

Buzaushina, Almira

**Conference Paper**

## How important is China for the US exchange rate and current account?

Beiträge zur Jahrestagung des Vereins für Socialpolitik 2010: Ökonomie der Familie - Session: Trade, Capital Account and Currency Crises, No. B7-V3

**Provided in Cooperation with:**

Verein für Socialpolitik / German Economic Association

*Suggested Citation:* Buzaushina, Almira (2010) : How important is China for the US exchange rate and current account?, Beiträge zur Jahrestagung des Vereins für Socialpolitik 2010: Ökonomie der Familie - Session: Trade, Capital Account and Currency Crises, No. B7-V3, Verein für Socialpolitik, Frankfurt a. M.

This Version is available at:

<https://hdl.handle.net/10419/37443>

**Standard-Nutzungsbedingungen:**

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

**Terms of use:**

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*

# How important is China for the US exchange rate and current account?\*

Almira Buzaushina<sup>†</sup>

November 14, 2009

## Abstract

The purpose of this paper is to investigate New Open Economy Macroeconomics in an empirical way in order to analyze the ability of these models in explaining key variables: exchange rate and current account. A standard two-country dynamic stochastic general equilibrium model with nominal rigidities and imperfect competition is estimated using the maximum likelihood procedure. In contrast to previous literature, the estimation methods are fitted to the data of the USA and its main trading partners, including China and Mexico. The estimation results show that the consideration of the data for these countries on the opposite side of the US is important for explaining the US current account and exchange rate movements, as well as for getting confident estimates for some deep parameters which are controversial in the theoretical literature.

*Keywords:* New Open Economy Macroeconomics, Maximum Likelihood Estimation

*JEL Classification:* F41

---

\*We would like to thank seminar participants at the University of Bonn for helpful comments. The paper is a part of the author's PhD thesis. Disclaimer: The views expressed are those of the author and do not necessarily reflect those of the Deutsche Bundesbank.

<sup>†</sup>Deutsche Bundesbank, [almira.buzaushina@uni-bonn.de](mailto:almira.buzaushina@uni-bonn.de)

## 1 Introduction

Since the seminal contribution by Obstfeld and Rogoff (1995), there has been a growing research in theoretical international macroeconomics on new workhorse models known as New Open Economy Macroeconomic (NOEM) models. The common feature of these models is the introduction of nominal rigidities and imperfect competition into a dynamic stochastic general equilibrium (DSGE) model, specified with microeconomic foundations.<sup>1</sup> Furthermore, these models have become a fixture in most applied academic and policy work in international macroeconomics. However, while the theoretical work has developed rapidly, there are still less contributions on the empirical dimensions which prove and verify the accuracy of these models. Bergin (2003) and Bergin (2006) extend the NOEM into an empirical direction estimating and testing a small open economy and a two-country model, respectively, by adapting maximum likelihood procedure. Lubik and Schorfheide (2006) employ Bayesian techniques to study a two-country model following the NOEM paradigm. In the case of two-country models, previous literature has mostly considered the USA on one side and an aggregate of the remaining G-7 countries or the Euro Area on the other side. It thereby neglects China and Mexico, the two main trading partners of the USA after Canada. As for the policy analysis and applied work it is important to trust on NOEM models, this paper reexamines and extends a standard two-country DSGE model empirically, considering data of the USA on the home-country side and data of its main trading partners, including China and Mexico, on the foreign-country side. The estimation results show that the consideration of data for China and Mexico on the opposite side of the US current account is important for explaining the US current account and exchange rate movements, as well as for getting confident estimates for some deep parameters which are controversial in the theoretical literature.

In the present paper we assess a standard two-country DSGE model, based on Bergin (2006), featuring monopolistic competition, nominal rigidities, capital accumulation subject to adjustment costs, a debt-elastic country risk premium, and monetary policy specified in the form of an interest rate targeting rule. For this purpose, we estimate various structural parameters of the underlying theoretical model using the maximum likelihood procedure. There are five shocks to the economy: technology, monetary, taste, home bias, and UIP shocks. The estimation procedure will also estimate the correlation coefficients between the UIP and other structural shocks, in order to examine the potential sources of deviations from the UIP condition. We use five data series: output, prices, and the interest rate (all in country differences), the bilateral exchange rate against the US dollar, and the US current account. As China and Mexico are the main trading partners of the US and hold substantial amounts of US dollar assets, the empirical analysis whose interest lies, amongst others, in explaining the US current account and exchange rate movements, cannot be complete passing on data from these countries. Therefore, this paper addresses the question how the consideration of the main trading partners of the US in the data set changes the estimates of deep parameters and impacts the ability of the NOEM model to explain current account and exchange rate movements.

The obtained results indicate that the estimated model matches surprisingly well a small set of second moments considering that the estimation procedure is assigned to fit all aspects

---

<sup>1</sup>There is a comprehensive survey on the NOEM literature written by Lane (2001).

of the data. The standard deviations of the data series for the current account, the exchange rate, price and output differentials are matched very well by simulated model variables. Furthermore, the contemporaneous correlation between the current account and output is fitted exactly by the model. Regarding other correlation coefficients, the model performs well in fitting the correlations between the exchange rate and prices, the interest rate and output, and prices and output.

The estimates of the deep parameters are expected to bring some guiding light in the controversial debate on their values in the theoretical literature. In particular, one controversy regards the parameter which describes consumer preferences for home and foreign goods or, to be more precise, the degree of substitutability between home and foreign goods. Empirical studies based on micro-level evidence suggest high elasticities around five (Harrigan (1993)), while the common assumption in the theoretical literature is an elasticity of substitution of one, which makes NOEM models extremely tractable. Bergin (2006) furthermore provides a statistical significant estimate for this elasticity which is somewhat higher than unity (1.130), estimating the described NOEM model on data from the US and the remaining G-7 countries, and he therefore advocates a unit elasticity of substitution between home and foreign goods. In the present study, the additional data from China and Mexico on the side of the foreign country pushes down the elasticity of substitution, achieving a significant estimate below one. The other controversy deals with the currency in which prices are sticky. The traditional Keynesian approach assumes that prices are rigid only in exporter's currency (producer-currency pricing), so that nominal exchange rate changes induce demand shifts on the international goods market due to the expenditure-switching effect. Obstfeld and Rogoff (2000) provided empirical evidence supporting the assumption that nominal exchange rate changes play a key role in the short run in shifting world demand between countries. However, Kollmann (1997), Chari et al. (1997), and Betts and Devereux (2000) show the potential of local-currency pricing approach to replicate some controversial international business-cycle regularities, such as the high variability of nominal and real exchange rates and the low comovements in international consumption levels. In the underlying theoretical model both types of price rigidities are allowed to coexist, where the share of the local-currency pricing is a parameter that can be estimated. Our results do not provide, in contrast to Bergin (2006), an empirical support for local-currency pricing, estimating its share only at a low level. Furthermore, we estimate the sensitivity of the reaction of the country risk premium to changes in country's net foreign debt positions, as the debt-elastic country risk premium has become a common instrument for imposing stationarity on the net wealth positions. Therefore, we hope that this estimate will be useful for future theoretical work.

Furthermore, the econometric analysis here provides some insights into the nature of the UIP shocks, showing that the deviations from the UIP condition are not closely related to monetary shocks, they rather are positively correlated with technology shocks and shifts in the marginal utility of consumption. Moreover, we support the finding that UIP shocks are especially helpful in explaining fluctuations in the current account, pointing out that the movements on the capital account side of the balance-of-payments condition are important for the current account determination. However, exchange rate movements are mainly explained by the technology shock and its common distribution with the UIP shock. Overall, we hope that the underlying study provides many avenues for critical future research, e.g. current account determination and detection

of potential sources for the positive correlation between UIP and technology shocks.

The remainder of the paper is organized as follows. In Section 2 we describe the theoretical model. In Section 3 we present the estimation results from the maximum likelihood procedure and discuss their cyclical implications, impulse responses, and forecast error variance decompositions. The final section draws some conclusions.

## 2 The Model

Consider a two-country world, where the countries are called home and foreign. The population of the home country is a fraction  $n$  of the world population. Each country is inhabited by a representative household and a representative firm which produces a continuum of intermediate goods. Intermediate goods produced in the home country are indicated by an  $H$  subscript, and intermediate goods produced in the home country by an  $F$ . Variables which describe the foreign country, e.g. goods consumed by the foreign country, are expressed with an asterisk. All variables are written in per capita terms. Steady state levels are indicated by overbars, while tildes indicate percentage deviations from steady state. The following description focuses on the home country.

### 2.1 Market Structure

Final goods in the economy ( $Y_t$ ) are produced by aggregating over a continuum of intermediate home goods, produced by the representative home firm and indexed by  $i \in [0, 1]$ , and over a continuum of imported foreign goods, produced by the representative foreign firm and indexed by  $j \in [0, 1]$ . The technology for producing final goods is given by:

$$Y_t = \left[ \theta_t^\mu Y_{Ht}^{\frac{\mu-1}{\mu}} + (1 - \theta_t)^\mu Y_{Ft}^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}}, \mu > 0, \quad (1)$$

where

$$Y_{Ht} = \left( \int_0^1 y_{Ht}(i)^{\frac{1}{1+\nu}} di \right)^{1+\nu}, \nu > 0,$$

$$Y_{Ft} = \left( \int_0^1 y_{Ft}(j)^{\frac{1}{1+\nu}} dj \right)^{1+\nu}.$$

Here  $Y_{Ht}$  represents an aggregate of the home intermediate goods sold in the home country and  $Y_{Ft}$  an aggregate of the foreign intermediate goods imported by the home country, while lower case counterparts denote outputs of the individual firms. The share of home intermediate goods in the production of final goods is denoted by  $\theta_t$ , the so called home bias parameter, which is assumed to be subject to stochastic shocks.<sup>2</sup> The parameter  $\mu$  denotes the elasticity of substitution between home and foreign goods in the production of final goods, while the parameter  $\nu$  governs the elasticity of substitution between individual intermediate goods in the aggregation function which is given by  $(1 + \nu)/\nu$ .

<sup>2</sup>All stochastic shock processes are presented in Section 2.6.

Final good producers behave perfectly competitive and solve each period the following optimization problem:

$$\pi_t = \max_{Y_{Ht}, Y_{Ft}} P_t Y_t - P_{Ht} Y_{Ht} - P_{Ft} Y_{Ft},$$

where  $P_t$  is the overall price index of the final good,  $P_{Ht}$  ( $P_{Ft}$ ) is the price index of home (foreign) goods, all denominated in the home currency. It is assumed that a fraction  $\eta$  of firms producing intermediate goods (indexed by  $i = 0, \dots, \eta$ ) exhibits local-currency pricing, i.e. they set their prices in the currency of the buyer. The remaining fraction of firms ( $1 - \eta$ , indexed by  $i = \eta, \dots, 1$ ) exhibits producer-currency pricing, i.e. they set their prices in their own currency.

The price indexes are defined as:<sup>3</sup>

$$P_t = \left[ \theta_t P_{Ht}^{1-\mu} + (1 - \theta_t) P_{Ft}^{1-\mu} \right]^{\frac{1}{1-\mu}},$$

where

$$P_{Ht} = \left( \int_0^\eta p_{Ht}(i)^{-\frac{1}{\nu}} di + \int_\eta^1 p_{Ht}(i)^{-\frac{1}{\nu}} di \right)^{-\nu},$$

$$P_{Ft} = \left( \int_0^\eta p_{Ft}(j)^{-\frac{1}{\nu}} dj + \int_\eta^1 (s_t p_{Ft}(j))^{-\frac{1}{\nu}} dj \right)^{-\nu}.$$

The lower case counterparts of price indexes represent the prices set by individual firms. The nominal exchange rate ( $s_t$ ) is the home-currency price of one unit of foreign currency. The price index of home exports denominated in the foreign currency can be expressed as:

$$P_{Ht}^* = \left( \int_0^\eta p_{Ht}^*(i)^{-\frac{1}{\nu}} di + \int_\eta^1 \left( \frac{1}{s_t} p_{Ht}^*(i) \right)^{-\frac{1}{\nu}} di \right)^{-\nu}.$$

Given the aggregation technology (1), the profit maximization by the final goods producers leads to the following demand functions for home and foreign goods:

$$Y_{Ht} = \theta_t Y_t \left( \frac{P_t}{P_{Ht}} \right)^\mu, \quad (2)$$

$$Y_{Ft} = (1 - \theta_t) Y_t \left( \frac{P_t}{P_{Ft}} \right)^\mu, \quad (3)$$

with the following demand functions for individual home and foreign goods:<sup>4</sup>

$$y_{Ht}(i) = Y_{Ht} \left( \frac{p_{Ht}(i)}{P_{Ht}} \right)^{-(1+\nu)/\nu} \quad \text{for } i = 0, \dots, 1,$$

$$y_{Ft}(j) = Y_{Ft} \left( \frac{p_{Ft}(j)}{P_{Ft}} \right)^{-(1+\nu)/\nu} \quad \text{for } j = 0, \dots, \eta,$$

$$y_{Ft}(j) = Y_{Ft} \left( \frac{s_t p_{Ft}(j)}{P_{Ft}} \right)^{-(1+\nu)/\nu} \quad \text{for } j = \eta, \dots, 1.$$

Analogous conditions apply for the foreign country.

