NBER WORKING PAPER SERIES

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Working Paper 18753
http://www.nber.org/papers/w18753

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
February 2013

This paper was begun while Davis was a visiting researcher at the Bank of Estonia and while Crucini was a visiting Senior Fellow at the Globalization and Monetary Policy Institute, Federal Reserve Bank of Dallas. We would like to thank participants at the 2011 Midwest Macro Meetings and the 2012 meetings of the System Committee for International Economic Analysis at the Federal Reserve Bank of San Francisco, the 2013 North American Meetings of the Econometric Society, the 2013 Shanghai Macro Workshop, and the 2013 meeting of the Society for Economic Dynamics. In addition we would like to thank George Alessandria, Aurelijus Dabušinskas, Mick Devereux, Jonathan Heathcote, Finn Kydland, Sylvain Leduc, Andrea Raffo, Jian Wang, Lenno Uusküla and Mark Wynne for many helpful comments and suggestions. The views in this paper are those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of Dallas, the Federal Reserve System, or the National Bureau of Economic Research. Mario Crucini acknowledges the generous financial support of the National Science Foundation (SES #1030164).

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NBER Working Paper No. 18753
February 2013, Revised August 2013
JEL No. F1,F14,F44

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 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 one of the most important parameters in dynamic equilibrium models of international trade and business cycles. The parameter determines how quantities adjust in response to a change in relative prices, and thus determines how quantities of imports and exports adjust after a shift in the real exchange rate. Trade models rely on this parameter to determine the effect of trade policy and tariff rates on trade flows and welfare. Macro models rely on this parameter to determine the business cycle effects of certain macro shocks and the business cycle properties of international macro models.

The problem, as highlighted in Ruhl (2005) and Arkolakis, Eaton and Kortum (2012), is that the trade literature and the international macro literature don't agree on the value of this parameter. Macro models, which are concerned with short-run fluctuations, generally ascribe a low value to this parameter. In the workhorse international real business cycle model, Backus, Kehoe and Kydland (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 for values of the elasticity that are 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 specification, and thus an elasticity of 1, to aggregate home and foreign goods. Heathcote and Perri (2002) estimate the Armington elasticity from an equation that links changes in the real exchange rate to changes in net exports and relative production. They estimate a value of the Armington elasticity of around 0.9. Corsetti, Dedola and Leduc (2008) use a value of around 0.85. They arrive at this value by calibrating their model to match certain features of the data, most notably the second moments of international relative prices like the real exchange rate and the terms of trade. Enders, Müller and Scholl (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, Liebman and Wilson (1999) use quarterly data and find an average elasticity of about 0.81. Hooper, Johnson and Marquez (1998) and Gallaway, McDaniel and Rivera (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.

On the trade side, in their survey of the literature on trade costs, Anderson and van

Wincoop (2004) find 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 somewhere 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.

The discrepancy between short- and long-run estimates of the elasticity of substitution is closely related to the literature on the J-curve. As noted in Junz and Rhomberg (1973) and Magee (1973), after a change in international relative prices, like an exchange rate depreciation, quantities do not always adjust instantaneously. This is closely related to the famous Marshall-Lerner condition, which states that in order for a currency depreciation to lead to an improvement in the trade balance, the sum of the absolute values of the import demand elasticity and export demand elasticity must be greater than one. If the sum of the elasticities is smaller than one in the short run then the currency depreciation will actually lead to a worsening of the trade balance, but if the elasticities get larger with time, then the trade balance should improve in the long run following an exchange rate depreciation.[1]

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 this paper, traded goods need to be combined with a local non-traded component (distribution services) before they can be consumed. Frictions and bottlenecks within this distribution sector may lead to the slow adjustment of quantities following a change in relative prices.

By explicitly modeling a distribution sector, this paper is similar to Burstein, Neves and Rebelo (2003), Burstein, Eichenbaum and Rebelo (2005; 2007), Corsetti and Dedola (2005) and Corsetti, Dedola and Leduc (2008). These authors discuss how the observed import demand elasticity is different from the Armington elasticity of substitution when the cost of a local non-traded component makes up a large part of the cost of an imported good.[2]

[1] See Bahmani-Oskooee and Bolhasani (2008) and Boyd, Caporale and Smith (2001) for empirical evidence of a J-curve effect and evidence that the Marshall-Lerner condition holds in the long run but may not hold in the short run. See also Rose (1991) for evidence that the Marshall-Lerner condition does not hold and that the trade balance is largely independent of movements in the real exchange rate in at least the first two years following a change in the exchange rate.

[2] Anderson and van Wincoop (2004) report that distribution costs are responsible for 55% of the final

However, unlike these models, we assume that the inputs that are used for the distribution of domestic goods can't be reallocated to the distribution of imported goods in the short run. The technological elasticity of substitution between home and foreign goods may be high and they may be highly substitutable in the long run after the inputs used in distribution can be reallocated, but in the short run frictions in distribution may limit the response of relative quantities to a change in relative prices, making home and foreign goods appear as poor substitutes.

If in response to a positive foreign shock, home agents try to rapidly increase their purchases of imports, they strain the supply of this local component and face a steeply increasing marginal cost curve. In the short run the increasing marginal cost of the non-traded component largely cancels out the fall in the price of the imported good. As a result, the final prices paid by consumers may barely change in the short run in response to a change in relative price of imports.[3] As time passes, the supply of the non-traded component is able to adjust more easily and thus there is a greater response to the quantity of imports following a change in their relative wholesale price.

The rest of this paper is organized as follows. The model is presented in section 2. In the version of the model without local non-traded inputs, the model collapses to the benchmark IRBC model in Backus, Kehoe and Kydland (1994). The benchmark calibration of the model is presented in section 3. Here we will pay particular attention to the calibration of the key parameters involved in the distribution sector, and how the value of these parameters can be inferred from micro-data on prices. The results from the different versions of the model are presented in section 4. 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. Only the version of the model with a high elasticity of substitution but an inelastically supplied local non-traded component can replicate both the short-run properties of aggregate prices and quantities that we observe in the data while also reproducing the observed long-run import demand elasticity. Finally,

price of an imported good, Berger et al. (2012) argue that the distribution margin is between $50 - 70\%$.

