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International trade in durable goods: Understanding volatility, cyclicality, and elasticities

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ABSTRACT

Data for OECD countries document: 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; 3. net exports are counter-cyclical. Standard models fail to replicate the behavior of imports and exports, though they can match net exports relatively well. Inspired by the fact that a large fraction of international trade is in durable goods, we propose a two-country two-sector model in which durable goods are traded across countries. Our model can match the business cycle statistics on the volatility and comovement of the imports and exports relatively well. The model is able to match many dimensions of the data, which suggests that trade in durable goods may be an important element in open-economy macro models.

1. Introduction

One of the most established empirical regularities in international real business cycle (IRBC) analysis is the counter-cyclical behavior of net exports. In contrast, the behavior of imports and exports themselves has been largely neglected in the literature. They are much more volatile than GDP and both are pro-cyclical, facts which are at odds with the predictions of standard models.[1] The large drop in the volume of world trade in 2008–2009 has attracted ample notice. But the drop in international trade is generally consistent with the patterns of cyclical trade movements we have seen over the past 35 years. These data lead us to expect a large drop in the volume of trade when markets experience a steep recession, especially if it is expected to be prolonged. Inspired by the evidence that a large fraction of international trade is in durable goods, we propose a two-country two-sector model, in which durable goods are traded across countries. Simulation results show that our model can match the trade sector data much better than standard models.

We first document two empirical findings that are very robust across our 25-OECD-country data: 1. The standard deviations of real imports and exports are about two to three times as large as that of GDP.[2] 2. Real imports and exports are pro-cyclical and also positively correlated with each other. We label the first finding "trade volatility", and the second one "positive comovement". We also confirm in our dataset the well-documented negative correlation between net exports and output.

In standard international business cycle models, imports and exports are far less volatile than in the data — they are even less volatile than GDP. We demonstrate this in a variety of models, both real business cycle and sticky-price dynamic models. We emphasize that the issue is not resolved by building versions of the model with high real exchange rate volatility. Although a more volatile exchange rate helps to increase the volatility of imports and exports, it generates a negative correlation between imports and exports. This is at odds with the finding of "positive comovement".

We propose a model in which countries primarily trade durable goods, inspired by the fact that a large portion of international trade is in durable goods. In OECD countries, trade in durable goods on average accounts for about 70% of imports and exports. The importance of capital goods in international trade has also been

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[1] The only paper that examines import and export volatility to our knowledge is that of Zimmermann (1999). That paper uses exogenous exchange rate shocks to generate the volatility of imports and exports. This explanation is contradictory to the positive correlation between imports and exports. We give more details later.

[2] Similar results are also reported in Table 11.7 of Backus et al. (1995), Heathcote and Perri (2002), and Zimmermann (1999).

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documented by Eaton and Kortum (2001). Boileau (1999) examines an IRBC model with trade in capital goods. That study finds that allowing direct trade in capital goods improves the model's performance in matching the volatility of net exports and the terms of trade. Boileau's model shares some characteristics of the one we examine. It does not include consumer durable goods, which are necessary to understand some aspects of the data. Moreover, Boileau (1999) does not examine the implications of his model for imports and exports individually, which is the focus of our study. Erceg et al. (2008) also emphasize that trade in capital goods helps model to replicate trade volatility. They argue that trade balance adjustment may be triggered by investment shocks from either the home or foreign country and such adjustment may not cause substantial real exchange rate fluctuations. Warner (1994) finds that global investment demand has been an important determinant of US exports since 1967. However, we find that a model with trade in capital goods but not consumer durables is inadequate. In order to match the volatility of the trade data, a large share of traded goods must be durable. But if we take all of those traded goods to be capital, then the model would require, for example, that the US obtains almost all capital goods from imports while simultaneously exporting large quantities of capital.

Our model goes further by including both capital and durable consumption goods in international trade.[3] In our baseline two-country two-sector model, nondurable goods are nontraded. Durable consumption flows require both home and foreign durable goods varieties and capital goods are aggregated from home and foreign varieties of capital. Simulation results show that the benchmark model can successfully replicate "trade volatility" and "positive comovement". In addition, net exports in our model are counter-cyclical and as volatile as in the data. So our model can match the trade sector data much better than the standard models. This improvement is not at the cost of other desirable features of standard models. The aggregate variables such as output, consumption, investment and labor, can also match the data well.

Our finding that imports and exports are more volatile than GDP and pro-cyclical, and our model of durables in international trade, have the potential to explain a significant portion of the drop in international trade during the global financial crisis. Drawing on our work, and using disaggregated data on imports and exports, Levchenko et al. (2009) find strong evidence that the compositional effect played an important role in explaining the collapse of US trade in 2008: international trade occurs disproportionately in the sectors that domestic demand and production collapsed the most. The investment and durable consumption sectors are good examples. Since investment and durables expenditure are several times more volatile than GDP and international trade is highly concentrated in these durable goods, trade would be expected to experience larger swings than GDP as well. They also find evidence for the supply-chain/vertical linkage effect: trade fells more in sectors that are used intensively as intermediate inputs. The positive comovement of imports and exports documented in our paper suggests that both imports and exports decline during an economic downturn. The counter-cyclicality of net exports is caused by a sharper decline of imports than exports rather than an increase of exports during economic downturns.

We also consider a model in which both durable and nondurable goods are traded across countries. In this model, nondurable goods account for about 30% of trade as we found in OECD countries. The model generates results similar to our benchmark model. The only noticeable difference is that imports and exports become less volatile, but both of them are still more than twice as volatile as output.

An important empirical puzzle that has confronted international trade economists is the mismatch between estimated short-run and long-run elasticities of import demand. As Ruhl (2005) and others have discussed, typically short-run elasticities are estimated to be near unity, but long-run elasticities are generally found to be considerably higher. That pattern arises naturally in any model such as ours in which durable capital and consumer goods are traded, because durable stocks cannot be adjusted quickly in response to price changes. Another interesting feature of our model is its implications for understanding comovement of relative consumption and real exchange rates, as in the Backus and Smith (1993) puzzle. Our model suggests that it may be important to distinguish carefully consumption purchases (which include purchases of consumer durable goods) and consumption flows (which include the flow of services delivered from previously purchased durables).

The remainder of the paper is organized as follows: Section 2 displays statistics on "trade volatility" and "positive comovement". Section 3 describes our two-country two-sector benchmark model. Section 4 explains our calibration of the model. Section 5 compares simulation results of our benchmark model and the standard models used in the literature. Section 6 concludes.

2. Empirical findings and share of trade in durable goods

In this section, we first show some facts about international real business cycles: 1. Real imports and exports are about two to three times as volatile as GDP. 2. Both real imports and exports are pro-cyclical and positively correlated with each other. 3. Real net exports are counter-cyclical. Then we present evidence that trade in durable goods accounts for a large portion of imports and exports in OECD countries.

2.1. Trade volatility and cyclicality

Our dataset includes quarterly real GDP, real imports, and real exports, of 25 OECD countries during the period between 1973Q1 and 2006Q3.[4] The data are from the OECD Economic Outlook database. All variables are logged except net exports which are divided by GDP, and HP filtered with a smoothing parameter of 1600.

Table 1 shows the volatility of those variables and comovement of real imports and real exports with GDP. The standard deviation of GDP on average, is 1.51%. Both real imports and exports are much more volatile than GDP. On average, the imports are 3.3 times, and exports are 2.7 times as volatile as GDP. This result is not driven by outliers. The sample median is very close to the sample mean. The volatilities of imports and exports in the US are close to the sample mean. However, the ratio of net exports to GDP in the US is less volatile than it is in any other country.

Two things stand out for comovement of real imports and real exports with GDP. First, both imports and exports are pro-cyclical. This result is very robust: imports are positively correlated with GDP in all 25 countries. The average correlation is 0.63. The same is true for exports except in two countries: Denmark and Mexico. The average correlation between exports and GDP is 0.39. Second, imports and exports are positively correlated in all countries except Australia, Mexico, New Zealand and Spain. The average correlation between imports and exports is 0.38. In this table, we also confirm a well-documented finding in previous studies: net exports are counter-cyclical. This is true in all countries except Austria and Hungary. The average correlation between net exports and GDP is −0.24.

[3] Baxter (1992) has durable consumption in a two-sector model. The model setup is very different from ours and is used to address different issues. Sadka and Yi (1996) build a simple small-country real-business-cycle model with durable consumption goods. They use this model to demonstrate that the increase of consumption durables due to a permanent decrease in their prices may be an important element in explaining the 1980s US trade deficits.

[4] Austria starts from 1988Q1, Czech Republic from 1993Q1, and Hungary from 1991Q1. The data of Germany are for West Germany only which end in 1991Q1. The data after unification (1991Q1–2006Q3) show similar patterns.

Table 1
Volatility and comovements of international trade.

Country	SD of GDP (%)	Standard deviations relative to that of GDP			Correlation with GDP			$corr(IM,EX)$[b]
		Real import	Real export	$\frac{NetExport}{GDP}$[a]	Real import	Real export	$\frac{NetExport}{GDP}$[a]	
Australia	1.38	4.23	2.69	0.63	0.49	0.16	−0.33	−0.10
Austria	0.88	2.10	2.75	0.54	0.60	0.67	0.36	0.85
Belgium	1.03	2.74	2.36	0.67	0.73	0.74	−0.17	0.92
Canada	1.42	3.15	2.65	0.66	0.74	0.66	−0.12	0.62
Czech Republic	1.52	2.39	2.61	1.02	0.53	0.33	−0.09	0.74
Denmark	1.35	2.65	2.46	0.72	0.55	−0.09	−0.57	0.53
Finland	2.02	2.74	2.73	0.68	0.73	0.22	−0.41	0.36
France	0.86	3.97	3.22	0.58	0.77	0.68	−0.27	0.57
Germany	1.29	2.26	2.86	0.69	0.78	0.52	−0.06	0.40
Hungary	0.97	4.19	6.53	2.66	0.54	0.53	0.14	0.25
Iceland	2.18	3.22	1.91	1.28	0.59	0.45	−0.29	0.06
Ireland	1.62	3.04	1.96	0.73	0.38	0.50	−0.08	0.77
Italy	1.31	3.44	3.03	0.70	0.70	0.38	−0.26	0.38
Japan	1.22	4.19	3.51	0.36	0.60	0.16	−0.34	0.21
Korea	2.43	3.08	2.70	0.82	0.81	0.31	−0.62	0.28
Mexico	2.36	5.97	2.53	0.89	0.75	−0.20	−0.78	−0.32
Netherlands	1.28	2.28	1.99	0.62	0.61	0.62	−0.10	0.75
New Zealand	2.58	2.39	1.53	0.66	0.40	0.22	−0.18	−0.25
Norway	1.26	4.01	3.22	1.37	0.34	0.36	−0.03	0.13
Portugal	1.95	2.96	2.72	0.61	0.81	0.51	−0.38	0.44
Spain	1.04	4.23	2.86	0.77	0.56	0.05	−0.46	−0.14
Sweden	1.35	3.14	2.54	0.70	0.61	0.46	−0.25	0.53
Switzerland	1.51	2.78	2.08	0.54	0.66	0.68	−0.10	0.72
UK	1.36	2.72	2.17	0.39	0.61	0.45	−0.25	0.59
United States	1.52	3.33	2.63	0.25	0.83	0.41	−0.47	0.19
Mean	1.51	3.25	2.73	0.78	0.63	0.39	−0.24	0.38
Median	1.36	3.08	2.65	0.68	0.61	0.45	−0.25	0.40