<sup>3</sup>See appendix for a formal derivation of the price indexes.

<sup>4</sup>See appendix for a formal derivation of the demand functions for individual goods.

## 2.2 Firm

To produce intermediate goods firms rent capital ( $K_{t-1}$ ) at the real rental rate ( $r_t$ ), and hire labor ( $L_t$ ) at the nominal wage rate ( $W_t$ ). The assumption of price stickiness is introduced here by quadratic menu costs.

The optimization problem for local-currency pricing firms at home ( $i = 1, \dots, \eta$ ) can be summarized by:

$$\max E_t \sum_{\kappa=0}^{\infty} \rho_{t,t+\kappa} \pi_{Ht+\kappa}(i),$$

where

$$\begin{aligned} \pi_{Ht}(i) = & p_{Ht}(i)y_{Ht}(i) + s_t p_{Ht}^*(i) \left( \frac{1-n}{n} \right) y_{Ht}^*(i) \\ & - P_t r_t K_{t-1}(i) - W_t L_t(i) - P_t AC_{Ht}(i) - s_t P_t AC_{Ht}^*(i), \end{aligned} \quad (4)$$

subject to

$$\begin{aligned} AC_{Ht}(i) &= \frac{\psi_P}{2} \frac{(p_{Ht}(i) - p_{Ht-1}(i))^2}{P_t p_{Ht-1}(i)} y_{Ht}(i), \\ AC_{Ht}^*(i) &= \frac{\psi_P}{2} \frac{(p_{Ht}^*(i) - p_{Ht-1}^*(i))^2}{P_t p_{Ht-1}^*(i)} \left( \frac{1-n}{n} \right) y_{Ht}^*(i), \\ z_t(i) &= A_t K_{t-1}^\alpha(i) L_t^{1-\alpha}(i), \end{aligned} \quad (5)$$

$$z_t(i) = y_{Ht}(i) + \left( \frac{1-n}{n} \right) y_{Ht}^*(i), \quad (6)$$

and subject to the demand functions for  $y_{Ht}(i)$  and  $y_{Ht}^*(i)$  above.  $AC_{Ht}$  represents quadratic price adjustment costs, where  $\psi_P \geq 0$  is the price adjustment parameter. The production function is represented in (5), where  $z_t$  indicates the overall production. Here  $A_t$  represents technology common to all production firms in the country, and is subject to stochastic shocks. The parameter  $\alpha$  denotes the capital share in the production of each good, and the labor share is given by  $(1 - \alpha)$ . The discount factor  $\rho_{t,t+\kappa}$  is used to derive the present value of the date  $t + \kappa$  payoffs. Because the firms are assumed to be owned by the households, the future payoffs from production will be evaluated according to the household's intertemporal marginal rate of substitution in consumption,  $\rho_{t,t+\kappa} = \beta^\kappa \frac{P_t}{P_{t+\kappa}} \frac{U_{C,t+\kappa}}{U_{C,t}}$ , where  $U_{C,t+\kappa}$  is the household's marginal utility of consumption in period  $t + \kappa$ .  $E_t$  is the expectations parameter conditional on time  $t$  information.

The optimization problem for the producer-currency pricing firms ( $i = \eta, \dots, 1$ ) is the same, except that the price  $p_{Ht}^*$  is denominated in the home currency and (4) is replaced by:

$$\begin{aligned} \pi_{Ht}(i) = & p_{Ht}(i)y_{Ht}(i) + p_{Ht}^*(i) \left( \frac{1-n}{n} \right) y_{Ht}^*(i) \\ & - P_t r_t K_{t-1}(i) - W_t L_t(i) - P_t AC_{Ht}(i) - P_t AC_{Ht}^*(i). \end{aligned}$$

The optimal trade-off between labor and capital inputs depends on their relative costs:

$$P_t r_t K_{t-1}(i) = \frac{\alpha}{1-\alpha} W_t L_t(i). \quad (7)$$

The firms's marginal costs are:

$$MC_t = \frac{1}{A_t} \alpha^{-\alpha} (1-\alpha)^{\alpha-1} (P_t r_t)^\alpha W_t^{1-\alpha}.$$

Optimal price setting rules for firms can be derived by the maximization of the expected discounted sum of future profits with respect to the individual price under the constraints illustrated above and using the optimal trade-off between labor and capital. The optimal price setting rule for domestic sales of all home firms ( $i = 0, \dots, 1$ ) is:

$$\begin{aligned} & \frac{1+\nu}{\nu} \left( \frac{P_t r_t}{P_{Ht} \alpha A_t (L_t(i)/K_{t-1}(i))^{1-\alpha}} + \frac{\psi_P (p_{Ht}(i) - p_{Ht-1}(i))^2}{2 P_{Ht} p_{Ht-1}(i)} - \frac{p_{Ht}(i)}{P_{Ht}} \right) \\ & \times \left( \frac{Y_{Ht}}{y_{Ht}(i)} \right) \left( \frac{p_{Ht}(i)}{P_{Ht}} \right)^{-\frac{1+2\nu}{\nu}} + \frac{\psi_P}{2} E_t \left[ \rho_{t,t+1} \left( \frac{p_{Ht+1}^2(i)}{p_{Ht}^2(i)} - 1 \right) \frac{y_{Ht+1}(i)}{y_{Ht}(i)} \right] \\ & - \psi_P \left( \frac{p_{Ht}(i)}{p_{Ht-1}(i)} - 1 \right) + 1 = 0. \end{aligned} \quad (8)$$

The optimal price setting rule for exports of local-currency pricing firms ( $i = 0, \dots, \eta$ ) is:

$$\begin{aligned} & \frac{1+\nu}{\nu} \left( \frac{P_t r_t}{s_t P_{Ht}^* \alpha A_t (L_t(i)/K_{t-1}(i))^{1-\alpha}} + \frac{\psi_P (p_{Ht}^*(i) - p_{Ht-1}^*(i))^2}{2 P_{Ht}^* p_{Ht-1}^*(i)} - \frac{p_{Ht}^*(i)}{P_{Ht}^*} \right) \\ & \times \left( \frac{Y_{Ht}^*}{y_{Ht}^*(i)} \right) \left( \frac{p_{Ht}^*(i)}{P_{Ht}^*} \right)^{-\frac{1+2\nu}{\nu}} + \frac{\psi_P}{2} E_t \left[ \rho_{t,t+1} \left( \frac{p_{Ht+1}^{*2}(i)}{p_{Ht}^{*2}(i)} - 1 \right) \frac{s_{t+1} y_{Ht+1}^*(i)}{s_t y_{Ht}^*(i)} \right] \\ & - \psi_P \left( \frac{p_{Ht}^*(i)}{p_{Ht-1}^*(i)} - 1 \right) + 1 = 0. \end{aligned} \quad (9)$$

The optimal price setting rule for exports of producer-currency pricing firms ( $i = \eta, \dots, 1$ ) is:

$$\begin{aligned} & \frac{1+\nu}{\nu} \left( \frac{P_t r_t}{s_t P_{Ht}^* \alpha A_t (L_t(i)/K_{t-1}(i))^{1-\alpha}} + \frac{\psi_P (p_{Ht}^*(i) - p_{Ht-1}^*(i))^2}{2 s_t P_{Ht}^* p_{Ht-1}^*(i)} - \frac{p_{Ht}^*(i)}{s_t P_{Ht}^*} \right) \\ & \times \left( \frac{Y_{Ht}^*}{y_{Ht}^*(i)} \right) \left( \frac{p_{Ht}^*(i)}{s_t P_{Ht}^*} \right)^{-\frac{1+2\nu}{\nu}} + \frac{\psi_P}{2} E_t \left[ \rho_{t,t+1} \left( \frac{p_{Ht+1}^{*2}(i)}{p_{Ht}^{*2}(i)} - 1 \right) \frac{y_{Ht+1}^*(i)}{y_{Ht}^*(i)} \right] \\ & - \psi_P \left( \frac{p_{Ht}^*(i)}{p_{Ht-1}^*(i)} - 1 \right) + 1 = 0. \end{aligned} \quad (10)$$

### 2.3 Household

The household derives utility from consumption ( $C_t$ ) of the final good and disutility from supplying labor ( $L_t$ ). For simplicity, real cash balances ( $M_t/P_t$ ) used for facilitating transactions



are also directly introduced in the utility function, where  $M_t$  is the economy's money stock. The household's preferences can be described by:

$$E_t \sum_{\kappa=0}^{\infty} \beta^{\kappa} U \left( C_{t+\kappa}, \frac{M_{t+\kappa}}{P_{t+\kappa}}, L_{t+\kappa} \right), \quad (11)$$

where  $\beta$  denotes the household's time preference parameter. The instantaneous utility function takes the form:

$$U \left( C_t, \frac{M_t}{P_t}, L_t \right) = \frac{\tau_t}{1 - \sigma_1} (C_t)^{1 - \sigma_1} + \frac{1}{1 - \sigma_2} \left( \frac{M_t}{P_t} \right)^{1 - \sigma_2} - \frac{\sigma_3}{1 + \sigma_3} (L_t)^{\frac{1 + \sigma_3}{\sigma_3}}, \quad (12)$$

where  $\tau_t$  is the consumption preference or taste parameter which is subject to stochastic shocks. The parameters  $\sigma_i$  for  $i = 1, 2$ , and  $3$  denote the intertemporal elasticity terms for consumption, money demand, and labor supply, respectively, where  $\sigma_i > 0$  for  $i = 1, 2, 3$ .

The household derives its income by supplying labor at the nominal wage rate, renting capital to firms at the real rental rate, and receiving nominal profits from the two types of firm (local- and producer-currency firms) and government transfers ( $T_t$ ). In addition to money, the household holds two types of noncontingent nominal bonds, one denominated in home currency ( $B_t$ ) and paying return  $i_t$ , and one denominated in foreign currency ( $-B_t^*$ ) paying return  $i_t^*$ . Furthermore, the household accumulates the capital stock:

$$K_t = (1 - \delta)K_{t-1} + I_{t-1}, \quad (13)$$

where  $I_t$  denotes investment in period  $t$  and  $0 < \delta < 1$  the constant rate of capital depreciation. It is assumed that changes in the stock of capital are subject to quadratic capital adjustment costs:

$$AC_{It} = \frac{\psi_I}{2} \frac{(K_t - K_{t-1})^2}{K_{t-1}}, \quad (14)$$

where  $\psi_I \geq 0$  is the capital adjustment cost parameter.

The optimization problem faced by the household is to maximize its life-time utility (11) with respect to  $C_t$ ,  $M_t$ ,  $L_t$ ,  $K_t$ ,  $B_t$ , and  $B_t^*$ , subject to the budget constraint:

$$CA_t = \frac{B_t - B_{t-1}}{P_t} - \frac{s_t(B_t^* - B_{t-1}^*)}{P_t}, \quad (15)$$

where

$$\begin{aligned} CA_t = & \frac{W_t}{P_t} L_t + r_t K_{t-1} + \frac{1}{P_t} \int_0^1 \pi_{Ht}(i) di + T_t + \frac{i_{t-1} B_{t-1}}{P_t} - \frac{s_t i_{t-1}^* B_{t-1}^*}{P_t} \\ & - C_t - I_t - AC_{It} - \left( \frac{M_t}{P_t} - \frac{M_{t-1}}{P_t} \right). \end{aligned} \quad (16)$$

Here  $CA_t$  denotes the economy's current account in real terms.

