropped. As equality holds in the optimum, one can replace Y_{t+k} in the maximization problem by the constraint given in Equation (99). Multiplying by $\bar{P}_{H,t}$, dividing by $1-\varepsilon$ and reinserting Y_{t+k}, the according first order condition looks as follows:

$$\sum_{k=0}^{\infty} \theta^k E_t \left\{ Q_{t,t+k} Y_{t+k} (\overline{P}_{H,t} - \frac{\varepsilon}{\varepsilon - 1} MC_{t+k}^n) \right\} = 0\,. \tag{100}$$

Using the household's Euler Equation (29) and the fact that $E_t(Q_{t,t+1}) = \frac{1}{R_t}$, one can replace $E_t(Q_{t,t++k})$ by $\beta^k \left(\frac{C_t}{C_{t+k}}\right)^{\sigma} \frac{P_t}{P_{t+k}}$. Dividing by the period t terms results in

$$\sum_{k=0}^{\infty} (\beta\theta)^k E_t \left\{ \frac{1}{P_{t+k} C_{t+k}^{\sigma}} Y_{t+k} (\overline{P}_{H,t} - \frac{\varepsilon}{\varepsilon - 1} MC_{t+k}^n) \right\} = 0\,. \tag{101}$$

In preparation for log-linearization, split up the difference and notice that $MC_{t+k} \equiv \frac{MC_{t+k}^n}{P_{H,t+k}}$:

$$\sum_{k=0}^{\infty} (\beta\theta)^k E_t \left\{ \frac{\bar{P}_{H,t} Y_{t+k}}{P_{t+k} C_{t+k}^{\sigma}} \right\} = \sum_{k=0}^{\infty} (\beta\theta)^k E_t \left\{ \frac{\varepsilon Y_{t+k} MC_{t+k} P_{H,t+k}}{(\varepsilon - 1) P_{t+k} C_{t+k}^{\sigma}} \right\}. \tag{102}$$

Next I log-linearize around the zero inflation, perfect foresight, balanced trade steady state. For this, notice that at the steady state, $\bar{P}_{H,t} = P_{H,t+k}$,and $MC_{t+k} =$

$\frac{\varepsilon-1}{\varepsilon}$. Using small letters to denote percentage deviations around steady state, we get

$$\begin{aligned}\sum_{k=0}^{\infty} & (\beta\theta)^k E_t\left\{\bar{p}_{H,t}+y_{t+k}-p_{t+k}-\sigma c_{t+k}\right\} \\ & =\sum_{k=0}^{\infty}(\beta\theta)^k E_t\left\{y_{t+k}+\widehat{mc}_{t+k}+p_{H,t+k}-p_{t+k}-\sigma c_{t+k}\right\}, \quad (103)\end{aligned}$$

where I have already factored out and divided by the steady state values. Notice that I have written $\widehat{mc}_t$ instead of mc_t, to keep notation consistent with GM and Galí and Monacelli (2005b), who use $mc_t \equiv \log MC_t$, $mc_t^n \equiv \log MC_t^n$ and $\widehat{mc}_t \equiv mc_t - \overline{mc}$, where $\overline{mc} = \log \overline{MC} = \log \frac{\varepsilon-1}{\varepsilon} \equiv -\mu$ is the steady state real marginal cost. Simplifying the last equation using $\sum_{k=0}^{\infty}(\beta\theta)^k = 1/(1-\beta\theta)$ results in

$$\bar{p}_{H,t} = (1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k E_t\left\{\widehat{mc}_{t+k}+p_{H,t+k}\right\}. \quad (104)$$

Rewriting $\widehat{mc}_t^n = \widehat{mc}_t^n + p_{H,t}$, this can be transformed to

$$\bar{p}_{H,t} = (1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k E_t\{\widehat{mc}_{t+k}^n\}\ , \quad (105)$$

which is Equation (34) in Section 2.3.