Note:
The data are from *OECD Economic Outlook* database. They are quarterly data of OECD 25 countries during the period between 1973Q1 and 2006Q3. (Due to data limitation, Austria starts from 1988Q1, Czech Republic starts from 1993Q1, and Hungary starts from 1991Q1.)
The data of Germany are for West Germany only which end in 1991Q1. The data after unification (1991Q1–2006Q3) show similar patterns as reported in this table.
Real imports (exports) are more than twice as volatile as GDP in 22 (19) out of 25 countries at the 5% level in a one-side test. Real imports (exports) are positively correlated with GDP in 25 (21) out of 25 countries at the 5% level in a one-side test. Under the same test, real net exports are negatively correlated with GDP in 15 out of 25 countries and real imports and exports are positively correlated in 19 out of 25 countries. These results are obtained from 1000 bootstraps with replacement.
Similar volatility and cyclicality of imports and exports is also found in aggregate EU data. Results are available upon request.
[a] All variables are logged (except for $\frac{NetExport}{GDP}$), and HP filtered with a smoothing parameter of 1600.
[b] $corr(IM,EX)$ is the correlation of real imports and exports.

2.2. Trade in durable goods in OECD countries

Here we present some descriptive statistics on trade flows that help to motivate our model of trade in durables. We obtain our 25 OECD-country data from NBER–UN World Trade Data and use the latest available data (year 2000) to calculate the share of durable goods in international trade. The data are at the 1- or 2-digit SITC level. Table 2 shows how we divide imports and exports into categories of durable and nondurable goods. (See Appendix A for more details.)

Table 3 reports the share of durable goods in international trade. On average durable goods account for about 70% of imports and exports (excluding energy products SITC 3) in these countries. Results are similar if we also exclude raw materials (right panel of Table 3). In particular, machineries and transportation equipment (SITC 7) on average account for more than 40% of trade for OECD countries.[5] These findings are very similar to those reported by Baxter (1995) and Erceg et al. (2008).

We also examine the volatility of durable goods trade and other categories of trade in a data set for US trade only. We use quarterly nominal US trade data at the 2-digit SITC level from the US International Trade Commission (http://www.usitc.gov/). Import and export price indexes at the 2-digit SITC level are obtained from the Bureau of the Census through Haver Analytics. Nominal trade data are deflated by corresponding price indexes to calculate real imports and exports. In the end, we have real import and export data at the 2-digit SITC level for 1997Q1–2006Q2. Imports and exports are classified into three categories: raw materials, durable goods and nondurable goods according to the standard described above. Real imports and exports are logged and HP filtered with a smoothing parameter of 1600.

We calculate the standard deviation for each category. In exports, raw materials and durable goods are much more volatile than nondurable goods: the standard deviations of raw materials and durable goods are respectively 7.78% and 6.54%, but only 2.86% for nondurable goods. Imports show less dispersion in volatility: the standard deviations of raw materials and durable goods are 5.02% and 5.00% respectively. It is 4.89% for nondurable goods. We note that these statistics are not precise given our rough classification of goods into the durable and nondurable categories, and given that we use only 38 observations of HP filtered data.

Durable goods also show stronger correlation with GDP in our data. For imports, the correlation between durable goods and GDP is 0.53. It is −0.35 for raw materials and −0.17 for nondurable goods. For exports, the correlation between durable goods and GDP is 0.82. It is −0.02 for raw materials and 0.65 for nondurable goods.

3. A two-country benchmark model

There are two symmetric countries in our model, Home and Foreign. There are two production sectors in each country: nondurable and durable goods. All firms are perfectly competitive with flexible prices. Nondurable goods can only be used for domestic consumption. Durable goods are traded across countries and used for durable consumption and

[5] We note two outliers for exports. Exports of New Zealand and Iceland are mainly in category zero (FOOD AND LIVE ANIMALS).

Table 2
Dividing SITC categories into different sectors.

SITC	Description	Sector
0	Food and live animals	Nondurable
1	Beverages and tobacco	Nondurable
2	Crude materials, inedible, except fuels	Raw materials
3	Mineral fuels, lubricants and related materials	Energy products
4	Animal and vegetable oils, fats and waxes	Nondurable
5	Chemicals and related products, n.e.s.	Nondurable
6	Manufactured goods classified chiefly by material	
61	Leather, leather manufactures, n.e.s., and dressed furskins	Durable
62	Rubber manufactures, n.e.s.	Durable
63	Cork and wood manufactures (excluding furniture)	Nondurable
64	Paper, paperboard and articles of paper pulp, of paper or of paperboard	Nondurable
65	Textile yarn, fabrics, made-up articles, n.e.s., and related products	Nondurable
66	Non-metallic mineral manufactures, n.e.s.	Durable
67	Iron and steel	Durable
68	Non-ferrous metals	Durable
69	Manufactures of metals, n.e.s.	Durable
7	Machinery and transport equipment	Durable
8	Miscellaneous manufactured articles	
81	Prefabricated buildings; sanitary, plumbing, heating and lighting fixtures and fittings, n.e.s.	Durable
82	Furniture, and parts thereof; bedding, mattresses, mattress supports, cushions and similar stuffed furnishings	Durable
83	Travel goods, handbags and similar containers	Nondurable
84	Articles of apparel and clothing accessories	Nondurable
85	Footwear	Nondurable
87	Professional, scientific and controlling instruments and apparatus, n.e.s.	Durable
88	Photographic apparatus, equipment and supplies and optical goods, n.e.s.; watches and clocks	Durable
89	Miscellaneous manufactured articles, n.e.s.	Nondurable
9	Commodities and transactions not classified elsewhere in the SITC	
91	Postal packages not classified according to kind	Nondurable
93	Special transactions and commodities not classified according to kind	Nondurable
95	Coin, including gold coin; proof and presentation sets and current coin	Durable
96	Coin (other than gold coin), not being legal tender	Durable
97	Gold, non-monetary (excluding gold ores and concentrates)	Durable

Note:
See Appendix A for more details.

capital accumulation. Because of the symmetry between these two countries, we describe our model focusing on the Home country.[6]

Trade in capital goods and consumer durables would introduce too much volatility in trade, so we allow for installation costs. This is a well-known feature of international RBC models, but this also allows us to build a model consistent with another widely-recognized fact: trade elasticities are higher in the long run in response to persistent shocks than they are in the short run. In addition, we introduce an iceberg cost of trade. Here, we want to capture the idea that there is a "home bias" in the consumption of durables, as well as in the use of capital goods in production. Especially for large economic areas such as the US or the European Union, imports are a relatively small component of the overall consumption basket, or mix of inputs used in production. Because we model traded goods as being highly substitutable in the long-run, it does not seem natural to simultaneously introduce home bias directly into the utility function or production function. Instead, and consistent with much of the recent literature in trade, we posit that there are costs to trade which lead to this home bias even in the long run.

We note that there is a tension in modeling the behavior of trade volumes over the business cycle. Imports and exports are pro-cyclical and their standard deviation (in logs) is much larger than that of GDP. At the same time, they are apparently not very responsive in the short run to price changes. The model of consumer durables and investment goods captures these features for reasonable parameter values. We discuss the calibration in Section 4, after the presentation of the model.

3.1. Firms

There are two production sectors in each country: the nondurable goods sector and the durable goods sector. Nondurable and durable goods in the Home country are produced from capital and labor according to

$$Y^j_{Ht} = A^j_{Ht}\left(K^j_{Ht}\right)^{\chi}\left(L^j_{Ht}\right)^{1-\chi}, \tag{1}$$

where $j \in \{N, D\}$ denotes nondurable (N) and durable (D) goods sectors. A^j_{Ht} and L^j_{Ht} are respectively the TFP shock and labor in sector j. Capital K^j_{Ht} is a CES composite of Home- and Foreign-goods capital

$$K^j_{Ht} = \left(\alpha^{\frac{1}{\gamma}}\left(K^{jH}_{Ht}\right)^{\frac{\gamma-1}{\gamma}} + (1-\alpha)^{\frac{1}{\gamma}}\left(K^{jF}_{Ht}\right)^{\frac{\gamma-1}{\gamma}}\right)^{\frac{\gamma}{\gamma-1}}, \tag{2}$$

where in the notation such as K^{jk}_{it}, 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 goods. For instance, K^{NH}_{Ht} is the Home country produced durable good that is used in the nondurable goods sector of the Home country.

The firm buys labor and rents capital from households in competitive markets. For given wage (W_{Ht}) and rental price of capital (R^{jH}_{Ht} and R^{jF}_{Ht}), the firm chooses capital and labor to minimize the cost of production. Capital is not mobile across sectors though we assume that labor can move freely from one sector to another. The nondurable and durable goods markets are also competitive, so the price of nondurable and durable goods P^j_{Ht} is equal to the marginal cost

$$P^j_{Ht} = \left(A^j_{Ht}\right)^{-1}\left(R^j_{Ht}\right)^{\chi} W^{1-\chi}_{Ht}\chi^{-\chi}(1-\chi)^{\chi-1}. \tag{3}$$

From the firm's cost minimization problem, we can find the standard demand function for capital and labor by equating the marginal productivity to the real factor cost.

[6] We list all equilibrium conditions for both countries in an appendix posted on the authors' websites.

Table 3
Share of durable goods in trade.

Country	Exclude energy products		Exclude materials and energy	
	Import	Export	Import	Export
Australia	0.70	0.56	0.71	0.45
Austria	0.69	0.67	0.70	0.69
Belgium	0.66	0.66	0.67	0.66
Canada	0.77	0.64	0.77	0.69
Czech Rep	0.72	0.75	0.73	0.77
Denmark	0.60	0.47	0.61	0.48
Finland	0.72	0.61	0.73	0.65
France	0.67	0.68	0.68	0.68
Germany	0.69	0.71	0.70	0.71
Hungary	0.74	0.77	0.75	0.78
Iceland	0.55	0.28	0.56	0.28
Ireland	0.73	0.59	0.73	0.59
Italy	0.65	0.64	0.66	0.64
Japan	0.57	0.89	0.58	0.89
Korea	0.76	0.78	0.77	0.78
Mexico	0.73	0.78	0.74	0.78
Netherland	0.68	0.60	0.69	0.61
New Zealand	0.66	0.26	0.66	0.26
Norway	0.70	0.59	0.71	0.61
Portugal	0.65	0.53	0.66	0.54
Spain	0.68	0.65	0.69	0.66
Sweden	0.68	0.73	0.69	0.76
Switzerland	0.65	0.69	0.66	0.69
UK	0.69	0.74	0.70	0.74
US	0.69	0.75	0.70	0.77
Mean	0.68	0.64	0.69	0.65
Median	0.69	0.66	0.70	0.68

Note:
Data are from international trade data, NBER–United Nations World Trade Data (http://cid.econ.ucdavis.edu).
Entries are shares of durable goods in imports and exports (year 2000). Left panel of the table reports results for imports and exports excluding energy products (SITC 3). Raw materials (SITC 2) and energy products (SITC 3) are excluded from imports and exports in the right panel.
Share of durable goods in bilateral trade among Canada, EU, Japan and US is similar to the results reported in this table. Results are available upon request.