The household's optimization problem implies the following optimality conditions. The intertemporal Euler equation associated with the bond decision implies that the marginal utility

of one cash unit hold in home-currency bonds in time  $t$  is equal to the discounted expected marginal utility of the returns from this bond to the time  $t + 1$ :

$$\frac{\tau_t C_t^{-\sigma_1}}{P_t} = \beta(1 + i_t) E_t \left[ \frac{\tau_{t+1} C_{t+1}^{-\sigma_1}}{P_{t+1}} \right]. \quad (17)$$

This condition implies that the household prefers expected marginal utilities to be constant across the periods, unless the rate of return on savings exceeds the time preference parameter which would induce the household to lower its consumption today relative to the future. The first-order condition associated with cash holdings ( $M_t$ ) implies the money demand equation:

$$\left( \frac{M_t}{P_t} \right)^{-\sigma_2} = \tau_t C_t^{-\sigma_1} \frac{i_t}{1 + i_t}. \quad (18)$$

The first-order condition associated with the labor supply decision implies that at the optimum the household chooses consumption and labor such that the marginal rate of substitution between consumption and leisure is equal to their relative price:

$$\frac{L_t^{\frac{1}{\sigma_3}}}{\tau_t C_t^{-\sigma_1}} = \frac{W_t}{P_t}. \quad (19)$$

The intertemporal optimality condition with respect to capital equates the costs and expected benefits of an additional unit of capital:

$$\left( 1 + \frac{\psi_I(K_t - K_{t-1})}{K_{t-1}} \right) = \beta E_t \left[ \left( \frac{\tau_{t+1} C_{t+1}^{-\sigma_1}}{\tau_t C_t^{-\sigma_1}} \right) \left( r_{t+1} + (1 - \delta) + \frac{\psi_I}{2} \left( \frac{K_{t+1}^2 - K_t^2}{K_t^2} \right) \right) \right]. \quad (20)$$

Expected benefits on the right hand side are equal to the return from the rental of capital, its resale value after depreciation, and associated savings on future capital adjustment costs. The costs in the current period are given by the unit of investment and associated capital adjustment costs. The optimal portfolio choice can be derived by equating the intertemporal Euler equations with respect to home and foreign bonds:

$$E_t \left[ \frac{U_{Ct+1}}{U_{Ct}} \frac{s_{t+1}}{s_t} \frac{P_t}{P_{t+1}} (1 + i_t^*) \right] = E_t \left[ \frac{U_{Ct+1}}{U_{Ct}} \frac{P_t}{P_{t+1}} (1 + i_t) \right].$$

Up to a first-order approximation, this condition implies the model's uncovered interest parity (UIP) condition as follows:

$$E_t \left[ \frac{s_{t+1}}{s_t} (1 + i_t^*) \right] = (1 + i_t). \quad (21)$$

It is well known that this form of the UIP condition is strongly rejected by the data (Lewis (1995)). Therefore we generalize this expression by adding a 'debt-elastic' risk premium term:

$$RP_t = -\psi_B \left( \frac{B_t - s_t B_t^*}{P_t Y_t} \right)$$

to the left hand side of (21). This specification of the risk premium term, which is increasing in a country's net level of foreign debt relative to output, and where the parameter  $\psi_B > 0$  controls for the strength of the positive effect of the net foreign debt on the risk premium, ensures stationarity of the equilibrium dynamics, as demonstrated by Schmitt-Grohé and Uribe (2003). Given the incomplete asset markets, shocks can lead to permanent wealth reallocations which would induce nonstationarity and prevent computation of unconditional variances used in the estimation here. Moreover, this modification of the UIP condition is consistent with Lewis (1995) who finds empirical evidence for the existence of predicted interest rate differentials between home and foreign bonds which can be explained by differences in country risks. In steady state there is no net foreign debt and therefore no risk premium. The linearized form of the modified UIP condition is given by:<sup>5</sup>

$$\tilde{i}_t - \tilde{i}_t^* = \frac{1}{1 - \beta}(E_t \tilde{s}_{t+1} - \tilde{s}_t) - \frac{\beta}{1 - \beta} \psi_B (\tilde{B}_t - \bar{s} \tilde{B}_t^*) + \xi_t, \quad (22)$$

where  $\xi_t$  is a mean-zero disturbance, aimed at capturing time-varying deviations from UIP. This term is a common device in the literature (Kollmann (2002)), which was interpreted in different ways. In particular, McCallum and Nelson (1999) interpret this term as a representation of time-varying deviations from UIP omitted by linearization, while Mark and Wu (1999) and Jeanne and Rose (2002) derive it as a reflection of noise traders and a distribution of exchange rate expectations. More recently, Bacchetta and van Wincoop (2009) relate UIP deviations to infrequent portfolio decisions which can arise due to relatively small fees for active currency management. A similar UIP condition is implied by the foreign household's optimization. As a result, a bond allocation rule can be created to solve separately for  $\tilde{B}_t$  and  $\tilde{B}_t^*$ . However, in the present paper we look only at  $\tilde{B}_t - \bar{s} \tilde{B}_t^*$ , eliminating the need for the bond allocation rule.

## 2.4 Government and Monetary Authority

The government issues no debt. It finances consumption ( $G_t$ ) and government transfers ( $T_t$ ) through money creation (seignorage). The simple budget constraint of home government is given by:

$$T_t + G_t = \frac{1}{P_t}(M_t - M_{t-1}). \quad (23)$$

The monetary policy will be specified in terms of an interest rate targeting rule which can be expressed in the linearized form as follows:

$$\tilde{i}_t = a_1(\tilde{P}_t - \tilde{P}_{t-1}) + a_2 \tilde{Y}_t + a_3 \tilde{s}_t + \phi_t, \quad (24)$$

where  $a_1$ ,  $a_2$ , and  $a_3$  are monetary policy parameters and denote monetary policy responses to inflation, output, and exchange rate fluctuations, respectively. The parameter  $a_1$  is restricted to be above unity such that the Taylor principle is fulfilled. The parameter  $a_2$  is restricted to be positive, and  $\phi_t$  is a monetary policy shock.

<sup>5</sup>Here we linearize around the symmetric steady state, where steady state levels of home and foreign bonds are equal to zero. Therefore tildes over bonds indicate ratios to the nominal output in steady state.

## 2.5 Market Clearing Conditions

The market clearing condition for final goods equates production and absorption and is given by:

$$Y_t = C_t + I_t + G_t + AC_{It} + AC_{Ht} + AC_{Ht}^*. \quad (25)$$

The consolidated budget constraint of the economy results from combining the household's budget constraint with those of the firm and the government:

$$(B_t - B_{t-1}) - s_t(B_t^* - B_{t-1}^*) = P_{Ht}Y_{Ht} + \left(\frac{1-n}{n}\right) s_t P_{Ht}^* Y_{Ht}^* + i_{t-1}B_{t-1} - s_t i_{t-1}^* B_{t-1}^* - P_t(C_t + I_t + G_t + AC_{Ht} + AC_{Ht}^* + AC_{It}). \quad (26)$$

Using the market clearing condition for final goods and rewriting  $P_t Y_t$  in terms of home and imported goods, the consolidated budget constraint reduces to:

$$(B_t - B_{t-1}) - s_t(B_t^* - B_{t-1}^*) = P_{Ht}Y_{Ht} + \left(\frac{1-n}{n}\right) s_t P_{Ht}^* Y_{Ht}^* - (P_{Ht}Y_{Ht} + P_{Ft}Y_{Ft}) + i_{t-1}B_{t-1} - s_t i_{t-1}^* B_{t-1}^*. \quad (27)$$

The economy's trade balance in real terms ( $X_t$ ) is given by:

$$X_t = \underbrace{\left(\frac{1-n}{n}\right) \frac{s_t P_{Ht}^* Y_{Ht}^*}{P_t}}_{\text{Exports}} - \underbrace{\frac{P_{Ft} Y_{Ft}}{P_t}}_{\text{Imports}}. \quad (28)$$

Using the definition of the trade balance, the consolidated budget constraint can be expressed as:

$$\underbrace{(B_t - B_{t-1}) - s_t(B_t^* - B_{t-1}^*)}_{-\text{Capital Account}} = \underbrace{P_t X_t + i_{t-1}B_{t-1} - s_t i_{t-1}^* B_{t-1}^*}_{\text{Current Account}}. \quad (29)$$

This condition represents the economy's balance-of-payments condition, which requires that the current account (sum of the trade balance and net foreign interest payments) is equal to the negative of the capital account (change in net foreign assets).

## 2.6 Stochastic Shocks

The economy faces five shocks. The assumptions on the stochastic shocks can be represented as follows:

- home bias shock:

$$(\log \theta_t - \log \bar{\theta}) = \rho_\theta (\log \theta_{t-1} - \log \bar{\theta}) + \varepsilon_{\theta t}, \quad (30)$$

- technology shock:

$$(\log A_t - \log \bar{A}) = \rho_A (\log A_{t-1} - \log \bar{A}) + \varepsilon_{A t}, \quad (31)$$

- consumption preference (taste) shock:

$$\log \tau_t = \rho_\tau (\log \tau_{t-1}) + \varepsilon_{\tau t}, \quad (32)$$

- risk premium shock:

$$\xi_t = \rho_\xi (\xi_{t-1}) + \varepsilon_{\xi t}, \quad (33)$$

- monetary policy shock:

$$\phi_t = \rho_\phi (\phi_{t-1}) + \varepsilon_{\phi t}, \quad (34)$$

where  $[\varepsilon_{\theta t}, \varepsilon_{A t}, \varepsilon_{\tau t}, \varepsilon_{\xi t}, \varepsilon_{\phi t}]' \sim N(0, \Sigma)$ . The stationarity assumptions imply that all autoregressive coefficients are smaller than 1 in modulus. Note that the risk premium shock is allowed to be correlated with other shocks.

We solve the model numerically by linearizing the equilibrium conditions (optimality and market clearing conditions) around the deterministic, fully symmetric steady state and by expressing these conditions as country differences, home minus the foreign counterpart. The appendix lists all equilibrium conditions transformed in this way.

### 3 Empirical Investigation

#### 3.1 Data

Data from the USA will be used for the home country, and an aggregate of its main trading partners for the foreign country. The main trading partners are not only the remaining G-7 countries (Canada, France, Germany, Italy, Japan, and the United Kingdom), but also China and Mexico, which were neglected in the previous literature. Table 1 reports annual trade weights of the US with its main trading partners calculated as each country's share in total trade of the US with these countries. For example, in 2005 the shares of China and Mexico lie at 0.19 and 0.18, while those of France and Italy lie at 0.04 and 0.03, respectively. Due to numbers reported in Table 1, Mexico accounts for around 10-20% of the US trade with the mentioned countries in the selected time period, while China's share rises gradually over time, from 9% in 1999 to 20% in 2005. The five series used will be the exchange rate and the current account, which are of primary interest, as well as the interest rate, output, and the price level. The interest rate and output are included to help identifying monetary and technology shocks, respectively. The price level is important for investigating the role of price stickiness in the model. Moreover, these three variables have been widely used in tests regarding how well macroeconomic models can explain exchange rates (Meese and Rogoff (1983)).

All data are quarterly series at annual rates for the period 1980:1 to 2007:1, obtained from the International Financial Statistics and the Direction of Trade Statistics (both are provided by the International Monetary Fund), and are, except for interest rate, seasonally adjusted. Because the quarterly data for China is not available for earlier periods, China is included only from 1999:1 onwards. The exchange rate for each country is measured as the bilateral rate with the US Dollar (US Dollar per unit of foreign currency). The current account series for the US obtained from the International Financial Statistics is deflated using the GDP deflator. The output is measured

as the national gross domestic product (GDP) deflated by the GDP deflator or consumer price index (CPI) for China as GDP deflator is not available for China. The price level is the CPI, and the interest rate is a treasury bill rate or a call money rate.<sup>6</sup> Foreign aggregate variables are computed as a geometric weighted average, using time-varying trade weights based on each country's share of US trade (exports+imports) only with countries in the sample of the foreign aggregate. All series except for the current account are logged. Because the steady-state value of the current account in the theoretical model is necessarily zero and negative values of the current account are possible, the current account cannot be expressed in a form that represents percentage deviations from steady state in a log form. Instead the current account is scaled by taking it as a ratio to the mean of the US real output. Finally, all series are Hodrick-Prescott (HP) filtered with a smoothing parameter of 1600 to obtain deviations from trend, and the data other than the exchange rate and the current account are transformed in country differences, home minus the foreign counterpart.

### 3.2 Econometric Methods

The econometric procedure fits the linear approximation of the structural model to the data, discussed above, adapting a maximum likelihood algorithm developed by Leeper and Sims (1994) and extended by Kim (2000).

The solution of the model can be expressed in the following autoregressive form:

$$\tilde{x}_t = \Theta_1 \tilde{x}_{t-1} + \Theta_0 \varepsilon_t, \varepsilon_t \sim N(0, \Sigma), \quad (35)$$

where  $\tilde{x}_t$  is a vector containing all variables of the model transformed in the way discussed in Section 2 and shown in the appendix,  $\Theta_1$  and  $\Theta_0$  are matrices, where each cell is a potentially nonlinear function of the structural parameters,  $\varepsilon_t$  is a vector containing the five structural disturbances with the remaining elements equal to zero, and  $\Sigma$  is the variance-covariance matrix of these disturbances. To fit this model to the data of five observable variables, an algorithm is used to search for values of certain structural parameters and elements of the variance-covariance matrix ( $\Sigma$ ), which will maximize the likelihood function, computed in a recursive way by the Kalman filtering method.

Some structural parameters are not estimated here, but are instead fixed at the values common in the real business cycle literature. This is because the data set used in the estimation omits relevant information or relevant series for these parameters, e.g. capital and labor. In particular, we set the capital share in the production of intermediate goods to be equal to  $\alpha = 0.3$ , the capital depreciation rate to  $\delta = 0.026$  which implies an annual depreciation rate of 10%. The labor supply elasticity is set at unity ( $\sigma_3 = 1$ ), and the steady state share of home intermediate goods in the home final goods aggregate is set to  $\bar{\theta} = 0.8$ . Following Rotemberg and Woodford (1992), the parameter  $\nu$  which denotes the elasticity of substitution between individual intermediate goods in the aggregation function is set to 0.2, which implies a steady state price mark-up over marginal costs for intermediate goods of 1.2, consistent with the empirical findings of Martins et al. (1996). Finally, we set the time preference parameter  $\beta$  to be equal to 0.97 which results in  $\bar{i} = 0.03$ .

<sup>6</sup>The treasury bill rate is used for Canada, France, Italy, Mexico, the United Kingdom, and the USA. The call money rate is used for China, Germany, and Japan.