A.6 Derivation of the Inflation Dynamics Equation

In the Calvo pricing scheme, the domestic price level given in equation (7) can be rewritten as the combination of previous period's price and the newly set price:

$$P_{H,t} = [\theta P_{H,t-1}^{1-\varepsilon} + (1-\theta)\overline{P}_{H,t}^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}}\ . \quad (106)$$

Log-linearizing this equation around a zero inflation steady state results in

$$p_{H,t} = \theta p_{H,t-1} + (1-\theta)\bar{p}_{H,t}. \quad (107)$$

From the previous paragraph, notice that Equation (105) can be rewritten as a first-order difference equation in $p_{H,t}$. Leading the equation by one, taking conditional expectations and multiplying by $\beta\theta$ and subtracting this from the original equation gives

$$\bar{p}_{H,t} = (1-\beta\theta)(\widehat{mc}_t^n) + \beta\theta E_t\{\bar{p}_{H,t+1}\}. \quad (108)$$

Now, multiply this equation by $(1-\theta)$. Then, replace $(1-\theta)\bar{p}_{H,t}$ by making use of Equation (107), both at date t and date $t+1$. This results in

$$p_{H,t} - \theta p_{H,t-1} = (1-\theta)(1-\beta\theta)(\widehat{mc}_t^n) + \beta\theta E_t\{p_{H,t+1} - \theta p_{H,t}\}. \quad (109)$$

Using $\widehat{mc}_t^n = \widehat{mc}_t + p_{H,t}$ and simplifying, we obtain

$$\pi_{H,t} = \beta E_t\{\pi_{H,t+1}\} + \lambda(\widehat{mc}_t), \quad \lambda \equiv \frac{(1-\theta)(1-\beta\theta)}{\theta}, \tag{110}$$

which is the small open economy part of Equation (35) in Section 2.3. The world inflation is determined analogously.

A.7 Derivation of the Canonical Representation

In this section, I derive the dynamic IS equation and the New Keynesian Phillips Curve (NKPC) for the world economy and the small open economy.

Writing the foreign analog of the household's log-linear Euler Equation (30) in terms of foreign currency, using the market clearing condition (24), one obtains a difference equation for world output:

$$y_t^* = E_t\{y_{t+1}^*\} - \frac{1}{\sigma}(r_t^* - E_t\{\pi_{t+1}^*\}) \,. \tag{111}$$

For the small open economy, an analog can be achieved in eight steps: First, I write down the market clearing condition (25) for a domestically produced good i. Then, I use the demand functions (26) and (27) as well as its world analogs. Here, notice that under producer currency pricing the substitution elasticity for domestically produced goods has to be considered. Third, I replace total consumption in the small open economy by world output, following Equation (31):

$$\begin{aligned} Y_t(i) &= C_{H,t}(i) + \frac{1}{1-\kappa} C_{H,t}^*(i) && (112) \\ &= \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon} \left[\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} (1-\alpha) C_t + \left(\frac{P_{H,t}}{\mathscr{E}_t P_t^*}\right)^{-\eta} \frac{\alpha^*}{1-\kappa} Y_t^* \right] && (113) \\ &= \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon} \vartheta Y_t^* \left[\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} (1-\alpha) \mathscr{Q}_t^{\frac{1}{\sigma}} + \left(\frac{P_{H,t}}{\mathscr{E}_t P_t^*}\right)^{-\eta} \frac{\alpha}{1-\kappa} \right] && (114) \end{aligned}$$

In the fourth step, define domestic output like consumption as in Equation (3) to be

$$Y_t \equiv \left(\int_0^1 Y_t(i)^{1-\frac{1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{115}$$

and plug Equation (114) into this definition:

$$
\begin{aligned}
Y_t &= \left[\int_0^1 Y_t(i)^{1-\frac{1}{\epsilon}} d_i\right]^{\frac{\epsilon}{\epsilon-1}} \\
&= \left[\int_0^1 \left\{\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\epsilon} \vartheta Y_t^* \left[\left(\frac{P_{H,t}}{P_t}\right)^{-\eta}(1-\alpha)\mathcal{Q}_t^{\frac{1}{\sigma}} + \left(\frac{P_{H,t}}{\mathcal{E}_t P_t^*}\right)^{-\eta}\frac{\alpha}{1-\kappa}\right]^{\frac{\epsilon-1}{\epsilon}}\right\} di\right]^{\frac{\epsilon}{\epsilon-1}} \\
&= \left[\left[\vartheta Y_t^* \left\{\left(\frac{P_{H,t}}{P_t}\right)^{-\eta}(1-\alpha)\mathcal{Q}_t^{\frac{1}{\sigma}} + \mathcal{S}^{\eta}\frac{\alpha}{1-\kappa}\right\}\right]^{\frac{\epsilon-1}{\epsilon}} P_{H,t}^{\epsilon-1}\int_0^1 P_{H,t}(i)^{1-\epsilon} di\right]^{\frac{\epsilon}{\epsilon-1}} \\
&= \left[\left[\vartheta Y_t^* \left\{\left(\frac{P_{H,t}\mathcal{Q}_t}{\mathcal{E}_t P_t^*}\right)^{-\eta}(1-\alpha)\mathcal{Q}_t^{\frac{1}{\sigma}} + \mathcal{S}^{\eta}\frac{\alpha}{1-\kappa}\right\}\right]^{\frac{\epsilon-1}{\epsilon}} P_{H,t}^{\epsilon-1}\int_0^1 P_{H,t}(i)^{1-\epsilon} di\right]^{\frac{\epsilon}{\epsilon-1}} \\
&= \left[\left[\vartheta Y_t^* \left\{\mathcal{S}^{\eta}\mathcal{Q}_t^{-\eta}(1-\alpha)\mathcal{Q}_t^{\frac{1}{\sigma}} + \mathcal{S}^{\eta}\frac{\alpha}{1-\kappa}\right\}\right]^{\frac{\epsilon-1}{\epsilon}} P_{H,t}^{\epsilon-1}\int_0^1 P_{H,t}(i)^{1-\epsilon} di\right]^{\frac{\epsilon}{\epsilon-1}} \\
&= \vartheta Y_t^* \mathcal{S}^{\eta}\left[(1-\alpha)\mathcal{Q}_t^{\frac{1}{\sigma}-\eta} + \frac{\alpha}{1-\kappa}\right] P_{H,t}^{\epsilon}\left[\int_0^1 P_{H,t}(i)^{1-\epsilon} di\right]^{\frac{\epsilon}{\epsilon-1}} \\
&= \vartheta Y_t^* \mathcal{S}^{\eta}\left[(1-\alpha)\mathcal{Q}_t^{\frac{1}{\sigma}-\eta} + \frac{\alpha}{1-\kappa}\right] P_{H,t}^{\epsilon}(P_{H,t}^{1-\epsilon})^{\frac{\epsilon}{\epsilon-1}} \\
&= \vartheta Y_t^* \mathcal{S}^{\eta}\left[(1-\alpha)\mathcal{Q}_t^{\frac{1}{\sigma}-\eta} + \frac{\alpha}{1-\kappa}\right].
\end{aligned} \tag{116}
$$

Notice that I have made use of $\frac{P_{H,t}}{P_t} = \frac{P_{H,t}\mathcal{Q}_t}{\mathcal{E}_t P_t^*}$ and $\frac{P_{H,t}}{\mathcal{E}_t P_t^*} = \mathcal{S}_t^{-1}$ during the calculations.

Step five is log-linearization around the steady state, following the principle $Y_t = Ye^{y_t} \approx Y(1+y_t)$. Simplifying,

$$
Y_t = \vartheta Y_t^* \mathcal{S}_t^{\eta}(1-\alpha)\mathcal{Q}_t^{\frac{1}{\sigma}-\eta} + \frac{\alpha\vartheta}{1-\kappa} Y_t^* \mathcal{S}_t^{\eta}, \tag{117}
$$

this is well approximated by

$$
\begin{aligned}
Y(1+y_t) &= \vartheta Y^* \mathcal{S}^{\eta}(1-\alpha)\mathcal{Q}^{\frac{1}{\sigma}-\eta}[1 + y_t^* + \eta s_t + (\frac{1}{\sigma}-\eta)q_t] \\
&\quad + \frac{\alpha\vartheta}{1-\kappa} Y^* \mathcal{S}^{\eta}(1 + y_t^* + \eta s_t).
\end{aligned} \tag{118}
$$