3.2. 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

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

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

$$u_t = \frac{\left[\left(\mu^{\frac{1}{\zeta}} D_{Ht}^{\frac{\zeta-1}{\zeta}} + (1-\mu)^{\frac{1}{\zeta}} C_{Ht}^{\frac{\zeta-1}{\zeta}}\right)^{\frac{\zeta}{\zeta-1}} - \rho L_{Ht}^{\upsilon}\right]^{1-\sigma}}{1-\sigma}. \tag{4}$$

It is an augmented Greenwood et al. (1988), (GHH henceforth) 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}^H) and Foreign (D_{Ht}^F) durable consumption stocks

$$D_{Ht} = \left[\psi^{\frac{1}{\theta}}\left(D_{Ht}^H\right)^{\frac{\theta-1}{\theta}} + (1-\psi)^{\frac{1}{\theta}}\left(D_{Ht}^F\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}, \tag{5}$$

where ψ is the weight of Home durable goods in the durable consumption stock and θ is the elasticity of substitution between the Home and Foreign durable goods. The law of motion for durable consumption is

$$D_{Ht+1}^k = (1-\delta_D)D_{Ht}^k + d_{Ht}^k, \tag{6}$$

where $k \in \{H, F\}$ denotes the Home and Foreign countries. d_{Ht}^k 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

$$\Delta_{Ht}^k = \frac{1}{2}\phi_1\left(d_{Ht}^k - \delta_D D_{Ht}^k\right)^2 / D_{Ht}, \tag{7}$$

where Δ_{Ht}^k is the cost of changing durables produced by country k.[7]

If there were no adjustment costs to durables, durable consumption purchases would be very volatile in response to shocks. Empirical work (see for example, Mankiw, 1982 and Gali, 1993), finds that durable consumption adjusts more smoothly and is less volatile than a model with no adjustment costs would imply. Gali (1993) suggests that adjustment costs may account for the excess smoothness of durable consumption, and indeed Startz (1989) finds that adjustment costs can account for the behavior of durable consumption in a permanent income model. Bertola et al. (2005) find support on micro level data for a model with a fixed cost of adjustment. Aggregate consumption is not likely to exhibit the same lumpiness as micro data, so we adopt the standard quadratic adjustment cost formulation (as in Startz, 1989).

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

$$K_{Ht+1}^{jk} = (1-\delta)K_{Ht}^{jk} + I_{Ht}^{jk}, \tag{8}$$

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

$$\Lambda_{Ht}^{jk} = \frac{1}{2}\phi_2\left(I_{Ht}^{jk} - \delta K_{Ht}^{jk}\right)^2 / K_{Ht}^j, \tag{9}$$

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

The Home and Foreign countries can only trade real bonds, which are in terms of the Home durable goods. It is well-known that transient shocks have a permanent wealth effect in a linearized open-economy model with incomplete international financial markets. To make our model stationary, we follow Kollmann (2004) to introduce a quadratic bond holding cost $\left(\frac{1}{2}\Phi B_{Ht+1}^2\right)$. Φ is very close to zero and the cost does not affect any results in our model.[8]

For the given production structure, the household's budget constraint is

$$\begin{aligned} &P_{Ht}^N C_{Ht} + P_{Ht}^{DH}\left(d_{Ht}^H + \Delta_{Ht}^H + I_{Ht}^{NH} + \Lambda_{Ht}^{NH} + I_{Ht}^{DH} + \Lambda_{Ht}^{DH} + \frac{B_{Ht+1}}{1+i_t} + \frac{1}{2}\Phi B_{Ht+1}^2\right) \\ &\quad + P_{Ht}^{DF}\left(d_{Ht}^F + \Delta_{Ht}^F + I_{Ht}^{NF} + \Lambda_{Ht}^{NF} + I_{Ht}^{DF} + \Lambda_{Ht}^{DF}\right) \\ &\quad \le W_{Ht}L_{Ht} + P_{Ht}^{DH}B_{Ht} + R_{Ht}^{NH}K_{Ht}^{NH} + R_{Ht}^{NF}K_{Ht}^{NF} + R_{Ht}^{DH}K_{Ht}^{DH} + R_{Ht}^{DF}K_{Ht}^{DF}, \end{aligned} \tag{10}$$

[7] Adjustment costs are scaled by the total durable consumption stock (D_{Ht}) so that the cost of adding new durable consumption $(d_{Ht}^H - \delta_D D_{Ht}^H$ and $d_{Ht}^F - \delta_D D_{Ht}^F)$ is the same for both types of durable consumption. The same format is also used in the capital adjustment cost functions.

[8] There are several other techniques used in the literature to deal with this nonstationarity problem. See Schmitt-Grohé and Uribe (2003) for more discussion.

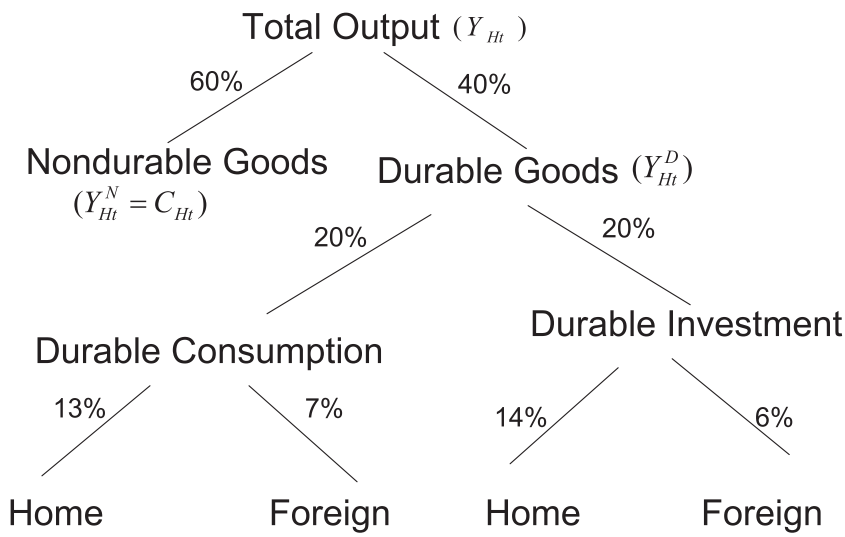

Fig. 1. Structure of benchmark model.
Note: Numbers in this figure are percentage of total output.

where P^{DF}_{Ht} is the price of Foreign country produced durable goods, which is in terms of the Home country's currency. i_t is the return to the real bond B_{Ht+1}. Subject to this budget constraint, the household maximizes expected lifetime utility.

3.3. Other equilibrium conditions

Nondurable goods can only be used for domestic nondurable consumption. So the market clearing condition for Home nondurable goods is

$$Y^N_{Ht} = C_{Ht}. \tag{11}$$

Durable goods are used for durable consumption and capital investment in both countries. We also assume there is an iceberg trade cost for international trade. Only a fraction $1-\tau$ of goods arrives in the destination country, so the market clearing condition for Home durable goods is

$$Y^D_{Ht} = d^H_{Ht} + \Delta^H_{Ht} + I^{NH}_{Ht} + \Lambda^{NH}_{Ht} + I^{DH}_{Ht} + \Lambda^{DH}_{Ht} + \frac{1}{2}\Phi B^2_{Ht+1} + \frac{d^H_{Ft} + \Delta^H_{Ft} + I^{NH}_{Ft} + \Lambda^{NH}_{Ft} + I^{DH}_{Ft} + \Lambda^{DH}_{Ft} + \frac{1}{2}\Phi B^2_{Ft+1}}{1-\tau}. \tag{12}$$

The labor and bond markets clearing conditions are

$$L_{Ht} = L^N_{Ht} + L^D_{Ht} \tag{13}$$

$$B_{Ht} + B_{Ft} = 0. \tag{14}$$

We assume that after taking into account the trade cost, the law of one price holds

$$P^{DF}_{Ht} = \frac{S_t P^{DF}_{Ft}}{1-\tau} \tag{15}$$

$$\frac{P^{DH}_{Ht}}{S_t(1-\tau)} = P^{DH}_{Ft}, \tag{16}$$

where P^{DF}_{Ht} is the price of Foreign durable goods in the Home country. S_t is the nominal exchange rate defined as the value of one unit of Foreign currency in terms of the Home currency.

In Section 5, we report real exchange rates based on the consumer price index (CPI). In the Home country, the CPI is defined by:

$$P_{Ht} = \left(P^N_{Ht}\right)^{\omega_1}\left(P^{DH}_{Ht}\right)^{\omega_2}\left(P^{DF}_{Ht}\right)^{\omega_3}, \tag{17}$$

where ω_1 is the steady-state expenditure share of nondurable consumption. ω_2 and ω_3 are respectively the steady-state expenditure shares of Home and Foreign durable consumption. This is not the same as the utility-based CPI, but is closer to the CPI measure used in national accounts. The CPI deflated real exchange rate is defined by

$$Q_t = \frac{S_t P_{Ft}}{P_{Ht}}. \tag{18}$$

To solve our model, we divide all nominal prices in the Home country by the price of nondurable goods (P^N_{Ht}). That is, we use the nondurable goods as numeraire. In the Foreign country, all nominal prices are divided by the price of Foreign nondurable goods (P^N_{Ft}).

4. Calibration

We calibrate our model such that in the steady state, the structure of the economy is the same as in Fig. 1.[9] In our benchmark economy, durable goods account for 40% of output. Among durable goods, half are used for consumption (equivalent to 20% of total output) and the other half are used for investment (20% of total output).[10] Among durable consumption goods, 65% is used for domestic consumption (13% of total output) and 35% is used for exports (7% of total output). Among durable investment goods, 70% is used for domestic investment (14% of total output) and 30% is used for exports (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 4 shows parameter values that we use to match our benchmark model with the described economy structure. We set the shares of home goods in capital (α) and durable consumption (ψ) at 50%. That is, there is no home bias exogenously built into our

[9] Details about how to solve the steady state can be found in an appendix posted on the authors' websites.

[10] Durable expenditure 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.

Table 4
Calibration.