Moreover, for the model to be well defined, some parameters are restricted within the region specified in Table 2. In particular, the monetary policy reaction to inflation ( $a_1$ ) is bounded below to fulfill the Taylor principle and rule out indeterminacy such that  $a_1 > 1$ . Autoregressive coefficients on shock processes are greater than zero and less than unity. The covariances between shocks are restricted such that the implied correlations lie between -1 and 1.

### 3.3 Estimation Results

The log-likelihood value of 1431.32 is achieved at the end of the estimation procedure. Bergin (2006) reports the associated value of 1797.55 by estimating the model on the data from the USA and the remaining G-7 countries. The lower log-likelihood value in our estimation does not indicate that the model using our parameter estimates performs worse than the model using the estimates of Bergin (2006), as several model solutions and the underlying data differ. In this sense, there is no direct standard of comparison for the log-likelihood value obtained here and in Bergin (2006). We rather evaluate the performance of the estimated model parameters in terms of fitting contemporaneous unconditional second moments of the data which is a standard fit measure in the DSGE literature. The maximum likelihood estimation used here is trying to fit a set of hundreds of moments and does not place the weight specifically on the set of second moments. Therefore, it is not obvious *ex ante* how well the estimates will match the small set of second moments. Thus by assessing the fit of the estimation, it is of high interest to look at the cyclical implications of the obtained parameter estimates. Table 3 reports standard deviations and contemporaneous correlations of the simulated model variables and the data. The results show, that for the transformed simulated model and data series (both types of series are HP filtered), the standard deviation of the exchange rate in the model (5.8309) matches very well that of the data (5.8509). Moreover, the standard deviations of the current account, price, and output from the data (0.1172, 2.6185, and 2.4958, respectively) are fitted well by the model (0.0999, 2.8069, and 2.4525, respectively). For the interest rate, the standard deviation of the model is less than that of the data. The correlation coefficient between the current account and output in the data given by -0.1501 is exactly matched by the model (-0.1500). Regarding other correlation coefficients, the model performs well in fitting the correlations between exchange rate and price, interest rate and output, and price and output. Overall, the model matches all the signs of the second moments, except for correlations between the current account and the exchange rate, and between the exchange rate and the interest rate. However, the correlations between these pairs of variables implied by the model are only slightly negative.

Table 4 shows obtained parameter estimates together with standard errors. Mostly all parameter estimates are reasonable, statistically significant, and lie within the specified intervals. The consumption elasticity term ( $\sigma_1$ ) is statistically significantly estimated at 0.0604. The interest rate elasticity term of money demand ( $\sigma_2$ ) is estimated at 0.0022 and implies together with the consumption elasticity term ( $\sigma_1$ ) the income elasticity of money demand ( $\sigma_1/\sigma_2$ ) of around 27. However, the estimate of  $\sigma_2$  is not statistically significant and has a very large variance. The estimation procedure shows the likelihood is flat at this and any other point, indicating that the interest rate elasticity term of money demand is not identifiable. The parameter associated with investment adjustment costs ( $\psi_I$ ) is estimated very close to zero, implying that there are almost no capital adjustment costs. The parameter associated with price adjustment costs ( $\psi_P$ )

is estimated at 0.6259.

In the present estimation procedure we also estimate some parameters which are controversial in the theoretical literature. In particular, one such controversy regards the parameter which describes consumer preferences for home and foreign goods or, to be more precise, the degree of substitutability between home and foreign goods. As shown in Tille (2001), Van der Ploeg (1993), and Svensson and van Wijenbergen (1989), the degree of substitutability between home and foreign goods determines the strength of the expenditure switching effect of monetary policy and is therefore important for the international welfare implications of monetary shocks. Moreover, the level of the elasticity of substitution between home and foreign goods controls volatility of consumer prices ( $P$ ), such as by given output volatilities of home and foreign final goods, a lower elasticity of substitution between home and foreign goods induces a higher volatility of consumer prices. There is a clear agreement that the elasticity of substitution between domestic goods and imports should be lower than the elasticity of substitution within a variety of the same good. However, there is a controversy about the exact magnitude of this elasticity. In particular, empirical studies based on micro-level evidence suggest high elasticities around five (Harrigan (1993)), while the common assumption in the theoretical literature is the elasticity of substitution of one, which makes NOEM models extremely tractable, allowing closed-form solutions. Bergin (2006) furthermore provides a statistically significant estimate for this elasticity which is somewhat higher than unity (1.130), estimating the described NOEM model on data from the US and the remaining G-7 countries, and he therefore advocates the unit elasticity of substitution between home and foreign goods. In the present estimation procedure, using in addition the data from China and Mexico, the elasticity of substitution between home and foreign goods ( $\mu$ ) is statistically significantly estimated at 0.7549, which is less than the value of unity. However, the reported statistical significance only indicate that this estimate is significantly different from zero and not from unity. Given the asymptotic normality of maximum likelihood estimates<sup>7</sup>, we can use a lower one-sided  $t$ -test to verify the null hypothesis that  $\mu \geq 1$ . The obtained  $t$ -statistic (-14.5030) is sufficiently high in absolute terms and negative, therefore we reject the null hypothesis that the elasticity of substitution between home and foreign goods is higher or equal to one. The lower elasticity of substitution estimated here could result from using the additional data of emerging markets, China and Mexico, as goods imported from these countries to the US stem from different production sectors and do not compete directly with goods produced in the US.

The possibilities of modeling nominal rigidities open up another controversial issue in the theoretical literature. In the international setup, the debate occurs about the currency, in which prices are sticky. The traditional Keynesian approach assumes that prices are rigid only in exporters' currencies (producer-currency pricing) and not in importers' currency, so that nominal exchange rate depreciations lead to a proportional increase in the domestic-currency value of domestic imports and in foreign-currency value of domestic exports. Therefore, domestic demand switches from imports toward domestic goods, and foreign demand shifts toward domes-

<sup>7</sup>The asymptotic normality and consistency of maximum likelihood estimates of the parameters of a state-space model are given under two regularity conditions which are fulfilled in our case. First, the state equation has to define a covariance stationary process. Second, the true parameters have not to lie on the boundary of the parameter space (Canova (2007)).



tic products too. Thus, in the producer-currency framework, nominal exchange rate changes have significant short-run effects on international competitiveness and trade. Obstfeld and Rogoff (2000) provided empirical evidence supporting the assumption that nominal exchange rate changes play a key role in the short run in shifting world demand between countries. Under the alternative assumption of local-currency pricing, a nominal currency depreciation has no expenditure-switching effect in the short run. In dynamic general-equilibrium settings, Kollmann (1997), Chari et al. (1997), and Betts and Devereux (2000) show the potential of local-currency pricing approach to replicate some controversial international business-cycle regularities, such as the high variability of nominal and real exchange rates and the low comovements in international consumption levels. In the theoretical model presented here, both types of price rigidities are allowed to coexist, and we estimate the share of local-currency pricing firms,  $\eta$ . Table 4 shows that this parameter is estimated at 0.3936 at a 0.05 significance level, implying that around 60% of home firms price their goods in domestic currency, and indicating that there is no strong empirical support for local-currency pricing in NOEM models, at least as long as these models are up to explain the macroeconomic variables examined here. Contrariwise, Bergin (2006) provides an empirical evidence for local-currency pricing estimating  $\eta$  very close to its upper bound of unity. Our result indicates that China and Mexico as well as the change in the time sample (from 1980:1 to 2007:1) affect the result for the exchange rate pass-through contradicting the common view that recent globalization and, especially, the emergence of China dampen the exchange-rate pass-through and thus increase local-currency pricing. There are several studies which documented the decline in exchange rate pass-through in industrial countries pointing to a "China effect" as an explanatory factor, for example Marazzi et al. (2005) and Murray (2008). This "China" or globalization effect can be summarized into two main aspects. First, the increased importance of emerging market economies in US trade and the pegging of their exchange rates to the US dollar might decrease the exchange rate pass-through of the US imports. Second, the competitive reaction of other exporting countries to the increased or potential supply from the emerging markets leads to a constrained increase of US import prices denominated in US dollars in case of exporter's currency appreciations. However, in our theoretical model, home and foreign countries are fully symmetric and, as the US dollar not only acts as a vehicle currency for US imports but also for US exports and the emergence of China and Mexico not only drives the import side of the US trade but also its export side, there is a significant amount still assigned to the producer-currency pricing.

The parameter  $\psi_B$  which controls the strength of the positive effect of net foreign debt on the risk premium, is estimated at 0.0487. Although this estimate is not statistically significant, this result supports a portfolio balance approach linking inversely the nominal interest rate differential to the ratio of net foreign assets to GDP. The point estimate implies that when a country in our sample runs a ratio of net foreign debt to GDP of 20%, its domestic nominal interest rate would rise by 97.40 basis points. The corresponding significant estimates obtained by Lane and Milesi-Ferretti (2001) from cross-sectional and panel regressions on the data of industrial countries, in which they relate the real interest rate differential to the ratio of net foreign assets to exports, are fairly lower in absolute values and lie at -0.0107 from cross-sectional regressions and at -0.0254 from panel regressions. By looking at the result from panel regressions, their estimate implies that a 20 percentage points improvement in the ratio of net foreign assets to

exports leads to a 50.80 basis points reduction in the real interest rate differential. Bergin (2006) estimates the parameter  $\psi_B$  at 0.00384 which implies that by the 20% ratio of net foreign debt to GDP the nominal interest rate would rise only by 7.68 basis points. The higher estimate obtained in our estimation procedure could result from including in our sample two emerging market economies, China and Mexico, which generally experience a higher country risk premium than industrial countries. In spite of its non-significance, we hope that this estimate would still provide a useful information for calibrations in future theoretical work.

Finally, Table 4 also lists estimates for parameters in the monetary policy reaction function which attempts to stabilize inflation, output, and exchange rate fluctuations. As it is well known, such a rule may lead to (local) indeterminacy. In our estimation strategy, we constrained the inflation parameter to be higher than unity and estimated monetary policy parameters only within the determinacy region. The response to inflation ( $a_1$ ) is statistically significantly estimated at 1.3017, the response to output ( $a_2$ ) is estimated very close to its lower bound of zero implying that there is no evidence for active output stabilization. Although the estimated positive response to the exchange rate is not statistically significant, this indicates that there is an active exchange rate stabilization as the depreciation in exchange rate (increase in  $s$ ) will be counteracted by a higher nominal interest rate. However, one has to bear in mind that in the model which is transformed to country differences, the parameter  $a_3$  is the sum of home and foreign monetary policy responses to bilateral exchange rates and, for this reason, we cannot identify an exchange rate response of a particular monetary authority. Regarding monetary policy parameters, Bergin (2006) gets similar results, finding evidence for active exchange rate stabilization and no evidence for active output simulation. He estimated the response to inflation very close to its lower bound of the determinacy region.

Table 4 provides also some information about the nature of structural shocks, in particular about the nature of UIP shocks which have different interpretations in the literature. The estimated results show that monetary policy does not account for deviations from the UIP condition. Instead, the technology shock which is highly responsible for deviations from the UIP since it exhibits a high positive and significant correlation with the UIP shock (the correlation coefficient is estimated at 0.8334). Furthermore, the UIP shock is positively correlated with the taste shock (the correlation coefficient is estimated at 0.5009). This result is interesting, as the taste shock directly affects marginal utility which is an important element in the risk premium term that dropped from the UIP condition due to linearization. Therefore, the positive correlation between UIP and taste shocks would confirm one possible interpretation of the UIP shocks as time-varying deviations from the UIP condition omitted by linearization. We also find a small negative correlation of the UIP shock with the home bias shock (the correlation coefficient is significantly estimated at -0.2280). This evidence can be interpreted through the link between the capital and the current account. In the case of an unexpected positive UIP shock, the higher interest rate for home bonds leads to a reallocation of home and foreign wealth towards home bonds, inducing a positive capital account in the home country. By the balance-of-payments condition, the positive capital account translates into a negative current account implying higher imports than exports. Therefore the negative correlation between UIP and home bias shocks proves true by the fact that the negative current account is reinforced by the negative home bias shock. The estimates of shock autocorrelations show that the taste shock is highly persistent,

while all other shocks have a lower or medium-size degree of persistence.

By looking at impulse responses, one gets a better intuition about the estimated parameters and what these imply for the dynamics of the economy. Figure 1 shows impulse response functions to a one standard deviation technology shock for five series of interest: current account, exchange rate, interest rate, price, and output. The technology shock increases production of home intermediate goods relative to production of foreign intermediate goods. Higher output in the intermediate goods sector leads to lower home intermediate prices, which decreases partly production costs of final goods. Consequently, the production of final goods increases. Since the augmented supply of final goods is to some extent covered by a higher demand, the price of final goods decreases only slightly. As capital gets more productive and its rental price increases, home consumers invest and consume more borrowing in addition from the foreign country and accumulating foreign debt. The increased net foreign debt raises the country risk premium which, due to the UIP condition, leads to an expected exchange rate appreciation. Therefore the exchange rate depreciates initially, followed by the appreciation. In the beginning, the depreciated exchange rate leads to a negligible deterioration in the current account, which is succeeded by a current account improvement of an insignificant amount. Due to the monetary policy reaction to the exchange rate depreciation, the nominal interest rate increases. Overall, the economy converges fast to its steady state as the technology shock is not highly persistent in our model.

