International Trade in Durable Goods in Sticky Price Models

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Abstract

Engel and Wang (2008) argue that trade in durable goods is important for international real-business-cycle models to replicate the behavior of real imports and exports. We extend such a model with Calvo-style price stickiness. We find that the model with producer currency pricing (PCP) for investment goods and local currency pricing (LCP) for durable consumption performs better than the model with PCP or LCP only in matching the trade sector data. Price stickiness brings the cross-country correlations of output and consumption closer to the data, though the consumption correlation is still much lower than in the data.

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1 Introduction

Net exports are found counter-cyclical in the data and this behavior can be replicated in standard international-real-business-cycle (IRBC) models. For instance, see Backus, Kehoe, and Kydland (1992, 1994), and Raffo (2008). However, Engel and Wang (2008) find that the standard IRBC models fail to replicate the behavior of real imports and exports. Real imports and exports are much more volatile than output, and both are pro-cyclical. Inspired by the fact that a large fraction of international trade among OECD countries is in durable goods, Engel and Wang (2008) show that a model with trade in durable goods can replicate trade sector data better than the standard IRBC models. In this paper, we extend Engel and Wang (2008) to a sticky-price model. We find that the model can still replicate the trade sector data well even when prices are sticky. However, the model’s performance is affected by in which currency international trade is priced. In addition, price stickiness brings some other dimensions of the model closer to the data.

Engel and Wang (2008) document two robust empirical findings for OECD countries: 1. the standard deviations of real imports and exports are about three times as large as GDP’s; 2. real imports and exports are pro-cyclical and positively correlated (positive comovement). Engel and Wang (2008) show that a model with trade in durable goods (durable consumption and investment) can replicate these empirical findings. The positive comovement in the model with trade in durable goods suggests that the volatility of imports and exports are driven by the forward-looking nature of investment decisions and decisions to purchase consumer durables, instead of relative price changes of imports and exports. As a result, we believe that the introduction of price stickiness may not affect our model’s ability in replicating the behavior of imports and exports, though it may impose constraint on relative price movements.

We follow the same two-country two-sector model in Engel and Wang (2008), but modify it with monopolistic competitions and Calvo staggered price settings. Each country has two sectors with differentiated goods: durable and nondurable sectors. Only durable goods are traded across countries and can be used for the accumulation of capital or durable consumption in both countries. In sticky-price open-economy macro models, the setup of price-setting currency affects the model’s performance and its policy implication. For instance, see Betts and Devereux (2000), Devereux and Engel (2002, 2003). We compare three setups of price setting currencies. First, all prices are set in the producer’s currency (PCP). Second, all prices are set in the local market’s currency (LCP). Survey data and empirical studies suggest that the usage of price setting currency is more likely to be a mixture of PCP and LCP. In the third setup, we assume that prices of investment goods are set in the producer’s currency while prices of durable consumer goods are set in the buyer’s currency (LCP). This setup is consistent with our observation that prices of consumer durables,
such as automobiles, are generally priced in the buyer’s currency.

Several studies have found that the extent of price stickiness varies across sectors.\(^1\) Among these studies, Bouakez, Cardia, and Ruge-Murcia (forthcoming) find that prices of durable goods are less sticky than prices of nondurable goods in their estimates. Following their findings, we assume the durable goods producers on average reset prices every two quarters while nondurable goods producers reset prices every four quarters. Under this setup, we find that the model with a mixture of PCP and LCP can match data better than the model with either PCP or LCP only. Although all sticky-price models can replicate the volatility of real imports and exports, real imports and exports are generally negatively correlated in the models with either PCP or LCP only.

The cross-country correlation of output in our sticky-price models is much closer to the data than it in the flexible-price model. The consumption correlation also increases in the sticky-price model, but it is still much lower than it in the data. In all sticky-price models, labor and consumption are too volatile. They have about the same volatility as output, but are less volatile than output in the data. This may be caused by that wage is flexible in our model. Wage and therefore labor adjust to help the model to reach its new equilibrium levels while other prices are fixed in the short term. Adding sticky wages in our model is desirable in future.

The reminder of the paper is organized as follows: Section 2 describes our model. Section 3 discusses our calibration of the model. Section 4 shows simulation results and Section 5 concludes.