[3] Thus the mechanism in the model is similar to that in any model where a change in relative prices at the wholesale level doesn't pass through into final prices. Campa and Goldberg (2005) and many other papers document the low pass through of exchange rate changes into import prices. Drozd and Nosal (2012) construct a search model where sales require some marketing capital. In this search framework, consumers initially may not notice a change in the relative price of imported goods. In their model, marketing capital is acquired slowly but can be lost quickly. As such, sellers have an incentive to keep transitory price changes from passing through into final goods prices.

section 5 concludes.

2 The Model

2.1 Production

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.

An aggregate good is used by households for consumption, C_t, investment in production capital, I_t, and investment in distribution capital, $I_{d,t}$. This aggregate good, y_t, is formed through the combination of domestic and imported retail goods, which are combined in an Armington (1969) aggregator function with an elasticity of substitution ρ.

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

where $\tilde{y}_{D,t}$ is the retail quantity of domestically produced goods and $\tilde{y}_{M,t}$ is the retail quantity of imported goods.

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

$$\begin{aligned} \tilde{y}_{D,t} &= \omega (\tilde{p}_{D,t})^{-\rho} y_t \\ \tilde{y}_{M,t} &= (1-\omega)(\tilde{p}_{M,t})^{-\rho} y_t \end{aligned} \tag{2}$$

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.

Substituting these demand functions into the aggregator function in (1) yields:

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

The retail quantity of the domestic good, $\tilde{y}_{D,t}$, is formed from the combination of a quantity of the domestic good, $y_{D,t}$, and good specific distribution services $d_{D,t}$.

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

where κ is the weight on distribution services, and γ is the elasticity of substitution between tangible goods and distribution. This same production technology is used to define $\tilde{y}_{M,t}$:

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

where $y_{M,t}$ is the quantity of imported goods, and $d_{M,t}$ are distribution services employed in the distribution of these imports. In the functions for $\tilde{y}_{D,t}$ and $\tilde{y}_{M,t}$, when $\kappa = 0$, the technology for domestic goods condenses to $\tilde{y}_{D,t} = y_{D,t}$ and $\tilde{y}_{M,t} = y_{M,t}$, and the model collapses to Backus et al. (1994). From this production function, the retail prices of domestic and imported goods relative to the home aggregate price deflator are:

$$\begin{aligned} \tilde{p}_{D,t} &= \left[(p_{D,t})^{1-\gamma} + \kappa (c_{D,t})^{1-\gamma} \right]^{\frac{1}{1-\gamma}} \\ \tilde{p}_{M,t} &= \left[(p_{M,t})^{1-\gamma} + \kappa (c_{M,t})^{1-\gamma} \right]^{\frac{1}{1-\gamma}} \end{aligned} \tag{3}$$

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.

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.

Wholesale goods used domestically or exported to the foreign country, $y_{D,t}$ and $y_{M,t}^*$, exhaust current period production:

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

where N_t and K_t are labor and capital employed in the production of home country goods, and A_t is a country specific total factor productivity parameter.

From this production function, the demand for labor and capital are given by $N_t = (1-\alpha) \frac{MC_t}{w_t} \left(y_{D,t} + y_{M,t}^* \right)$ and $K_t = \alpha \frac{MC_t}{r_t} \left(y_{D,t} + y_{M,t}^* \right)$ 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 $MC_t = \frac{1}{A_t} \left(\frac{w_t}{1-\alpha} \right)^{1-\alpha} \left(\frac{r_t}{\alpha} \right)^{\alpha}$.

Domestic distribution services employed in the final sales of domestic and imported goods,

$d_{D,t}$ and $d_{M,t}$, are given by:

$$
\begin{aligned}
d_{D,t} &= A_t \left[(1-\hat{\alpha}_d)^{\frac{1}{\eta}} (N_{dD,t})^{\frac{\eta-1}{\eta}} + (\hat{\alpha}_d)^{\frac{1}{\eta}} (K_{dD,t})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \\
d_{M,t} &= A_t \left[(1-\hat{\alpha}_d)^{\frac{1}{\eta}} (N_{dM,t})^{\frac{\eta-1}{\eta}} + (\hat{\alpha}_d)^{\frac{1}{\eta}} (K_{dM,t})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}
\end{aligned}
\tag{5}
$$

where $N_{dD,t}$ and $K_{dD,t}$ are the labor and capital employed in the distribution of domestic goods, and $N_{dM,t}$ and $K_{dM,t}$ are the labor and capital employed in the distribution of imported goods.[4]

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

$$
\begin{aligned}
c_{D,t} &= \frac{1}{A_t} \left[(1-\hat{\alpha}_d)(w_t)^{1-\eta} + \hat{\alpha}_d (r_{D,t})^{1-\eta} \right]^{\frac{1}{1-\eta}} \\
c_{M,t} &= \frac{1}{A_t} \left[(1-\hat{\alpha}_d)(w_t)^{1-\eta} + \hat{\alpha}_d (r_{M,t})^{1-\eta} \right]^{\frac{1}{1-\eta}}
\end{aligned}
\tag{6}
$$

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. The demand functions for capital and labor in the distribution of both domestic and imported goods are given by $K_{dD,t} = (1-\hat{\alpha}_d)\left(\frac{r_{D,t}}{c_{D,t}}\right)^{-\eta} \frac{d_{D,t}}{A_t^{1-\eta}}$, $K_{dM,t} = (1-\hat{\alpha}_d)\left(\frac{r_{M,t}}{c_{M,t}}\right)^{-\eta} \frac{d_{M,t}}{A_t^{1-\eta}}$, $N_{dD,t} = \hat{\alpha}_d \left(\frac{w_t}{c_{D,t}}\right)^{-\eta} \frac{d_{D,t}}{A_t^{1-\eta}}$, $N_{dM,t} = \hat{\alpha}_d \left(\frac{w_t}{c_{M,t}}\right)^{-\eta} \frac{d_{M,t}}{A_t^{1-\eta}}$.

