Distribution capital and the short- and long-run import demand elasticity*

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Abstract

The elasticity of substitution between home and foreign goods is one of the most important parameters in international economics. The international macro literature, which is primarily concerned with short-run business cycle fluctuations, assigns a low value to this parameter. The international trade literature, which is more concerned with long-run changes in trade flows following a change in relative prices, assigns a high value to this parameter. This paper constructs a model where this discrepancy between the short- and long-run elasticities is due to frictions in distribution. Goods need to be combined with a local non-traded input, distribution capital, which is good specific. Home and foreign goods may be close substitutes, but if distribution capital is slow to adjust then agents cannot shift their consumption in the short run following a change in relative prices, and home and foreign goods appear as poor substitutes in the short run. In the long run this distribution capital can be reallocated, and agents

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can shift their purchases following a change in relative prices. Thus the observed substitutability gets larger as time passes.

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1 Introduction

The elasticity of substitution between home and foreign goods, also called the Armington elasticity, is arguably the key parameter in dynamic equilibrium models of international trade. The Armington elasticity ties the time series variation in exports and imports to movements in the terms of trade via a static first-order condition present in many workhorse models. Trade models demonstrate the importance of this parameter in determining the impact of trade policy on trade flows and welfare. Macro models rely on this parameter to determine the business cycle effects of certain macro shocks and the general business cycle properties of international macro models.

The problem, as highlighted in Ruhl (2005) and Arkolakis et al. (2012), is that the trade literature and the international macro literature do not agree on the value of this parameter. Macro models, which are concerned with short-run fluctuations, generally ascribe a low value to this parameter. Backus et al. (1994) assign a value of 1.5 to the Armington elasticity and discuss how the model fails to replicate the negative co-movement between the terms of trade and net exports when the elasticity is too high (above 3). In the calibration of their model, Kose and Yi (2006) use this same value. Stockman and Tesar (1995) use a Cobb-Douglas (unitary elasticity) to aggregate home and foreign goods. Heathcote and Perri (2002) estimate the Armington elasticity to be 0.9, using an equation that links changes in the real exchange rate to changes in net exports and relative production. Corsetti et al. (2008b) use a value close to this, 0.85. They arrive at this value by calibrating their model to match certain features of the data, most notably, second moments of the real exchange rate and the terms of trade. Enders et al. (2011) construct a model to specifically explain the path of the real exchange rate and the terms of trade following either a productivity or government spending shock. They find that the model calibrated with a high elasticity of substitution yields counterfactual results as to the response of the real exchange rate following a shock. Similarly, in estimations using data on relative prices and import shares, Blonigen et al. (1999) use quarterly data and find an average elasticity of about 0.81.

On the trade side, in their survey of the literature on trade costs, Anderson and van Wincoop (2004) report that the import demand elasticity is generally found to lie between 5 and 10. Hillberry et al. (2001) find long run estimates of the elasticity between 4 and 8. Hummels (1999) backs the elasticity parameter out of an estimated gravity model after estimating the elasticity of trade costs with respect to distance and finds the elasticity is about 5. In a similar fashion, Obstfeld and Rogoff (2000) find that when the elasticity of substitution is equal to 6, the observed home bias in trade can be reconciled with estimated international trade costs. Head and Reis (2001), Clausing (2001), and Romalis (2007) each

estimate the elasticity using U.S.-Canadian trade data from before and after the passage of the Canada-U.S. Free Trade Agreement and find the elasticity is between 6 and 11. Eaton and Kortum (2002) estimate a parameter that can be thought of as an import demand elasticity and find a value of 8.

Hooper et al. (1998) and Gallaway et al. (2003) use a regression framework that allows them to distinguish between short- and long-run elasticities. They find that import demand elasticities are typically much larger in the long run than they are in the short run. The mechanism most often associated with these conflicting short-run and long-run responses is the notion that changes in relative prices at the wholesale level do not pass through into final consumer prices. Campa and Goldberg (2005) and many other papers document the low pass through of exchange rate changes into import prices.

This paper presents a novel mechanism to explain why exports and imports may be slow to respond to a change in relative prices, and thus why the observed import demand elasticity may be low in the short run but high in the long run. In the model, traded goods need to be combined with local distribution services before they are consumed. However, these services are allocated separately to the distribution of home and foreign goods. Specifically, labor employed in distribution is assumed to be costless to reallocate across sectors within the period, whereas distribution capital is predetermined and costly to reallocate across sectors.¹ While the home and foreign goods may be viewed as highly substitutable by consumers (parameterized by a high Armington elasticity) distribution capacity creates a short-run bottleneck, the result of which is to make trade quantities appear unresponsive to trade prices in the short-run as seen in the data. In practical terms, distribution capital could be anything from port capacity, which can impose a capacity constraint on the quantity of imported goods until port capacity is expanded, to good-specific retail outlets, like a BMW dealership or a Louis-Vuitton store, which would limit retail sales of imported varieties of a good (cars or handbags) until more retail space can be built. Intuitively, the short-run decline of import prices brought on by a foreign productivity improvement is partially cancelled out by the increase in the marginal cost of distribution of imports, mitigating the demand for imports in the current period. As time passes, distribution capital is reallocated across sectors and the response of trade to the changing wholesale price is greater, consistent with a higher elasticity of substitution.

So in this paper we make two contributions. First, we empirically show that there is a role for a local-non-traded input in the production of retail goods. To show this our empirical strategy is to make use of a panel of micro-price data. What we observe is the fact that

¹In the U.S. input-output tables, labor's share of value added in the retail and wholesale trade and transportation sectors is about 58%.

when the time-series variation in micro-prices is divided into a good-specific component and a location-specific component; the local component of the price displays a lot of volatility and persistence and is only imperfectly correlated across sectors. This is consistent with the notion that the pass-through of wholesale price changes (or cost shocks from the perspective of retailers) is both incomplete and heterogeneous across locations. The fact that retail prices do not move one-to-one with import prices is the familiar question that is the focus of the well-developed international exchange-rate pass-through literature. The asymmetries across sectors is novel here and points to frictions that impede the reallocation of distribution services across goods in the same location. While this mechanism is likely to be ubiquitous, it is quite compelling in terms of home versus foreign (imported) goods.

In our second contribution, we take what we learn about the retail goods production technology and incorporate this into the workhorse international real business cycle model in Backus et al. (1994). We build on Corsetti et al. (2008b) who develop a two-country general equilibrium business cycle model with a distribution sector. They show that this modification, along with incomplete markets leads to significant improvements in the ability of real business cycle models to account for a number of existing international finance puzzles. In their formulation, as well as in Burstein et al. (2003) it is assumed that the sale of a physical unit of the final good in the home market requires a fixed quantity of non-traded inputs. This assumption makes the traded price index a time invariant linear combination of the wholesale price index of tradables and the price index of non-tradables.²

We build upon these models that incorporate a distribution sector by specifying that capital used in distribution is a specific factor which is costly to adjust across the distribution of home and foreign goods, and thus our model can help account for the cross-sector heterogeneity in the location-specific component of prices that we observe in the micro-price data.³ When the parameters of this equilibrium model are calibrated to match the volatility and co-movement of the traded and non-traded components of the micro-price data, the model predicts that the empirical elasticity of substitution between home and foreign goods is low in the short run but gets larger as time passes and these short-run frictions in the distribution sector dissipate. Moreover, because capital adjustment is endogenous, the time horizon

²It is also important to point out similarities and differences between our model and the models of Corsetti and Dedola (2005) and Corsetti et al. (2008a). These models rely on market power at the level of the traded good firm, and thus the presence of a distribution sector can endogenously lead to firm pricing-to-market behavior and violations of the law of one price. We intentionally abstract from firm market power in this paper and instead focus on goods produced in highly competitive markets, so here distribution affects the final consumer price of a good, not the wholesale producer price.

³Thus by explicitly modeling the distribution sector and short-run supply constraints in the distribution sector, this paper provides a basis for the reduced-form import adjustment cost function in Erceg et al. (2005) or the convex costs to adjusting the stocks of domestic and imported durable goods in Engel and Wang (2011).

along which the short-run and long-run elasticities are reconciled is also endogenous. Thus our contribution lies both in a substantive extension of the Corsetti et al. (2008b) model and in the unique microeconomic data that is used to calibrate and estimate the facets of the distribution sector that our model highlights.

A number of important contributions also attempt to reconcile the short-run and long-run elasticity of substitution across the trade and macroeconomic literature. Attention was first drawn to this issue by Ruhl (2005) who contrasts the response of trade flows to temporary productivity shocks and permanent tariff changes along with associated shift in adjustment from the intensive to the extensive margin. Ramanarayanan (2013) emphasizes the role of investment irreversibility in production and importation of intermediate inputs in generating a slow buildup in the response of quantities to permanent trade liberalization. These papers emphasize different channels and manufacturing decisions while abstracting from the distribution sector, which is our focus. Close in spirit to our model is Drozd and Nosal (2012b) who construct a search model where sales require some marketing capital. This marketing capital is sluggish, and thus quantities demanded will adjust slowly in the short run following a change in international relative prices.⁴

In all of these models, short-run frictions (be they stickiness in buyer-supplier relationships or sluggishness in market share and marketing capital) are a form of short-run trade friction that prevent the quantity demanded of imports from adjusting fully in the short term following a change in international relative prices. To this list of short-run frictions this paper adds a durable and specific factor in the production of retail goods, distribution capital. The size of this short-run friction in distribution is then calibrated using micro-price data to show how this friction in distribution is indeed a type of short-run trade friction that can help to reconcile observations of a low short-run import demand elasticity with observations of a high long-run import demand elasticity.