Figure 2 shows impulse response functions of the five variables to a one standard deviation shock to the monetary policy rule. A rise in the domestic nominal interest rate relative to the foreign interest rate leads to an immediate fall in domestic output and the overall price level, indicating that demand of final goods deteriorates initially more than output. Due to the UIP condition, the increase in the interest rate induces an exchange rate appreciation which is followed by an expected depreciation. The monetary contraction also involves a small worsening in the current account.

In the following we look at impulse response functions of the five series of interest to the UIP shock, as illustrated in Figure 3. The UIP shock can be understood as a shock which leads to a portfolio shift away from home assets, such that a positive interest rate differential between home and foreign assets is required to restore the demand for home assets. In our economy, the UIP shock leads to an exchange rate depreciation which is followed by an expected appreciation. The nominal interest rate increases slightly in a reaction to the exchange rate depreciation, and induces a fall in the consumption of final goods. Given initial prices, the production of final goods, however, decreases more, leading to a rise in the price level. The current account improves initially, deteriorating over time and even getting slightly negative during the convergence to its steady state. Overall, in our economy, the UIP shock, often included in the literature to create a high variation in the nominal exchange rate, implies not only a considerable response in the nominal exchange rate, but even in the production of final goods.

Figure 4 shows impulse responses to a one standard deviation of the taste shock. The positive taste shock induces an increase in the marginal utility of consumption leading to a rise in consumption of final goods which even crowds out new investment. The production of final goods heightens not strong enough to cover the induced rise in consumption, implying an increase in the price level. As the demand for final goods increases, the demand for intermediate home and foreign goods increases too, as they are production factors in the final goods sec-

tor. However, due to the home bias, the increase in the demand for home intermediate goods is higher relative to this for foreign goods, which leads to a depreciation of the exchange rate. Because of a monetary policy reaction to the increase in the overall price level and to the depreciation of the exchange rate, the nominal interest rate goes up. The implied dynamics of the current account are negligibly small, the current account improves marginally at the beginning and worsens slightly later due to a tiny amount of newly accumulated foreign debt.

Finally, we look at the impulse responses of the five series of interest to a one standard deviation shock to the home bias. The positive home bias shock shifts the demand from foreign to home intermediate goods improving initially the current account through the trade balance. As the demand for home intermediate goods increases and their price rises, the demand for their production factors, namely capital and labor, rises too. Due to higher investment and consumption, the production of final goods increases. However, initial demand of final goods increases less than supply which induces overall prices to fall. The improvement in the current account induces the accumulation of net foreign wealth which diminishes the country risk premium. Due to the UIP condition, the lower risk premium involves an exchange rate appreciation followed by an expected depreciation. Because of monetary policy reaction to the initial changes in the price level and the exchange rate, the nominal interest rate falls in the beginning.

Once the model is estimated, the results can be used to evaluate the exogenous sources of fluctuations over the sample period. We use the matrix form of the solution presented in (35) and evaluated at values of the estimated parameters to calculate the fraction of the forecast error variance for each variable explained by each shock for different time horizons. The only difficulty in the calculation arises from the fact that the UIP shock is correlated with the other four structural shocks and one has to orthogonalize the shocks in order to disentangle the contributions of other shocks to the UIP shock. We orthogonalize shocks through a Cholesky decomposition of the covariance matrix of the exogenous variables, where the UIP shock is ordered last. The ordering of the remaining four shocks does not matter since they are not correlated with each other, i.e. they are already orthogonal to each other. Using this procedure we attribute any joint distribution between the UIP and four other shocks to these other shocks. Table 5 reports the variance of the observed variables decomposed into fractions that are explained by the shocks to technology, monetary policy, taste, home bias, and the UIP condition. The percentages of each variable's forecast error variance due to the five shocks are computed at different time horizons: from 1 to 5 quarters, 10 quarters, 20 quarters, and infinite time horizon, where the latter shows the fraction of the variance of each variable which each shock would explain in an infinitely long simulation of the estimated model. Note that the sum of five numbers in each row is 100%.

Table 5 shows that the independent part of the UIP shock explains about 95% of current account movements in the first period and remains very important for the variance explanation even in subsequential periods, e.g. the importance is around 60% in the medium run (10 and 20 quarters). An intuitive explanation for this is that UIP shocks can be understood as portfolio shifts on the international asset market which directly affect country's capital accounts. Therefore UIP shocks should affect the current account through the balance-of-payments condition. This finding is comparable to the results of Bergin (2006), who finds a fraction of the UIP shock in the forecast error variance of the current account to be around 60% in the short run, i.e. in the first 5 quarters. As Bergin (2006) already mentioned, the high importance of the UIP shocks

may be linked to the fact that international capital flows are the main driving factor of the current account and not, as presumed before, the optimal intertemporal savings decision. The second most important shock depends on the forecast horizon. In the very short run (the 1st period) and in the infinite horizon the home bias shock advocates for around 5-6% of the current account movements. This arises from the fact that the home bias shock has initially a direct effect on the current account through the trade balance by shifting home demand towards home intermediate goods. In the short and medium run (from the 2nd to the 20th period) the technology shock explains around 20% of the current account fluctuations. The technology shock brings home residents in our economy to invest and consume more by borrowing from abroad, which drives the capital account and therefore the current account.

In contrast, Table 5 shows that around 65% of the exchange rate movements are explained by the technology shock. One link through which the technology shock affects exchange rate movements is partly explained above. The technology shock induces home residents to invest and consume more because of a positive wealth effect by borrowing from abroad. The higher net foreign debt increases the country risk premium which in turn drives, due to the UIP condition, the exchange rate to depreciate followed by an expected appreciation. Furthermore, the technology shock has an impact on the production level in the home intermediate goods sector, inducing changes in the price and output of final goods. The following nominal interest rate response creates exchange rate fluctuations via the UIP condition. Moreover, the major component of the UIP shock which drives the exchange rate is highly and positively correlated with the technology shock and is, due to our orthogonalization procedure, entirely attributed to the technology shock. The last explanation also applies to the second most important shock for exchange rate fluctuations, namely the taste shock, as its positive correlation with the UIP shock is completely ascribed to it. Otherwise, the taste shock, through its effect on the marginal utility of consumption, induces exchange rate fluctuations via price and quantity movements on the international intermediate goods market.

For the forecast error variance of the interest rate, we see from Table 5 that the monetary policy shock alone accounts for more than 90% of interest rate fluctuations over the whole forecast horizon. This is because the monetary policy shock directly affects the interest rate. The second most important shock is the taste shock which explains around 5% of the interest rate fluctuations. The taste shock, which influences the marginal utility of consumption, is positively correlated with the UIP shock. Since we orthogonalized the UIP shocks such that the joint distribution of the UIP and taste shock is completely attributed to the taste shock, we can conclude that the taste shock also contributes to the deviation of the UIP condition, and therefore drives partly the interest rate movements. The other explanation is that the taste shock also affects the money demand through its effect on the marginal utility of consumption, driving the interest rate as a variable equating money demand and supply.

The most important factor for price movements is the taste shock. It explains steadily over time around 80% of the price movements. The taste shock drives price fluctuations through its effect on the marginal utility of consumption and therefore on the demand for final goods as well as for home and foreign intermediate goods. The second most important shock for the price movements is the monetary policy shock, which explains around 15-20% of price fluctuations over time. There is a feedback of the monetary policy shock on the inflation and real activities

which explains the importance of the monetary policy shock for the price fluctuations.

Table 5 shows that the most important factor for the forecast error variance of the output is the technology shock which steadily accounts for around 60% of output fluctuations. The second most important shock for understanding output fluctuations is the home bias shock which links home household's preferences towards home intermediate goods inducing the increase in the demand and thus in the productions of final goods. The home bias shock accounts for around 30-40% of output fluctuations over the whole forecast horizon.

Summing up, the results from the variance decomposition for the current account show that primarily the independent part of the UIP shock drives the current account fluctuations. Given that this outcome also confirms the findings of Bergin (2006), we conclude that the fluctuations on the capital account side of the balance-of-payments, which then drive the adjustment in saving and investment on the current account side, deserve closer researchers' attention if they are interested in modeling and explaining current account movements. Regarding the exchange rate fluctuations, we find that, in contrast to Bergin (2006), the technology shock and its joint distribution with the UIP shock are the main driving forces. If we look again at the impulse responses of the UIP and the technology shock and keep in mind that these two shocks are strongly positively correlated, then we will better understand how the model succeeds in matching the high variance in the exchange rate and the very low variance in the current account. The combination of the positive UIP and the positive technology shock propagates the initial exchange rate depreciation, leaving the current account almost unchanged. For the future theoretical work, it would be interesting to find and investigate potential sources of the positive correlation between the UIP and the technology shock.

## 4 Conclusion

This paper has made an attempt at reassessing the NOEM model, used by Bergin (2006), in its ability to fit to the data from the US and its main trading partners, including China and Mexico, which were neglected in the previous literature. For this purpose, we estimated a two-country dynamic stochastic general equilibrium model with nominal rigidities and monopolistic competition on the data from the US and the remaining G7-countries, China, and Mexico, using the maximum likelihood procedure. The model fits to the data reasonably well, although the achieved likelihood value is below the one reported by Bergin (2006). The small set of contemporaneous second moments is matched surprisingly well, considering that the estimation procedure is designed to fit all aspects of the data. We recognize that the model performs well in matching the standard deviations of the current account, exchange rate, price, and the output. The contemporaneous correlation between the current account and output is fitted exactly by the model. Regarding the estimates for the structural parameters which are controversial in the theoretical literature, we get answers that are different from those provided by Bergin (2006). This fact indicates that the consideration of the two main trading partners, China and Mexico, in the foreign country aggregate for the US is important as long as the model attempts to explain the macroeconomic variables considered in the estimation procedure here. For example, in contrast to Bergin (2006), we do not support the common assumption in the theoretical literature of a unit elasticity of substitution between home and foreign goods. We significantly estimate

this elasticity at 0.7549 and reject the null hypothesis that this parameter is higher or equal to one. Furthermore, we do not provide an empirical support for complete local-currency pricing, as the share of pricing-to-market among all home intermediate producers is estimated only at 0.3936. Although this estimate is statistically significant at a 0.05 significance level, it indicates that China and Mexico as well as the change in the time sample (from 1980:1 to 2007:1) affect the result for the exchange rate pass-through contradicting the common view that the recent globalization and, especially, the emergence of China dampens the exchange-rate pass-through and thus increase local-currency pricing. However, in our theoretical model, home and foreign countries are fully symmetric and, as the US dollar not only acts as a vehicle currency for US imports but also for US exports, and the emergence of China and Mexico not only drives the import side of the US trade but also its export side. Hence there is a significant amount still assigned to the producer-currency pricing. We also provide an estimate how the country risk premium reacts to changes in a country's net foreign debt position, reporting a higher value of 0.0487 than the corresponding estimate of Bergin (2006). This points to the inclusion of China and Mexico in our data set which generally face a higher risk premium than industrial countries. Furthermore, the econometric analysis shows that the deviations from the UIP condition are not closely related to monetary shocks, they are rather positively correlated with technology shocks and shifts in the marginal utility of consumption. Moreover, we find that the independent part of the UIP shock is especially helpful in explaining fluctuations in the current account, while the technology shock and its common distribution with the UIP shock are helpful in explaining movements in the nominal exchange rate. As we support Bergin (2006) in identifying UIP shocks, and thus financial shocks on the capital account side, as driving forces for the current account, we strongly emphasize the importance of modeling international portfolio choices as factors moving the current account. Overall, we hope that the underlying study provides many avenues for critical future research, e.g. detecting potential sources for the positive correlation between the UIP and the technology shock as well as analyzing welfare implications of different monetary and fiscal policy instruments using estimates of structural parameters provided here.

## References

- Bacchetta, P. and van Wincoop, E. (2009). Infrequent portfolio decisions: A solution to the forward discount puzzle. *American Economic Review*, forthcoming.
- Bergin, P. R. (2003). Putting the "new open economy macroeconomics" to a test. *Journal of International Economics*, 60:3–34.
- Bergin, P. R. (2006). How well can the new open economy macroeconomics explain the exchange rate and current account? *Journal of International Money and Finance*, 25:675–701.
- Betts, C. and Devereux, M. B. (2000). Exchange rate dynamics in a model of pricing-to-market. *Journal of International Economics*, 50:215–244.
- Canova, F. (2007). *Methods for Applied Macroeconomic Research*. Princeton University Press, Princeton and Oxford.