2.2 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:

$$
E_0 \sum_{t=o}^{\infty} \beta_t \frac{1}{1-\sigma} \left[(1-h_t)^{\theta} (C_t)^{1-\theta} \right]^{1-\sigma}
\tag{7}
$$

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

We assume that international asset markets are complete. We can model this by assuming

[4] $\hat{\alpha}_d$ 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 3 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 $\hat{\alpha}_d$.

households share one worldwide budget constraint:

$$\begin{aligned} & C_t + I_t + I_{d,t} + q_t \left(C_t^* + I_t^* + I_{d,t}^* \right) \\ = \; & w_t h_t + r_t K_t + r_{D,t} K_{dD,t} + r_{M,t} K_{dM,t} + q_t \left(w_t^* h_t^* + r_t^* K_t^* + r_{D,t}^* K_{dD,t}^* + r_{M,t}^* K_{dM,t}^* \right). \end{aligned} \tag{8}$$

2.3 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:

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

Distribution capital is earmarked for domestic or imported distribution services. We will consider two cases about how this capital is allocated for distribution of domestic or imported goods. 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:

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

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:

$$\begin{aligned} K_{dD,t+1} &= (1 - \delta) K_{dD,t} + \phi \left(\frac{I_{dD,t}}{K_{dD,t}} \right) K_{dD,t} \\ K_{dM,t+1} &= (1 - \delta) K_{dM,t} + \phi \left(\frac{I_{dM,t}}{K_{dM,t}} \right) K_{dM,t} \end{aligned} \tag{11}$$

where 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, Dedola and Leduc (2008).

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 this 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 make 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 or potentially completely offset the initial fall in the price of foreign goods at the wholesale level.

3 Calibration

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.

In the next section, simulations of the model under different values of the Armington elasticity, ρ, and the parameter controlling the distribution share, κ, are used to examine the importance of the distribution sector in affecting the substitutability of home and foreign traded goods. The rest of the model's parameters and their benchmark values are found in table 1.

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, Kehoe and Kydland (1994) and found throughout the international real business cycle literature.

The next four parameters, γ, α_d, η, and χ are the key parameters in distribution.[5] To

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

identify these parameters, we will calculate certain second moments of wholesale prices and distribution margins from the data and then calibrate the value of these four parameters so that the model can match specific moments of the data.

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 data-set is described in Crucini and Landry (2012). The dataset covers over 300 goods, but we exclude the goods that are very close to the definition of a non-traded good (like domestic cleaning help), and aggregate the remaining goods into four sectors, grocery items, non-food consumer goods, clothing, and transportation. The full list of goods in the dataset and how they are grouped into four categories is presented in the appendix. We restrict our attention to 13 U.S. cities, the list of these 13 cities is also presented in the appendix.

Before we discuss how the data is used, consider the price indices for the retail price and the marginal cost of distribution in (3) and (6). If we linearize these price indices, then the fluctuations in the final good price, $\tilde{p}_{it}$, can be expressed as a combination of the fluctuations in the wholesale price, $\hat{p}_{it}$, the wage rate (non-sector specific input into distribution), $\hat{w}_t$, and the rental rate for sector specific distribution capital, $\hat{r}_{it}$:

$$\tilde{p}_{it} = (1-s)\,\hat{p}_{it} + s\,(1-\alpha_d)\,\hat{w}_t + s\alpha_d \hat{r}_{it}$$

where s measures the steady state distribution margin, $s = \kappa \left(\frac{c_D}{\tilde{p}_D}\right)^{1-\gamma} = \kappa \left(\frac{c_M}{\tilde{p}_M}\right)^{1-\gamma}$.

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 Landry (2012) also provide data on the distribution margin for each good in the dataset, s_i.[6] Given these prices and the distribution margins we can estimate the following regression:

$$\tilde{p}_{ijt} = (1-s_i)\,\mu_{it} + s_i\mu_{jt} + s_i\mu_{ijt} \tag{12}$$

where μ_{it} is sector specific fixed effect intended to capture variation in wholesale prices ($\hat{p}_{it}$), and μ_{jt} is a city-fixed effect intended to capture variation in the city, but not good specific component of distribution ($\hat{w}_t$). Furthermore we can calculate the total distribution cost, $\hat{c}_{it} = \frac{\tilde{p}_{ijt}-(1-\kappa_i)\mu_{it}}{\kappa_i}$.

With time series of $\hat{w}_t$, $\hat{p}_{it}$, $\hat{c}_{it}$ we can calculate the variance, the persistence, and the co-movement of each one of the components of the retail price. These statistics are presented in table 2. In this table, these statistics are computed using a few different detrending methods. The price data, $\tilde{p}_{ijt}$, is nominal, so the first step is to remove the nominal trend. In columns 1-3, the nominal trend is removed by including a time dummy in the regression in equation (12). In columns 4-6, the nominal trend is removed by dividing all prices by the consumer

[6] The distribution margins, s, are good specific, but is common across all locations and time.

price index, and in columns 7-9, there is no nominal detrending. Comparing each set of three columns shows that nominal detrending really doesn't have much of an effect on these statistics. This is due to the fact that the data is taken from 13 U.S. cities over the period 1990-2005, a period when inflation was low and stable.

But even after taking out a nominal trend, over this period there have been shifts in relative productivity between sectors, which would lead to non-stationary relative price changes that we would want to filter out before using the data to calibrate a stationary model (e.g. productivity improvements in the technology sector have led to a non-stationary fall in the relative price of computers over this period). To account for these non-stationary shifts in sectoral prices, we can either filter the sectoral price data, $\tilde{p}_{ijt}$, using an HP filter (with smoothing parameter 100 for annual data) or taking first-differences. Thus within each set of three columns in table 2, the first column filters each sectoral price with an HP filter, the second uses first-differences, and the third does nothing.

The first thing to notice is that the wholesale goods price, $\hat{p}_{it}$, is extremely volatile when no filter is used. This is due to non-stationary shifts in relative prices across sectors. Once we use a filter to remove these non-stationary shifts in relative prices, the results in the table are largely invariant to which filter we use. The only noticeable difference is that the first-order autocorrelation coefficient is much lower using the first-differenced data, but all other statistics are largely the same. Thus in the following calibration exercise, we simply use the first column, the data using the time dummy for nominal detrending and the HP filter for additional detrending, as the benchmark set of statistics.