Parameter	Value	Description
α	0.5	Share of home goods in capital when trade cost is zero
χ	0.36	Capital share in production
γ	9.1	(Long-run) Elasticity of substitution between home and foreign capital
τ	0.1	(Iceberg) International trade cost
β	0.99	Subjective discount factor
δ	0.013	Depreciation rate of capital
δ_D	0.05	Depreciation rate of durable consumption
μ	0.23	Share of durable consumption stock in consumption bundle
ν	1.65	Preference parameter of labor supply
ψ	0.5	Share of home goods in durable consumption when trade cost is zero
ρ	5.83	Preference parameter
σ	2	Preference parameter
θ	6.85	(Long-run) Elasticity of substitution b/t home and foreign durable consumption
ζ	1.1	Elasticity of substitution b/t durable and nondurable consumption
ϕ_1	1.4[a]	Durable consumption adjustment cost
ϕ_2	8.5[a]	Capital adjustment cost
Φ	0.00001	Bond holding cost
Ξ_1	0.87	AR(1) coefficient of technology shock in nondurable goods sector
Ξ_2	0.9	AR(1) coefficient of technology shock in durable goods sector
$\sigma(\varepsilon^N_{Ht})$	0.0096	Standard deviation of productivity shock in nondurable goods sector
$\sigma(\varepsilon^D_{Ht})$	0.036	Standard deviation of productivity shock in durable goods sector

[a] Entries are values used in the benchmark model. In other models, they are adjusted to match the volatility of durable consumption and aggregate investment.

economy structure. Instead, we generate the observed low trade share from the iceberg trade cost τ. We will discuss this more later. As in Backus et al. (1992), the capital share in production (χ) is set to 36%, and the subjective discount factor is set to 0.99. The depreciation rate of durable consumption (δ_D) is set to 0.05, which implies a 20% annual depreciation rate for consumption durables. A similar depreciation rate has been used by Bernanke (1985) and Baxter (1996).

Given those parameters, we choose other parameters to match the economy structure as in Fig. 1. We first choose the preference parameter μ and the depreciation rate of capital (δ) jointly to match the relative size of durable and nondurable goods sectors, and the size of investment in durable goods. μ is set to 0.23 and δ is set to 0.013 such that 1. the durable goods sector accounts for 40% of total output and, 2. investment accounts for 50% of durable goods, or equivalently 20% of total output. Consumption durables account for the remaining 50% of durable goods, or equivalently 20% of total output.

Two methods have been used in the literature to estimate the elasticity of substitution between the Home and Foreign goods. In the data, the trade share of output increases substantially over time after a small but permanent decrease in the tariff. The estimates from this strand of literature range from 6 to 15 with an average of 8.[11] In another strand of literature, the same elasticity is estimated from transitory relative price changes at the business cycle frequency. Estimates found in these studies are much smaller, roughly around one.[12]

Several studies have offered explanations for this puzzle with a common feature that the long-run elasticity of substitution is high, but the short-run elasticity is low due to some market frictions. Ruhl (2005) proposes a model in which firms must pay a fixed cost to change their export status. The benefits from changing export status are not enough to recover the fixed cost under transitory shocks, so the elasticity of substitution is low when shocks are transitory. However, in the face of persistent shocks, firms will pay the fixed cost and change their export status, which leads to a large increase of trade share even for a small, but permanent price change. Drozd and Nosal (2007) use the friction of international marketing to reduce the response of output to relative price changes. In Ramanarayanan's (2007) model, importers use foreign goods as intermediate inputs in production. Home and Foreign intermediate goods are perfectly substitutable in the long run, but switching between them in the short run is very costly. Following this literature, we assume that the Home and Foreign are highly substitutable in the long run, but in the short run there is a quadratic cost for adjusting the durable consumption and capital stocks. We will show later that our model can also deliver a reasonable short-run elasticity of substitution.

The trade cost (τ) and the elasticity of substitution between the home and foreign goods are calibrated to match two empirical findings: 1. the trade share of total output is about 13%; 2. the long-run elasticity of substitution between the Home and Foreign goods is high. In our calibration, the long-run elasticity of substitution between the home and foreign capital (γ) is set to 9.1. The elasticity of substitution between the home and foreign durable consumption (θ) is set to 6.85. In steady state, trade in capital goods (durable consumption goods) accounts for 46% (54%) of total trade. This calibration of γ and θ implies an overall elasticity of 7.9, which is the same as in Head and Ries (2001).[13] The trade cost (τ) is calibrated to 0.1, that is, 90% of goods arrive in their destination countries in international trade. For given γ and θ, this trade cost generates a trade share of 13%.

We use different values for γ and θ to generate different home bias levels for capital and durable consumption. Capital is more biased towards home goods than durable consumption (70% vs. 65%). For given trade costs, the degree of home bias increases with the elasticity of substitution, so we assign a higher elasticity of substitution to capital goods. Alternatively, we can assume the same elasticity of substitution, but higher trade costs for capital goods. In either method, capital can have a higher level of home bias than durable consumption. We used the first method because it matches a pattern observed in the data. For a given decrease in trade cost, the first method predicts that the share of investment goods in international trade increases relative to the share of durable consumption. Intuitively, investment goods are more substitutable across countries than durable consumption under this setup. So when the trade cost decreases, there is more substitution for investment goods than for durable consumption. As a result, the share of investment goods in trade increases. The same pattern is also found in the US data: from 1994 to 2006—the share of capital goods except automotive in total export goods increased from 34.4% to 45.1%.[14]

The preference parameters σ and ν are set to their standard levels used in the GHH utility function. The parameter ρ is chosen such that labor supply is one third in steady state. We assume that the elasticity of substitution between durable and nondurable consumption is low ($\zeta = 1.1$).[15] The adjustment cost of durable consumption (ϕ_1) is chosen to match the volatility of durable expenditure, which is about

[11] For instance, see Feenstra and Levinsohn (1995), Head and Ries (2001), and Lai and Trefler (2002). Yi (2003) also points out that to replicate this empirical finding in a general equilibrium model, we need an elasticity of more than 14, arising from the fact that measured trade grossly overstates the value added component of exports.

[12] The cross-industry average in Reinert and Roland-Holst (1992) is 0.91 and it is 0.81 in Blonigen and Wilson (1999). In aggregate models, Heathcote and Perri (2002) find a point estimate of 0.9. Bergin (2006) estimates a New Open Economy Macro model and obtains an estimate of 1.13. Corsetti et al. (2008a) estimate a trade elasticity that corresponds to an elasticity of substitution of 0.85.

[13] $9.1 \times 46\% + 6.85 \times 54\% \approx 7.9$.

[14] The data are from Haver Analytics (US International Transactions). Of course, this pattern is also consistent with another explanation: the trade cost decreases more for capital goods than for durable consumption goods.

[15] Whelan (2003) calibrates this parameter to be 1. Baxter (1996) finds that a reasonable range for this variable is between 0.5 and 2.5.

three times as volatile as output in the data. The adjustment cost of capital stock (ϕ_2) is calibrated to match the volatility of investment, which is about three times as volatile as output in the data.

We follow Erceg and Levin (2006) in calibrating productivity shocks in the durable and nondurable goods sectors. However, there is no information about the cross-country spillovers of those shocks in their closed-economy model. Empirical findings usually suggest small cross-country spillovers. For instance, Baxter and Crucini (1995) find no significant international transmission of shocks, except for possible transmission between US and Canada. In Kollmann's (2004) estimate between the US and three EU countries, the spillover is 0.03. In Corsetti et al. (2008a), the spillover is −0.06 for traded goods and 0.01 for nontraded goods. We will first set those spillovers at zero and then choose some values used in the literature to check whether our results are robust under different shock structures.

Let A_{it}^N and A_{it}^D be respectively, the productivity shocks in nondurable and durable goods sectors of country $i\in\{H, F\}$. They follow univariate $AR(1)$ processes in the benchmark model

$$A_{it+1}^N = \Xi_1 A_{it}^N + \varepsilon_{it+1}^N \tag{19}$$

$$A_{it+1}^D = \Xi_2 A_{it}^D + \varepsilon_{it+1}^D. \tag{20}$$

As in Erceg and Levin (2006), the $AR(1)$ coefficient Ξ_1 is set to 0.87 and Ξ_2 is set to 0.9. The variance–covariance matrix of innovations $[\varepsilon_{Ht}^N\ \varepsilon_{Ht}^D\ \varepsilon_{Ft}^N\ \varepsilon_{Ft}^D]'$ takes the form of

$$\Sigma = \begin{bmatrix} \sigma_N^2 & \sigma_{DN} & \rho_N \times \sigma_N^2 & 0 \\ \sigma_{DN} & \sigma_D^2 & 0 & \rho_D \times \sigma_D^2 \\ \rho_N \times \sigma_N^2 & 0 & \sigma_N^2 & \sigma_{DN} \\ 0 & \rho_D \times \sigma_D^2 & \sigma_{DN} & \sigma_D^2 \end{bmatrix} \tag{21}$$

where σ_N^2 is the variance of ε_{Ht}^N (ε_{Ft}^N). σ_D^2 is the variance of ε_{Ht}^D (ε_{Ft}^D) and σ_{DN} is the covariance. As in Erceg and Levin (2006), the standard deviation of ε_{Ht}^N (σ_N) is 0.0096 and it is 0.036 for σ_D. Within each country, the innovations are correlated across sectors. The correlation $\frac{\sigma_{DN}}{\sigma_D\sigma_N}$ is set to 0.29 as in Erceg and Levin (2006). The cross-country correlation of innovations in the durable goods sector (ρ_D) is 0.258 by following BKK and it is set to zero in nondurable goods sector ($\rho_N=0$). (Corsetti et al. (2008a) estimate ρ_N to be zero.) This shock structure corresponds to the Benchmark model in Table 6. Alternative shock structures are also considered and will be discussed when we present our results.

5. Model performance

The model is solved and simulated using first-order perturbation methods. The model's artificial time series are logged (except for net exports) and Hodrick–Prescott filtered with a smoothing parameter of 1600. The reported statistics in this section are averages across 100 simulations. Our benchmark model can match the observed IRBC statistics, including "trade volatility" and the "positive comovement" of imports and exports as documented in Section 2.1, and can replicate the elasticity puzzle in the trade literature.

5.1. International RBC statistics

5.1.1. Performance of standard models

In this subsection, we show that the standard models in the literature and their extensions cannot replicate trade volatility and positive comovement simultaneously.

We consider two types of models: the IRBC model and the DSGE model. Table 5 shows simulation results for these models. We use exactly the structure of the bond-economy model as in Heathcote and Perri (2002) in our standard IRBC model (labeled HP in Table 5). This model has the same structure as BKK's model, but limits the financial market to a real-bond market only. Baxter and Crucini (1995) compare this incomplete financial market model with the model with perfect risk-sharing and find that they behave very similarly if the productivity shock is not extremely persistent or the cross-country spillover of productivity shocks is high. Table 5 also reports results for the DSGE model. This is the extension of the IRBC model that assumes monopolistic competition, trade in nominal bonds, Calvo staggered price setting, and a monetary policy (Taylor) rule. Those models are often used in the studies of monetary policy in open economies.