The rest of this paper is organized as follows. The decomposition of final goods prices in our micro-price data into traded and non-traded components is presented in section 2. From these micro-prices we can learn more about the retail goods production technology and the specific factors that are involved in the distribution of wholesale goods. The equilibrium international real business cycle model is presented in section 3. In the version of the model without local non-traded inputs, the model collapses to the benchmark IRBC model in Backus et al. (1994). Using the information gained from the decomposition of the micro-price data, the benchmark calibration of the model is presented in section 4. The results

⁴Similarly, demand persistence is introduced in a reduced form way into a Ricardian model of trade by Arkolakis et al. (2012) with consumers switching to the lowest price source with some probability or staying with the existing source otherwise.

from the different versions of the model are presented in section 5. First we solve analytically for the observed import demand elasticity following a change in the relative price of imports. We then compare the different versions of the model, the version with a high elasticity of substitution as measured in the international trade literature, the version with the low elasticity as measured in the international macro literature, and the version with the high elasticity of substitution but a local non-traded component that is inelastically supplied in the short run. The version of the model with the high Armington elasticity of substitution combined with distribution-specific capital is able to reconcile the seemingly contradictory calibrations of trade and business cycles models. Finally, section 6 concludes.

2 The Distribution Sector

Much of what is known about the size of the distribution sector comes from the US National Income and Product Accounts (NIPA). Specifically, sectoral data showing the amount paid by consumers relative to the value received by manufacturers for goods sold. The difference between these two monetary values as a ratio of consumer expenditure is referred to as the distribution margin. In an accounting sense, this margin includes shipping costs associated with the movement of goods from the factory gate to the final consumer, value added in the distribution sector, and markups at each point in the vertically integrated market chain. The aggregate US distribution margin is approximately 50% (Crucini and Yilmazkuday, 2014) with only a fraction of this wedge attributable to traditional trade costs.

Whereas the steady-state properties of the distribution wedge have recently been established, little is known about their business cycle properties. This section is intended to fill this void. To accomplish this, we use a panel dataset of retail prices for over 300 goods in 123 cities where the price of each good in each city is observed annually from 1990-2005. The dataset covers over 300 items representative of what consumers regularly purchase. We exclude pure labor services (e.g., domestic cleaning help) and aggregate the items into six sectors: food, clothing, property and rents, transportation, utilities and other consumer goods. The full list of goods in the dataset and how they are grouped into six categories is presented in the appendix. Because our model abstracts from nominal rigidities and nominal exchange rate fluctuations, we restrict our empirical work to 13 U.S. cities, the list of these 13 cities is also presented in the appendix.

In this decomposition of the micro-price data, we allow there to be three components of the final good price: a good-specific component, μ_{it} , a location-specific component, μ_{jt} , and a location and good specific component, μ_{ijt} . In the data set we observe $\tilde{p}_{ijt}$, the retail price of the good from sector i in city j at time t . Crucini and Yilmazkuday (2014) estimate the

distribution margin for each good in the EIU dataset and the sectoral distribution shares used here, s_i , are averages of their good-level estimates within each of our six sectors.⁵ Given these prices and the distribution margins the following regression is estimated:

$$\tilde{p}_{ijt} = (1 - s_i) \mu_{it} + s_i \mu_{jt} + s_i \mu_{ijt} \quad (1)$$

and further, we can calculate the total distribution cost, $\hat{c}_{ijt} = \frac{\tilde{p}_{ijt} - (1 - s_i) \mu_{it}}{s_i}$.

We begin with a variance decomposition of the retail price into the contributions of the wholesale price, wage margin and rental margin (and the sum of the latter two, the distribution margin). The variance decomposition uses the covariances between the retail price and the estimated fixed effects components to avoid arbitrary assignment of covariances among the components.⁶ Table 1 reports the variance decomposition of the prices in each sector into that caused by time-series fluctuations in the sector-specific price component $((1 - s_i) \mu_{it})$, the location-specific price component $(s_i \mu_{jt})$, and the sector and location specific component $(s_i \mu_{ijt})$. The table also reports the number of micro-prices used in the aggregation to the consumption category level and the simple average share of traded goods in value (s_i is the distribution share). The categories are ordered from those with the lowest distribution share (food at 0.38) to the highest (property at 0.93).

The most obvious feature of the decomposition is that most of the business cycle movements in retail prices are accounted for by the idiosyncratic component, which in the model is the sector and location-specific distribution cost. The next most dominant contribution is the good-specific component. The city-specific component common to all goods is not inconsequential, but is relatively minor quantitatively. Next we will turn to see how the workhorse international real business cycle model can be modified to reflect the fact that in the micro-price data, such a large component of the fluctuations in the price of a good seems to be driven by this location-specific component (distribution) and a large share of this distribution component of the price seems to be sector-specific (distribution capital).

3 The Model

There are two countries, home and foreign. Foreign variables are written with an asterisk (*) and home variables are not. In the following description of the model, foreign equations are omitted for brevity.

⁵The distribution margins, s_i , are good specific, but common across all locations and constant time.

⁶The variance decomposition method follows Crucini and Landry (2012).

3.1 Firms

For the purposes of exposition, it is useful to think of each country as comprised of two sectors. Firms in one sector produce wholesale goods using capital and labor. Firms in the second sector distribute either home produced goods or imported goods to final consumers. These firms combine wholesale goods with distribution services.

Distribution services are produced using labor and distribution capital:

$$d_{Z,t} = A_t \left[(1 - \hat{\alpha}_d)^{\frac{1}{\eta}} (N_{dZ,t})^{\frac{\eta-1}{\eta}} + (\hat{\alpha}_d)^{\frac{1}{\eta}} (K_{dZ,t})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \quad Z = D, M \quad (2)$$

where N_d and K_d are the labor and capital employed in the distribution sector, and A_t is a country specific total factor productivity parameter. Notice that this production function is the same for domestic goods, denoted with subscripts D , and imported goods, denoted with subscripts M .⁷ The input demand functions for capital and labor in distribution sector Z are given by: $K_{dZ,t} = (\hat{\alpha}_d) \left(\frac{r_{Z,t}}{c_{Z,t}} \right)^{-\eta} \frac{d_{Z,t}}{A_t^{1-\eta}}$, $N_{dZ,t} = (1 - \hat{\alpha}_d) \left(\frac{w_t}{c_{Z,t}} \right)^{-\eta} \frac{d_{Z,t}}{A_t^{1-\eta}}$, $Z = D, M$.

Firms in the distribution sector combine wholesale goods ($y_{Z,t}$) and distribution services ($d_{Z,t}$) to produce the retail quantity of the good, $\tilde{y}_{Z,t}$, according to a CES production function:

$$\tilde{y}_{Z,t} = \left[(y_{Z,t})^{\frac{\gamma-1}{\gamma}} + \kappa^{\frac{1}{\gamma}} (d_{Z,t})^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}}, \quad Z = D, M \quad (3)$$

where κ is the weight on distribution services, and γ is the elasticity of substitution between wholesale goods and distribution services. In the absence of distribution costs ($\kappa = 0$), $\tilde{y}_{D,t} = y_{D,t}$ and $\tilde{y}_{M,t} = y_{M,t}$, and the model collapses to Backus et al. (1994).

The resource constraint for the home produced good is:

$$y_{D,t} + y_{M,t}^* = A_t N_t^{1-\alpha} K_t^\alpha \quad (4)$$

where $y_{D,t}$ and $y_{M,t}^*$, are domestic uses of the home good and exports, respectively. N_t and K_t are labor and capital employed in the production of home country goods. From this production function, the demand for labor and capital are given by $N_t = (1 - \alpha) \frac{MC_t}{w_t} (y_{D,t} + y_{M,t}^*)$ and $K_t = \alpha \frac{MC_t}{r_t} (y_{D,t} + y_{M,t}^*)$ where w_t is the home real wage rate (in terms of the home consumption good), r_t is the rental rate of physical capital employed in the production of home goods, and $MC_t = \frac{1}{A_t} \left(\frac{w_t}{1-\alpha} \right)^{1-\alpha} \left(\frac{r_t}{\alpha} \right)^\alpha$.

⁷ $\hat{\alpha}_d$ is the weight on capital in the production function, if the elasticity of substitution, $\eta = 1$, $\hat{\alpha}_d$ would also be the share of distribution costs devoted to capital. When $\eta \neq 1$, the capital share is instead a function of the steady state wage and rental rate, $\alpha_d = \frac{\hat{\alpha}_d(r)^{1-\eta}}{\hat{\alpha}_d(r)^{1-\eta} + (1-\hat{\alpha}_d)(w)^{1-\eta}}$. In section 4 where we calibrate this parameter, to gain intuition we will calibrate capital's share of distribution costs, α_d , but for a given steady state wage and rental rate, there is a one-to-one relationship between the capital share, α_d , and the parameter $\hat{\alpha}_d$.

3.2 Aggregate Demand

Following Backus et al. (1994), home and imported goods are combined in an Armington (1969) aggregator function with an elasticity of substitution ρ to provide households with consumption, C_t , investment in capital used in production of the home good, I_t , and investment in distribution capital, $I_{d,t}$:

$$C_t + I_t + I_{d,t} = y_t = \left[(\omega)^{\frac{1}{\rho}} (\tilde{y}_{D,t})^{\frac{\rho-1}{\rho}} + (1-\omega)^{\frac{1}{\rho}} (\tilde{y}_{M,t})^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}. \quad (5)$$

The demand for domestically produced or imported final goods as a function of aggregate expenditure is:

$$\begin{aligned} \tilde{y}_{D,t} &= \omega (\tilde{p}_{D,t})^{-\rho} y_t \\ \tilde{y}_{M,t} &= (1-\omega) (\tilde{p}_{M,t})^{-\rho} y_t \end{aligned} \quad (6)$$

where $\tilde{p}_{D,t}$ ($\tilde{p}_{M,t}$) is the retail price of domestic (imported) goods relative to the price of the home consumption good.

3.3 Prices

This section presents a number of useful analytical expressions linking firm marginal costs and market prices to price indices.

Substituting the demand functions in (6) into the aggregator function in (5) yields:

$$\left[\omega (\tilde{p}_{D,t})^{1-\rho} + (1-\omega) (\tilde{p}_{M,t})^{1-\rho} \right]^{\frac{1}{1-\rho}} = 1$$

From the production function in (3), the retail prices of domestic and imported goods relative to the home aggregate price deflator are:

$$\begin{aligned} \tilde{p}_{D,t} &= \left[(p_{D,t})^{1-\gamma} + \kappa (c_{D,t})^{1-\gamma} \right]^{\frac{1}{1-\gamma}} \\ \tilde{p}_{M,t} &= \left[(p_{M,t})^{1-\gamma} + \kappa (c_{M,t})^{1-\gamma} \right]^{\frac{1}{1-\gamma}} \end{aligned} \quad (7)$$

where $p_{D,t}$ ($p_{M,t}$) is the wholesale price of the domestic (imported) good, and $c_{D,t}$ ($c_{M,t}$) is the cost of domestic (import) distribution services. The parameter κ and the steady state prices of the final good and of distribution services are used to compute the steady state distribution margin, $s = \kappa \left(\frac{c_D}{\tilde{p}_D} \right)^{1-\gamma} = \kappa \left(\frac{c_M}{\tilde{p}_M} \right)^{1-\gamma}$.