Simulated method of moments are employed to find the combination of γ, α_d, η and χ that minimizes the squared distance between the moments presented in the first column of table 2 and the corresponding moments from simulations of the model. These estimated parameters are listed in the bottom four rows of table 1.

The 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 tables 3 and 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 of table 3. The simulated method of moments exercise finds that the optimal value of γ is 0.02, implying that tangible goods and distribution services are nearly 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 costs falls 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 nearly 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 prices that we see in the data. Our estimates of a near perfect complementarity between wholesale goods and distribution services largely validates the calibration by Burstein, Neves and Rebelo (2003), Burstein, Eichenbaum and Rebelo (2007), and Corsetti, Dedola and Leduc (2008).

In columns 7-11 of the same table we vary α_d, the labor share in the production of distribution services from 0.16 to 0.56. Again we see that varying α_d has little effect on the volatility or persistence of the wage rate. Allowing the labor share to increase does have some effect on the relative volatilities of the wholesale price and the distribution costs, but the major effect of increasing 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 small, and thus there is very little labor used in distribution, the model predicts that the co-movement between the two should be almost 0. As α_d increases and thus there is more labor used in distribution, the correlation between the two will increase. However, as α_d gets too big, 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 0.36.

Similarly, in the data, the correlation between the wage rate and wholesale prices is about -0.27. In the model, when α_d is small, the two are nearly uncorrelated, but as α_d increases, this correlation falls, but again, to replicate the negative, but modest, correlation, α_d should be about 0.36.

In columns 2-6 of table 4 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 0.4.

Finally, columns 7-11 of table 4 present the results from simulation 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 tables 3 and 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 0.82. 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 0.18.

3.1 Shock Process

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:

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

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 (5). Alternatively we can assume that there is a separate TFP process for the distribution sector, and thus the A_t in (5) 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:

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

where $\mathbf{A}_t = \left[\begin{array}{cccc} A_t & A_t^* & A_t^d & A_t^{d*} \end{array}\right]'$ and $E\left(\boldsymbol{\varepsilon}_t\boldsymbol{\varepsilon}_t'\right) = \mathbf{\Omega}$, where

$$\boldsymbol{\rho} = \left[\begin{array}{cccc} 0.78 & 0.06 & 0.07 & -0.19 \\ 0.06 & 0.78 & -0.19 & 0.07 \\ 0.00 & 0.02 & 0.84 & -0.07 \\ 0.02 & 0.00 & -0.07 & 0.84 \end{array}\right]$$

and

$$\mathbf{\Omega} = \mathbf{10}^{-1} \times \left[\begin{array}{cccc} 6.92 & 0.63 & 0.32 & 0.77 \\ 0.63 & 6.92 & 0.77 & 0.32 \\ 0.32 & 0.33 & 0.97 & 0.47 \\ 0.33 & 0.32 & 0.47 & 0.97 \end{array}\right]$$

4 Results

4.1 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:

$$\varepsilon_t = \frac{d\ln\left(\frac{y_{M,t}}{y_{D,t}}\right)}{d\ln\left(\frac{p_{D,t}}{p_{M,t}}\right)} \tag{13}$$

To find this elasticity in terms of the model's structural parameters, consider the demand functions in (2) and find an expression for $\ln\left(\frac{\tilde{y}_{M,t}}{\tilde{y}_{D,t}}\right)$:[7]

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

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

[7] The model is calibrated such that γ, the elasticity of substitution between intermediate goods and distribution services is equal to zero. In this derivation of the observed elasticity of substitution we are using that fact in order to simplify and say $d\ln\left(\frac{\tilde{y}_{M,t}}{\tilde{y}_{D,t}}\right) = d\ln\left(\frac{y_{M,t}}{y_{D,t}}\right)$. If instead $\gamma > 0$, then the expression linking wholesale quantities and retail quantities will be more complicated, but the intuition is the same.

time relative to that at the retail level, then the elasticity ε_t becomes a function of other parameters in the model, and generally time varying.

To see this, expand the elasticity expression in (13):

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

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.[8] Given the expressions for the final consumer prices in (3), 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 (6), fluctuations in the ratio of the two distribution margins, $d\ln\left(\frac{c_{D,t}}{c_{M,t}}\right)$, can be written as:

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

Thus the observed elasticity of substitution, ε_t, is:

$$\varepsilon_t = \rho\left((1-s) + s(1-\alpha_d)\frac{d\ln\left(\frac{r_{D,t}}{r_{M,t}}\right)}{d\ln\left(\frac{p_{D,t}}{p_{M,t}}\right)}\right) \tag{14}$$

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

[8]See Crucini and Yilmazkuday (2009) for empirical evidence using micro-level price data of how distribution costs lead to a long-run disconnect between producer and consumer prices.

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 $\varepsilon_t = (1-s)\,\rho$.

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:[9]

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

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 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 (13) for 40 quarters following a shock in the 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 line in the figure refers to the case the Armington elasticity is equal to 0.9 and there is

[9]Empirically, 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%.

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.

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, $\varepsilon_t = (1 - s)\,\rho$.

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.

4.2 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 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.[10]

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 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 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.

4.3 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. In the first four columns from simulations of the model (Model 1), exports and imports (and thus net exports and GDP) are measured with prices that are allowed to vary over the cycle. Exports and imports are measured with constant (steady-state) prices in the last four columns of the table (Model 2).

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 positive co-movement between output and net exports, a low cross-country co-movement in production side variables like output, investment and employment, and a high cross-country co-movement in consumption.

These features of the model where shown earlier in the impulse response analysis. Following a positive shock in one country, the country that experienced the positive shock can

[10] A 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.

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.

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.

In the last four columns of the table exports and imports are measured with constant (steady state) prices. In the main results, 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.[11]

The table shows that measuring exports and imports with constant prices has little effect on most variables in the model. None of the variances or co-movements involving GDP, net exports, exports, or imports are significantly affected. The volatility of exports and imports drops when measured with constant prices. The key result, that the model with frictions in the distribution margin can reproduce many of the short-run business cycle moments that we see in a model with a low Armington elasticity, still holds when exports and imports are measured with constant prices. Thus these frictions in distribution are affecting export and import volumes, not simply prices.