After subtracting the steady state $Y = \Phi_{SS2}\vartheta Y^*$ given in Equation (78), this becomes

$$\begin{aligned} y_t &= \Phi_{SS2}^{-1}\Phi_{PHP}^{\frac{1}{\sigma}-\eta}(1-\alpha)[y_t^* + \eta s_t + (\frac{1}{\sigma}-\eta)q_t] + \Phi_{SS2}^{-1}\frac{\alpha}{1-\kappa}(y_t^*+\eta s_t) \\ &= y_t^* + \eta s_t + \left(1 - \frac{\alpha}{(1-\kappa)\Phi_{SS2}}\right)(\frac{1}{\sigma}-\eta)q_t \\ &= y_t^* + \left[\eta + (\frac{1}{\sigma}-\eta)(1-\alpha')\left(1-\frac{\alpha}{1-\kappa}\Phi_{SS2}^{-1}\right)\right]s_t \qquad (119) \\ &= y_t^* + \frac{\omega}{\sigma}s_t\ , \qquad (120) \end{aligned}$$

where $\omega \equiv \sigma\eta + (1-\sigma\eta)(1-\alpha')\left(1-\frac{\alpha}{1-\kappa}\Phi_{SS2}^{-1}\right)$. Notice that in the case of zero trade costs, ω equals the parameter ω_α in GM, and the last equation simplifies to

$$y_t = y_t^* + \frac{\omega_\alpha}{\sigma}s_t\ , \quad \omega_\alpha \equiv 1 + \alpha(2-\alpha)(\sigma\eta - 1) > 0\ .$$

As a sixth step, one can use the consumption ratio given in Equation (32), substitute out s_t and get an equation that relates c_t to domestic and world output:

$$c_t = \Phi_c y_t + (1-\Phi_c)y_t^*\ , \qquad (121)$$

where the parameter $\Phi_c \equiv \frac{1-\alpha'}{\omega}$. In the seventh step, Equation (121) is used to replace consumption in the household's Euler Equation (30), and first differences of Equation (20) is used to replace CPI inflation by domestic goods inflation:

$$\Phi_c y_t + (1-\Phi_c)y_t^* = E_t\left\{\Phi_c y_{t+1} + (1-\Phi_c)y_{t+1}^*\right\} - \frac{1}{\sigma}(r_t - E_t\{\pi_{H,t+1} + \alpha'\Delta s_{t+1}\})\ . \qquad (122)$$

Finally, the eighth and last step is to substitute out Δs_{t+1} using equation (120) and to solve for y_t. One then obtains a dynamic IS equation for the small open economy:

$$y_t = E_t\{y_{t+1}\} - \frac{\omega}{\sigma}(r_t - E_t\{\pi_{H,t+1}\}) + (\omega - 1)E_t\{\Delta y_{t+1}^*\}\ . \qquad (123)$$

To derive the New Keynesian Phillips Curves, I start from Equation (35) derived in this appendix Section A.6. The marginal costs in these equations shall be replaced by output. Remember from Section 2.2.2, that $MC_t^n = MC_t P_{H,t} = (1-\tau)W_t/A_t$, so the log deviation of the real marginal costs of the small open and the world economy are

$$\widehat{mc}_t = w_t - a_t - p_{H,t} \quad \text{and} \quad \widehat{mc}_t^* = w_t^* - a_t^* - p_t^*. \qquad (124)$$

For the world economy, the household's intratemporal first-order condition $w_t^* - p_t^* = \sigma c_t^* + \varphi n_t^*$ and aggregate production $y_t^* = n_t^* + a_t^*$, analogously to Equations (30) and (33), can be used to rewrite

$$\widehat{mc}_t^* = (\sigma + \varphi)y_t^* - (1+\varphi)a_t^*\ . \qquad (125)$$

For the small open economy, the same steps and additionally Equation (20) result in

$$\widehat{mc}_t = \sigma c_t + \varphi y_t + \alpha' s_t - (1+\varphi) a_t . \tag{126}$$

Now, using Equation (32) allows for replacing consumption by world output and terms of trade,

$$\widehat{mc}_t = \sigma y_t^* + \varphi y_t + s_t - (1+\varphi) a_t . \tag{127}$$

Finally, Equation (120) enables us to substitute out s_t. So marginal costs can be rewritten just in terms of both types of output and domestic productivity:

$$\widehat{mc}_t = \left(\frac{\sigma}{\omega} + \varphi\right) y_t + \sigma\left(1 - \frac{1}{\omega}\right) y_t^* - (1+\varphi) a_t . \tag{128}$$