Wholesale goods are produced by firms engaged in perfect competition, and thus the price of a home produced good is equal to its marginal cost of production, MC_t , and the

price of a foreign produced good is equal to its marginal cost of production, MC_t^* . The relative price of the domestic good in the home market is thus $p_{D,t} = MC_t$ while the relative price in the home market of the imported good is $p_{M,t} = \frac{MC_t^*}{Q_t}$, where Q_t is the real exchange rate defined as the foreign price level divided by the home price level.

From the production functions for domestic and imported distribution services, the marginal costs of distribution are given by:

$$\begin{aligned} c_{D,t} &= \frac{1}{A_t} [(1 - \hat{\alpha}_d) (w_t)^{1-\eta} + \hat{\alpha}_d (r_{D,t})^{1-\eta}]^{\frac{1}{1-\eta}} \\ c_{M,t} &= \frac{1}{A_t} [(1 - \hat{\alpha}_d) (w_t)^{1-\eta} + \hat{\alpha}_d (r_{M,t})^{1-\eta}]^{\frac{1}{1-\eta}} \end{aligned} \quad (8)$$

where $r_{D,t}$ is the rental rate of capital used for domestic distribution services, $r_{M,t}$ is the rental rate for capital used in import distribution.

3.4 Capital Stocks

There are three separate types of capital in each country, capital used in production, K_t , and capital used in distribution of either domestic or imported goods, $K_{dD,t}$ and $K_{dM,t}$. Capital employed in the production of goods evolves according to the usual capital accumulation equation:

$$K_{t+1} = (1 - \delta) K_t + I_t \quad (9)$$

Distribution capital is earmarked for domestic or imported distribution services. We will consider two cases for how this capital is allocated. In the first case we assume that there is one stock of capital dedicated to distribution. This stock of distribution capital, $K_{d,t}$, evolves according to the following capital accumulation equation:

$$K_{d,t+1} = (1 - \delta) K_{d,t} + \phi \left(\frac{I_{d,t}}{K_{d,t}} \right) K_{d,t} \quad (10)$$

where this distribution capital can be allocated to domestic goods distribution or imported goods distribution, $K_{d,t} = K_{dD,t} + K_{dM,t}$. The adjustment cost for distribution capital is described by the concave function $\phi(\cdot)$ ($\phi' > 0$ and $\phi'' < 0$).

In the second case, the two markets for distribution capital are segmented in the sense that capital cannot be reallocated between the distribution of domestic goods and the distribution of imports. The two types of distribution capital each evolve according to their own capital

accumulation equation:

$$K_{dZ,t+1} = (1 - \delta) K_{dZ,t} + \phi \left(\frac{I_{dZ,t}}{K_{dZ,t}} \right) K_{dZ,t}, \quad Z = D, M. \quad (11)$$

The total investment in distribution capital, $I_{d,t}$, is allocated to investment in domestic or imported goods distribution, $I_{d,t} = I_{dD,t} + I_{dM,t}$.

The difference between these two cases highlights the key mechanism in this paper. In the first case, where there is only one stock of distribution capital, capital can be reallocated between domestic goods distribution and imported goods distribution within the period, and thus the rental rates of these two types of capital must be equal in equilibrium $r_{D,t} = r_{M,t}$. This ensures that in equilibrium the cost of domestic goods distribution is the same as the cost of imported goods distribution, $c_{D,t} = c_{M,t}$.

This first case, where the costs of distribution are equal across goods, is very similar to the distribution sector in Corsetti et al. (2008b). In the second case, where the markets for the two types of distribution capital are segmented, this equality in distribution costs holds in a long-run steady state, but need not hold in the short run. Specifically, this market segmentation forms a friction in the market for distribution services, and it leads to the result that highly substitutable home and foreign goods may appear as poor substitutes in the short run. If there is a sudden shift in international relative prices that makes foreign goods cheaper at the wholesale level, the quantity demanded of imports will increase. However, if distribution capital cannot be reallocated away from domestic goods distribution to imported goods distribution, this increased quantity demanded for imports will strain the existing stock of imported goods distribution capital, leading to a bottleneck in the distribution of imported goods. The cost of imported goods distribution, $c_{M,t}$, will increase, and this will partially reverse the initial fall in the price of foreign goods at the wholesale level.

3.5 Households

The one representative household per country derives utility from consumption and leisure. The household in the home country maximizes expected lifetime utility given by:

$$E_0 \sum_{t=0}^{\infty} \beta_t \frac{1}{1 - \sigma} \left[(1 - h_t)^\theta (C_t)^{1-\theta} \right]^{1-\sigma} \quad (12)$$

where σ is the coefficient of relative risk aversion and $h_t = N_t + N_{dD,t} + N_{dM,t}$.

International asset markets are complete and thus, households share one worldwide bud-

get constraint:

$$\begin{aligned} C_t + I_t + I_{d,t} + Q_t (C_t^* + I_t^* + I_{d,t}^*) \\ = w_t h_t + r_t K_t + r_{D,t} K_{dD,t} + r_{M,t} K_{dM,t} + Q_t (w_t^* h_t^* + r_t^* K_t^* + r_{D,t}^* K_{dD,t}^* + r_{M,t}^* K_{dM,t}^*) \end{aligned} \quad (13)$$

3.6 Productivity

In this real business cycle model, fluctuations in total factor productivity drive business cycle fluctuations. The A_t and A_t^* variables in (4) are exogenous country-specific shocks. Using data on gross value added, total employment, and gross fixed capital formation from the OECD's STAN database, we estimate two series of total factor productivity for the United States and the combination of Germany, France, Italy, the Netherlands, Belgium, Austria, and Finland from 1977-2007. The data is available at annual frequency, we first estimate a VAR(1) with the two series using the annual data, and then we impose symmetry and convert this annual process to a quarterly process. The resulting quarterly shock process for the model is:

$$\begin{bmatrix} A_{t+1} \\ A_{t+1}^* \end{bmatrix} = \begin{bmatrix} 0.83 & 0 \\ 0 & .083 \end{bmatrix} \begin{bmatrix} A_t \\ A_t^* \end{bmatrix} + \begin{bmatrix} \varepsilon_t \\ \varepsilon_t^* \end{bmatrix} \quad (14)$$

where $\text{var}(\varepsilon_t) = \text{var}(\varepsilon_t^*) = 0.12$ and $\text{corr}(\varepsilon_t, \varepsilon_t^*) = 0.31$.

This shock process assumes that TFP is the same across both the production sector and the distribution sector within a country, as in the production functions in (4) and (2). Alternatively we can assume that there is a separate TFP process for the distribution sector, and thus the A_t in (2) is replaced with A_t^d . There are now four TFP processes to estimate, so with the STAN data, instead of considering total value added, total employment, and total capital formation in order to find aggregate TFP, we can consider these same series separated into industry and service sectors. Thus using both industrial and service sector TFP for both the U.S. and Europe, we can estimate a VAR(1) with the four TFP variables, A_t , A_t^* , A_t^d , and A_t^{d*} . Again, this data is available at an annual frequency, so after estimating the annual process, imposing symmetry across countries, and converting to a quarterly process, the resulting shock process for the model is:

$$\mathbf{A}_{t+1} = \rho \mathbf{A}_t + \varepsilon_t$$

where $\mathbf{A}_t = \begin{bmatrix} A_t & A_t^* & A_t^d & A_t^{d*} \end{bmatrix}'$ and $E(\varepsilon_t \varepsilon_t') = \mathbf{\Omega}$, where

$$\rho = \begin{bmatrix} 0.78 & 0.06 & 0.07 & -0.19 \\ 0.06 & 0.78 & -0.19 & 0.07 \\ 0.00 & 0.02 & 0.84 & -0.07 \\ 0.02 & 0.00 & -0.07 & 0.84 \end{bmatrix}$$

and

$$\Omega = 10^{-1} \times \begin{bmatrix} 6.92 & 0.63 & 0.32 & 0.77 \\ 0.63 & 6.92 & 0.77 & 0.32 \\ 0.32 & 0.33 & 0.97 & 0.47 \\ 0.33 & 0.32 & 0.47 & 0.97 \end{bmatrix}$$

4 Model Parameters

A full list of the model's parameters and their values is found in table 2. The first six parameters: θ , the exponent on leisure in the Cobb-Douglas utility function, σ , the coefficient of relative risk aversion, α , the capital share, β , the discount factor, ω , the weight on domestic goods in the Armington aggregator function, and δ , the capital depreciation rate, are all taken from Backus et al. (1994) and found throughout the international real business cycle literature.

4.1 Distribution Sector Parameters

The last four parameters in table 2, γ , α_d , η , and χ are the key parameters in distribution.⁸ To identify these parameters, second moments of the good-specific, location-specific, and good and location-specific components of the final goods estimated in the second section are used in a moment matching exercise.

First calculate the variance, persistence, and the co-movement of each one of the components of the retail price which were identified in the second section. These statistics are presented in table 3.⁹ From the micro-price data we estimate six series of the sector-specific price component (μ_{it}), thirteen series of the location-specific price component (μ_{jt}) and 78

⁸ χ describes the capital adjustment cost for capital used in distribution. Specifically $\chi = \frac{\phi''\left(\frac{I_{dD,t}}{K_{dD,t}}\right) I_{dD,t}}{\phi'\left(\frac{I_{dD,t}}{K_{dD,t}}\right) K_{dD,t}} = \frac{\phi''\left(\frac{I_{dM,t}}{K_{dM,t}}\right) I_{dM,t}}{\phi'\left(\frac{I_{dM,t}}{K_{dM,t}}\right) K_{dM,t}}$.