4.3.1 The S-curve

As discussed in Backus, Kehoe and Kydland (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

[11] Kehoe and Ruhl (2008) show how movements in the terms of trade can potentially have a large effect on business cycle moments in model simulations.

is high, frictions in the distribution sector ensure that home and foreign goods are poor substitutes in the short run.[12]

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.

[12] The fact that the contemporaneous correlation between the terms of trade and the trade balance may be positive or negative is related to the famous Marshall-Lerner condition. When there is a depreciation in the terms of trade, the relative price of imports increases, this means that the quantity demanded of imports will certainly fall and the quantity demanded of a country's exports will certainly rise. Thus when measuring net exports with constant (steady-state) prices, there will certainly be a positive correlation between the terms of trade and the trade balance, as shown in the results for Model-2. However, when we use current prices to calculate the trade balance, the relative price of imports may increase, and thus the quantity demanded of imports will fall, but if the import demand elasticity is less than 1 then the fall in quantity demanded is not as great as the rise in the price, so the total spending on imports will actually increase, resulting in a negative contemporaneous correlation between the terms of trade and the trade balance.

4.3.2 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 6. 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.

5 Summary and 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 price 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 changes in relative prices.

This paper presents a model that can explain 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.

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A Data Appendix - Not for publication

The EIU dataset used for the calibration of parameters specific to the distribution sector contains the prices of over 300 goods from 123 cities. These prices are available annually from 1990-2005. We excluded goods that were non-tradable to very close to non-tradeable. We then combined the goods into four sectors: Grocery Items, Non-food consumer goods, clothing, and transportation. In addition, Crucini and Landry (2012) provide data on the distribution margin, calculated from input-output tables, for each good in the dataset. The list of goods we use and their grouping into one of the four categories is as follows:

	Description	Sector	Assumed s
1	White bread, 1 kg (supermarket)	Grocery Items	0.3606
2	White bread, 1 kg (mid-priced store)	Grocery Items	0.3606
3	Butter, 500 g (supermarket)	Grocery Items	0.3606
4	Butter, 500 g (mid-priced store)	Grocery Items	0.3606
5	Margarine, 500g (supermarket)	Grocery Items	0.3606
6	Margarine, 500g (mid-priced store)	Grocery Items	0.3606
7	White rice, 1 kg (supermarket)	Grocery Items	0.3606
8	White rice, 1 kg (mid-priced store)	Grocery Items	0.3606
9	Spaghetti (1 kg) (supermarket)	Grocery Items	0.3606
10	Spaghetti (1 kg) (mid-priced store)	Grocery Items	0.3606
11	Flour, white (1 kg) (supermarket)	Grocery Items	0.3606
12	Flour, white (1 kg) (mid-priced store)	Grocery Items	0.3606
13	Sugar, white (1 kg) (supermarket)	Grocery Items	0.3606
14	Sugar, white (1 kg) (mid-priced store)	Grocery Items	0.3606
15	Cheese, imported (500 g) (supermarket)	Grocery Items	0.3606
16	Cheese, imported (500 g) (mid-priced store)	Grocery Items	0.3606
17	Cornflakes (375 g) (supermarket)	Grocery Items	0.3606
18	Cornflakes (375 g) (mid-priced store)	Grocery Items	0.3606
19	Yoghurt, natural (150 g) (supermarket)	Grocery Items	0.3606
20	Yoghurt, natural (150 g) (mid-priced store)	Grocery Items	0.3606
21	Milk, pasteurized (1 l) (supermarket)	Grocery Items	0.3606
22	Milk, pasteurized (1 l) (mid-priced store)	Grocery Items	0.3606
23	Olive oil (1 l) (supermarket)	Grocery Items	0.3606
24	Olive oil (1 l) (mid-priced store)	Grocery Items	0.3606
25	Peanut or corn oil (1 l) (supermarket)	Grocery Items	0.3606
26	Peanut or corn oil (1 l) (mid-priced store)	Grocery Items	0.3606
27	Potatoes (2 kg) (supermarket)	Grocery Items	0.5229
28	Potatoes (2 kg) (mid-priced store)	Grocery Items	0.5229
29	Onions (1 kg) (supermarket)	Grocery Items	0.5229
30	Onions (1 kg) (mid-priced store)	Grocery Items	0.5229
31	Mushrooms (1 kg) (supermarket)	Grocery Items	0.5229
32	Mushrooms (1 kg) (mid-priced store)	Grocery Items	0.5229
33	Tomatoes (1 kg) (supermarket)	Grocery Items	0.5229
34	Tomatoes (1 kg) (mid-priced store)	Grocery Items	0.5229
35	Carrots (1 kg) (supermarket)	Grocery Items	0.5229
36	Carrots (1 kg) (mid-priced store)	Grocery Items	0.5229
37	Oranges (1 kg) (supermarket)	Grocery Items	0.5229
38	Oranges (1 kg) (mid-priced store)	Grocery Items	0.5229
39	Apples (1 kg) (supermarket)	Grocery Items	0.5229
40	Apples (1 kg) (mid-priced store)	Grocery Items	0.5229
41	Lemons (1 kg) (supermarket)	Grocery Items	0.5229
42	Lemons (1 kg) (mid-priced store)	Grocery Items	0.5229
43	Bananas (1 kg) (supermarket)	Grocery Items	0.5229
44	Bananas (1 kg) (mid-priced store)	Grocery Items	0.5229
45	Lettuce (one) (supermarket)	Grocery Items	0.5229
46	Lettuce (one) (mid-priced store)	Grocery Items	0.5229