- Chari, V. V., Kehoe, P. J., and McGrattan, E. R. (1997). Monetary shocks and real exchange rates in sticky price models of international business cycles. NBER Working Paper No. 5876.
- Harrigan, J. (1993). Oecd imports and trade barriers in 1983. *Journal of International Economics*, 35:91–111.
- Jeanne, O. and Rose, A. K. (2002). Noise trading and exchange rate regimes. *Quarterly Journal of Economics*, 117:537–569.
- Kim, J. (2000). Constructing and estimating a realistic optimizing model of monetary policy. *Journal of Monetary Economics*, 45(2):329–359.
- Kollmann, R. (1997). The exchange rate in a dynamic-optimizing current account model with nominal rigidities: A quantitative investigation. IMF Working Paper No. 97/7.
- Kollmann, R. (2002). Monetary policy rules in the open economy: effects on welfare and business cycles. *Journal of Monetary Economics*, 49:989–1015.
- Lane, P. R. (2001). The new open economy macroeconomics: A survey. *Journal of International Economics*, 54(2):235–266.
- Lane, P. R. and Milesi-Ferretti, G. M. (2001). Long-term capital movements. NBER Working Paper No. 8366.
- Leeper, E. M. and Sims, C. A. (1994). Toward a modern macroeconomic model usable for policy analysis. NBER Working Paper No. 4761.
- Lewis, K. (1995). Puzzles in international financial markets. In Grossman, G. and Rogoff, K., editors, *Handbook of International Economics*, volume III, pages 1913–1971. Elsevier, Amsterdam.
- Lubik, T. and Schorfheide, F. (2006). A bayesian look at new open economy macroeconomics. *NBER Macroeconomics Annual 2005*, 20:313–366.
- Marazzi, M., Sheets, N., Vigfusson, R., Faust, J., Gagnon, J., Marquez, J., Martin, R., Reeve, T., and Rogers, J. (2005). Exchange rate pass-through to u.s. import prices: Some new evidence. Board of Governors of the Federal Reserve System, International Finance Discussion Papers No. 833.
- Mark, N. and Wu, Y. (1999). Rethinking deviations from uncovered interest parity: the role of covariance risk and noise. *Economic Journal*, 108:1686–1706.
- Martins, J., Scarpetta, S., and Pilat, D. (1996). Mark-up pricing, market structure and the business cycle. *OECD Economic Studies*, 27:71–105.
- McCallum, B. T. and Nelson, E. (1999). Nominal income targeting in a open-economy optimizing model. *Journal of Monetary Economics*, 43:553–578.



- Meese, R. A. and Rogoff, K. (1983). Empirical exchange rate models of the seventies: Do they fit out of sample? *Journal of International Economics*, 14:3–24.
- Murray, J. (2008). Some puzzles related to exchange rate pass-through. mimeo, Bank of Canada.
- Obstfeld, M. and Rogoff, K. (1995). Exchange rate dynamics redux. *Journal of Political Economy*, 103(3):624–660.
- Obstfeld, M. and Rogoff, K. (2000). New directions for stochastic open economy models. *Journal of International Economics*, 50:117–153.
- Rotemberg, J. and Woodford, M. (1992). Oligopolistic pricing and the effects of aggregate demand on economic activity. *Journal of Political Economy*, 100:1153–1207.
- Schmitt-Grohé, S. and Uribe, M. (2003). Closing small open economy models. *Journal of International Economics*, 61:163–185.
- Svensson, L. and van Wijenbergen, S. (1989). Excess capacity, monopolistic competition, and international transmission of monetary disturbances. *Economic Journal*, 99:785–805.
- Tille, C. (2001). The role of consumption substitutability in the international transmission of monetary shocks. *Journal of International Economics*, 53:421–444.
- Van der Ploeg, F. (1993). Channels of international policy transmission. *Journal of International Transmission*, 34:245–267.

## A Appendix

### A.1 Market Structure

Formally, the price indexes for home intermediate goods sold in the home country ( $P_{Ht}$ ) and for imported foreign intermediate goods solve the following problems for  $P_{Ht}$ :

$$\begin{aligned} \min_{y_{Ht}(i)} \int_0^1 p_{Ht}(i) y_{Ht}(i) di \\ \text{s.t. } Y_{Ht} = \left( \int_0^1 y_{Ht}(i)^{\frac{1}{1+\nu}} di \right)^{1+\nu} = 1, \end{aligned}$$

and for  $P_{Ft}$ :

$$\begin{aligned} \min_{y_{Ft}(j)} \int_0^\eta p_{Ft}(j) y_{Ft}(j) dj + \int_\eta^1 s_t p_{Ft}(j) y_{Ft}(j) dj \\ \text{s.t. } Y_{Ft} = \left( \int_0^1 y_{Ft}(j)^{\frac{1}{1+\nu}} dj \right)^{1+\nu} = 1. \end{aligned}$$

The price index for final goods solves the problem:

$$\begin{aligned} \min_{Y_{Ht}, Y_{Ft}} P_{Ht} Y_{Ht} + P_{Ft} Y_{Ft} \\ \text{s.t. } Y_t = \left[ \theta_t^\mu Y_{Ht}^{\frac{\mu-1}{\mu}} + (1 - \theta_t)^\mu Y_{Ft}^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}} = 1. \end{aligned}$$

The following optimization problem leads to the solution for the demand function for individual home goods:

$$\begin{aligned} \max_{y_{Ht}(i)} Y_{Ht} = \left( \int_0^1 y_{Ht}(i)^{\frac{1}{1+\nu}} di \right)^{1+\nu} \\ \text{s.t. } \int_0^1 p_{Ht}(i) y_{Ht}(i) di = I, \end{aligned}$$

where  $I$  is any fixed total nominal expenditure on goods.

### A.2 Transformed equilibrium conditions

The equilibrium conditions (optimality and market clearing conditions) are used in the linearized form and are expressed as country differences. The system may be written in the following 19 variables:  $\tilde{C}_t - \tilde{C}_t^*$ ,  $\tilde{M}_t - \tilde{M}_t^*$ ,  $\tilde{i}_t - \tilde{i}_t^*$ ,  $\tilde{L}_t - \tilde{L}_t^*$ ,  $\tilde{K}_t - \tilde{K}_t^*$ ,  $\tilde{I}_t - \tilde{I}_t^*$ ,  $\tilde{Y}_t - \tilde{Y}_t^*$ ,  $\tilde{Y}_{Ht} - \tilde{Y}_{Ft}^*$ ,  $\tilde{Y}_{Ft} - \tilde{Y}_{Ht}^*$ ,  $\tilde{z}_t - \tilde{z}_t^*$ ,  $\tilde{B}_t - \tilde{B}_t^*$ ,  $\tilde{r}_t - \tilde{r}_t^*$ ,  $\tilde{P}_t - \tilde{P}_t^*$ ,  $\tilde{W}_t - \tilde{W}_t^*$ ,  $\tilde{P}_{Ht} - \tilde{P}_{Ft}^*$ ,  $\tilde{P}_{Ft} - \tilde{P}_{Ht}^*$ ,  $\tilde{s}_t$ ,  $\tilde{X}_t$ ,  $\tilde{CA}_t$ . Numbered below are the 19 linearized conditions that determine these sequences. Considering the intertemporal Euler equation (17), the steady-state nominal interest rate is:

$$\bar{i} = \frac{1 - \beta}{\beta}.$$

The linearized home intertemporal Euler equation (17):

$$\sigma_1 \tilde{C}_t - \tilde{\tau}_t = \sigma_1 E_t \tilde{C}_{t+1} - E_t \tilde{\tau}_{t+1} + E_t \tilde{P}_{t+1} - \tilde{P}_t - (1 - \beta) \tilde{i}_t$$

together with the foreign counterpart is transformed to:

$$\begin{aligned} \sigma_1 (\tilde{C}_t - \tilde{C}_t^*) - (\tilde{\tau}_t - \tilde{\tau}_t^*) &= \sigma_1 E_t (\tilde{C}_{t+1} - \tilde{C}_{t+1}^*) - E_t (\tilde{\tau}_{t+1} - \tilde{\tau}_{t+1}^*) \\ &+ E_t (\tilde{P}_{t+1} - \tilde{P}_{t+1}^*) - (\tilde{P}_t - \tilde{P}_t^*) - (1 - \beta) (\tilde{i}_t - \tilde{i}_t^*). \end{aligned} \quad (36)$$

The linearized money demand function (18):

$$\sigma_1 \tilde{C}_t + \sigma_2 \tilde{P}_t - \sigma_2 \tilde{M}_t - \tilde{\tau}_t - \beta \tilde{i}_t = 0$$

combined with the foreign counterpart is expressed as a country difference:

$$\sigma_1 (\tilde{C}_t - \tilde{C}_t^*) + \sigma_2 (\tilde{P}_t - \tilde{P}_t^*) - \sigma_2 (\tilde{M}_t - \tilde{M}_t^*) - (\tilde{\tau}_t - \tilde{\tau}_t^*) - \beta (\tilde{i}_t - \tilde{i}_t^*) = 0. \quad (37)$$

The linearized labor supply function (19):

$$\frac{1}{\sigma_3} \tilde{L}_t = \tilde{\tau}_t - \sigma_1 \tilde{C}_t + \tilde{W}_t - \tilde{P}_t$$

results in the following country difference:

$$\frac{1}{\sigma_3} (\tilde{L}_t - \tilde{L}_t^*) = (\tilde{\tau}_t - \tilde{\tau}_t^*) - \sigma_1 (\tilde{C}_t - \tilde{C}_t^*) + (\tilde{W}_t - \tilde{W}_t^*) - (\tilde{P}_t - \tilde{P}_t^*). \quad (38)$$

Considering the intertemporal optimality condition with respect to capital (20) and using the steady-state level of the nominal interest rate ( $\bar{i}$ ), the steady-state level of the real rental rate is:

$$\bar{r} = 1/\beta - (1 - \delta) = \bar{i} + \delta.$$

The linearized form for the optimal capital accumulation condition (20):

$$\begin{aligned} (1 + \beta) \psi_I \tilde{K}_t - \beta \psi_I E_t \tilde{K}_{t+1} - \psi_I \tilde{K}_{t-1} - (1 - \beta(1 - \delta)) E_t \tilde{r}_{t+1} \\ - \sigma_1 \tilde{C}_t + \sigma_1 E_t \tilde{C}_{t+1} + \tilde{\tau}_t - E_t \tilde{\tau}_{t+1} = 0. \end{aligned}$$

together with the foreign counterpart results in the following country difference:

$$\begin{aligned} (1 + \beta) \psi_I (\tilde{K}_t - \tilde{K}_t^*) - \beta \psi_I E_t (\tilde{K}_{t+1} - \tilde{K}_{t+1}^*) - \psi_I (\tilde{K}_{t-1} - \tilde{K}_{t-1}^*) \\ - (1 - \beta(1 - \delta)) E_t (\tilde{r}_{t+1} - \tilde{r}_{t+1}^*) - \sigma_1 (\tilde{C}_t - \tilde{C}_t^*) \\ + \sigma_1 E_t (\tilde{C}_{t+1} - \tilde{C}_{t+1}^*) + (\tilde{\tau}_t - \tilde{\tau}_t^*) - E_t (\tilde{\tau}_{t+1} - \tilde{\tau}_{t+1}^*) = 0. \end{aligned} \quad (39)$$

Considering the capital stock transition function (13), the steady-state level of investment is:

$$\bar{I} = \delta \bar{K}.$$

The linearized form of the capital stock transition function (13) expressed as a country difference is given by:

$$\delta(\tilde{I}_t - \tilde{I}_t^*) = (\tilde{K}_t - \tilde{K}_t^*) - (1 - \delta)(\tilde{K}_{t-1} - \tilde{K}_{t-1}^*). \quad (40)$$

The production function for intermediate goods (5) in the linearized form and expressed as a country difference is given by:

$$(\tilde{z}_t - \tilde{z}_t^*) = (\tilde{A}_t - \tilde{A}_t^*) + \alpha(\tilde{K}_{t-1} - \tilde{K}_{t-1}^*) + (1 - \alpha)(\tilde{L}_t - \tilde{L}_t^*). \quad (41)$$

The linearized form of the optimal trade-off between capital and labor expressed a a country difference is:

$$(\tilde{P}_t - \tilde{P}_t^*) + (\tilde{r}_t - \tilde{r}_t^*) + (\tilde{K}_{t-1} - \tilde{K}_{t-1}^*) = (\tilde{W}_t - \tilde{W}_t^*) + (\tilde{L}_t - \tilde{L}_t^*). \quad (42)$$

Using the steady-state condition of the optimal price setting rule for domestic sales of all home firms (8), which implies that a steady-state price-marginal cost markup factor of intermediate goods is  $1 + \nu$ :

$$\bar{P}_H = (1 + \nu) \underbrace{\frac{\bar{P}\bar{r}}{\alpha\bar{A}(\bar{L}(i)/\bar{K}(i))^{(1-\alpha)}}}_{MC},$$

and the fact that all home firms produce the same and set the same price for their domestic sales:

$$\bar{y}_H(i) = \bar{Y}_H, \bar{p}_H(i) = \bar{P}_H,$$

the linearized form of the optimal price setting rule for domestic sales of local- and producer-currency pricing firms will be derived as:

$$\begin{aligned} \nu(\tilde{y}_{Ht}(i) - \tilde{Y}_{Ht}) + \tilde{m}c_t - (1 + \nu)\tilde{P}_{Ht} + [\nu - (1 + \beta)\nu\psi_P]\tilde{p}_{Ht}(i) \\ + \nu\psi_P\tilde{p}_{Ht-1}(i) + \beta\nu\psi_P E_t\tilde{p}_{Ht+1}(i) = 0, \end{aligned}$$

where

$$\tilde{m}c_t = \tilde{P}_t + \tilde{r}_t - \tilde{A}_t + (1 - \alpha)\tilde{K}_{t-1} - (1 - \alpha)\tilde{L}_t.$$