⁹Since the price data, $\tilde{p}_{ijt}$, is nominal, the first step is to remove the nominal trend. This can be done in a number of different ways, like removing the U.S. CPI, or using a time dummy. There are also non-stationary shifts in relative prices that may complicate any attempt to measure short-run fluctuations of micro-price data. We test the robustness of our estimates of the moments of μ_{it} , μ_{jt} , and $\hat{c}_{ijt}$ to different detrending methods. The details and the results from those robustness tests are presented in the appendix.

series of the sector and location specific component ($\hat{c}_{ijt}$). A simple average of the individual moments from each one of these series is reported in table 3.

Within the model we linearize our retail price index (7) and the marginal cost of distribution (8), then fluctuations in the price of the final good, $\tilde{p}_{ijt}$, may be expressed as a combination of the fluctuations in the wholesale price, $\hat{p}_{it}$, the wage rate (non-sector specific input into distribution in location j), $\hat{w}_{jt}$, and the rental rate for sector-specific distribution capital in the same location, $\hat{r}_{ijt}$:

$$\tilde{p}_{ijt} = (1 - s_i) \hat{p}_{it} + s_i (1 - \alpha_d) \hat{w}_{jt} + s_i \alpha_d \hat{r}_{ijt}$$

The model described in the previous section is solved with a linear approximation and simulated in order to produce moments and impulse responses of key variables. A moment matching exercise is employed to find the combination of γ , α_d , η and χ that minimizes the squared distance between the moments presented in table 3 and the corresponding moments from simulations of the model. This requires simulating the model over a four-dimensional grid. The combination of the four parameters that minimize the square deviation from the estimated moments are listed in the bottom four rows of table 2. The EIU data is available at a yearly frequency, so the moments are calculated from yearly data. The model is a quarterly model, but when considering the second moments of the price components $\hat{w}_t$, $\hat{p}_{it}$, and $\hat{c}_{it}$ for this moment matching exercise, we will use the simulated prices at a yearly frequency.

The optimal combination of γ , α_d , η and χ is chosen by varying all four parameters simultaneously, but to gain some intuition about the separate role of each of these four parameters related to the distribution sector, in table 4 we vary one of these four parameters, while holding the other three constant.

The effect of varying the elasticity of substitution between tangible goods and distribution services, γ , is shown in columns 2-6 from the top half of table 4. The simulated method of moments exercise finds that the optimal value of $\gamma \approx 0$, implying that tangible goods and distribution services are perfect compliments. The table reports the effect of increasing γ while holding all other parameters constant. As γ increases, there is very little change in either the volatility or the persistence of the wage rate, $\hat{w}_t$. However, the relative volatility of both the wholesale price and distribution cost fall as γ increases. In the data, both wholesale prices, $\hat{p}_i$, and distribution costs, $\hat{c}_i$, are about two-thirds as volatile as the wage rate. When wholesale goods and distribution services are perfect compliments, the model is able to replicate these relative volatilities. As γ increases and the two become more substitutable, these relative volatilities fall, when $\gamma = 0.8$, the price of wholesale goods and the cost of distribution are both about a third as volatile as the wage rate. Hence, γ

must be small, implying that wholesale goods and distribution services are compliments, to replicate the volatility of price components that we see in the data. Our estimates of a perfect complementarity between wholesale goods and distribution services largely validates the calibration by Burstein et al. (2003), Burstein et al. (2007), and Corsetti et al. (2008b).

In columns 7-11 of the top half of the table we vary α_d , the capital share in the production of distribution services from 0.16 to 1. Again we see that varying α_d has little effect on the volatility of the wage rate. Allowing the capital share to decrease reduces the relative volatilities of the wholesale price and the distribution costs. The major effect of decreasing α_d is in the co-movement between the wage rate and wholesale prices or between the wage rate and distribution costs. In the data, the correlation between the wage rate and the cost of distribution is about 0.34. When α_d is high, and thus there is very little labor used in distribution, the model predicts that the co-movement between the two should be negative. As α_d decreases and thus there is more labor used in distribution, the correlation between the two will increase. However, as α_d gets too small, the correlation between the two gets too large, so to replicate the positive but modest correlation between the wage rate and the cost of distribution, α_d should be about 0.58.

Similarly, in the data, the correlation between the wage rate and wholesale prices is about -0.27 . In the model, when α_d is large, the two are positively correlated, but as α_d decreases, this correlation falls, but again, to replicate the negative, but modest, correlation, α_d should be about 0.58.

In columns 2-6 of the bottom half of the table we vary η , the elasticity of substitution between capital and labor in the production of distribution services. Again we see that allowing η to vary has little effect on the volatility or the persistence of the wage rate. However, as η increases capital and labor in distribution become more substitutable, and the relative volatilities of both the distribution cost and the wholesale price falls. When η is small, and capital and labor in distribution are nearly perfect compliments, both distribution costs and the wholesale prices should be about as volatile as the wage rate. When η is higher and capital and labor are closer substitutes, these two prices are about half as volatile as the wage rate, in order to match the relative volatilities that we observe in the data, η should be about 0.32.

Finally, columns 7-11 in the bottom half of the table present the results from simulations of the model where χ , the distribution capital adjustment cost parameter varies. Again, allowing χ to vary has little effect on the volatility or the persistence of the wage rate. Note that in contrast to the other three cases in table 4, only when we vary χ do we see any significant effect on persistence. In the data, both the distribution cost and the wholesale price have a first-order autocorrelation coefficient of about 0.45. When $\chi = 0$, implying that

there are no costs to adjusting the stocks of distribution capital, the persistence of these two variables is counterfactually low. Similarly, when χ is low, the relative volatilities of the two prices is too low, the correlation between the wage rate and the cost of distribution is too low, and the correlation between the wage rate and wholesale prices is too high. In order to replicate the moments we observe in the data, the model needs a modest investment adjustment cost parameter of 0.125.

The four distribution parameters are calibrated to ensure that simulations of the model produce the moments of the price components, $\hat{w}_t$, $\hat{p}_{it}$, and $\hat{c}_{it}$, presented in table 3. These model simulations are carried out under the estimated productivity shock process described in section 3. If instead of using the estimated shock process we were to assume a more persistent shock process then the optimal calibrated parameters would change.

The results from this exercise are presented in the online appendix. As the assumed shock persistence increases the calibrated value of the capital adjustment cost parameter, χ_d , increases. The reason for this is simple. This is because as the shock persistence rises, so do the gains from expanding distribution capacity and thus distributors are more willing to pay the adjustment cost. In order to enable simulations of the model to match certain properties of the micro-price data, namely the volatility of the distribution margin, the capital adjustment cost parameter must increase as assumed shock persistence increases. As is shown in the online appendix, when the model is re-simulated with the more persistent shock process and the new optimal value of the capital adjustment cost parameter, the key results do not change.

Of course, in this calibration exercise, the selected parameter values depend on the particular model and shock process. The micro-price data includes prices for hundreds of goods over 13 locations. Each of these good-location observations is potentially subject to its own idiosyncratic fluctuations, arising from everything from demand or taste shocks to measurement error. This data is then used to calibrate a model with two locations and two shocks that conforms to the standard workhorse international real business cycle model. We do acknowledge that the mapping between observed micro-prices and a stylized model of the business cycle is imperfect. Combining these hundreds of goods into six broad sectors eliminates a lot of this idiosyncratic variation.

Since direct observations of the distribution margin are for the most part unavailable, one needs to rely on an indirect empirical strategy. Our empirical justification for distribution capital is based on the observation that the law-of-one-price does not hold at the retail level: there is both a good and a location specific component to prices of traded goods, and the local component displays a lot of volatility and persistence while being imperfectly correlated across sectors. The only way to justify these facts in a model with perfect competition and

the free movement of goods is to introduce a location and sector specific component to the retail goods production technology.

Relaxing the assumption of perfect competition and the free movement of goods segments markets there are mechanisms (including markup variation across markets) through which idiosyncratic demand or taste shocks could explain the same observations. In defense of our assumption, the goods in this micro-price dataset are disproportionately grocery items and the locations are exclusively U.S. cities. Thus, our sample is drawn from a sub-set of the consumption basket that is more likely to be characterized by our maintained assumption of perfect competition and the free movement of goods. There are, of course, many other items in the consumption basket that fail to satisfy these stylized assumptions, such as medical services, non-generic drugs and other trade-marked goods. Models featuring marketing capital, imperfect competition and search, such as in Drozd and Nosal (2012) offer insights into sources of price dispersion in these sectors of the economy, which would be further amplified for cross-border city pairs as emphasized in the voluminous pricing-to-market literature.

Under these assumptions, our results confirm the findings and assumptions in other papers that highlight the role of distribution, like the complementarity between wholesale goods and distribution services in Burstein et al. (2003), Burstein et al. (2007), and Corsetti et al. (2008b). In addition to this, however, our model provides a potential explanation for the elasticity puzzle at the intersection of the international trade and international macro literatures. The fact that the workhorse international real business cycle model, when calibrated to reflect that the law-of-one-price does not hold at the retail level, can explain this puzzle is evidence in favor of the fact that there is a location and sector specific component to distribution capital.

5 Results

5.1 Distribution costs and the observed elasticity of substitution

The elasticity of substitution between home and foreign goods is defined as the percentage change in relative quantities divided by the percentage change in relative prices:

$$\varepsilon_t = \frac{d \ln \left(\frac{y_{M,t}}{y_{D,t}} \right)}{d \ln \left(\frac{p_{D,t}}{p_{M,t}} \right)} \quad (15)$$

To find this elasticity in terms of the model's structural parameters, consider the demand

functions in (6) and find an expression for $\ln\left(\frac{\tilde{y}_{M,t}}{\tilde{y}_{D,t}}\right)$.¹⁰

$$\ln\left(\frac{\tilde{y}_{M,t}}{\tilde{y}_{D,t}}\right) = \ln\left(\frac{1-\omega}{\omega}\right) - \rho \ln\left(\frac{\tilde{p}_{M,t}}{\tilde{p}_{D,t}}\right)$$

If $\tilde{p}_{D,t} = p_{D,t}$ and $\tilde{p}_{M,t} = p_{M,t}$, then the elasticity, ε_t equals the structural parameter ρ . If however, the price of imports relative to domestic goods at the wholesale level varies over time relative to that at the retail level, then the elasticity ε_t becomes a function of other parameters in the model, and in general is time varying.