	Description	Sector	Assumed s
47	Eggs (12) (supermarket)	Grocery Items	0.3606
48	Eggs (12) (mid-priced store)	Grocery Items	0.3606
49	Peas, canned (250 g) (supermarket)	Grocery Items	0.3606
50	Peas, canned (250 g) (mid-priced store)	Grocery Items	0.3606
51	Tomatoes, canned (250 g) (supermarket)	Grocery Items	0.3606
52	Tomatoes, canned (250 g) (mid-priced store)	Grocery Items	0.3606
53	Peaches, canned (500 g) (supermarket)	Grocery Items	0.3606
54	Peaches, canned (500 g) (mid-priced store)	Grocery Items	0.3606
55	Sliced pineapples, canned (500 g) (supermarket)	Grocery Items	0.3606
56	Sliced pineapples, canned (500 g) (mid-priced store)	Grocery Items	0.3606
57	Beef: filet mignon (1 kg) (supermarket)	Grocery Items	0.3606
58	Beef: filet mignon (1 kg) (mid-priced store)	Grocery Items	0.3606
59	Beef: steak, entrecote (1 kg) (supermarket)	Grocery Items	0.3606
60	Beef: steak, entrecote (1 kg) (mid-priced store)	Grocery Items	0.3606
61	Beef: stewing, shoulder (1 kg) (supermarket)	Grocery Items	0.3606
62	Beef: stewing, shoulder (1 kg) (mid-priced store)	Grocery Items	0.3606
63	Beef: roast (1 kg) (supermarket)	Grocery Items	0.3606
64	Beef: roast (1 kg) (mid-priced store)	Grocery Items	0.3606
65	Beef: ground or minced (1 kg) (supermarket)	Grocery Items	0.3606
66	Beef: ground or minced (1 kg) (mid-priced store)	Grocery Items	0.3606
67	Veal: chops (1 kg) (supermarket)	Grocery Items	0.3606
68	Veal: chops (1 kg) (mid-priced store)	Grocery Items	0.3606
69	Veal: fillet (1 kg) (supermarket)	Grocery Items	0.3606
70	Veal: fillet (1 kg) (mid-priced store)	Grocery Items	0.3606
71	Veal: roast (1 kg) (supermarket)	Grocery Items	0.3606
72	Veal: roast (1 kg) (mid-priced store)	Grocery Items	0.3606
73	Lamb: leg (1 kg) (supermarket)	Grocery Items	0.3606
74	Lamb: leg (1 kg) (mid-priced store)	Grocery Items	0.3606
75	Lamb: chops (1 kg) (supermarket)	Grocery Items	0.3606
76	Lamb: chops (1 kg) (mid-priced store)	Grocery Items	0.3606
77	Lamb: Stewing (1 kg) (supermarket)	Grocery Items	0.3606
78	Lamb: Stewing (1 kg) (mid-priced store)	Grocery Items	0.3606
79	Pork: chops (1 kg) (supermarket)	Grocery Items	0.3606
80	Pork: chops (1 kg) (mid-priced store)	Grocery Items	0.3606
81	Pork: loin (1 kg) (supermarket)	Grocery Items	0.3606
82	Pork: loin (1 kg) (mid-priced store)	Grocery Items	0.3606
83	Ham: whole (1 kg) (supermarket)	Grocery Items	0.3606
84	Ham: whole (1 kg) (mid-priced store)	Grocery Items	0.3606
85	Bacon (1 kg) (supermarket)	Grocery Items	0.3606
86	Bacon (1 kg) (mid-priced store)	Grocery Items	0.3606
87	Chicken: frozen (1 kg) (supermarket)	Grocery Items	0.3606
88	Chicken: frozen (1 kg) (mid-priced store)	Grocery Items	0.3606
89	Chicken: fresh (1 kg) (supermarket)	Grocery Items	0.3606
90	Chicken: fresh (1 kg) (mid-priced store)	Grocery Items	0.3606
91	Frozen fish fingers (1 kg) (supermarket)	Grocery Items	0.2188
92	Frozen fish fingers (1 kg) (mid-priced store)	Grocery Items	0.2188

	Description	Sector	Assumed s
93	Fresh fish (1 kg) (supermarket)	Grocery Items	0.2188
94	Fresh fish (1 kg) (mid-priced store)	Grocery Items	0.2188
95	Instant coffee (125 g) (supermarket)	Grocery Items	0.3606
96	Instant coffee (125 g) (mid-priced store)	Grocery Items	0.3606
97	Ground coffee (500 g) (supermarket)	Grocery Items	0.3606
98	Ground coffee (500 g) (mid-priced store)	Grocery Items	0.3606
99	Tea bags (25 bags) (supermarket)	Grocery Items	0.3606
100	Tea bags (25 bags) (mid-priced store)	Grocery Items	0.3606
101	Cocoa (250 g) (supermarket)	Grocery Items	0.3606
102	Cocoa (250 g) (mid-priced store)	Grocery Items	0.3606
103	Drinking chocolate (500 g) (supermarket)	Grocery Items	0.3606
104	Drinking chocolate (500 g) (mid-priced store)	Grocery Items	0.3606
105	Coca-Cola (1 l) (supermarket)	Grocery Items	0.3606
106	Coca-Cola (1 l) (mid-priced store)	Grocery Items	0.3606
107	Tonic water (200 ml) (supermarket)	Grocery Items	0.3606
108	Tonic water (200 ml) (mid-priced store)	Grocery Items	0.3606
109	Mineral water (1 l) (supermarket)	Grocery Items	0.3606
110	Mineral water (1 l) (mid-priced store)	Grocery Items	0.3606
111	Orange juice (1 l) (supermarket)	Grocery Items	0.3606
112	Orange juice (1 l) (mid-priced store)	Grocery Items	0.3606
113	Wine, common table (1 l) (supermarket)	Grocery Items	0.3606
114	Wine, common table (1 l) (mid-priced store)	Grocery Items	0.3606
115	Wine, superior quality (700 ml) (supermarket)	Grocery Items	0.3606
116	Wine, superior quality (700 ml) (mid-priced store)	Grocery Items	0.3606
117	Wine, fine quality (700 ml) (supermarket)	Grocery Items	0.3606
118	Wine, fine quality (700 ml) (mid-priced store)	Grocery Items	0.3606
119	Beer, local brand (1 l) (supermarket)	Grocery Items	0.3606
120	Beer, local brand (1 l) (mid-priced store)	Grocery Items	0.3606
121	Beer, top quality (330 ml) (supermarket)	Grocery Items	0.3606
122	Beer, top quality (330 ml) (mid-priced store)	Grocery Items	0.3606
123	Scotch whisky, six years old (700 ml) (supermarket)	Grocery Items	0.3606
124	Scotch whisky, six years old (700 ml) (mid-priced store)	Grocery Items	0.3606
125	Gin, Gilbey's or equivalent (700 ml) (supermarket)	Grocery Items	0.3606
126	Gin, Gilbey's or equivalent (700 ml) (mid-priced store)	Grocery Items	0.3606
127	Vermouth, Martini & Rossi (1 l) (supermarket)	Grocery Items	0.3606
128	Vermouth, Martini & Rossi (1 l) (mid-priced store)	Grocery Items	0.3606
129	Cognac, French VSOP (700 ml) (supermarket)	Grocery Items	0.3606
130	Cognac, French VSOP (700 ml) (mid-priced store)	Grocery Items	0.3606
131	Liqueur, Cointreau (700 ml) (supermarket)	Grocery Items	0.3606
132	Liqueur, Cointreau (700 ml) (mid-priced store)	Grocery Items	0.3606
133	Soap (100 g) (supermarket)	Consumer Goods	0.4050
134	Soap (100 g) (mid-priced store)	Consumer Goods	0.4050
135	Laundry detergent (3 l) (supermarket)	Consumer Goods	0.4050
136	Laundry detergent (3 l) (mid-priced store)	Consumer Goods	0.4050
137	Toilet tissue (two rolls) (supermarket)	Consumer Goods	0.3405
138	Toilet tissue (two rolls) (mid-priced store)	Consumer Goods	0.3405
139	Dishwashing liquid (750 ml) (supermarket)	Consumer Goods	0.4050
140	Dishwashing liquid (750 ml) (mid-priced store)	Consumer Goods	0.4050