2 A Two-country Benchmark Model

The model has the same structure as in Engel and Wang (2008), but is modified with monopolistic competition and Calvo-staggard price settings. There are two symmetric countries in our model, Home and Foreign. Each country has two production sectors: the nondurable goods and durable goods sectors. Nondurable goods can only be used for domestic consumption. This setup is motivated by the finding in Engel and Wang (2008) that nondurable goods only account for a small part of international trade for OECD countries. Engel and Wang (2008) also find that durable goods account for much of the volatility and procyclicality of imports and exports. In addition, there is no guidance from the literature on the calibration of the productivity shocks in an open economy with both tradable and nontradable nondurables. Durable goods are traded across countries and used for durable consumption and capital accumulation. Because of the symmetry between these two countries, we describe our model focusing on the Home country.

\(^1\)For instance, see Bils and Klenow (2004) and Nakamura and Steinsson (2008).
2.1 Nondurable Goods Sector

There is a continuum of differentiated goods in the nondurable goods sector. Each variety of nondurable goods is produced from capital and labor by a single firm index by $i$ ($i \in [0, 1]$):

$$Y_{Ht}^N(i) = A_{Ht}^N(K_{Ht}^N(i))^\chi[L_{Ht}^N(i)]^{1-\chi}. \quad (1)$$

where $A_{Ht}^N$ is the productivity shock in the nondurable goods sector. $K_{Ht}^N(i)$ and $L_{Ht}^N(i)$ are respectively, capital and labor used by firm $i$ in production. Capital $K_{Ht}^N(i)$ is a CES composite of Home- and Foreign-good capital

$$K_{Ht}^N = \left(\alpha \frac{1}{\gamma} (K_{NHt}^N)^{\frac{\gamma-1}{\gamma}} + (1-\alpha) \frac{1}{\gamma} (K_{NFt}^N)^{\frac{\gamma-1}{\gamma}}\right)^{\frac{\gamma}{\gamma-1}}, \quad (2)$$

where in the notation such as $K_{it}^{jk}$, we use the subscript $i$ to denote the country in which the capital is used, the first superscript $j$ to denote the sector (nondurable or durable) and the second superscript $k$ to denote the origin of the good. For instance, $K_{Ht}^N$ is the Home-country produced durable good that is used in the nondurable good sector of the Home country.

Given rental and labor costs ($R_{Ht}^N$ and $W_{Ht}$), we can derive firms’ marginal cost from equation (1):

$$MC_{Ht}^N = (A_{Ht}^N)^{-1}(R_{Ht}^N)^\chi W_{Ht}^{1-\chi} \chi^{\gamma} (1-\chi)^{\gamma-1}. \quad (3)$$

Households buy differentiated nondurable goods and aggregate them into a CES composite for consumption:

$$Y_{Ht}^N = \left[\int_0^1 (Y_{Ht}^N(i))^{\frac{\phi-1}{\phi}} di\right]^{\frac{\phi}{\phi-1}}, \quad (4)$$

where $\phi$ is the elasticity of substitution between differentiated nondurable goods. From equation (4), we have the demand function for $Y_{Ht}^N(i)$:

$$Y_{Ht}^N(i) = \left(\frac{P_{Ht}(i)}{P_{Ht}^N}\right)^{-\phi} Y_{Ht}^N. \quad (5)$$

Given the demand function in equation (5) and the marginal cost in equation (3), firm $i$ chooses a price to maximize its expected profit. We follow Calvo (1983) in modeling price stickiness. In each period, a firm resets its price with a probability of $1-\lambda_N$. Otherwise, the price is fixed at its level in the last period. When
firms reset its price, it solve the profit maximization problem of

$$\max_{P_{Ht}^N} \sum_{k=0}^{\infty} E_t \left\{ \lambda_N \Gamma_{Ht,t+k} (P_{Ht}^N)^{-1} \left[ (P_{Ht}^N - MC_{Ht+k}^N) \left( \frac{P_{Ht}^N}{P_{Ht+k}^N} \right)^{-\phi} Y_{Ht+k}^N \right] \right\},$$

where \(\Gamma_{Ht,t+k}\) is the pricing kernel between period \(t\) and \(t+k\). We assume all firms are owned by home households, and therefore \(\Gamma_{t,t+k}\) is the marginal rate of substitution between time \(t\) and time \(t+k\) consumption in the home country. \(P_{Ht}^N\) is the optimal price for firms that reset their prices at time \(t\). From the profit maximization problem, we have

$$P_{Ht}^N = \frac{\sum_{k=0}^{\infty} \lambda_N E_t \left[ \Gamma_{t,t+k} MC_{Ht+k}^N (P_{Ht+k}^N)^{\phi-1} Y_{Ht+k}^N \right]}{\sum_{k=0}^{\infty} \lambda_N E_t \left[ \Gamma_{t,t+k} (P_{Ht+k}^N)^{\phi-1} Y_{Ht+k}^N (\phi - 1) \right]}.$$  \hfill (6)