To see this, expand the elasticity expression in (15):

$$\varepsilon_t = \frac{d \ln\left(\frac{\tilde{y}_{M,t}}{\tilde{y}_{D,t}}\right)}{d \ln\left(\frac{\tilde{p}_{D,t}}{\tilde{p}_{M,t}}\right)} \frac{d \ln\left(\frac{\tilde{p}_{D,t}}{\tilde{p}_{M,t}}\right)}{d \ln\left(\frac{p_{D,t}}{p_{M,t}}\right)} = \rho \frac{d \ln\left(\frac{\tilde{p}_{D,t}}{\tilde{p}_{M,t}}\right)}{d \ln\left(\frac{p_{D,t}}{p_{M,t}}\right)}$$

Thus the change in relative quantities following a change in wholesale prices is the Armington elasticity of substitution between home and foreign goods, ρ , multiplied by the elasticity of relative prices at the consumer level with respect to changes in relative prices at the wholesale level. Given the expressions for the final consumer prices in (7), this elasticity can be written as:

$$\frac{d \ln\left(\frac{\tilde{p}_{D,t}}{\tilde{p}_{M,t}}\right)}{d \ln\left(\frac{p_{D,t}}{p_{M,t}}\right)} \approx \frac{(1-s) d \ln\left(\frac{p_{D,t}}{p_{M,t}}\right) + s d \ln\left(\frac{c_{D,t}}{c_{M,t}}\right)}{d \ln\left(\frac{p_{D,t}}{p_{M,t}}\right)}$$

Thus the observed elasticity of substitution between domestic and imported goods following a change in wholesale prices is:

$$\varepsilon_t = \rho \left((1-s) + s \frac{d \ln\left(\frac{c_{D,t}}{c_{M,t}}\right)}{d \ln\left(\frac{p_{D,t}}{p_{M,t}}\right)} \right)$$

There are two inputs into the production of distribution services, non-sector specific labor and sector specific capital. From equation (8), fluctuations in the ratio of the two distribution

¹⁰The model is calibrated such that γ , the elasticity of substitution between intermediate goods and distribution services is equal to zero. As such, the ratio of imported to domestic goods inclusive of distribution inputs moves in exact proportion to actual trade flows of physical goods: $d \ln\left(\frac{\tilde{y}_{M,t}}{\tilde{y}_{D,t}}\right) = d \ln\left(\frac{y_{M,t}}{y_{D,t}}\right)$. If instead $\gamma > 0$, then the expression linking wholesale quantities and retail quantities will be more complicated, but the intuition is the same.

margins, $d \ln \left(\frac{c_{D,t}}{c_{M,t}} \right)$, can be written as:

$$d \ln \left(\frac{c_{D,t}}{c_{M,t}} \right) = (1 - \alpha_d) d \ln \left(\frac{w_t}{w_t} \right) + \alpha_d d \ln \left(\frac{r_{D,t}}{r_{M,t}} \right) = \alpha_d d \ln \left(\frac{r_{D,t}}{r_{M,t}} \right)$$

Thus the observed elasticity of substitution, ε_t , is:

$$\varepsilon_t = \rho \left((1 - s) + s \alpha_d \frac{d \ln \left(\frac{r_{D,t}}{r_{M,t}} \right)}{d \ln \left(\frac{p_{D,t}}{p_{M,t}} \right)} \right) \quad (16)$$

This expression for the observed elasticity of substitution, ε_t , highlights the difference between the two cases regarding the market for distribution capital described by the capital accumulation equations in (10) and (11). In the case with integrated markets for domestic goods and import distribution capital, capital can be reallocated between the two within the period, and the equality $r_{D,t} = r_{M,t}$ will always hold in equilibrium. Thus the expression for the observed elasticity of substitution becomes $\varepsilon_t = (1 - s) \rho$ as in Corsetti et al. (2008b).

In the second case there are segmented markets for domestic good and import distribution capital. Following the shift in the quantity demanded of imported and domestic wholesale goods, the demand for imported goods distribution services will increase and the demand for domestic goods distribution services will fall. Labor used in the production of distribution services can be reallocated within the period, but distribution capital cannot be reallocated. Thus following a change in relative wholesale prices that leads to an increased demand for imports and a decreased demand for domestic goods, there is an excess demand for imported goods distribution capital and an excess supply of domestic goods distribution capital. This implies that the equilibrium cost of domestic goods distribution capital should fall and the cost of imported goods distribution capital should rise. Thus the following inequality holds in the short run:¹¹

$$\frac{d \ln \left(\frac{r_{D,t}}{r_{M,t}} \right)}{d \ln \left(\frac{p_{D,t}}{p_{M,t}} \right)} < 0$$

Given this excess demand in one market and the excess supply in another, agents will change their future investment plans. Investment in imported goods distribution capital will increase and investment in domestic good distribution capital will decrease.

If there are no adjustment costs in the capital accumulation equations in (11) then plans for investment in new domestic or import distribution capital are changed and the capital

¹¹Empirically, Goldberg and Campa (2010) find that following a 1% exchange rate depreciation that results in a 1% increase in the price of foreign currency denominated imports at the dock, the distribution cost of imports falls by 0.47%.

stocks reach their new efficient level in the next period. If there are capital adjustment costs then the adjustment may be slower and it may take multiple periods to clear out any excess demand or supply in the market for distribution services and reach a point where $r_{D,t} = r_{M,t}$.

Given this change in the relative distribution costs, in the short run $\varepsilon_t < (1 - s)\rho$, and as time passes and capital is reallocated, ε_t approaches $(1 - s)\rho$.

The path of the observed elasticity of substitution following a productivity shock is presented in figure 1. The figure presents the path of the observed elasticity of substitution, as measured by (15) for 40 quarters following a shock in four different cases. The solid line in the figure refers to the case where the Armington elasticity of substitution between home and foreign goods is equal to 4 and there is no distribution sector. The dashed line in the figure refers to the case the Armington elasticity is equal to 0.9 and there is no distribution sector. The dotted line refers to the case where the Armington elasticity is equal to 8 but distribution costs make up approximately 50% of the final cost of a good, and the markets for the two types of distribution capital are integrated. The line with stars refers to the case where the Armington elasticity is equal to 8 but distribution costs make up approximately 50% of the final cost of a good, and the markets for the two types of distribution capital are segmented. The figure on the left presents the observed elasticity of substitution in a model with a stationary shock process, the figure on the right presents the observed elasticity under a near-unit-root shock process.

In the two cases where there is no distribution sector the observed elasticity of substitution is simply equal to the Armington elasticity. When there is a distribution sector but the markets for distribution capital are integrated the observed elasticity is simply a constant and proportional to the Armington elasticity, $\varepsilon_t = (1 - s)\rho$. Thus given the parameter values, the dotted line lies on top of the solid line.

When the markets for the two types of distribution capital are segmented, the observed elasticity is initially close to zero since distribution capital is a state variable and cannot be instantaneously reallocated from the domestic goods sector to the imported goods sector (the reason it isn't exactly zero is that some labor can be shifted into distribution in the high demand sector, but since the elasticity of substitution between capital and labor in the distribution sector is low, the benefits of this labor reallocation are small). Agents cannot reallocate existing capital but can change investment plans subject to investment adjustment costs, so over time capital in one sector is allowed to depreciate without replacement while the stock of distribution capital increases in the other. Over time, as the stocks of distribution capital change, the observed substitutability between home and foreign goods increases.

Since the arguments in the numerator and denominator for the observed elasticity of substitution in (15) are deviations from the steady state, after a while this expression for the

observed elasticity of substitution becomes nonsensical as variables return to their steady-state values in a model with stationary shocks. So while the observed elasticity definitely starts at a low value and increases with time, the elasticity is less precisely measured as the time from the initial shock increases. This is not so when shocks are nearly permanent. Here variables do not return to their steady state values, so the expression for the observed elasticity of substitution remains accurate. The figure shows that in a model with a near unit-root shock process, the observed elasticity of substitution in the model with frictions that prevent the reallocation of distribution capital begins at a low value and over time approaches its horizontal asymptote, $(1 - s)\rho$.

5.2 Impulse Responses

The responses of home and foreign GDP and its components to a positive home TFP shock are presented in figures 2 and 3. Figure 2 presents the responses of home and foreign GDP and investment under the four cases mentioned earlier, where the Armington elasticity, ρ , is equal to 4 and the distribution margin is equal to 0, where the Armington elasticity is equal to 0.9 and the distribution margin is equal to 0, where the Armington elasticity is equal to 8, the distribution margin is set to 50% and there are no frictions in the market for distribution capital, and where the Armington elasticity is equal to 8, the distribution margin is set to 50% and there are frictions in the market for distribution capital. Figure 3 does the same for consumption and net exports.

For the case where the elasticity is equal to 4 but there is no distribution sector, the figures show the familiar result for an international real business cycle model with complete international asset markets and a high degree of substitutability between home and foreign goods. Following a productivity shock in the home country, there is a sharp increase in home investment demand. The foreign country does not have the same increase in investment demand and any increase in foreign investment is tempered in order to ship goods to fuel the productivity induced investment boom in the home country. Thus in the immediate aftermath of the shock, before the benefits of the shock in terms of increased home production are felt, the home country runs a current account deficit and the foreign country runs a current account surplus.

Within a few quarters there is a reversal in the current account as the higher production leads to increased saving in the home country, some of this increased savings is shipped abroad in the form of high home current account surpluses. Thus after the first few quarters, the home country runs a large and persistent current account surplus and the foreign country runs a large and persistent deficit.

The current account dynamics change in significant ways when home and foreign goods are less substitutable. When the elasticity of substitution is equal to 0.9, the foreign goods can't as easily be used to fuel a home country investment boom, so there is more of an increase in foreign investment in the aftermath of the shock. Furthermore, once the increased home productivity leads to an increase in home production and home saving, foreign agents can't as easily consume the benefits of the productivity fueled boom in the home country and thus do not run large current account deficits when substitutability is low.