	Description	Sector	Assu
141	Insect-killer spray (330 g) (supermarket)	Consumer Goods	
142	Insect-killer spray (330 g) (mid-priced store)	Consumer Goods	
143	Light bulbs (two, 60 watts) (supermarket)	Consumer Goods	
144	Light bulbs (two, 60 watts) (mid-priced store)	Consumer Goods	
145	Batteries (two, size D/LR20) (supermarket)	Consumer Goods	
146	Batteries (two, size D/LR20) (mid-priced store)	Consumer Goods	
147	Frying pan (Teflon or good equivalent) (supermarket)	Consumer Goods	
148	Frying pan (Teflon or good equivalent) (mid-priced store)	Consumer Goods	
149	Electric toaster (for two slices) (supermarket)	Consumer Goods	
150	Electric toaster (for two slices) (mid-priced store)	Consumer Goods	
151	Laundry (one shirt) (standard high-street outlet)	Consumer Goods	
152	Laundry (one shirt) (mid-priced outlet)	Consumer Goods	
153	Dry cleaning, man's suit (standard high-street outlet)	Consumer Goods	
154	Dry cleaning, man's suit (mid-priced outlet)	Consumer Goods	
155	Dry cleaning, woman's dress (standard high-street outlet)	Consumer Goods	
156	Dry cleaning, woman's dress (mid-priced outlet)	Consumer Goods	
157	Dry cleaning, trousers (standard high-street outlet)	Consumer Goods	
158	Dry cleaning, trousers (mid-priced outlet)	Consumer Goods	
159	Aspirins (100 tablets) (supermarket)	Consumer Goods	
160	Aspirins (100 tablets) (mid-priced store)	Consumer Goods	
161	Razor blades (five pieces) (supermarket)	Consumer Goods	
162	Razor blades (five pieces) (mid-priced store)	Consumer Goods	
163	Toothpaste with fluoride (120 g) (supermarket)	Consumer Goods	
164	Toothpaste with fluoride (120 g) (mid-priced store)	Consumer Goods	
165	Facial tissues (box of 100) (supermarket)	Consumer Goods	
166	Facial tissues (box of 100) (mid-priced store)	Consumer Goods	
167	Hand lotion (125 ml) (supermarket)	Consumer Goods	
168	Hand lotion (125 ml) (mid-priced store)	Consumer Goods	
169	Shampoo & conditioner in one (400 ml) (supermarket)	Consumer Goods	
170	Shampoo & conditioner in one (400 ml) (mid-priced store)	Consumer Goods	
171	Lipstick (deluxe type) (supermarket)	Consumer Goods	
172	Lipstick (deluxe type) (mid-priced store)	Consumer Goods	
173	Man's haircut (tips included) (average)	Consumer Goods	
174	Woman's cut & blow dry (tips included) (average)	Consumer Goods	
175	Cigarettes, Marlboro (pack of 20) (supermarket)	Consumer Goods	
176	Cigarettes, Marlboro (pack of 20) (mid-priced store)	Consumer Goods	
177	Cigarettes, local brand (pack of 20) (supermarket)	Consumer Goods	
178	Cigarettes, local brand (pack of 20) (mid-priced store)	Consumer Goods	
179	Pipe tobacco (50 g) (average)	Consumer Goods	
180	Business suit, two piece, medium weight (chain store)	Clothing	
181	Business suit, two piece, medium weight (mid-priced/branded store)	Clothing	
182	Business shirt, white (chain store)	Clothing	
183	Business shirt, white (mid-priced/branded store)	Clothing	
184	Men's shoes, business wear (chain store)	Clothing	
185	Men's shoes, business wear (mid-priced/branded store)	Clothing	
186	Mens raincoat, Burberry type (chain store)	Clothing	
187	Men's raincoat, Burberry type (mid-priced/branded store)	Clothing	