The dynamics of \(P_{Ht}^N\) is given by

$$(P_{Ht}^N)^{1-\phi} = (1 - \lambda_N)(P_{Ht}^{N*})^{1-\phi} + \lambda_N(P_{Ht-1}^N)^{1-\phi}. \hfill (7)$$

### 2.2 Durable Goods Sector

The production function in durable goods sector takes a similar form:

$$Y_{Ht}^D(j) = A_{Ht}^D [R_{Ht}^D(j)]^\chi [L_{Ht}^D(j)]^{1-\chi}. \hfill (8)$$

We use \(j \in [0,1]\) to index firms in durable goods sector. \(Y_{Ht}^D(j)\) can be used for durable consumption and capital accumulation in both countries. Let \(Y_{Ht}^{DH}(j)\) be home-produced durable goods used in the home country. \(Y_{Ht}^{HC}(j)\) and \(Y_{Ht}^{HI}(j)\) are home-produced goods that are used in the foreign country for durable consumption and investment respectively. There is an iceberg trade cost for international trade: only a fraction of \((1 - \tau)\) goods arrives in the importing country. From the market clearing condition, we have

$$Y_{Ht}^D(j) = Y_{Ht}^{DH}(j) + \frac{Y_{Ht}^{HC}(j) + Y_{Ht}^{HI}(j)}{1 - \tau}. \hfill (9)$$

The differentiated goods are aggregated into CES composites for durable consumption and capital ac-
cumulation according to:

\[ Y_{DH}^{HI} = \left[ \int_0^1 (Y_{DH}^{HI}(j))^\frac{\phi-1}{\phi} \, \frac{\phi}{\phi-1} \, di \right]^\frac{\phi}{\phi-1} \]  
(10)

\[ Y_{HC}^{FI} = \left[ \int_0^1 (Y_{HC}^{FI}(j))^\frac{\phi-1}{\phi} \, \frac{\phi}{\phi-1} \, di \right]^\frac{\phi}{\phi-1} \]  
(11)

\[ Y_{H1}^{FI} = \left[ \int_0^1 (Y_{H1}^{FI}(j))^\frac{\phi-1}{\phi} \, \frac{\phi}{\phi-1} \, di \right]^\frac{\phi}{\phi-1} \]  
(12)

Each firm charges three different prices: price in domestic market \( (P_{DH}^{HI}(j)) \), price for durable consumption in foreign market \( (P_{HC}^{HI}(j)) \), and price for investment in foreign market \( (P_{H1}^{HI}(j)) \). \( P_{DH}^{HI}(j) \) is always set in the producer’s currency. \( P_{HC}^{HI}(j) \) and \( P_{H1}^{HI}(j) \) can be set in either the producer’s or importing country’s currency in practice. We consider two setups when choosing price setting currencies. In the first case, \( P_{H1}^{HI}(j) \) is set in the producer’s currency (producer currency pricing, or PCP) while price \( P_{HC}^{HI}(j) \) is set in the consumer’s currency (local currency pricing, or LCP). We denote this case as PCP+LCP. In the second case, we use LCP for both \( P_{HC}^{HI}(j) \) and \( P_{H1}^{HI}(j) \).

From equations (10), (11), and (12), we have demand functions:

\[ Y_{DH}^{HI}(j) = \left( \frac{P_{DH}^{HI}(j)}{P_{DH}^{HI}(j)} \right)^{\phi} Y_{DH}^{HI} \]  
(13)

\[ Y_{HC}^{HI}(j) = \left( \frac{P_{HC}^{HI}(j)}{P_{HC}^{HI}(j)} \right)^{\phi} Y_{HC}^{HI} \]  
(14)

\[ Y_{H1}^{HI}(j) = \left( \frac{P_{H1}^{HI}(j)}{P_{H1}^{HI}(j)} \right)^{\phi} Y_{H1}^{HI} \]  
(15)

For the given demand and production functions, firms choose prices to maximize expected profit. As in nondurable goods sector, prices are set in a Calvo style. In each period, each firm has a probability of \( 1 - \lambda_D \)
to reset its price. Solve the profit optimization problems in the case of PCP+LCP, we have

$$P_{D^H}^* = \frac{\sum_{k=0}^{\infty} \lambda_{D}^k E_t \left[ \left( \frac{Y_{D^H}^*}{Y_{H}^*} \right)^{\phi} \Gamma_{t,t+k} MC_{H}^D (P_{D^H}^* (P_{D^H}^* + 1)) \right] }{\sum_{k=0}^{\infty} \lambda_{D}^k E_t \left[ \left( \frac{Y_{D^H}^*}{Y_{H}^*} \right)^{\phi} \Gamma_{t,t+k} (P_{D^H}^* + 1) \right] }$$