The responses from the model with a distribution sector but no frictions in distribution are very similar to the responses when the Armington elasticity is equal to 4. In both cases, home and foreign goods are highly substitutable, and the output from one country can easily be consumed in the other country, leading to a large a persistent current account surplus in the country that experiences the positive productivity shock.

The responses from the model with a distribution sector and frictions in distribution are very similar to the responses when the Armington elasticity is equal to 0.9. The observed long-run elasticity of substitution between home and foreign goods may be equal to 4, but in the short run, home and foreign goods are poor substitutes. The figure shows that there is more of an increase in foreign investment in the immediate aftermath of the shock as foreign goods are not as easily diverted for use in the home country investment boom. Furthermore, without adequate distribution channels, foreign agents cannot as easily substitute the excess production from the home country for their own goods, so foreign agents import less and run a smaller trade deficit.

Following a shock to productivity in one country, prices and quantities need to adjust to restore equilibrium. Figures 2 and 3 show that when there is low substitutability between home and foreign goods, there is not much response to net exports following a shock, so it must be that most of the burden of adjustment falls on international relative prices.¹²

Figure 4 shows the responses of the home country terms of trade and the real exchange rate following a positive home TFP shock. When the technological elasticity of substitution is equal to 4 and there is no distribution sector there is little movement in either the terms of trade or net exports following a shock. This is also true when there is a distribution sector, but there are no frictions in distribution. When the elasticity of substitution is equal to 0.9, there is much more movement in both the terms of trade and the real exchange rate. Similarly when the Armington elasticity of substitution is equal to 8 but there are frictions in distribution there is significant movement in both the terms of trade and the real

¹²A similar argument (but one that relied on incomplete pass-through to explain the low substitutability) is given in Devereux and Engel (2002) to explain the high volatility of exchange rates that we observe in the data.

exchange rate following the shock. Thus when there are distribution costs and a distribution sector that is slow to adjust, the economy with a high elasticity of substitution acts a lot like the economy with a low elasticity of substitution, following a shock, quantity variables like exports and imports cannot adjust quickly to restore equilibrium, so the burden of adjustment falls on prices like the terms of trade and the real exchange rate.

5.3 Volatility and co-movement of certain macro variables

The standard deviation and co-movement of GDP, the components of GDP, and international prices like the terms of trade and the real exchange rate are listed in table 5. The first column of the table lists these moments calculated from U.S. data. The data is quarterly from 1984 to 2007. The rest of the table presents these moments as calculated from simulations of the model.

The simulations of the model are conducted under the four alternative parameterizations that were used in the impulse response analysis. The table shows that when the Armington elasticity is equal to 4 and there is no distribution sector, simulations of the model yield too little volatility in both consumption and international prices like the terms of trade or the real exchange rate, a low cross-country co-movement in production variables like output, investment and employment, and a high cross-country co-movement in consumption.

These features of the model were shown earlier in the impulse response analysis. Following a positive shock in one country, the country that experienced the positive shock can easily export their surplus production to the less productive country. This leads to too much consumption smoothing, and since quantities adjust so easily in order to clear markets internationally, there is not much movement in either the terms of trade or the real exchange rate. The high substitutability of home and foreign goods means that agents are willing to change the composition of their consumption basket and take advantage of productivity differentials across countries to maximize total consumption, and this results in a low cross-country correlation in production and a high cross-country correlation in consumption.

When the elasticity of substitution between home and foreign goods is 0.9, the low substitutability between home and foreign goods means that the country that experiences a positive shock cannot as easily export their surplus production to the foreign country. This implies that net exports are less volatile and consumption is more volatile. Lower substitutability means that production responsibilities cannot as easily be "shared" between countries, so cross-country output co-movement is higher and cross-country consumption co-movement is lower.

Given that home and foreign goods are not as easily substitutable, international prices

like the real exchange rate and the terms of trade must move more to restore equilibrium following a shock. The relative volatilities of the terms-of-trade and the real exchange are much higher in the model with the low elasticity than in the model with the high elasticity. It should be noted that the relative volatilities are still far smaller than we observe in the data. This is a common feature of the international real business cycle model. Heathcote and Perri (2002) and Corsetti et al. (2008b) show that this problem of counterfactually small relative volatilities of the terms-of-trade and the real exchange rate is a feature of the international real business cycle model with complete markets. Chari et al. (2002) show that one needs to include sticky prices, preferences that are separable in consumption and leisure, and monetary shocks in order to replicate the relative volatilities of these two prices in a model.

In the version of the model where the Armington elasticity of substitution between home and foreign goods is equal to 8, there is a distribution sector, and there exists one integrated market for both domestic and import distribution capital, the volatility and co-movement from simulations of the model are very close to the moments predicted from the model with the high Armington elasticity. There is a distribution sector in this version of the model, but since distribution capital can be reallocated within the period, there are no frictions to limit the substitutability of home and foreign goods in the short run.

In the version of the model where the Armington elasticity of substitution between home and foreign goods is equal to 8, there is a distribution sector, and there are frictions in distribution due to the segmented markets for domestic and import distribution capital, the volatility and co-movement from simulations of the model are very close to the moments from the model with the low Armington elasticity. Even though the Armington elasticity is high, since distribution channels cannot be adjusted quickly following a shock, at short horizons home and foreign goods are much less substitutable. As a result, net exports are not very volatile, and the model can replicate the high volatility of the real exchange rate and the terms of trade even when the observed long-run elasticity of substitution between home and foreign goods is equal to 4 ($\varepsilon = \rho(1 - s)$). Since home and foreign goods are poor substitutes in the short run, there is less consumption smoothing, lower cross-country consumption correlation, and higher cross-country correlation in output, investment and employment.

As shown by Kehoe and Ruhl (2008), a discrepancy can arise between the definition of real *GDP* in the model and that in the data due to the fact that when calculating real *GDP* in the model, the quantity of imports is multiplied by the terms-of-trade. Kehoe and Ruhl (2008) show how large movements in the terms of trade can thus lead to a change in real *GDP* even though there was no actual change in real activity. Thus when exports and imports

are measured with current prices, there is the possibility that changes in the moments of *GDP* and net exports are not due to an actual change in quantities but are simply due to movements in the terms of trade. Measuring exports and imports with constant prices removes this possibility. The results from these simulations are presented in the appendix. There is no change in this paper’s main results.

5.3.1 The S-curve

As discussed in Backus et al. (1994), the contemporaneous correlation between international relative prices like the terms of trade or the real exchange rate and net exports is low and maybe even negative, and the last two rows of table 5 show that the correlation between the terms of trade and net exports or between the real exchange rate and net exports is negative in the United States. Furthermore, the table shows that simulations of the model where the Armington elasticity is equal to 4 yields a high contemporaneous correlation between relative prices and net exports. In the model, when there is a depreciation in the real exchange rate or the terms of trade that makes home goods relatively less expensive than goods produced abroad, there is an instantaneous improvement in the trade balance.

The table shows that when home and foreign goods are less substitutable, the contemporaneous correlation between relative prices and net exports falls. The model with a low substitutability between home and foreign goods predicts that the contemporaneous correlation between the terms of trade and net exports is about -0.36 .

The version of the model with a distribution sector but no frictions in distribution also leads to a very high correlation between these international relative prices and net exports, reflecting the high elasticity of substitution between home and foreign goods. On the other hand, the model with frictions in distribution can replicate negative correlation between the real exchange rate and net exports. In this model, even though the Armington elasticity is high, frictions in the distribution sector ensure that home and foreign goods are poor substitutes in the short run.

Backus et al. go on to describe the S-curve. The fact that the correlation between the terms of trade at time t and net exports at time $t+n$ looks like a horizontal letter S as n goes from some negative integer to some positive integer. Most importantly, the S-curve shows the fact that the contemporaneous correlation between net exports and international relative prices is negative, but the correlation between relative prices today and net exports at time $t+n$ is positive for some positive n , implying that the immediate impact of an exchange rate depreciation may be a fall in the trade balance, but a depreciation eventually leads to an increase in net exports.

This S-like relationship between relative prices like the real exchange rate or the terms

of trade and lags or leads of net exports is presented in figure 5. The figure shows the correlation between relative prices at time t and net exports at time $t + n$ as observed in the data for the United States and the Euro Area, and as predicted by the four versions of the model.

As observed from the S-curves in the data, the correlation between relative prices at time t and net exports at time $t + n$ is increasing as n increases. Thus there is a negative contemporaneous correlation between either the terms of trade or the real exchange rate and the current value of net exports, but this correlation increases for future values of net exports. When the Armington elasticity is equal to 4 and there is no distribution sector, or when there is a distribution sector but no frictions in distribution, the model cannot replicate this finding. Counterfactually the model finds that the correlation between relative prices at time t and net exports at time $t + n$ falls as n increases.

However, when the short-run substitutability of home and foreign goods is low, either because the Armington elasticity is low or because frictions in the distribution sector hamper substitutability in the short run, the model can replicate the fact that the correlation between relative prices at time t and net exports at time $t + n$ starts at an initially low level and increases as n increases.

5.3.2 Permanent Shocks

The results presented in table 5 are found from simulations of the model under the calibrated shock process in (14). The results under this stationary shock process show that the fact that distribution capital used to distribute domestic goods cannot be reallocated to the distribution of imported goods creates a friction whereby highly substitutable home and foreign goods are actually poor substitutes in the short run.

Rabanal et al. (2011) show that the shock process driving shocks in the U.S. and the rest of the world is well captured by a vector error correction model, implying that shocks driving U.S. and rest of the world business cycles may have a unit-root component. We re-run this exercise using a near unit-root shock process. Specifically we calibrate the model such that the transition matrix in (14) is a 2x2 diagonal matrix with diagonal elements 0.999.

The simulated moments from this calibration of the model are presented in table 6. The table shows that just as before, the model with a distribution sector where frictions prevent the reallocation of distribution capital from domestic goods distribution to imported goods distribution can be calibrated with the high elasticity of substitution from the trade literature but match the short-run business cycle moments from the international macro literature. This international real business cycle model with flexible prices and complete financial markets still cannot replicate the high volatility of these international relative prices

that we observe in the data, but the model with distribution capital and frictions that slow the cross-sector reallocation of this capital leads to a significant increase in the volatility of these relative prices, bringing them more in line with the data than a model without distribution capital.