The linearized form of the price index for domestic sales of home goods is:

$$\tilde{P}_{Ht} = \eta\tilde{p}_{Ht}(lcp) + (1 - \eta)\tilde{p}_{Ht}(pcp),$$

where *lcp* and *pcp* indicate local- and producer-currency pricing, respectively. Substituting price setting rules into the price index above leads to:

$$\tilde{m}c_t - [1 + (1 + \beta)\nu\psi_P]\tilde{P}_{Ht} + \nu\psi_P\tilde{P}_{Ht-1} + \beta\nu\psi_P E_t\tilde{P}_{Ht+1} = 0.$$

The foreign counterpart is:

$$\tilde{m}c_t^* - [1 + (1 + \beta)\nu\psi_P]\tilde{P}_{Ft}^* + \nu\psi_P\tilde{P}_{Ft-1}^* + \beta\nu\psi_P E_t\tilde{P}_{Ft+1}^* = 0,$$

where

$$\widetilde{m}c_t^* = \widetilde{P}_t^* + \widetilde{r}_t^* - \widetilde{A}_t^* + (1 - \alpha)\widetilde{K}_{t-1}^* - (1 - \alpha)\widetilde{L}_t^*.$$

Then the country difference results in:

$$\begin{aligned} & (\widetilde{m}c_t - \widetilde{m}c_t^*) - [1 + (1 + \beta)\nu\psi_P](\widetilde{P}_{Ht} - \widetilde{P}_{Ft}^*) \\ & + \nu\psi_P(\widetilde{P}_{Ht-1} - \widetilde{P}_{Ft-1}^*) + \beta\nu\psi_P E_t(\widetilde{P}_{Ht+1} - \widetilde{P}_{Ft+1}^*) = 0. \end{aligned} \quad (43)$$

The linearized form of the optimal price setting rule for exports of home local-currency pricing firms (9) is:

$$\begin{aligned} & \nu(\widetilde{y}_{Ht}^*(lcp) - \widetilde{Y}_{Ht}^*) + \widetilde{m}c_t - (1 + \nu)\widetilde{P}_{Ht}^* + [\nu - (1 + \beta)\nu\psi_P]\widetilde{p}_{Ht}^*(lcp) \\ & + \nu\psi_P\widetilde{p}_{Ht-1}^*(lcp) + \beta\nu\psi_P E_t\widetilde{p}_{Ht+1}^*(lcp) - \widetilde{s}_t = 0, \end{aligned}$$

and for producer-currency pricing firms (10), this is:

$$\begin{aligned} & \nu(\widetilde{y}_{Ht}^*(pcp) - \widetilde{Y}_{Ht}^*) + \widetilde{m}c_t - (1 + \nu)\widetilde{P}_{Ht}^* + [\nu - (1 + \beta)\nu\psi_P]\widetilde{p}_{Ht}^*(pcp) \\ & + \nu\psi_P\widetilde{p}_{Ht-1}^*(pcp) + \beta\nu\psi_P E_t\widetilde{p}_{Ht+1}^*(pcp) - (1 + \nu)\widetilde{s}_t = 0. \end{aligned}$$

The linearized form of the export price index for home goods is:

$$\widetilde{P}_{Ht}^* = \eta\widetilde{p}_{Ht}^*(lcp) + (1 - \eta)\widetilde{p}_{Ht}^*(pcp) - (1 - \eta)\widetilde{s}_t.$$

Substituting price setting rules of local- and producer-currency pricing firms into the export price index leads to:

$$\begin{aligned} & \widetilde{m}c_t - [1 + (1 + \beta)\nu\psi_P]\widetilde{P}_{Ht}^* + \nu\psi_P\widetilde{P}_{Ht-1}^* + [\beta\nu\psi_P]E_t\widetilde{P}_{Ht+1}^* \\ & - [(1 - \eta)(1 + \beta)\nu\psi_P + 1]\widetilde{s}_t + (1 - \eta)\nu\psi_P\widetilde{s}_{t-1} + (1 - \eta)\beta\nu\psi_P E_t\widetilde{s}_{t+1} = 0. \end{aligned}$$

The counterpart for foreign country exports is given by:

$$\begin{aligned} & \widetilde{m}c_t^* - [1 + (1 + \beta)\nu\psi_P]\widetilde{P}_{Ft} + \nu\psi_P\widetilde{P}_{Ft-1} + [\beta\nu\psi_P]E_t\widetilde{P}_{Ft+1} \\ & + [(1 - \eta)(1 + \beta)\nu\psi_P + 1]\widetilde{s}_t - (1 - \eta)\nu\psi_P\widetilde{s}_{t-1} - (1 - \eta)\beta\nu\psi_P E_t\widetilde{s}_{t+1} = 0. \end{aligned}$$

We combine these two expressions to get the following country difference:

$$\begin{aligned} & -(\widetilde{m}c_t - \widetilde{m}c_t^*) - [1 + (1 + \beta)\nu\psi_P](\widetilde{P}_{Ft} - \widetilde{P}_{Ht}^*) + \nu\psi_P(\widetilde{P}_{Ft-1} - \widetilde{P}_{Ht-1}^*) \\ & + [\beta\nu\psi_P]E_t(\widetilde{P}_{Ft+1} - \widetilde{P}_{Ht+1}^*) - 2[(1 - \eta)(1 + \beta)\nu\psi_P + 1]\widetilde{s}_t \\ & + 2(1 - \eta)\nu\psi_P\widetilde{s}_{t-1} + 2(1 - \eta)\beta\nu\psi_P E_t\widetilde{s}_{t+1} = 0. \end{aligned} \quad (44)$$

The price indexes linearized around the fully symmetric steady state are:

$$\begin{aligned} \widetilde{P}_t &= \bar{\theta}\widetilde{P}_{Ht} + (1 - \bar{\theta})\widetilde{P}_{Ft}, \\ \widetilde{P}_t^* &= \bar{\theta}\widetilde{P}_{Ft}^* + (1 - \bar{\theta})\widetilde{P}_{Ht}^*. \end{aligned}$$

Then the country difference is:

$$(\tilde{P}_t - \tilde{P}_t^*) = \bar{\theta}(\tilde{P}_{Ht} - \tilde{P}_{Ft}^*) + (1 - \bar{\theta})(\tilde{P}_{Ft} - \tilde{P}_{Ht}^*). \quad (45)$$

The linearized aggregate home demands for home and foreign goods (2), (3) are:

$$\begin{aligned} \tilde{Y}_{Ht} &= \tilde{Y}_t + \mu\tilde{P}_t - \mu\tilde{P}_{Ht} + \tilde{\theta}_t, \\ \tilde{Y}_{Ft} &= \tilde{Y}_t + \mu\tilde{P}_t - \mu\tilde{P}_{Ft} - \left(\frac{\bar{\theta}}{1 - \bar{\theta}}\right)\tilde{\theta}_t. \end{aligned}$$

The foreign counterparts are:

$$\begin{aligned} \tilde{Y}_{Ft}^* &= \tilde{Y}_t^* + \mu\tilde{P}_t^* - \mu\tilde{P}_{Ft}^* + \tilde{\theta}_t^*, \\ \tilde{Y}_{Ht}^* &= \tilde{Y}_t^* + \mu\tilde{P}_t^* - \mu\tilde{P}_{Ht}^* - \left(\frac{\bar{\theta}}{1 - \bar{\theta}}\right)\tilde{\theta}_t^*, \end{aligned}$$

Then the country differences are:

$$(\tilde{Y}_{Ht} - \tilde{Y}_{Ft}^*) = (\tilde{Y}_t - \tilde{Y}_t^*) + \mu(\tilde{P}_t - \tilde{P}_t^*) - \mu(\tilde{P}_{Ht} - \tilde{P}_{Ft}^*) + (\tilde{\theta}_t - \tilde{\theta}_t^*), \quad (46)$$

$$(\tilde{Y}_{Ft} - \tilde{Y}_{Ht}^*) = (\tilde{Y}_t - \tilde{Y}_t^*) + \mu(\tilde{P}_t - \tilde{P}_t^*) - \mu(\tilde{P}_{Ft} - \tilde{P}_{Ht}^*) - \left(\frac{\bar{\theta}}{1 - \bar{\theta}}\right)(\tilde{\theta}_t - \tilde{\theta}_t^*). \quad (47)$$

Using the linearized final goods demand (25):

$$\tilde{Y}_t = \frac{\bar{C}}{\bar{Y}}\tilde{C}_t + \frac{\bar{I}}{\bar{Y}}\tilde{I}_t + \frac{\bar{G}}{\bar{Y}}\tilde{G}_t$$

together with the foreign counterpart:

$$\tilde{Y}_t^* = \frac{\bar{C}}{\bar{Y}}\tilde{C}_t^* + \frac{\bar{I}}{\bar{Y}}\tilde{I}_t^* + \frac{\bar{G}}{\bar{Y}}\tilde{G}_t^*,$$

results in the following country difference:<sup>8</sup>

$$(\tilde{Y}_t - \tilde{Y}_t^*) = \frac{\bar{C}}{\bar{Y}}(\tilde{C}_t - \tilde{C}_t^*) + \frac{\bar{I}}{\bar{Y}}(\tilde{I}_t - \tilde{I}_t^*) + \frac{\bar{G}}{\bar{Y}}(\tilde{G}_t - \tilde{G}_t^*). \quad (48)$$

The linearized home goods market clearing condition (aggregated over individual firms (6)) is:

$$\bar{\theta}\tilde{Y}_{Ht} + (1 - \bar{\theta})\tilde{Y}_{Ht}^* = \tilde{z}_t,$$

Combined with the foreign counterpart, this results in the country difference:

$$\bar{\theta}(\tilde{Y}_{Ht} - \tilde{Y}_{Ft}^*) - (1 - \bar{\theta})(\tilde{Y}_{Ft} - \tilde{Y}_{Ht}^*) = (\tilde{Z}_t - \tilde{Z}_t^*). \quad (49)$$

<sup>8</sup>Given parameter values  $\alpha, \beta, \delta, \nu$ , and abstracting from government expenditures in a steady state, we can define the steady-state ratio of investment to output as  $\alpha\delta/[(1 + \nu)(1/\beta - (1 - \delta))]$ . The steady-state ratio of consumption to output is then  $1 - \bar{I}/\bar{Y}$ .

The linearized form of the trade balance (deviations are taken as a ratio to GDP ( $Y_t$ )) is:

$$\frac{1}{1-\theta}\tilde{X}_t = \tilde{s}_t - (\tilde{P}_{Ft} - \tilde{P}_{Ht}^*) - (\tilde{Y}_{Ft} - \tilde{Y}_{Ht}^*). \quad (50)$$

The linearized form of the current account (deviations are taken as a ratio to GDP) is:

$$\widetilde{CA}_t = (\tilde{B}_t - \bar{s}\tilde{B}_t^*) - (\tilde{B}_{t-1} - \bar{s}\tilde{B}_{t-1}^*). \quad (51)$$

Then the linearized form of the balance-of-payments condition (29) is:

$$\tilde{X}_t + \frac{1}{\beta}(\tilde{B}_{t-1} - \bar{s}\tilde{B}_{t-1}^*) - (\tilde{B}_t - \bar{s}\tilde{B}_t^*) = 0. \quad (52)$$

The linearized form of the modified interest rate parity condition as discussed in Section 2 is:

$$\tilde{i}_t - \tilde{i}_t^* = \frac{1}{1-\beta}(E_t\tilde{s}_{t+1} - \tilde{s}_t) - \frac{\beta}{1-\beta}\psi_B(\tilde{B}_t - \bar{s}\tilde{B}_t^*) + \xi_t. \quad (53)$$

In addition, the linearized version of the interest rate targeting rule (24) completes the set of equilibrium conditions:

$$\tilde{i}_t = a_1(\tilde{P}_t - \tilde{P}_{t-1}) + a_2\tilde{Y}_t + a_3\tilde{s}_t + \phi_t. \quad (54)$$