(16)

$$P_{H^C}^* = \frac{\sum_{k=0}^{\infty} \lambda_{D}^k E_t \left[ \left( \frac{Y_{H^C}^*}{Y_{H}^*} \right)^{\phi} \Gamma_{t,t+k} MC_{H}^D (P_{H^C}^* (P_{H^C}^* + 1)) \right] }{\sum_{k=0}^{\infty} \lambda_{D}^k E_t \left[ \left( \frac{Y_{H^C}^*}{Y_{H}^*} \right)^{\phi} \Gamma_{t,t+k} (P_{H^C}^* + 1) \right] }$$

(17)

$$P_{H^I}^* = \frac{\sum_{k=0}^{\infty} \lambda_{D}^k E_t \left[ \left( \frac{Y_{H^I}^*}{Y_{H}^*} \right)^{\phi} \Gamma_{t,t+k} MC_{H}^D (P_{H^I}^* (P_{H^I}^* + 1)) \right] }{\sum_{k=0}^{\infty} \lambda_{D}^k E_t \left[ \left( \frac{Y_{H^I}^*}{Y_{H}^*} \right)^{\phi} \Gamma_{t,t+k} (P_{H^I}^* + 1) \right] }$$

(18)

Prices $P_{D^H}^*$, $P_{H^C}^*$, and $P_{H^I}^*$ have similar dynamics as in equation (7).

In the case of LCP, the optimal price for $P_{H^I}^*$ becomes

$$P_{H^I}^* = \frac{\sum_{k=0}^{\infty} \lambda_{D}^k E_t \left[ \left( \frac{Y_{H^I}^*}{Y_{H}^*} \right)^{\phi} \Gamma_{t,t+k} MC_{H}^D (P_{H^I}^* (P_{H^I}^* + 1)) \right] }{\sum_{k=0}^{\infty} \lambda_{D}^k E_t \left[ \left( \frac{Y_{H^I}^*}{Y_{H}^*} \right)^{\phi} \Gamma_{t,t+k} (P_{H^I}^* + 1) \right] }$$

(19)

2.3 Households

In the Home country, the representative household supplies labor, accumulates and rents capital to firms, chooses nondurable consumption and accumulates durable consumption stock to maximize expected lifetime utility

$$E_t \sum_{j=0}^{\infty} \beta^j u(D_{Ht+j}, C_{Ht+j}, L_{Ht+j}),$$

where the period utility $u(D_{Ht+j}, C_{Ht+j}, L_{Ht+j})$ is a function of durable consumption ($D_{Ht+j}$), nondurable consumption ($C_{Ht+j}$), and labor supply ($L_{Ht+j}$). The period utility function takes the form of

$$u_t = \left[ \left( \frac{1}{\phi} \right)^{\frac{s-1}{s}} + (1 - \mu)^{\frac{s-1}{s}} C_{Ht}^{\frac{s-1}{s}} \right]^{\frac{1}{\phi}} - \rho L_{Ht}^{\nu}$$

(20)

It is an augmented GHH utility function with consumption as a CES composite of durable and nondurable consumption. The stock of durable consumption is a function of the Home ($D_{Ht}$) and Foreign ($D_{Ht}$) durable consumption stocks

$$D_{Ht} = \left[ \left( \frac{1}{\phi} \right)^{\frac{s-1}{s}} + (1 - \psi)^{\frac{s-1}{s}} (D_{Ht}^{D^H})^{\frac{s-1}{s}} \right]^{\frac{1}{\phi - 1}},$$

(22)
where $\psi$ is the weight of Home durable goods in the durable consumption stock and $\theta$ is the elasticity of substitution between the Home and Foreign durable goods. The law of motion for durable consumption is

$$D^k_{Ht+1} = (1 - \delta_D)D^k_{Ht} + d^k_{Ht},$$

(23)

where $k \in \{H, F\}$ denotes the Home and Foreign countries. $d^k_{Ht}$ is the $k$-country durable consumption goods purchased by the household at time $t$. As in Erceg and Levin (2006) and Whelan (2003), the household also has to pay a cost to adjust the durable consumption stock

$$\Delta^k_{Ht} = \frac{1}{2} \phi_1 \left( d^k_{Ht} - \delta_D D^k_{Ht} \right)^2 / D^k_{Ht},$$

(24)

where $\Delta^k_{Ht}$ is the cost of changing durables produced by country $k$.