To use the conventional notation in terms of gaps, the output gap shall be defined as the deviation of the log-linearized variable from its natural level, which would occur under flexible prices and thereby constant marginal costs $\log MC_t = mc_t = \log MC_t^* = mc_t^* = -\mu$. This implies that the log deviations of marginal costs from this flex-price steady state are always zero, $\widehat{mc}_t = \widehat{mc}_t^* = 0$. Thus, I have $\tilde{y}_t \equiv y_t - \overline{y}_t$ and analogously $\tilde{y}_t^* \equiv y_t^* - \overline{y}_t^*$, where bars above variables with time index are used to denote their natural levels. To obtain these natural levels of output, solve Equations (128) and (125) in the flex-price situation for the respective output:

$$\overline{y}_t = \frac{\omega(1+\varphi)}{\sigma + \omega\varphi} a_t + \frac{\sigma(1-\omega)}{\sigma+\omega\varphi} y_t^* \quad \text{and} \quad \overline{y}_t^* = \frac{1+\varphi}{\sigma+\varphi} a_t^* . \tag{129}$$

Subtracting the flex-price version of Equation (125) from the sticky price version yields

$$\begin{aligned} \widehat{mc}_t^* &= (\sigma+\varphi)(y_t^* - \bar{y}_t^*) \\ &= (\sigma+\varphi)\tilde{y}_t^* . \end{aligned} \tag{130}$$

Similarly, for the small open economy we obtain

$$\begin{aligned} \widehat{mc}_t &= \left(\frac{\sigma}{\omega} + \varphi\right)(y_t - \bar{y}_t) \\ &= \left(\frac{\sigma}{\omega_\xi} + \varphi\right)\tilde{y}_t . \end{aligned} \tag{131}$$

Notice that foreign output does not show up, as for the calculation of the domestic output gap world output is assumed to be exogenous, both in the flex-price and in the sticky price world.

After inserting the results for marginal costs from Equations (130) and (131) in the inflation dynamics equations given in (35), I obtain the New Keynesian Phillips curves (NKPC) for the small open economy and for the world economy, linking inflation to its expected future value and to the output gap:

$$\pi_{H,t} = \beta E_t\{\pi_{H,t+1}\} + \Phi_{NKPC}\tilde{y}_t \,, \tag{132}$$
$$\pi_t^* = \beta E_t\{\pi_{t+1}^*\} + \Phi_{NKPC^*}\tilde{y}_t^* \,, \tag{133}$$

where $\Phi_{NKPC} \equiv \lambda\left(\frac{\sigma}{\omega} + \varphi\right)$ and $\Phi_{NKPC^*} \equiv \lambda(\sigma + \varphi)$.

For the dynamic IS equations, start with the difference equation for world output given in equation (111). Evaluate it twice, once for sticky prices and once for flexible prices. In doing so, notice that

$$\bar{r}_t^* - E_t\{\bar{\pi}_{t+1}^*\} = -\sigma(1-\rho_a^*)\Gamma_0 a_t^* \equiv \overline{rr}_t^*. \tag{134}$$

is the natural expected real rate of interest in the world economy, which would prevail under completely flexible prices. It can be derived by solving Equation (111) for the flexible price situation characterized by equation (129). Subtract the flex-price outcome from the sticky price outcome to obtain

$$\tilde{y}_t^* = E_t\{\tilde{y}_{t+1}^*\} - \frac{1}{\sigma}(r_t^* - E_t\{\pi_{t+1}^*\} - \overline{rr}_t^*)\,. \tag{135}$$

Analogously, the small open economy's dynamic IS equation is obtained by subtracting Equation (129) from Equation (123) and simplifying:

$$\tilde{y}_t = E_t\{\tilde{y}_{t+1}\} - \frac{\omega}{\sigma}(r_t - E_t\{\pi_{H,t+1}\} - \overline{rr}_t) \tag{136}$$

with the domestic natural expected real rate of interest

$$\overline{rr}_t \equiv -\frac{\sigma(1+\varphi)(1-\rho_a)}{\sigma+\omega\varphi}a_t - \varphi\frac{\sigma(1-\omega)}{\sigma+\omega\varphi}E_t\{\Delta y_{t+1}^*\}, \tag{137}$$

again derived evaluating Equation (123) at the flexible price situation described by equation (129). Equations (132), (133), (136) and (135) are equations (38), (39), (40) and (41) in Section 2.3.4.

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