GHH is the DSGE model with the preference function proposed by Greenwood et al. (1988). We use the same class of utility function in our benchmark model. We include this model to show that our benchmark model results are not driven by this choice of utility function. We also report results for two more extensions of the DSGE model: the model with low intertemporal elasticity of substitution (Lo-elast) and one with an uncovered interest rate parity shock (UIP). The standard international RBC model and DSGE models cannot replicate the volatility of the real exchange rate. We use those two methods to increase this volatility to see if it helps the model's performance in matching the behavior of imports and exports.

Since the model setups and calibrations are very standard in the literature (for instance, see Backus et al., 1992), we leave them in an appendix available on the authors' websites. The parameters of utility are calibrated so that the intertemporal elasticity of substitution is 0.5, the elasticity of substitution between Home and Foreign goods is 0.9 in IRBC models (following Heathcote and Perri, 2002) and 1.5 in DSGE models, and the share of Home goods in the aggregate Home consumption good is 0.85.

Panel A of Table 5 reports the standard deviations of aggregate variables relative to that of GDP. In the standard IRBC model (HP), imports and exports are even less volatile than GDP. The same discrepancy has also been reported in Table 2 of Heathcote and Perri (2002).[16] That study finds that the assumption of financial autarky can improve the volatility of imports and exports in a very limited way. The added features in the DSGE model and GHH models cannot solve this problem. Imports and exports are still far less volatile than what they are in the data. However, the GHH utility function does make the volatility of net exports much closer to the data. This follows because imports and exports are more volatile (due to more variable consumption in the GHH model), and imports and exports are less correlated than what they are in the DSGE model.

Panel B shows the correlations of real imports, real exports, and real net exports with GDP, as well as the correlation between real imports and exports. Imports and exports are measured at their steady-state prices (constant price). The models of HP, DSGE and GHH match the data in that real imports and exports are pro-cyclical and positively correlated with each other. Net exports are counter-cyclical in these models. That is, the standard models can replicate the "positive comovement" feature, though they fail the "trade volatility". Panel C reports the same statistics as Panel B, but imports, exports and net exports are measured in terms of final consumption goods, instead of constant prices. The results are similar to those in Panel B. [17]

Besides the volatility of imports and exports relative to GDP, another feature missing from the standard DSGE model is the high volatility of the real exchange rate. A natural question is whether we can increase the volatility of imports and exports in a model with more volatile real exchange rates. We follow Chari et al.'s (2002) "elasticity method" to increase real exchange rate volatility by

[16] Zimmermann (1999) finds similar results in a sticky-price model.

[17] Raffo (2008) finds that real net exports measured with constant prices are pro-cyclical under a standard utility function. We find that this conclusion may be sensitive to the volatility of investment and the elasticity of substitution between Home and Foreign goods.

Table 5
Performance of standard models.

	Panel A: Standard deviations relative to that of real GDP					
	Consumption	Investment	Real import	Real export	$\frac{RealNetExport}{RealGDP}$	Real ER[#]
Data[†]	0.798	2.890	3.335	2.626	0.250	2.432
HP[‡]	0.462	2.663	0.727	0.608	0.087	0.385
DSGE[‡]	0.545	2.830	0.826	0.835	0.077	0.375
GHH[‡]	0.613	2.697	0.935	0.947	0.173	0.284
Lo-elast.[‡]	0.401	2.767	1.651	1.625	0.467	1.216
UIP[‡]	0.925	2.875	3.477	3.466	1.016	1.458
CDL[‡]	0.521	2.441	2.196	2.048	0.636	3.092

	Panel B: Correlation with real GDP			
	Real import	Real export	$\frac{RealNetExport}{RealGDP}$	$corr(RIM_t, REX_t)$[#]
Data[†]	0.827	0.415	−0.467	0.194
HP[‡]	0.929	0.588	−0.551	0.628
DSGE[‡]	0.801	0.663	−0.214	0.809
GHH[‡]	0.894	0.278	−0.497	0.252
Lo-elast.[‡]	−0.647	0.973	0.852	−0.799
UIP[‡]	0.286	0.069	−0.112	−0.894
CDL[‡]	0.997	−0.980	−0.991	−0.992

	Panel C: Correlation with real GDP			
	Real import	Real export	$\frac{RealNetExport}{RealGDP}$	$corr(RIM_t, REX_t)$[#]
HP[‡]	0.999	0.500	−0.819	0.491
DSGE[‡]	0.988	0.601	−0.552	0.634
GHH[‡]	0.985	0.241	−0.608	0.152
Lo-elast.[‡]	0.369	0.984	0.848	0.212
UIP[‡]	0.569	0.070	−0.181	−0.749
CDL[‡]	−0.976	−0.973	0.984	0.999

Real ER is the (CPI-based) real exchange rate. $corr(RIM_t, REX_t)$ is the correlation of real imports and exports. In Panels A and B, the imports, exports and net exports are measured in constant (steady-state) prices. They are measured in Panel C in terms of final consumption goods.
† US data as in Table 1.
‡ HP (Heathcote and Perri, 2002) is the standard IRBC model with incomplete financial market (real bonds only). DSGE is the standard DSGE model as described in an appendix available on the authors' websites.. GHH is the DSGE model with GHH utility function. Lo-elast is the DSGE model with low intertemporal elasticity of substitution ($\sigma = 5$), UIP is the DSGE model with the uncovered interest rate parity shock, and CDL is the HP model with low elasticity of substitution between home and foreign goods following Corsetti et al. (2008a).
Statistics are based on logged (except for $\frac{RealNetExport}{RealGDP}$) and HP filtered data. Entries are averages over 100 simulations of length 120.

decreasing the value of the intertemporal elasticity of substitution. Corsetti et al. (2008c) examine this approach in an incomplete markets model in which a single bond is traded. They show that this approach can generate high exchange rate volatility without exogenous unreasonable monetary noise provided the model included two sectors (nontradables and tradables). Some authors have also used an uncovered interest rate parity (UIP) shock to generate exchange rate variations in DSGE models.[18] Recently, Corsetti et al. (2008a) emphasize the wealth effect of productivity shocks in driving the real exchange rate. They show in a model with low elasticity of substitution between home and foreign goods, the real exchange rate can be very volatile (as 75% volatile as in the data). In addition, they find in their model that a country's terms of trade and the real exchange rate appreciate when its productivity increases relative to the rest of the world, which is consistent with the US data.[19] In the model CDL of Table 5, we set the elasticity of substitution between home and foreign goods at a low level (0.32) and generate similar results as in Corsetti et al. (2008a). In our simulation results, we find that the volatilities of real imports, exports and the exchange rate all increase in those three models. Under certain calibrations of the UIP shock, the model can also replicate the pro-cyclical movement of imports and exports, though the correlation between exports and output is nearly zero. However, there is a striking departure of these models from the data: real imports and exports are highly negatively correlated in those models.

In standard models, Home and Foreign intermediate goods are used to produce final goods. The final goods are used for consumption and investment. There are two factors affecting the volatility of imports: 1. the volatility of demand for final goods and, 2. the substitution between Home and Foreign goods. Under the standard calibration, the majority (about 75%) of final goods (and therefore imports) goes to consumption. Consumption is less volatile than GDP in the data. So if we want to match the volatility of consumption, demand for final goods will not be very volatile. Given the low volatility of demand for final goods, we can still have very volatile imports and exports if there is a lot of substitution between home and foreign goods. The model with low intertemporal elasticity of substitution and the UIP model increase the volatility of the terms of trade and therefore the volatility of imports and exports.

Exchange rate movements induce fluctuations in the relative price of imports and exports. In return, the substitution between Home and Foreign goods increases the volatility of imports and exports. But when the terms of trade changes, imports and exports move in opposite directions. So this method produces a negative correlation between imports and exports, which is contradictory to the data. Baxter and Stockman (1989) find little evidence of systematic difference in the volatilities of real imports and exports when countries switch from fixed to flexible exchange rate regimes, though the real exchange rates became substantially more variable during this period. This finding also suggests that the high volatility of international trade flows is unlikely to come from the exchange rate fluctuations.

[18] For instance, see Kollmann (2004) and Wang (2010). This approach is similar to Zimmermann's (1999), which adds an exogenous source of exchange rate volatility.
[19] Another reason that the terms of trade may improve after an increase of productivity is because the productivity increase may come in the form of lower costs for new goods. See Corsetti et al. (2007) for details.

Table 6
Simulation results of benchmark model.

	Panel A: Standard deviations relative to that of real GDP							
	C	I	DC	L	RIM	REX	RNX	Q
Data[a]	0.798	2.890	2.983	0.670	3.335	2.626	0.250	2.432
Benchmark[b]	0.878	2.594	2.473	0.547	2.633	2.678	0.337	1.262
High spillover	0.948	2.905	2.738	0.539	1.826	1.775	0.322	1.297
Medium spillover	0.917	2.894	2.754	0.549	2.652	2.615	0.393	1.271
High correlation	0.920	2.750	2.680	0.549	2.880	2.936	0.402	1.058
High correlation 2	0.874	2.666	2.381	0.544	2.558	2.596	0.266	0.435
No correlation	0.902	2.757	2.658	0.549	2.619	2.678	0.596	1.470
High persistence	0.922	2.840	2.473	0.539	2.423	2.411	0.580	1.282
Technology costs	0.961	2.828	2.551	0.535	2.726	2.779	0.355	1.041
Traded nondurable	0.748	2.950	2.892	0.571	2.048	2.082	0.302	1.113
Low durable share	0.748	2.612	2.628	0.569	0.960	0.933	0.240	0.803

	Panel B: Correlation with GDP						
	RIM	REX	RNX	$corr(RIM, REX)$	Elasticity[c]	$\sigma_{Y,Y}$	$\sigma_{C,C}$
Data[a]	0.827	0.415	−0.467	0.194	0.90 (0.12)	0.68	0.60
Benchmark[b]	0.606	0.411	−0.187	0.421	1.05 (0.20)	0.01	−0.17
High spillover	0.576	0.405	−0.129	0.160	0.69 (0.13)	−0.03	0.23
Medium spillover	0.599	0.324	−0.228	0.171	0.89 (0.19)	−0.01	−0.14
High correlation	0.630	0.337	−0.288	0.265	1.19 (0.19)	0.03	−0.20
High correlation 2	0.801	0.554	−0.177	0.577	1.89 (0.27)	0.56	0.39
No correlation	0.564	0.375	−0.135	0.215	1.07 (0.26)	−0.02	−0.23
High persistence	0.618	0.333	−0.180	0.097	0.95 (0.19)	0.16	0.03
Technology costs	0.560	0.232	−0.292	0.386	1.41 (0.13)	0.08	−0.09
Traded nondurable	0.714	0.388	−0.331	0.550	0.69 (0.11)	0.002	−0.08
Low durable share	0.828	0.220	−0.374	0.228	0.70 (0.13)	−0.04	−0.08

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., 2008a).
[a] Data as in Table 1.
[b] The standard deviation of GDP in benchmark model is 2.26%. All variables are logged (except for RNX) and HP filtered with a smoothing parameter of 1600. Entries are averages over 100 simulations of length 120.
[c] This column reports the estimates of the short-run elasticity of substitution between home and foreign goods. The estimate in the first row is from Heathcote and Perri (2002). Other values are estimated with data simulated from our models. Entries are averages over 100 simulations. Standard errors are in parentheses.