The law of motion for capital stocks in the durable and nondurable sectors is given by

$$K^{jk}_{Ht+1} = (1 - \delta)K^{jk}_{Ht} + I^{jk}_{Ht},$$

(25)

where $j \in \{D, N\}$ and $k \in \{H, F\}$. We follow the literature to include capital adjustment costs in our model. In the Home country, it takes the following form

$$\Lambda^{jk}_{Ht} = \frac{1}{2} \phi_2 \left( I^{jk}_{Ht} - \delta K^{jk}_{Ht} \right)^2 / K^{jk}_{Ht},$$

(26)

where $j \in \{D, N\}$ and $k \in \{H, F\}$. Symmetric adjustment costs exist in the Foreign country.

The Home and Foreign countries trade nominal bonds that are denominated in the issuing country’s currency. The budget constraint in the home country for the case of PCP+LCP is

$$P^N_{Ht} C^H_{Ht} + P^{DH}_{Ht} \left( d^H_{Ht} + \Delta^H_{Ht} + I^{NH}_{Ht} + \Lambda^{NH}_{Ht} + I^{DH}_{Ht} + \Lambda^{DH}_{Ht} \right) + B^H_{Ht+1} \frac{1}{1 + i_t} + P^{DH}_{Ht} \frac{1}{2} \phi_d \left( \frac{B^{DH}_{Ht+1}}{P^{DH}_{Ht}} \right)^2$$

$$+ \frac{S_t B^F_{Ht+1}}{1 + i_t} + P^{FC}_{Ht} \frac{1}{2} \phi_f \left( \frac{B^F_{Ht+1}}{P^{DF}_{Ft}} \right)^2 + P^{FC}_{Ht} \left( d^F_{Ht} + \Delta^F_{Ht} \right) + S_t P^{FI}_{Ft} \left( I^{NF}_{Ht} + \Lambda^{NF}_{Ht} + I^{DF}_{Ht} + \Lambda^{DF}_{Ht} \right)$$

$$\leq W^{Ht} L^{Ht} + B^H_{Ht} + S_t B^F_{Ht} + R^{NH}_{Ht} K^{NH}_{Ht} + R^{NF}_{Ht} K^{NF}_{Ht} + R^{DH}_{Ht} K^{DH}_{Ht} + R^{DF}_{Ht} K^{DF}_{Ht} + \tilde{\pi}^{N}_{Ht} + \tilde{\pi}^{D}_{Ht},$$

(27)

Adjustment costs are scaled by the total durable consumption stock ($D_{Ht}$) so that the cost of adding new durable consumption ($d^H_{Ht} - \delta_D D^H_{Ht}$ and $d^F_{Ht} - \delta_D D^F_{Ht}$) is the same for both types of durable consumption. The same format is also used in the capital adjustment cost functions.
where $\tilde{\pi}^N_{Ht}$ ($\tilde{\pi}^D_{Ht}$) is profit from firms producing nondurable (durable) goods. $B^i_{Ht}$ is nominal bonds issued by country $i$, where $i = H, F$. Bond holding costs $\frac{1}{2} \Phi_d \left( \frac{B^i_{Ht+1}}{P^i_{Ht}} \right)^2$ and $\frac{1}{2} \Phi_f \left( \frac{B^i_{Ht+1}}{P^i_{Ft}} \right)^2$ are introduced to guarantee the stationarity of the model. These costs are quantitatively small and have no effects on our results.\footnote{There are several other techniques used in the literature to deal with this nonstationarity problem. See Schmitt-Grohé and Uribe (2003) for more discussions.} In the case of LCP, the exchange rate $S_t$ in front of $P^F_{Ht}$ in the budget constraint drops out. Subject to the above budget constraint, households choose consumption, investment, labor supply, and bond holdings to maximize expected lifetime utility.

\section{2.4 Monetary Policy Rules}

Interest rate rules are symmetric in the home and foreign countries. They take a forward looking format with interest smoothing as in Clarida, Gali, and Gertler (1998):

\[ i_t = (1 - \rho_i) i^T_t + \rho_i i_{t-1} + \varphi_t, \tag{28} \]

where $\rho_i$ is an interest-rate smoothing parameter, $i^T_t$ is the targeted interest rate, and $\varphi_t$ is the monetary shock. $i^T_t$ is determined by the long-run interest rate $i$ and the expected percentage deviation of CPI inflation and GDP from their steady state levels at time $t + 1$:

\[ i^T_t = i + \Xi_i E_t \left[ \log \left( \frac{\pi_{t+1}}{\pi} \right) \right] + \Xi_y E_t \left[ \log \left( \frac{GDP_{t+1}}{GDP} \right) \right]. \tag{29} \]

A symmetric policy rule holds in the foreign country.