Figure 6 plots the volatility of the terms of trade as the Armington elasticity increases from 0.4 to 10 (Rabanal et al. (2011) use 0.62, we use 8). We do this for 3 models, the model with no distribution sector, the model with a distribution sector but no frictions to prevent the reallocation of distribution capital in the short run and our benchmark model with a distribution sector, but with frictions preventing the reallocation of distribution capital in the short run. The figure plots the volatility of the terms of trade as a function of the Armington elasticity in each of the three models under the assumption of a near-unit-root shock process and our baseline shock persistence (autoregressive parameters of 0.999 and 0.83). Consistent with the findings of Rabanal et al. (2011), the volatility of the terms of trade increases rapidly as the shocks approach a unit root, but only when the Armington elasticity is very low. In particular, shock persistence has little effect on terms-of-trade volatility when the Armington elasticity is the high value measured by the trade literature.

5.3.3 No capital adjustment costs

In the version of the model where frictions prevent the reallocation of distribution capital from the domestic goods sector to the imported goods sector, when agents want to reallocate the stocks of distribution capital they must increase investment in one sector and decrease investment in the other sector. The capital accumulation equations in (11) assume that there is a cost to adjusting the stock of distribution capital, so reallocation takes multiple periods. In this way, the observed substitutability between home and foreign goods is low in the short run and with time approaches its long-run level.

If instead we assume no costs to capital adjustment, then capital used in distribution is still predetermined, but through investment complete reallocation can be achieved by the next period. In this case, the observed substitutability between home and foreign goods may be low in the period when the shock occurs, but reaches its steady-state level within one period. The volatility and co-movement of GDP and its components under this assumption are presented in table 7. The results in this table show that when there are no costs to adjusting the stocks of distribution capital, the results from the model where frictions prevent the reallocation of distribution capital from domestic goods distribution to imported goods distribution look very similar to the results from the model where there is just one stock of distribution capital that can be reallocated across different goods. Specifically, the model predicts low volatilities of international relative prices, it results in a much higher

co-movement between net exports and GDP , it predicts lower cross-country business cycle co-movement, and it cannot replicate the negative co-movement between international relative prices and net exports. Thus the key feature of the model with distribution capital that allows it to replicate the short-run business cycle moments while still calibrated to match the high Armington elasticity from the trade literature is the slow readjustment of stocks of domestic goods and imported goods distribution capital.

5.3.4 Separate shocks in the production and distribution sectors

The results presented so far have assumed that both the production and distribution sectors within a country are affected by the same country-specific TFP shock. This was done to ensure that the results from the model without the distribution sector could be easily compared with the results from the model with a distribution sector. However, as mentioned in section 3, it may be more realistic to assume that within each country there are two shocks, a production sector shock, A_t , that affects the manufacturing sector, and a service sector shock, A_t^d , that affects the distribution sector. We use data from the OECD's STAN database to calculate country and sector specific TFP processes for both the manufacturing sector and the service sector, and the results from the estimation of this VAR(1) process with these four shocks was presented in section 3.

The results from simulations of this model are presented in table 8. Now the comparison between the model with no distribution sector and the model with a distribution sector is not as easy. Since the shocks to the production sector are more volatile than shocks to the services sector, it is not as clear-cut to compare a model where all of the economy is engaged in manufacturing to one where half is manufacturing and half is distribution.

That said, in the model with both sector- and country-specific shocks, most of the same features of the model with only country-specific shocks continue to hold. Namely the fact that in the model with a high elasticity of substitution, consumption volatility will be counterfactually low, the volatility of the terms of trade and the real exchange rate will be too low, cross-country GDP co-movement will be too low, and cross-country consumption correlation will be too high. These key failings of the model were brought on by the fact that home and foreign goods were too highly substitutable, and thus home and foreign agents could too easily smooth consumption following a county-specific shock. The model with both sector- and country-specific TFP shocks can still lead to key improvements in the ability of the model to match the data since frictions in the distribution sector still hamper the substitutability of home and foreign goods in the short run.

6 Conclusion

In the international macro literature a low elasticity of substitution between home and foreign goods is needed to explain short business cycle fluctuations, particularly movements in international relative prices such as the terms of trade and the real exchange rate. At the same time the international trade literature estimates a high value for this elasticity using data on the longer term change in trade patterns following a change in relative prices.

This paper presents a model that helps to reconcile these two apparently contradictory results. The true elasticity of substitution between home and foreign goods is high, like in the trade literature. However, in the short run there are frictions in distribution that makes home and foreign goods appear much less substitutable in the short run. The model is parameterized to produce this high long-term elasticity, but simulations of the model show that in the short run it behaves like an international macro model parameterized with a low elasticity of substitution. Specifically, the model is able to replicate the short-run volatility of the real exchange rate and the terms of trade. The model can also replicate the negative co-movement between relative prices and both GDP and net exports while still maintaining the high long-run substitutability that would satisfy the international trade literature.

In this model, frictions in the distribution of imported goods produce this time-varying elasticity. These distribution frictions can be thought of as one possible explanation for the larger phenomenon of the low pass through of changes in international relative prices into the relative prices of home and foreign goods at the consumer level. This is closely related, but not identical to the practice of firm pricing-to-market. As reviewed by Drozd and Nosal (2012a), distribution is one of a handful of explanations in the international macroeconomics literature for this pricing-to-market behavior. Pricing-to-market requires market power at the level of the wholesale good firm, and thus they can set a different price for the home and foreign markets. In this paper we have intentionally abstracted from firm market power and pricing-to-market.

By studying the behavior of consumer prices at the level of the individual good across locations, the empirical results in this paper suggest that there is a significant local non-traded component in the retail goods production technology and that there are significant frictions that make this local non-traded component sector specific in the short run. The empirical results in this paper are based on prices for goods in highly competitive markets, where prices are close to marginal costs. This allows us to highlight the retail goods production technology. An interesting direction for further research would be to then combine these insights with the literature that relies on firm market power and pricing-to-market to form a more complete picture of why changes in international relative prices may not fully pass

through into the relative prices of home and foreign goods at the consumer level.

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Table 1: Variance Decompositions of the final goods prices in six sectors

Sector	$1 - s_i$	Total variance $\tilde{p}_{ijt}$	Good-specific $(1 - s_i) \mu_{it}$	City-specific $s_i \mu_{jt}$	Idiosyncratic $s_i \mu_{ijt}$
Food	0.62	0.10	1.28	-0.16	-0.12
Other	0.49	0.09	0.54	-0.09	0.56
Transportation	0.48	0.09	0.16	0.18	0.65
Clothing	0.48	0.15	0.26	0.15	0.59
Utilities	0.19	0.27	0.10	0.28	0.61
Property	0.07	0.31	—	-0.08	1.08
Average	0.39	0.17	0.39	0.05	0.56

Table 2: Parameter Values

Symbol	Value	Description
θ	0.66	weight on leisure in the household's utility function
σ	2	coefficient of relative risk aversion
α	0.36	capital share in the production of traded goods
β	0.99	discount factor
ω	0.85	exogenous preference for home goods
δ	0.025	capital depreciation rate
γ	.0001	elasticity of substitution between wholesale goods and distribution services
α_d	0.58	capital share in distribution costs
η	0.32	elasticity of substitution between capital and labor in distribution
χ	0.125	capital adjustment cost parameter for capital used in distribution

Table 3: Volatility, persistence, and co-movement of the traded and non-traded price components in the micro-price data.

St. Dev.	μ_{jt}	0.12
St. Dev. relative to μ_{jt}	μ_{it}	0.69
	c_{ijt}	0.65
Autocorrelation	μ_{jt}	0.66
	μ_{it}	0.45
	c_{ijt}	0.45
Correlation	μ_{it}, μ_{jt}	-0.27
	c_{ijt}, μ_{jt}	0.34
	μ_{it}, c_{ijt}	-0.44

Table 4: Calibrating the value of the parameters used in distribution

		$\gamma =$							$\alpha_d =$			
		Data	0.00	0.2	0.40	0.60	0.80	1.00	0.79	0.58	0.37	0.16
St. Dev. relative to $\hat{w}_t$	$\hat{w}_t$	0.12	0.56	0.57	0.58	0.59	0.59	0.59	0.56	0.56	0.58	0.62
	$\hat{p}_{it}$	0.69	0.68	0.56	0.49	0.43	0.39	1.05	0.88	0.68	0.50	0.39
	$\hat{c}_{it}$	0.65	0.63	0.51	0.43	0.37	0.33	1.04	0.85	0.63	0.42	0.27
Autocorrelation	$\hat{w}_t$	0.66	0.85	0.83	0.82	0.82	0.81	0.97	0.92	0.85	0.78	0.70
	$\hat{p}_{it}$	0.45	0.48	0.52	0.55	0.58	0.60	0.45	0.45	0.48	0.59	0.86
	$\hat{c}_{it}$	0.45	0.46	0.50	0.54	0.57	0.59	0.45	0.44	0.46	0.54	0.84
Correlation	$\hat{p}_{it}, \hat{w}_t$	-0.27	-0.33	-0.35	-0.35	-0.35	-0.34	0.18	-0.07	-0.33	-0.62	-0.67
	$\hat{c}_{it}, \hat{w}_t$	0.34	0.30	0.30	0.30	0.29	0.28	-0.19	0.04	0.30	0.60	0.72
	$\hat{p}_{it}, \hat{c}_{it}$	-0.44	-0.99	-0.98	-0.98	-0.98	-0.97	-0.99	-0.99	-0.99	-0.97	-0.94
		$\eta =$							$\chi =$			
		Data	0.16	0.24	0.32	0.40	0.48	0.00	0.06	0.125	0.19	0.25
St. Dev. relative to $\hat{w}_t$	$\hat{w}_t$	0.12	0.55	0.55	0.56	0.57	0.57	0.61	0.58	0.56	0.55	0.54
	$\hat{p}_{it}$	0.69	0.81	0.74	0.68	0.64	0.60	0.43	0.61	0.68	0.73	0.77
	$\hat{c}_{it}$	0.65	0.77	0.70	0.63	0.58	0.54	0.37	0.56	0.63	0.68	0.72
Autocorrelation	$\hat{w}_t$	0.66	0.89	0.87	0.85	0.83	0.82	0.85	0.86	0.85	0.84	0.83
	$\hat{p}_{it}$	0.45	0.42	0.45	0.48	0.50	0.53	0.27	0.40	0.48	0.52	0.55
	$\hat{c}_{it}$	0.45	0.40	0.43	0.46	0.48	0.51	0.19	0.37	0.46	0.51	0.54
Correlation	$\hat{p}_{it}, \hat{w}_t$	-0.27	-0.26	-0.30	-0.33	-0.36	-0.38	0.06	-0.23	-0.33	-0.40	-0.44
	$\hat{c}_{it}, \hat{w}_t$	0.34	0.23	0.27	0.30	0.32	0.34	-0.14	0.18	0.30	0.37	0.42
	$\hat{p}_{it}, \hat{c}_{it}$	-0.44	-0.99	-0.99	-0.99	-0.99	-0.98	-0.92	-0.98	-0.99	-0.99	-0.99

Table 5: Volatility and co-movement of GDP and its components in the data and from simulations of the model under different elasticities of substitution and distribution costs.