5.1.2. Models with trade in durable goods

In this subsection, we present simulation results of our model with trade in durable goods. Table 6 shows simulation results for nine models. All of these models can match the data fairly well.

5.1.2.1. Benchmark model. As in standard IRBC models, our benchmark model can replicate the volatility (relative to that of GDP) of aggregate variables such as consumption, investment, durable expenditure, and labor. In addition, our model matches the trade sector data much better than the standard models: imports and exports are about three times as volatile as GDP and both of them are pro-cyclical and positively correlated with each other. Our model can also match the well-known finding that net exports are counter-cyclical.

When productivity shocks are persistent, it is well understood that investment will be volatile. Agents wish to change the capital stock quickly to take advantage of current and anticipated productivity shocks. This effect contributes to the high volatility our model produces for imports and exports, because capital goods are traded. A positive productivity shock leads to a desire to increase Home's stock of domestically produced and foreign-produced capital. This leads to the increase in demand for imports when there is a positive productivity shock. A positive productivity shock also increases the supply of Home's export good, lowering its world price, and thus increasing exports.

These effects are standard in RBC models, and explain why the models can generate pro-cyclical imports and exports. However, if only investment goods are durable, and consumption goods are nondurable, the model does not produce sufficient volatility in imports and exports.[20] When we introduce a consumer durable sector, there is an additional source of volatility. Demand for consumer durables, like demand for investment goods, is forward-looking, but it is not expected productivity per se, but rather higher wealth from higher expected future income that leads to volatility in demand for durable consumer goods.

Fig. 2 shows impulse response functions of our benchmark model for a one-standard-deviation shock in the home durable goods sector. In the face of a positive shock in the home durable goods sector, the price of durable goods (relative to nondurable goods) decreases, which leads to substitution from nondurables to durables. Because the shock is persistent, there is also a significant wealth effect that pushes up demand for both home and foreign durable consumption goods. As a result, purchases of durable goods (both home- and foreign-produced durable consumption goods) in the home country increase while consumption of nondurable goods declines. Aggregate consumption in the home country rises because the increase of durable purchases exceeds the decline of nondurable consumption. The price of foreign-produced durables relative to home-produced durables also increases: the terms of trade (import prices divided by export

[20] For instance, if we change the depreciation rate of durable consumption (δ_D) in our benchmark model to one and the adjustment cost to zero, the (relative) standard deviation of imports and exports decreases from 2.6 to 2. In this exercise, the capital adjustment cost is changed such that the (relative) standard deviation of investment is the same as in our benchmark model (2.6). We also change the elasticity of substitution between the home and foreign consumption goods to 0.9, which reflects the fact that the short-run elasticity of substitution is low in our benchmark model due to adjustment costs.

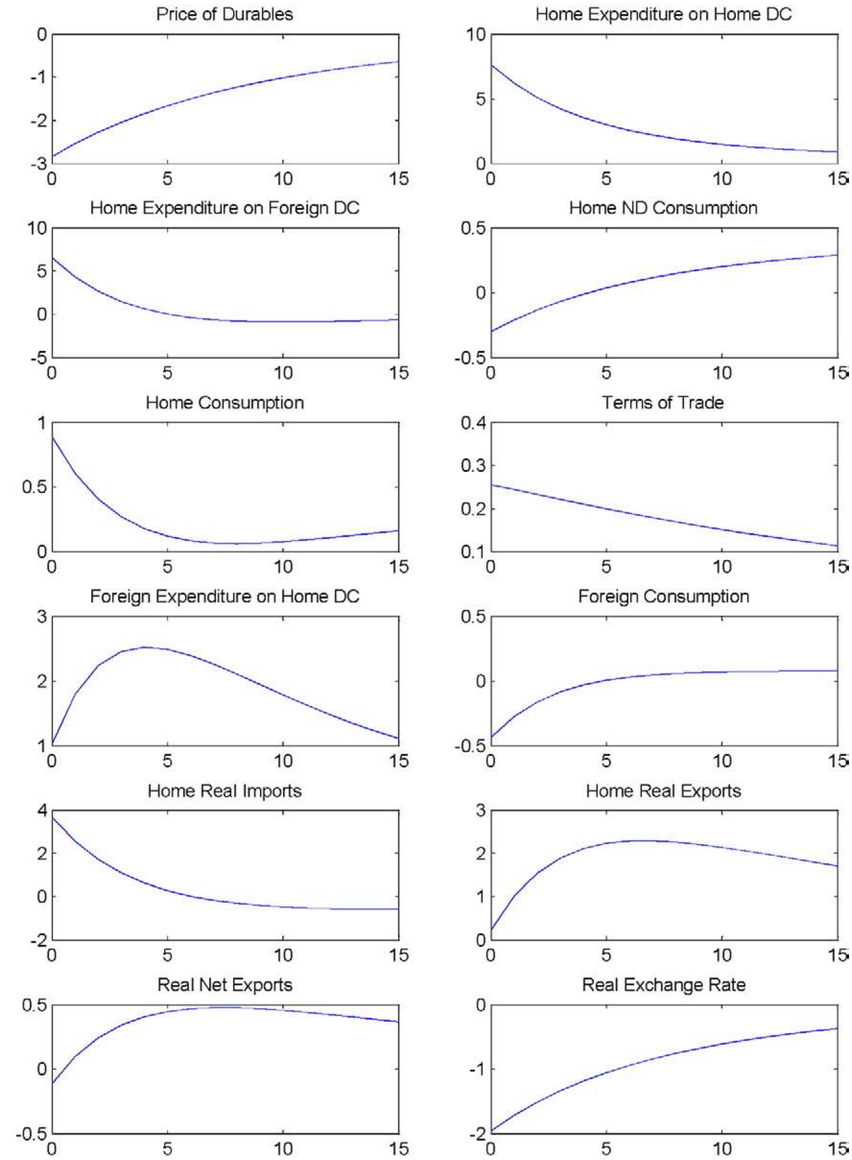

Fig. 2. Impulse response functions.

Note: The impulse response functions are with respect to a one-standard-deviation shock in the durable goods sector of home country for the benchmark model. The vertical axis shows percentage deviation from the steady state and the horizontal axis shows the number of periods after the shock. DC is the abbreviation for Durable Consumption. XX Expenditure on YY DC means country XX's expenditure on durable consumption goods that are produced in country YY. ND is the abbreviation for Nondurable.

prices) worsen in Fig. 2. The change in the terms of trade leads to substitution toward home-produced durables. As a result, the foreign country consumes more home durable goods, though foreign aggregate consumption declines. Similarly, the home country also shifts from foreign-produced durable goods toward home-produced durable goods because of this substitution effect. But under the wealth effect, domestic consumers raise their demand for both domestic and foreign tradable (durable) goods, even if the latter are more expensive in terms of the former. Overall, the wealth effect and the effect of the decline in the price of durables relative to nondurables lead to an increase in import demand, despite the increase in the price of foreign durables relative to home durables. Indeed, total expenditure on imports increases more than the value of exports, leading to a decline in the trade balance. However, part of that increase in import expenditure comes from the increased price of imports. But overall, the model still generates pro-cyclical movements of import and export quantities.

The wealth effect is an important channel for our model to generate pro-cyclical demand for foreign durable consumption goods. Following King (1990), we first calculate the welfare gain to home households of a positive shock in the home durable good sector. We then examine the consumption behavior of these households assuming they receive instead an initial wealth shock (in the form of an endowment of foreign bonds) that increases welfare in the same amount, holding all prices (including wages) constant at their steady-state levels. The size of the shock is calibrated to match the welfare increase after a one-standard-deviation positive shock in home durable goods sector. Fig. 3 shows the impulse response functions for various variables from this shock in our general equilibrium model and from the wealth shock to home households. Due to the wealth effect, home country's consumption of nondurable and durable goods increases while labor supply declines. The wealth effect accounts for about 25% of the increase in home-produced durable consumption goods and about 50% of the increase in foreign-produced durable consumption goods. We also consider a case in which there is no cost for adjusting durable consumption. In this case, the wealth effect accounts for a smaller (about 30%) share of the increase in home country's consumption of foreign-produced durable consumption goods.

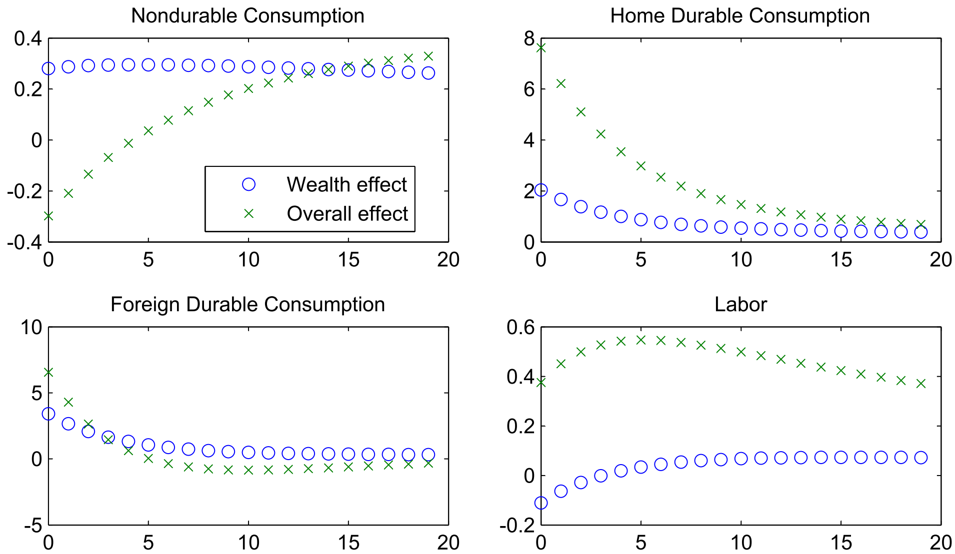

Fig. 3. Impulses response functions of home country variables.

Note: The impulse response functions of overall effect are with respect to a one-standard-deviation shock in the durable goods sector of home country in the benchmark model. The impulse response functions of wealth effect are with respect to a positive shock to the initial bond holding of the home country. All prices are fixed at their steady-state levels and the size of the initial bond holding shock is calibrated to match the welfare increase after a one-standard-deviation shock in the durable goods sector of home country in the benchmark model. The vertical axis shows percentage deviation from the steady state and the horizontal axis shows the number of periods after the shock. All impulse response functions are for variables in the home country. Home Durable Consumption is home country's expenditure of home-produced durable consumption goods. Foreign Durable Consumption is home country's expenditure of foreign-produced durable consumption goods.