The model is closed with market clearing conditions for nondurable goods, durable goods, labor, and nominal bonds markets

\begin{align*}
Y^N_{Ht} &= C^N_{Ht} \tag{30} \\
Y_{Ht}^D &= d^H_{Ht} + \Delta^H_{Ht} + I_{Ht}^N + I_{Ht}^D + \Lambda_{Ht}^N + \Lambda_{Ht}^D + \frac{1}{2} \Phi_d \left( \frac{B^H_{Ht+1}}{P^H_{Ht}} \right)^2 \tag{31} \\
Y_{Ht}^{FC} &= d^F_{Ht} + \delta^F_{Ht} + \frac{1}{2} \Phi_f \left( \frac{B^F_{Ht+1}}{P^F_{Ht}} \right)^2 \tag{32} \\
Y_{Ht}^{FI} &= I_{Ht}^F + \Lambda_{Ht}^F + I_{Ht}^{DF} + \Lambda_{Ht}^{DF} \tag{33} \\
L_{Ht} &= L_{Ht}^N + L_{Ht}^D \tag{34} \\
B^H_{Ht} + B^F_{Ht} &= 0. \tag{35}
\end{align*}
Symmetric market clearing conditions hold in the foreign country.

3 Calibration

The model is calibrated to match the structure of the economy as shown in Figure 1. It is the same as the structure in Engel and Wang (2008). In the steady state of the model, nondurable goods account for 60% of total output and durable goods account for the remaining 40%. Among the durable goods, half of them are used for consumption (equivalent to 20% of total output) and the other half are used for investment (equivalent to 20% of total output). Among durable consumption goods, 65% are used for domestic consumption (equivalent to 13% of total output) and 35% are used for exports (equivalent to 7% total output). Among durable investment goods, 70% are used for domestic investment (equivalent to 14% of total output) and 30% are used for exports (equivalent to 6% of total output). In this economy, investment accounts for 20% of total output and consumption (durable plus nondurable) accounts for the remaining 80%. The trade share of output is 13%. Those features match the US data closely.

Table 1 shows parameter values that we use to match our benchmark model with the described economy structure. Most parameters have the same value as in Engel and Wang (2008). We skip details about the calibration of these parameters and focus only on new parameters. The elasticity of substitution between differentiated goods ($\phi$) is set to 6 for both durable and nondurable goods. It implies a 20% profit margin. The price stickiness parameter is set to 0.75 for nondurable goods $\lambda_N$, and 0.3 for durable goods ($\lambda_D$). These parameter values are consistent with Bouzkez, Cardia, and Ruge-Murcia (forthcoming). They find that prices are less sticky for durable goods than nondurables and services. The monetary policy parameters are calibrated according to Clarida, Gali, and Gertler (1998). The policy parameter $\Xi_\pi$ is set to 1.79 and $\Xi_y$ is set to 0.07. The smoothing parameter $\rho_i$ is set to 0.92.

The productivity shocks are calibrated in the same way as Engel and Wang (2008) by following Erceg and Levin (2006) and Corsetti, Dedola, and Leduc (forthcoming). The standard deviation of monetary shocks ($\sigma_\varrho$) is chosen such that the 2-standard deviation band for monetary shocks shocks to the annual nominal interest rate is 1 percent. The cross-country correlation of monetary shocks is zero in the benchmark model. Other values are also used in robustness tests.

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4Durable consumption in our calibration is higher than the US data, which is about 15% of output. However, many goods with characteristics of durables—such as shoes and clothing—are classified as nondurables in the data.

5To match the same structure of the economy, we only recalibrate the depreciation rate of capital, which is changed from 0.013 to 0.02. This change is due to the introduction of monopolistic competition in this paper.

6We think one percent is a reason value for the interest rate shock. In addition, we find that under this calibration, the standard deviation of nominal interest rate is less than half of the steady state nominal interest rate in our model. It guarantees that the nominal interest rate is positive in most of our simulations.
4 Model Performance

Table 2 shows simulation results. We compare each model with the US data that is reported in Engel and Wang (2008). Engel and Wang (2008) document two empirical findings in OECD data: 1. imports and exports are about three times as volatile as GDP (trade volatility); 2. imports and exports are pro-cyclical and also positively correlated with each other (positive comovement). They show that a wide range of standard open-economy macro models fail to replicate these empirical findings. In that paper, we propose a flexible-price model in which countries trade durable goods only and find the model can match the trade sector data better than the standard models. We confirm this result in the model of Flexible Price in Table 2.