			Distribution	No	No	Yes	Yes
			Elasticity	4	0.9	8	8
			Frictions	N/A	N/A	No	Yes
St. Dev.	GDP	Data		0.75	0.70	0.60	0.55
	NX	0.28		0.19	0.14	0.05	0.08
Volatility Relative to GDP	C	0.89		0.23	0.27	0.26	0.30
	I	3.14		3.84	3.67	4.68	4.49
	N	0.85		0.55	0.53	0.40	0.30
	Ex	3.86		1.16	1.02	0.82	1.04
	Im	3.37		1.13	1.13	0.71	1.30
	Tot	2.14		0.16	0.40	0.35	1.02
	Q	4.14		0.11	0.28	0.16	0.37
Co-movement with GDP	C	0.84		0.91	0.92	0.89	0.92
	I	0.91		0.96	0.98	0.98	0.98
	NX	-0.41		-0.42	-0.53	0.48	-0.49
	N	0.81		0.99	0.99	0.97	0.98
	Ex	0.54		0.26	0.41	0.86	0.09
	Im	0.82		0.87	0.99	0.25	0.83
	Tot	0.29		0.27	0.41	0.59	0.50
	Q	-0.02		0.27	0.41	0.37	0.45
Cross-country co-movement	GDP	0.52		0.26	0.42	0.25	0.50
	C	0.76		0.61	0.36	0.64	0.46
	I	0.67		-0.12	0.09	-0.04	0.25
	N	0.47		0.17	0.44	-0.17	0.77
	Ex	0.63		-0.07	0.36	-0.19	-0.39
Correlation	Tot,NX	-0.13		0.34	-0.65	0.93	-0.97
	Q,NX	-0.05		0.34	-0.65	0.96	-0.81

Notes: The statistics taken from the data are from quarterly U.S. data from 1984-2007. The cross-country statistics are between the U.S. and the Euro Area. Notes: All variables, both from the data and those from model simulations, are logged (except NX) and HP filtered with a smoothing parameter of 1600.

Table 6: Volatility and co-movement of GDP from simulations of the model under different elasticities of substitution and distribution costs and a near permanent shock process.

		Distribution	No	No	Yes	Yes
		Elasticity	4	0.9	8	8
		Frictions	N/A	N/A	No	Yes
St. Dev.	GDP		0.69	0.55	0.58	0.52
	NX		0.22	0.04	0.06	0.10
Volatility Relative to GDP	C		0.49	0.67	0.64	0.75
	I		3.66	2.11	3.47	2.82
	N		0.45	0.23	0.33	0.16
	Ex		1.31	0.91	1.07	1.28
	Im		1.25	1.09	0.89	1.70
	Tot		0.22	1.08	0.41	1.22
	Q		0.15	0.76	0.26	0.67
Co-movement with GDP	C		0.84	1.00	0.88	0.98
	I		0.89	0.99	0.89	0.91
	NX		-0.44	-0.45	0.57	-0.38
	N		0.91	0.98	0.79	0.72
	Ex		0.04	0.94	0.91	0.29
	Im		0.79	0.99	0.24	0.77
	Tot		0.28	0.45	0.64	0.51
Cross-country co-movement	Q		0.28	0.45	0.55	0.54
	GDP		-0.01	0.58	0.12	0.41
	C		0.88	0.59	0.88	0.74
	I		-0.72	0.35	-0.69	-0.41
	N		-0.74	0.55	-0.94	-0.64
Correlation	Ex		-0.42	0.93	-0.15	-0.25
	Tot,NX		0.48	-0.93	0.96	-0.89
	Q,NX		0.48	-0.93	1.00	-0.76

Notes: All variables are logged (except NX) and HP filtered with a smoothing parameter of 1600.

Table 7: Volatility and co-movement of GDP and its components from simulations of the model. Simulated assuming there are no costs to adjusting the stock of distribution capital.

		Distribution	Yes	Yes
		Elasticity	8	8
		Frictions	No	Yes
St. Dev.	GDP		0.62	0.61
	NX		0.04	0.08
Volatility Relative to GDP	C		0.24	0.25
	I		6.01	6.07
	N		0.45	0.43
	Ex		0.82	1.17
	Im		0.74	1.11
	Tot		0.28	0.59
	Q		0.17	0.18
Co-movement with GDP	C		0.85	0.85
	I		0.35	0.40
	NX		0.31	−0.11
	N		0.99	0.98
	Ex		0.82	0.41
	Im		0.58	0.62
	Tot		0.56	0.41
	Q		0.31	0.34
Cross-country co-movement	GDP		0.29	0.36
	C		0.59	0.60
	I		0.27	0.31
	N		0.10	0.25
	Ex		0.35	−0.31
Correlation	Tot,NX		0.79	−0.69
	Q,NX		0.85	0.44

Notes: All variables are logged (except NX) and HP filtered with a smoothing parameter of 1600.

Table 8: Volatility and co-movement of GDP and its components in the data and from simulations of the model under different elasticities of substitution and distribution costs. Simulated assuming separate shocks for the production and distribution sectors.

		Distribution	No	No	Yes	Yes
		Elasticity	4	0.9	8	8
St. Dev.	GDP	Frictions	N/A	N/A	No	Yes
			0.75	0.70	0.70	0.55
	NX		0.19	0.14	0.44	0.14
Volatility Relative to GDP	C		0.23	0.27	0.21	0.28
	I		3.84	3.67	4.61	5.41
	N		0.55	0.53	0.57	0.77
	Ex		1.16	1.02	4.38	2.30
	Im		1.13	1.13	4.49	2.49
	Tot		0.16	0.40	1.44	4.58
	Q		0.11	0.28	0.17	0.34
Co-movement with GDP	C		0.91	0.92	0.79	0.88
	I		0.96	0.98	0.51	0.65
	NX		-0.42	-0.53	0.57	-0.09
	N		0.99	0.99	0.53	0.15
	Ex		0.26	0.41	0.53	-0.11
	Im		0.87	0.99	-0.56	0.03
	Tot		0.27	0.41	0.60	0.02
Cross-country co-movement	Q		0.27	0.41	-0.25	0.26
	GDP		0.26	0.42	0.12	0.78
	C		0.61	0.36	0.74	0.57
	I		-0.12	0.09	0.60	0.85
	N		0.17	0.44	0.10	-0.03
Correlation	Ex		-0.07	0.36	-0.82	0.02
	Tot,NX		0.34	-0.65	1.00	-0.96
	Q,NX		0.34	-0.65	-0.67	-0.77

Notes: All variables are logged (except NX) and HP filtered with a smoothing parameter of 1600.

Figure 1: Observed Elasticity of Substitution following a TFP shock. The solid line and the dashed line represent the model with no distribution and where the Armington elasticity is equal to 4 and 0.9, respectively. The dotted line and the line with stars represent the model where the structural elasticity is equal to 8 and there is distribution. In the dotted line distribution capital can be reallocated across sectors within the period. In the line with stars frictions prevent the reallocation of distribution inputs in the short run.

Figure 2: The responses of home and foreign GDP and investment to a positive home TFP shock. The solid line and the dashed line represent the model with no distribution and where the Armington elasticity is equal to 4 and 0.9, respectively. The dotted line and the line with stars represent the model where the structural elasticity is equal to 8 and there is distribution. In the dotted line distribution capital can be reallocated across sectors within the period. In the line with stars frictions prevent the reallocation of distribution inputs in the short run.

Figure 3: The responses of home and foreign consumption and net exports to a positive home TFP shock. The solid line and the dashed line represent the model with no distribution and where the Armington elasticity is equal to 4 and 0.9, respectively. The dotted line and the line with stars represent the model where the structural elasticity is equal to 8 and there is distribution. In the dotted line distribution capital can be reallocated across sectors within the period. In the line with stars frictions prevent the reallocation of distribution inputs in the short run.

Figure 4: The response of the home country terms of trade and the real exchange rate to a positive home TFP shock. The solid line and the dashed line represent the model with no distribution and where the Armington elasticity is equal to 4 and 0.9, respectively. The dotted line and the line with stars represent the model where the structural elasticity is equal to 8 and there is distribution. In the dotted line distribution capital can be reallocated across sectors within the period. In the line with stars frictions prevent the reallocation of distribution inputs in the short run.

Figure 5: The correlation between relative prices and lagged values of net exports. The solid line and the dashed line represent the model with no distribution and where the Armington elasticity is equal to 4 and 0.9, respectively. The dotted line and the line with stars represent the model where the structural elasticity is equal to 8 and there is distribution. In the dotted line distribution capital can be reallocated across sectors within the period. In the line with stars frictions prevent the reallocation of distribution inputs in the short run.

Figure 6: The standard deviation of the terms-of-trade as a function of the Armington elasticity in each of the three models. The blue lines represent the model with no distribution sector. The green lines represent the model where there is a distribution sector, but where distribution capital can be reallocated across sectors within the period. The red lines represent the model where there is a distribution sector, but distribution capital cannot be reallocated across sectors within the period. The solid lines represent the model under near-unit-root shocks and the dashed lines represent a stationary shock process.