Baxter and Crucini (1995) and Corsetti et al. (2008a) also discuss the impact of the wealth effect on the international transmission of shocks. They find that the scope for self-insurance via international trade may be limited when productivity shocks are close to having a unit root. In particular, Corsetti et al. (2008a) show that the wealth effect can be strong enough to generate an appreciation of the terms of trade after a positive shock if the productivity shock is very persistent and the Home and Foreign goods are highly substitutable. The long-run elasticity of substitution is high in our model. However, the adjustment costs of investment and durable consumption effectively reduce the short-run elasticity of substitution in our model. In addition, our productivity shocks are less persistent than those in Baxter and Crucini (1995) and Corsetti et al. (2008a). As a result, our model performs similarly to other standard IRBC models and predicts a depreciation of the terms of trade after a positive productivity shock.

The unconditional correlation of nondurable consumption and GDP is positive in our model though nondurable consumption is negatively correlated with GDP conditional on a shock in the durable goods sector. In our benchmark model, the correlation between nondurable consumption and GDP is 0.85 and it is 0.82 in the US data.[21] This is because the shocks in the nondurable goods sector play an important role in driving the volatility of GDP and nondurable consumption and GDP is positively correlated in the case of nondurable goods sector shocks. Durable expenditure is also positively correlated with GDP in our model. The unconditional correlation is 0.44 in the simulated data and it is 0.77 in the US data.

Our benchmark model can also match trade dynamics fairly well. Fig. 4 shows the correlations between GDP and real imports, exports and net exports at various leads/lags for the US data and the data simulated from our benchmark model. As noted by Ghironi and Melitz (2007), the correlation between GDP and imports exhibits a tent-shaped pattern, while the correlations of exports and net exports with GDP are S-shaped.[22]

Our model captures these qualitative patterns well. Note in particular that the model captures the fact that, while current imports are positively correlated with GDP, imports are negatively correlated with lagged GDP at longer horizons. However, our model's correlation of both imports and exports with lagged GDP declines quickly–too quickly–as the horizon increases. It appears especially that exports increase with a lagged response to a positive shock to GDP. It might be possible to capture this dynamic behavior by incorporating a lag between orders of durable goods and delivery.

Table 6 also reports the short-run elasticity of substitution between Home and Foreign goods that is estimated from our model. The estimated short-run elasticity of substitution in our benchmark model is 1.05 with a standard error of 0.20. The short-run elasticity of substitution implied by our model is very close to what is found in the empirical studies with business-cycle-frequency data, such as Bergin (2006) and Heathcote and Perri (2002), even though our model builds in a high long-run elasticity of substitution. The lower short-run elasticity arises because of the cost of adjusting the stocks of durable consumption and capital stocks. In a model with trade in durables, the lower short-run trade elasticity arises naturally and accords with the standard practice in macroeconomic modeling of the gradual accumulation of capital. That is, the trade elasticity puzzle is easy to understand in a context in which trade is in durables which are accumulated slowly over time.

5.1.2.2. Alternative specifications. The performance of our model is robust under alternative calibrations of productivity shocks in Table 6.

Models *High Spillover* and *Medium Spillover* in Table 6 release the constraint of no spillovers in the benchmark model. The process of shocks is modified to a *VAR*(1) format

$$A^N_{Ht+1} = \Xi_1 A^N_{Ht} + \Xi_3 A^N_{Ft} + \varepsilon^N_{Ht+1} \quad (22)$$

$$A^D_{Ht+1} = \Xi_2 A^D_{Ht} + \Xi_3 A^D_{Ft} + \varepsilon^D_{Ht+1} \quad (23)$$

$$A^N_{Ft+1} = \Xi_1 A^N_{Ft} + \Xi_3 A^N_{Ht} + \varepsilon^N_{Ft+1} \quad (24)$$

$$A^D_{Ft+1} = \Xi_2 A^D_{Ft} + \Xi_3 A^D_{Ht} + \varepsilon^D_{Ft+1}, \quad (25)$$

[21] The quarterly US data is from the Bureau of Economic Analysis during 1973Q1 and 2007Q2. Both the US data and the simulated data are logged and HP filtered before calculating the correlations.

[22] Ghironi and Melitz (2007) have also implicitly observed the procyclicality of imports and exports in their Fig. 1.

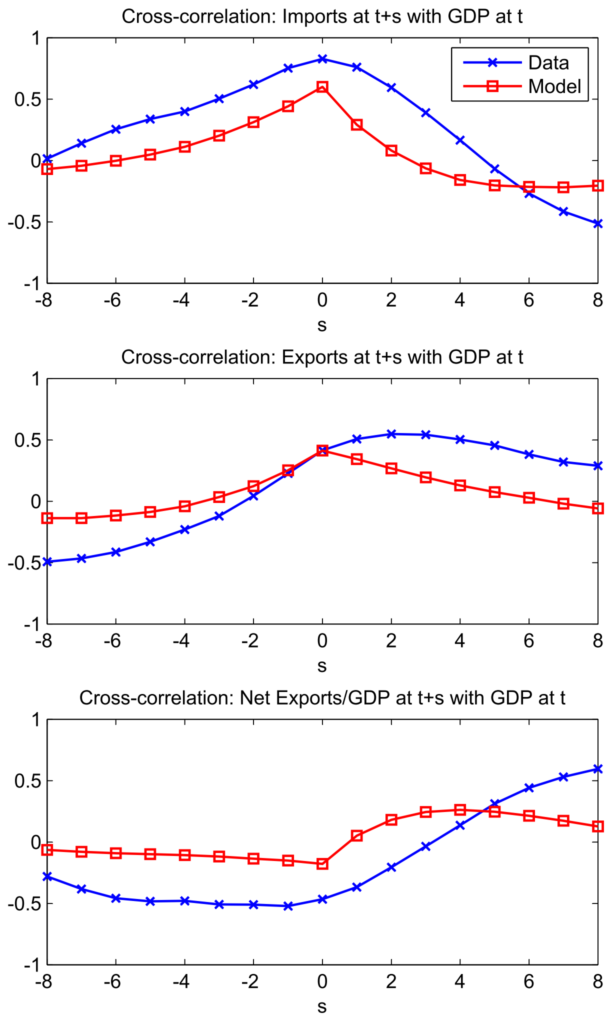

Fig. 4. Cross-correlation in different lags.

Note: The data are quarterly US data from *OECD Economic Outlook* dataset during 1973Q1–2006Q3. The model is our benchmark model. Model Statistics are averages over 100 simulations of length 120. All variables are logged (except for Net Exports/GDP) and HP filtered with a smoothing parameter of 1600.

where coefficient Ξ_3 is the cross-country spillover of productivity shocks.[23] BKK find a relatively large spillover of 0.088. In the model of High Spillover, Ξ_3 is set to this value. It is set to a medium level of 0.044 in the model of Medium Spillover.

In the model *High Correlation*, the cross-country correlation of productivity shocks in the durable goods sector (ρ_D) is set to a relatively high level, 0.468, which is found in Corsetti et al. (2008a). Cross-country output correlation is nearly zero in the standard IRBC models,[24] though this correlation is usually large in the data. Our model provides little insight on this issue. We find that the cross-country correlation of output increases if we allow innovations to be highly correlated across countries. Our motivation here is that Solow residuals measure productivity shocks with considerable error. To the extent that the measurement errors are uncorrelated across countries, the measured cross-country correlation of productivity may be severely downward biased.

In the model *High Correlation 2*, we set cross-country correlation of innovations to 0.7 for both durable goods and nondurable goods sectors, the cross-country output correlation increases from 0.01 to 0.56, which is very close to the data. Indeed, most aspects of the model hold up well under this alternative specification, with the notable exception of real exchange rate volatility which is much lower than in other parameterizations.[25] In particular, the volatility of imports and exports and their correlation with GDP do not decline. We emphasize that we have not chosen the correlation of productivity shocks under this parameterization to match data. Further examination of the measurement of productivity shocks is warranted, but we leave this to future work.

Model *High Persistence* tries a different approach to improve the output correlation. We follow Baxter and Crucini (1995) to have highly persistent shocks. The AR(1) coefficients of shocks in durable and nondurable goods sectors are set to 0.95 in the model of High Persistence. Output and consumption under this setup become more correlated across countries than in our benchmark model, as shown in Baxter and Crucini (1995). The statistics on the cross-country correlations of output and consumption can be improved further as we increase the persistence of the shocks. However, such a parameterization leads to small import and export volatilities and negative correlation of imports and exports in our model.

Model *Technology Costs* in Table 6 considers a different model for the adjustment costs of capital and durable consumption stocks. Under this setup, it is costly to adjust the proportion of home to foreign capital (durable consumption). This is a crude way of capturing the notion that it takes time to change technologies. As a result, the proportion of home to foreign durables only changes gradually. Similar trade adjustment costs have been introduced in some recent papers. For instance, Bodenstein et al. (2007) allow for convex costs for adjusting the share of oil used in consumption and production. Erceg et al. (2009) incorporates adjustment costs that penalize rapid changes in bilateral trade shares. Such adjustment costs will dampen the short-run substitution effect between the Home and Foreign goods and induce a wedge between the short- and long-run trade elasticity. Ramanarayanan (2007) models this idea more explicitly with a putty-clay technology. In addition, we use adjustment costs for the total stock of capital (durable consumption) to match the volatility of investment in capital (durable consumption). This new setup generates results similar to our benchmark model. Cross-country output correlation in the Technology Costs model (0.08) comes slightly closer to the data than in the benchmark model (0.01). However we also note that we have more freedom in calibrating the "Technology Costs" model because it has more cost parameters than our benchmark model.

In the model of *Traded Nondurable* (Table 6), we allow Home and Foreign countries to trade part of their nondurable consumption goods.[26] This model has the same production function for the nondurable goods sector as our benchmark model. But unlike our benchmark model, a fraction of nondurable goods can be traded across countries. Home and Foreign traded nondurable consumption are aggregated into a traded nondurable consumption composite. This composite and the nontraded nondurable consumption are aggregated into nondurable consumption. The rest of the model follows the same setup of our benchmark model. We calibrate this model such that: 1. nondurable goods account for 30% of trade; 2. share of capital goods in trade is 43%; 3. trade accounts for 14% of output.

The model generates results similar to our benchmark model. The only noticeable difference is that imports and exports are less volatile in the model of Traded Nondurable. This result is not surprising because nondurable consumption is less volatile than durable expenditure and investment in our model. Diverting some trade to nondurable consumption decreases the overall volatility of the trade. Even in this case, imports and exports are still more than two times as

[23] As in Erceg and Levin (2006), we assume the cross-sector spillover is still zero.

[24] For instance, the cross-country output correlation in Backus et al. (1992) is −0.18.

[25] Our model's ability to match the trade sector data also holds up well in the case with zero cross-country correlation of productivity shocks (Model *No Correlation* in Table 6). We thank an anonymous referee for suggesting us this exercise.