A.3 Figures

Figure 1: Impulse responses to a one standard deviation technology shock

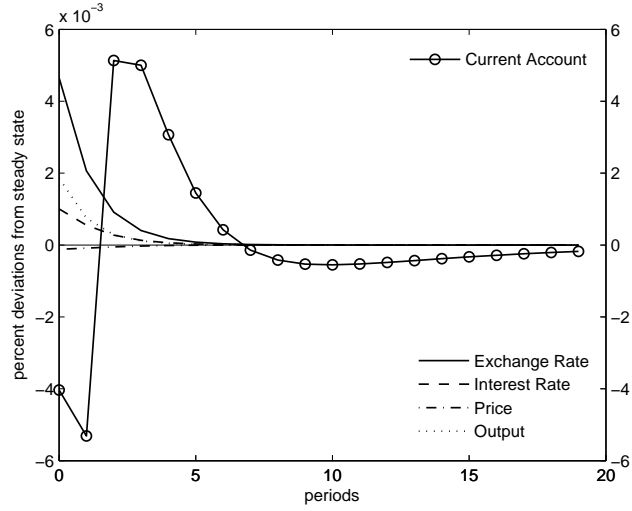


Figure 2: Impulse responses to a one standard deviation monetary policy shock

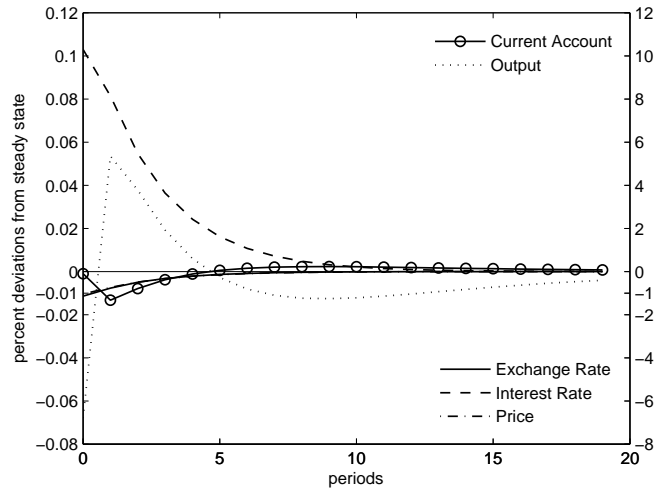




Figure 3: Impulse responses to a one standard deviation UIP shock

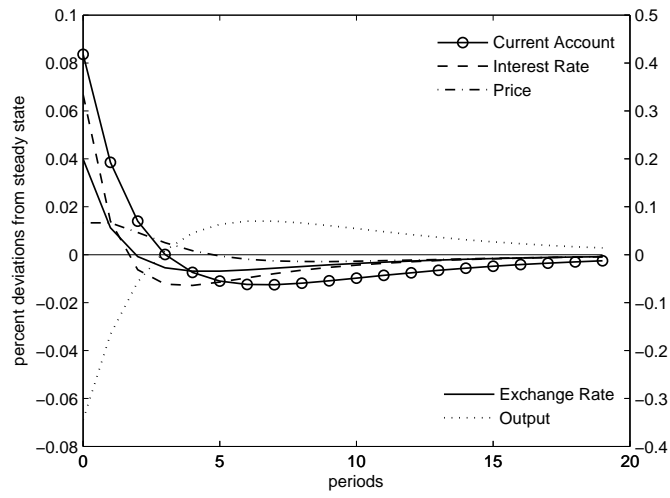


Figure 4: Impulse responses to a one standard deviation taste shock

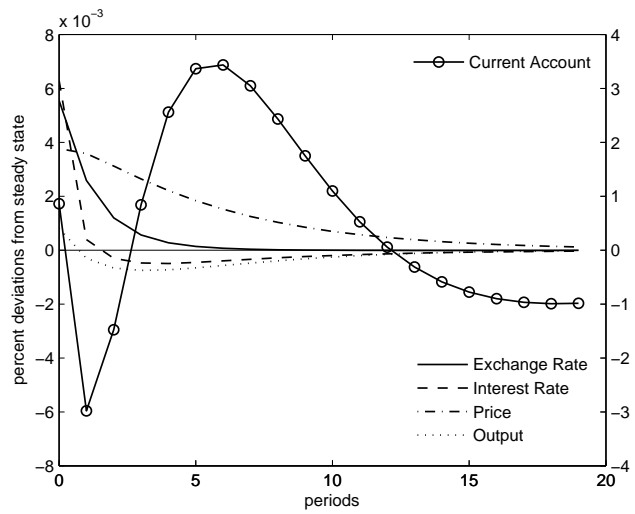
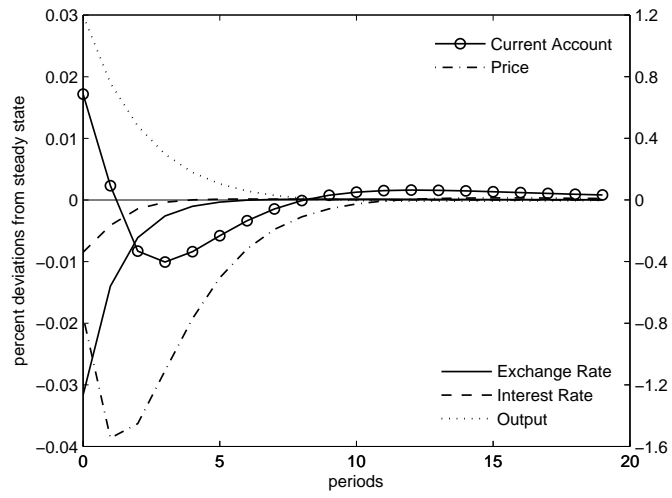


Figure 5: Impulse responses to a one standard deviation home bias shock



## A.4 Tables

Table 1: Annual trade weights of the US with its main trading partners

Year	Canada	China	France	Germany	Italy	Japan	Mexico	United Kingdom
1980	0.34		0.06	0.10	0.04	0.24	0.12	0.10
1981	0.34		0.05	0.09	0.04	0.24	0.13	0.10
1982	0.34		0.05	0.09	0.04	0.26	0.12	0.10
1983	0.36		0.05	0.09	0.04	0.26	0.10	0.09
1984	0.37		0.05	0.09	0.04	0.27	0.10	0.09
1985	0.35		0.05	0.09	0.05	0.29	0.10	0.08
1986	0.32		0.05	0.10	0.05	0.32	0.08	0.08
1987	0.34		0.05	0.10	0.04	0.30	0.09	0.08
1988	0.34		0.05	0.09	0.04	0.29	0.10	0.08
1989	0.34		0.05	0.09	0.04	0.29	0.11	0.08
1990	0.34		0.05	0.09	0.04	0.27	0.11	0.09
1991	0.34		0.06	0.09	0.04	0.27	0.12	0.08
1992	0.34		0.05	0.09	0.04	0.26	0.14	0.08
1993	0.36		0.05	0.08	0.03	0.26	0.14	0.08
1994	0.36		0.05	0.08	0.03	0.26	0.15	0.08
1995	0.37		0.04	0.08	0.03	0.26	0.15	0.08
1996	0.37		0.04	0.08	0.04	0.23	0.16	0.08
1997	0.37		0.04	0.08	0.03	0.22	0.18	0.08
1998	0.36		0.05	0.08	0.03	0.20	0.19	0.08
1999	0.33	0.09	0.04	0.08	0.03	0.18	0.18	0.07
2000	0.32	0.10	0.04	0.07	0.03	0.17	0.20	0.07
2001	0.32	0.11	0.04	0.08	0.03	0.16	0.20	0.07
2002	0.32	0.13	0.04	0.08	0.03	0.15	0.20	0.06
2003	0.32	0.15	0.04	0.08	0.03	0.14	0.19	0.06
2004	0.31	0.17	0.04	0.08	0.03	0.13	0.19	0.06
2005	0.31	0.19	0.04	0.08	0.03	0.12	0.18	0.06
2006	0.30	0.20	0.03	0.07	0.03	0.12	0.19	0.06

Trade weights are calculated as each country's share in total US trade (exports+imports) with these countries.

Table 2: Parameter restrictions

Parameters		Values/Regions
Home bias	$\bar{\theta}$	0.8
EoS between individual intermediate goods	$\nu$	0.2
Time preference	$\beta$	0.97
Labor supply elasticity	$\sigma_3$	1
Capital depreciation	$\delta$	0.026
Capital share in $z$	$\alpha$	0.3
Consumption elasticity	$\sigma_1$	$(0, \infty)$
Money demand elasticity	$\sigma_2$	$(0, \infty)$
Adjustment costs	$\psi_P, \psi_I, \psi_B$	$[0, \infty)$
Share of LCP	$\eta$	$[0, 1]$
EoS between $Y_H$ and $Y_F$	$\mu$	$(0, \infty)$
MP response to inflation	$a_1$	$(1, \infty)$
MP response to output	$a_2$	$[0, \infty)$
MP response to exchange rate	$a_3$	$(-\infty, \infty)$
Shocks autoregressive coefficients	$\rho_\theta, \rho_A, \rho_\tau, \rho_\xi, \rho_\phi$	$(0, 1)$
Correlations with UIP shock		$[-1, 1]$

Table 3: Unconditional second moments

Model Forecast (Data)	Current account	Exchange rate	Interest rate	Price	Output
Current account	0.0999 (0.1172)	-0.0802 (0.0519)	-0.0917 (-0.2708)	0.0338 (0.1180)	-0.1500 (-0.1501)
Exchange rate	-	5.8309 (5.8509)	-0.0456 (0.1303)	0.3896 (0.3443)	0.5792 (0.4829)
Interest rate	-	-	12.8141 (18.8383)	-0.2333 (-0.0446)	0.0440 (0.0910)
Price	-	-	-	2.8069 (2.6185)	-0.0729 (-0.1061)
Output	-	-	-	-	2.4525 (2.4958)

Standard deviations are expressed in percent.

Table 4: Parameter estimates

Behavioral Parameters:		
Consumption elasticity	$\sigma_1$	0.0604 (0.0189)
Money demand elasticity	$\sigma_2$	0.0022 (210.6821)
Investment adjustment cost	$\psi_I$	0.0000 (0.0000)
Price adjustment cost	$\psi_P$	0.6259 (0.3386)
Bond cost	$\psi_B$	0.0487 (0.0381)
Share of LCP	$\eta$	0.3936 (0.1970)
EoS between $Y_H$ and $Y_F$	$\mu$	0.7549 (0.0169)
Monetary Policy Rule Parameters:		
Response to inflation	$a_1$	1.3017 (0.4651)
Response to output	$a_2$	0.0000 (0.0000)
Response to exchange rate	$a_3$	0.2485 (0.2065)
Shock autocorrelations:		
Technology	$\rho_A$	0.3858 (0.0457)
Monetary	$\rho_\phi$	0.6650 (0.0381)
Taste	$\rho_\tau$	0.8214 (0.0062)
Home bias	$\rho_\theta$	0.5335 (0.0420)
UIP	$\rho_\xi$	0.4449 (0.0454)
Standard deviations of shocks:		
Technology	$\sigma_A$	0.0434 (0.0007)
Monetary	$\sigma_\phi$	0.1193 (0.0092)
Taste	$\sigma_\tau$	0.0220 (0.0008)
Home bias	$\sigma_\theta$	0.0044 (0.0001)
UIP	$\sigma_\xi$	1.0470 (0.0929)
Correlations with UIP shock:		
Technology		0.8334 (0.0003)
Monetary		-0.0197 (0.0116)
Tastes		0.5009 (0.0000)
Home bias		-0.2280 (0.0016)

Values in parenthesis indicate standard errors.

Table 5: Variance decompositions (in percent)

Variable	Period	Shocks				
		Technology	Monetary	Taste	Home bias	UIP
Current Account	1	0.22	0.02	0.04	4.04	95.68
	2	18.44	0.09	2.06	3.64	75.77
	3	22.91	0.09	5.96	4.66	66.38
	4	23.42	0.09	8.98	5.45	62.06
	5	23.06	0.11	10.74	5.84	60.25
	10	21.31	0.37	12.67	5.68	59.97
	20	20.47	0.52	13.58	5.56	59.87
	$\infty$	1.09	2.51	2.10	5.90	88.39
Exchange Rate	1	67.06	4.03	23.82	4.97	0.12
	2	66.22	4.84	23.93	4.90	0.11
	3	65.82	5.27	23.93	4.87	0.11
	4	65.65	5.48	23.91	4.85	0.11
	5	65.57	5.58	23.90	4.84	0.11
	10	65.51	5.64	23.89	4.84	0.12
	20	65.51	5.64	23.89	4.84	0.12
	$\infty$	66.23	4.85	23.85	4.93	0.14
Interest Rate	1	0.86	90.59	8.45	0.10	0.00
	2	0.71	93.81	5.40	0.08	0.00
	3	0.65	94.63	4.65	0.07	0.00
	4	0.62	94.91	4.40	0.07	0.00
	5	0.61	95.01	4.32	0.06	0.00
	10	0.59	95.05	4.30	0.06	0.00
	20	0.59	95.04	4.31	0.06	0.00
	$\infty$	0.69	93.20	6.03	0.08	0.00
Price	1	0.30	23.30	76.39	0.01	0.00
	2	0.25	19.34	80.38	0.02	0.01
	3	0.22	16.86	82.89	0.03	0.00
	4	0.19	15.27	84.50	0.03	0.01
	5	0.18	14.24	85.55	0.03	0.00
	10	0.15	12.49	87.33	0.03	0.00
	20	0.15	12.22	87.60	0.03	0.00
	$\infty$	0.23	17.54	82.18	0.03	0.01
Output	1	66.62	0.09	3.19	27.79	2.31
	2	60.02	0.08	2.87	34.58	2.45
	3	57.25	0.07	3.50	36.81	2.37
	4	55.89	0.07	4.37	37.35	2.32
	5	55.08	0.07	5.22	37.31	2.32
	10	53.59	0.09	7.21	36.52	2.59
	20	53.36	0.10	7.42	36.37	2.75
	$\infty$	58.31	0.17	9.28	29.53	2.71