In the model of Flexible Price, the price stickiness parameters ($\lambda_N$ and $\lambda_D$) are set to zero. That is, firms change their prices in each period.\footnote{In the flexible-price model, forward-looking Taylor rules are changed to present-looking rules to guarantee model determinacy.} As in Engel and Wang (2008), the model can match the trade sector data very well: 1. imports and exports are about three times as volatile as GDP; 2. imports and exports are pro-cyclical and positively correlated with each other; and 3. net exports are counter-cyclical. In addition, the flexible-price model can also replicate the volatility (relative to that of GDP) of aggregate variables such as consumption, investment, durable consumption, and labor. However, the model generates a much lower cross-country correlation for output and consumption. This is a shortcoming for all standard international business cycle models.

We consider three setups for sticky-price models. In the model of PCP, all prices are set in the producer’s currency. In contrast, all prices are set in the currency of local market in the model of LCP. We also consider a mixture of PCP and LCP. In the model of PCP+LCP, prices of investment goods are set in the producer’s currency while prices of durable consumption are set in the currency of local market.

The technology shocks are calibrated as in Engel and Wang (2008). In our benchmark setup, monetary shocks are uncorrelated across countries. Simulation results are reported in the Panel of Technology + Monetary Shocks (Benchmark). The model of PCP+LCP outperform models PCP and LCP in that real imports and exports are negatively correlated in these two models. Model LCP also fails to generate counter-cyclical net exports. These three models perform similarly in other dimensions. Cross-country correlation of output increases from nearly zero in the flexible-price model to more than 0.4 in sticky-price models, which is very close to the data. Cross-country correlation of consumption also increases from about -0.2 to a positive number. But it is still much lower than it in the data.

In the panel of Technology + Correlated Monetary Shocks, we increase the correlation of monetary shock...
to 0.5 following Chari, Kehoe, and McGrattan (2002). Our above findings do not change qualitatively when monetary shocks are correlated across countries. As in Chari, Kehoe, and McGrattan (2002), correlation of monetary shocks increases the correlation of output and consumption across countries. Our findings also hold when we set monetary shocks at zero. Results are reported in the panel of Technology Shocks Only.

We have noticed a shortcoming for all sticky-price models: labor and consumption are too volatile in these models, though the flexible-price model can match their volatility fairly well. Both labor and consumption are about as volatile as output in the sticky-price models. However, they are less volatile than output in the data. Wage is flexible in our model though other prices are sticky. Wage and therefore labor may fluctuate too much to help the model reach its equilibrium after a shock strikes.

5 Conclusion

To be written.
References


[38] Ruhl, K. 2005. Solving the Elasticity Puzzle in International Economics, University of Texas-Austin working paper.


Figure 1: Structure of Benchmark Model

Total Output ($Y_{ht}$)

- 60% Nondurable Goods ($Y^N_{ht} = C_{ht}$)
- 40% Durable Goods ($Y^D_{ht}$)