[26] See the appendix on the authors' websites for details.

volatile as output. In this model, we have assumed that productivity shocks are the same for traded and nontraded nondurable goods. In the US data reported in Section 2.2, nondurable imports and exports are more volatile than output. So the productivity shocks for traded nondurable goods may be more volatile than nontraded nondurable goods in the data. If we allow this difference in our model, the volatility of imports and exports in our model may come closer to the data.

Model *Low Durable Share* illustrates the importance of trade in durable goods for our model to match the trade data. An important difference between our model and the standard IRBC models is that our model has a larger share of durable goods in international trade. To highlight the importance of this structure, we modify our model such that it has the same share of durable goods in international trade as in the HP model (25.5%). The simulation results are reported in the model of Low Durable Share (Table 6). As in the HP model, both imports and exports become less volatile than output in this model.

In all of our calibrations, we note the following shortcomings: as in almost all RBC models, real exchange rate volatility is still lower than in the data. However, our model does quite well relative to the literature. The standard deviation of the real exchange rate in our benchmark model is roughly 50% of the standard deviation in the data.[27] Our model also generates stronger correlation between the real exchange rate and macroeconomic variables such as consumption than the data.[28] Adding features such as pricing to market, distribution costs and sticky prices into our model may help to match the disconnect between the exchange rate and macro economic variables in the data. Across all specifications, our model produces somewhat lower correlations of real imports with GDP than what appears in the data. And, perhaps as a consequence, net exports are not as negatively correlated with GDP as in the data.

5.2. Backus–Smith puzzle

When agents can trade a complete set of contingent claims, but face potentially different goods prices, in a variety of contexts models imply that relative cross-country consumption should be perfectly positively correlated with the real exchange rate. But, beginning with Backus and Smith (1993), several studies find empirically that the correlation between relative consumption and the real exchange rate is generally low, even negative in many countries. Some recent papers offer models to explain this correlation when capital markets are not perfect, and only bonds are traded, for instance, Corsetti et al. (2008a), and Benigno and Thoenissen (2008). Our model shares some features of these models, but also offers some new insight: the introduction of consumer durables raises interesting issues about how consumption should be measured in tests of the Backus–Smith puzzle. The dynamics of consumption and the real exchange rate in response to a shock to productivity in the durable sector looks very much like those in Benigno and Thoenissen (2008). As shown in Fig. 2, a positive shock lowers the price of the durable export (the terms of trade deteriorate), and because of home bias, that tends to work toward a real CPI depreciation. But that effect can be more than offset by the increase in the relative price of nondurable goods, which are not traded across countries. There are two forces working to push up the price of nontraded goods: first, there is the traditional Balassa–Samuelson effect. The increase in productivity pushes up the real wage, thus pushing up the relative price of nontradables. In addition, overall consumption in the home country increases from a wealth effect, because higher productivity increases lifetime income for the home country. Even if there were no factors mobile between sectors, that would tend to push up the price of the nontradable goods, and help foster a real appreciation. We have that aggregate consumption is increasing, and under our calibrations, a real appreciation.

The model's ability to explain the positive correlation between the real exchange rate and relative consumption hinges critically on the variability of nontradable prices, but empirical work has found a negligible role of nontradable prices movements in driving observed fluctuations in the real exchange rates.[29] In addition, the terms of trade and the real exchange rate are negatively correlated in our model though the opposite is true in the data. In response to a positive productivity shock, the terms of trade depreciates and therefore is negatively correlated with relative consumption in our model, which is at odds with the data. Obstfeld and Rogoff (2000) emphasize that the terms of trade and the real exchange rates are generally positively correlated in the data. Corsetti et al. (2008b) and Enders et al. (2008) also find in their empirically based VAR exercises that both the terms of trade and the real exchange rates appreciate after a positive productivity shock. Our model fails to replicate these findings and we leave this for our future research.

However, our model also offers some new insight into measurement issues that may ultimately shed light on this puzzle. Durable consumption measured in national accounts data is expenditures on new durable consumption goods. However, it is the service flow from the *stock* of durable consumption that enters the utility function. As emphasized by Obstfeld and Rogoff (1996, page 98), the consumer smoothes the service flow from the stock of durable consumption, instead of the path of expenditures on durables. We measure total consumption as in the data by the sum of nondurable consumption and the investment in durable consumption

$$TC_{Ht} = C_{Ht} + DC_{Ht}, \tag{26}$$

where TC_{Ht} is the total consumption in Home country. C_{Ht} is nondurable consumption and DC_{Ht} is durable consumption expenditure. Durable expenditure is defined as the sum of Home- and Foreign-good durable expenditure

$$DC_{Ht} = \hat{P}^{DH}_{Ht}\left(d^{H}_{Ht} + \Delta^{H}_{Ht}\right) + \hat{P}^{DF}_{Ht}\left(d^{F}_{Ht} + \Delta^{F}_{Ht}\right). \tag{27}$$

From the utility function, we know the “true” consumption (utility consumption) is

$$UC_{Ht} = \left(\mu^{\frac{1}{\zeta}}D_{Ht}^{\frac{\zeta-1}{\zeta}} + (1-\mu)^{\frac{1}{\zeta}}C_{Ht}^{\frac{\zeta-1}{\zeta}}\right)^{\frac{\zeta}{\zeta-1}}. \tag{28}$$

We calculate the correlation of 1. the (log) CPI-based real exchange rate and the (log) relative total consumption ($\log(TC_{Ht}) - \log(TC_{Ft})$), and 2. the utility-based real exchange rate and the (log) relative utility consumption ($\log(UC_{Ht}) - \log(UC_{Ft})$).[30] The correlation between the real exchange rate and total consumption differential ($\log(TC_{Ht}) - \log(TC_{Ht})$) is −0.23. So our model can replicate the negative correlation between the real exchange rate and relative consumption documented in the data. However, the correlation between the utility-based real exchange rate and the utility consumption differential ($\log(UC_{Ht}) - \log(UC_{Ht})$) is 0.26. Based on the fact that the financial market is limited to trade in non-state-contingent real bonds and leisure is nonseparable in the utility function, a correlation of 0.26 still implies a relatively good amount of risk-sharing between the Home and Foreign countries.

[27] Unlike in models with low intertemporal elasticity of substitution and exogenous exchange rate shocks (models Lo-elast. and UIP in Table 5), exchange rate volatility in our model is mainly from the fluctuations of nontradable prices.

[28] The correlation between the real exchange rate and nondurable consumption (durable expenditure) is 0.28 (−0.64) in our model. The corresponding correlation in the US data (1973Q1–2007Q2) is 0.10 (−0.01).

[29] See Engel (1999) and Chari et al. (2002).

[30] Please see an appendix posted on the authors' websites for details about how to calculate the utility-based real exchange rate.

6. Conclusion

The behavior of imports and exports is, of course, a key component of the linkages among economies. We document two important empirical regularities for these two variables that have been largely neglected in the literature: both imports and exports are much more volatile than GDP and both are pro-cyclical. Our model confronts and, to a degree, successfully explains these empirical regularities. By modeling trade in durables, we can understand the high volatility of imports and exports relative to output. Trade volatility has stimulated much discussion recently after the collapse of global trade in 2008 and 2009. Levchenko et al. (2009) find empirical evidence that the mechanism emphasized in our paper – trade in durable goods – has played an important role in the recent collapse of US trade. Trade in durables also offers a natural explanation for the trade elasticity puzzle — that the response of imports to changes in the terms of trade is low at business cycle frequencies, but is high when considering the long-run effect of permanent price changes. Our model performs well compared to other models, because it offers an explanation that is also consistent with the observation that imports and exports are both pro-cyclical, and positively correlated with each other, even when the terms of trade and real exchange rate are as volatile as in the data.

We believe that the forward-looking nature of investment decisions and decisions to purchase consumer durables are a key feature of trade behavior. Our model noticeably fails to account for the high correlation of output across countries, which is a failure shared by essentially all rational expectation equilibrium models. However, we think that modeling trade as durables may still be a promising avenue for dealing with this puzzle as well, through channels that are not explored in this paper. One possibility is that while the common (across countries) component of productivity shocks may account for a small share of the variance of productivity, it may be that agents typically receive strong signals about the future common component. If news helps to drive business cycles (as in Beaudry and Portier, 2007), then perhaps news about the common component of productivity shocks helps contribute to the high correlation of business cycles across countries. News about future productivity is especially important for durables, so the impact of news may be especially strong on the investment and consumer durables sectors.

Another avenue that may deserve further exploration is a model with nominal price stickiness, as in DSGE models. Our model of durable trade creates large swings in demand for imports, which indeed is what allows it to account for trade volatility. But an increase in Home demand for Foreign output has only a small effect on Foreign's output level. Instead, in our model, prices adjust so that more of Foreign's output is channeled toward Home. In a model with sticky prices, changes in demand may lead to changes in aggregate output, and so create a channel for international spillovers. While these channels do exist in current DSGE models, they are not strong because the models do not account for large pro-cyclical movements in imports and exports.

It is an empirical fact that a large fraction of trade is in durables. Indeed, we view explaining this phenomenon–rather than assuming it, as we do in this study–to be another interesting topic for future research. What we have accomplished here is to demonstrate that trade in durables significantly alters the behavior of imports and exports in an RBC model in a way that can account for some striking empirical facts.

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Appendix A. Dividing imports and exports into categories of durable and nondurable goods

SITC categories 0 (FOOD AND LIVE ANIMALS), 1 (BEVERAGES AND TOBACCO), and 4 (ANIMAL AND VEGETABLE OILS, FATS AND WAXES) are nondurable goods. Category 7 (MACHINERY AND TRANSPORT EQUIPMENT) belongs to durable goods. Category 2 is raw materials that exclude fuels such as petroleum. Category 3 contains energy products such as coal, petroleum, gas, etc. The remaining categories are more difficult to classify. This is particularly true for category 5 (CHEMICALS AND RELATED PRODUCTS, N.E.S.). Even if we go down to the 3-digit level, it is still unclear which categories belong to durable goods. We find that this category includes many nondurable goods, such as fertilizers, medicines, cleaning products, etc. To avoid exaggerating the share of durable goods, we put the whole category 5 into nondurable goods. But we note that this category does include some durable goods, such as plastic tubes, pipes, etc.

For categories 6, 8 and 9, we go down to the SITC 2-digit levels for more information about the durability of goods. Category 6 (MANUFACTURED GOODS CLASSIFIED CHIEFLY BY MATERIALS) classifies goods according to their materials. We assume that goods produced from leather, rubber, or metals are durables (61–62 and 66–69). Goods produced from wood (other than furniture), paper, or textile (63–65) are nondurables. Category 8 includes other manufactured products that are not listed in categories 6 and 7. We assume that construction goods (81), furniture (82), professional instruments (87), photographic equipments (88) are durable goods. Travel goods (83), clothing (84), footwear (85) and remaining goods (89) are classified as nondurables. Category 9 includes products that are not classified elsewhere. In this category, we assume that coins and gold (95–97) are durables. All remaining products are classified as nondurables.

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