Nondurable Goods

- 20% Durable Consumption
  - 13% Home
  - 7% Foreign

Durable Goods

- 20% Durable Investment
  - 14% Home
  - 6% Foreign

Note:
Numbers in this figure are percentage of total output.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>0.5</td>
<td>Share of Home Goods in Capital When Trade Cost Is Zero</td>
</tr>
<tr>
<td>$\chi$</td>
<td>0.36</td>
<td>Capital Share in Production</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>9.1</td>
<td>(Long-run) Elasticity of Substitution between Home and Foreign Capital</td>
</tr>
<tr>
<td>$\tau$</td>
<td>0.1</td>
<td>(Iceberg) International Trade Cost</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.99</td>
<td>Subjective Discount Factor</td>
</tr>
<tr>
<td>$\delta$</td>
<td>0.02</td>
<td>Depreciation Rate of Capital</td>
</tr>
<tr>
<td>$\delta_D$</td>
<td>0.05</td>
<td>Depreciation Rate of Durable Consumption</td>
</tr>
<tr>
<td>$\mu$</td>
<td>0.23</td>
<td>Share of Durable Consumption Stock in Consumption Bundle</td>
</tr>
<tr>
<td>$\nu$</td>
<td>1.65</td>
<td>Preference Parameter of Labor Supply</td>
</tr>
<tr>
<td>$\psi$</td>
<td>0.5</td>
<td>Share of Home Goods in Durable Consumption When Trade Cost Is Zero</td>
</tr>
<tr>
<td>$\rho$</td>
<td>5.83</td>
<td>Preference Parameter</td>
</tr>
<tr>
<td>$\sigma$</td>
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<td>Preference Parameter</td>
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<tr>
<td>$\theta$</td>
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<td>(Long-run) Elasticity of Substitution between Home and Foreign Durable Consumption</td>
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<tr>
<td>$\zeta$</td>
<td>1.1</td>
<td>Elasticity of Substitution between Durable and Nondurable Consumption</td>
</tr>
<tr>
<td>$\phi_1$</td>
<td>1.3†</td>
<td>Durable Consumption Adjustment Cost</td>
</tr>
<tr>
<td>$\phi_2$</td>
<td>7†</td>
<td>Capital Adjustment Cost</td>
</tr>
<tr>
<td>$\Phi_d$</td>
<td>0</td>
<td>Domestic Bond Holding Cost</td>
</tr>
<tr>
<td>$\Phi_f$</td>
<td>0.00001</td>
<td>Foreign Bond Holding Cost</td>
</tr>
<tr>
<td>$\Xi_1$</td>
<td>0.87</td>
<td>AR(1) Coefficient of Technology Shock in Nondurable Goods Sector</td>
</tr>
<tr>
<td>$\Xi_2$</td>
<td>0.9</td>
<td>AR(1) Coefficient of Technology Shock in Durable Goods Sector</td>
</tr>
<tr>
<td>$\sigma(\varepsilon_{Nt}^H)$</td>
<td>0.0096</td>
<td>Standard Deviation of Productivity Shock in Nondurable Goods Sector</td>
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<tr>
<td>$\sigma(\varepsilon_{Dt}^H)$</td>
<td>0.036</td>
<td>Standard Deviation of Productivity Shock in Durable Goods Sector</td>
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<td>$\phi$</td>
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<td>Elasticity of Substitution between Differentiated Goods</td>
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<tr>
<td>$\lambda_N$</td>
<td>0.75</td>
<td>Probability of Not Changing Prices in Nondurable Goods Sector</td>
</tr>
<tr>
<td>$\lambda_D$</td>
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<td>Probability of Not Changing Prices in Durable Goods Sector</td>
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<td>$\Xi_p$</td>
<td>1.79</td>
<td>Policy Parameter (Inflation Stabilization)</td>
</tr>
<tr>
<td>$\Xi_\eta$</td>
<td>0.07</td>
<td>Policy Parameter (Output Stabilization)</td>
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<tr>
<td>$\rho_i$</td>
<td>0.92</td>
<td>Interest Rate Smoothing Parameter</td>
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</table>

Note:†-Entries are values used in the benchmark model. In other models, they are adjusted to match the volatility of durable consumption and aggregate investment.
Table 2: Simulation Results of Benchmark Model

<table>
<thead>
<tr>
<th></th>
<th>Standard Deviations Relative to That of Real GDP</th>
<th>Correlation with GDP</th>
<th>( \sigma_{Y,Y} )</th>
<th>( \sigma_{C,C} )</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>I</td>
<td>DC</td>
<td>L</td>
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<tr>
<td>Data(^1)</td>
<td>0.798</td>
<td>2.890</td>
<td>2.983</td>
<td>0.670</td>
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<tr>
<td>Flexible Price</td>
<td>0.848</td>
<td>2.682</td>
<td>2.471</td>
<td>0.553</td>
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<table>
<thead>
<tr>
<th>Technology + Monetary Shocks (Benchmark)</th>
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</thead>
<tbody>
<tr>
<td>PCP</td>
</tr>
<tr>
<td>LCP</td>
</tr>
<tr>
<td>PCP+LCP</td>
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</tbody>
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<table>
<thead>
<tr>
<th>More Sticky Durable Goods Prices</th>
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</thead>
<tbody>
<tr>
<td>PCP</td>
</tr>
<tr>
<td>LCP</td>
</tr>
<tr>
<td>PCP+LCP</td>
</tr>
</tbody>
</table>

Note:
- C: consumption, I: investment, DC: durable consumption, L: labor, RIM: real imports, REX: real exports, RNX: real net exports defined as \( \frac{RealNetExport}{RealGDP} \), Q: CPI-based real exchange rate.
- \( corr(RIM,REX) \): correlation of real imports and exports, \( \sigma_{Y,Y} \): cross-country correlation of output, \( \sigma_{C,C} \): cross-country correlation of consumption. The cross-country correlations are between the United States and the rest of OECD countries (Corsetti et al. forthcoming).
- The standard deviation of GDP in benchmark model is 2.26%. All variables are logged (except for RNX) and H-P filtered with a smoothing parameter of 1600. Entries are averages over 100 simulations of length 120.