	Description	Sector	Assumed s
188	Socks, wool mixture (chain store)	Clothing	0.5193
189	Socks, wool mixture (mid-priced/branded store)	Clothing	0.5193
190	Dress, ready to wear, daytime (chain store)	Clothing	0.5193
191	Dress, ready to wear, daytime (mid-priced/branded store)	Clothing	0.5193
192	Women's shoes, town (chain store)	Clothing	0.5194
193	Women's shoes, town (mid-priced/branded store)	Clothing	0.5194
194	Women's cardigan sweater (chain store)	Clothing	0.5193
195	Women's cardigan sweater (mid-priced/branded store)	Clothing	0.5193
196	Women's raincoat, Burberry type (chain store)	Clothing	0.5193
197	Women's raincoat, Burberry type (mid-priced/branded store)	Clothing	0.5193
198	Tights, panty hose (chain store)	Clothing	0.5193
199	Tights, panty hose (mid-priced/branded store)	Clothing	0.5193
200	Child's jeans (chain store)	Clothing	0.5193
201	Child's jeans (mid-priced/branded store)	Clothing	0.5193
202	Child's shoes, dresswear (chain store)	Clothing	0.5194
203	Child's shoes, dresswear (mid-priced/branded store)	Clothing	0.5194
204	Child's shoes, sportswear (chain store)	Clothing	0.5892
205	Child' s shoes, sportswear (mid-priced/branded store)	Clothing	0.5892
206	Girl's dress (chain store)	Clothing	0.5193
207	Girl's dress (mid-priced/branded store)	Clothing	0.5193
208	Boy's jacket, smart (chain store)	Clothing	0.5193
209	Boy's jacket, smart (mid-priced/branded store)	Clothing	0.5193
210	Boy's dress trousers (chain store)	Clothing	0.5193
211	Boy's dress trousers (mid-priced/branded store)	Clothing	0.5193
212	Low priced car (900-1299 cc) (low)	Transportation	0.1668
213	Low priced car (900-1299 cc) (high)	Transportation	0.1668
214	Compact car (1300-1799 cc) (low)	Transportation	0.1668
215	Compact car (1300-1799 cc) (high)	Transportation	0.1668
216	Family car (1800-2499 cc) (low)	Transportation	0.1668
217	Family car (1800-2499 cc) (high)	Transportation	0.1668
218	Deluxe car (2500 cc upwards) (low)	Transportation	0.1668
219	Deluxe car (2500 cc upwards) (high)	Transportation	0.1668
220	Yearly road tax or registration fee (low)	Transportation	0.8560
221	Yearly road tax or registration fee (high)	Transportation	0.8560
222	Cost of a tune up (but no major repairs) (low)	Transportation	0.8480
223	Cost of a tune up (but no major repairs) (high)	Transportation	0.8480
224	Annual premium for car insurance (low)	Transportation	0.9420
225	Annual premium for car insurance (high)	Transportation	0.9420
226	Regular unleaded petrol (1 l) (average)	Transportation	0.1890
227	Taxi: initial meter charge (average)	Transportation	0.8560
228	Taxi rate per additional kilometer (average)	Transportation	0.8560
229	Taxi: airport to city centre (average)	Transportation	0.8560

The EIU dataset contains data from 123 cities, but to ensure that fluctuations in the nominal exchange rate don't cloud the results, we use data from 13 U.S. cities:

Cities
Atlanta
Boston
Chicago
Cleveland
Detroit
Houston
Los Angeles
Miami
New York
Pittsburgh
San Francisco
Seattle
Washington DC

Table 1: 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	0.02	elasticity of substitution between wholesale goods and distribution services
α_d	0.36	capital's share in distribution costs
η	0.40	elasticity of substitution between capital and labor in distribution
χ	0.18	capital adjustment cost parameter for capital used in distribution

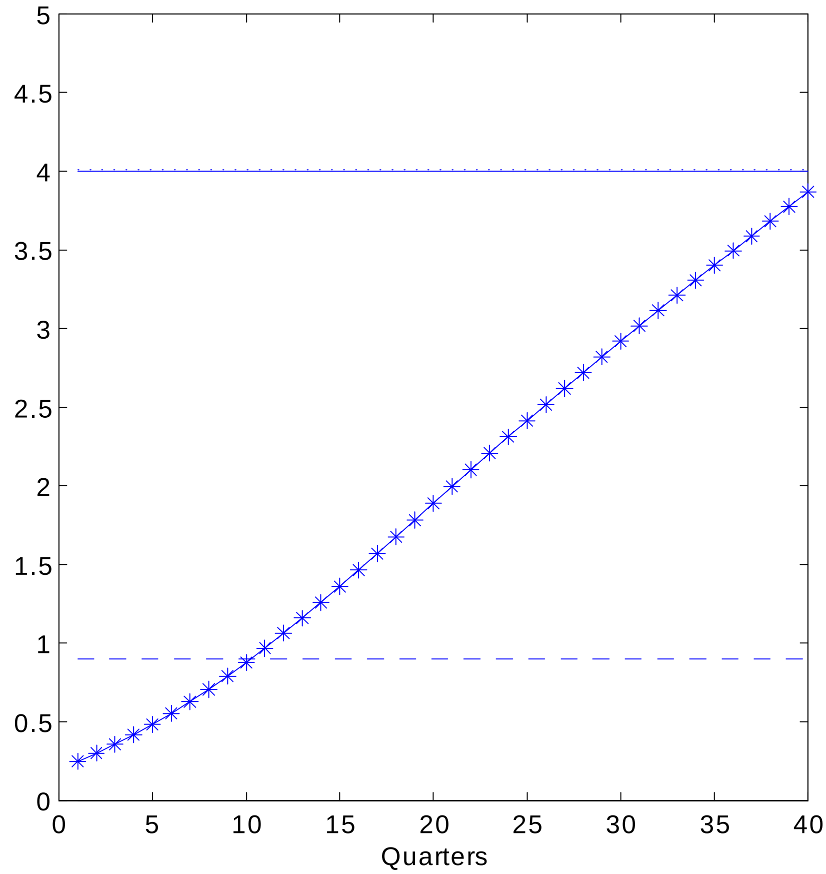

Figure 1: Observed Elasticity of Substitution following a TFP shock. In the solid line the structural elasticity is equal to 4 and there is no distribution. In the dashed line the structural elasticity is equal to 0.9 and there is no distribution. In the dotted line the structural elasticity is equal to 8, there is a distribution sector, but distribution capital can be instantaneously reallocated from distribution of domestic goods to the distribution of imports, and vice versa. In the line with stars the structural elasticity is equal to 8, there is a distribution sector, but frictions prevent the reallocation of distribution inputs in the short run.

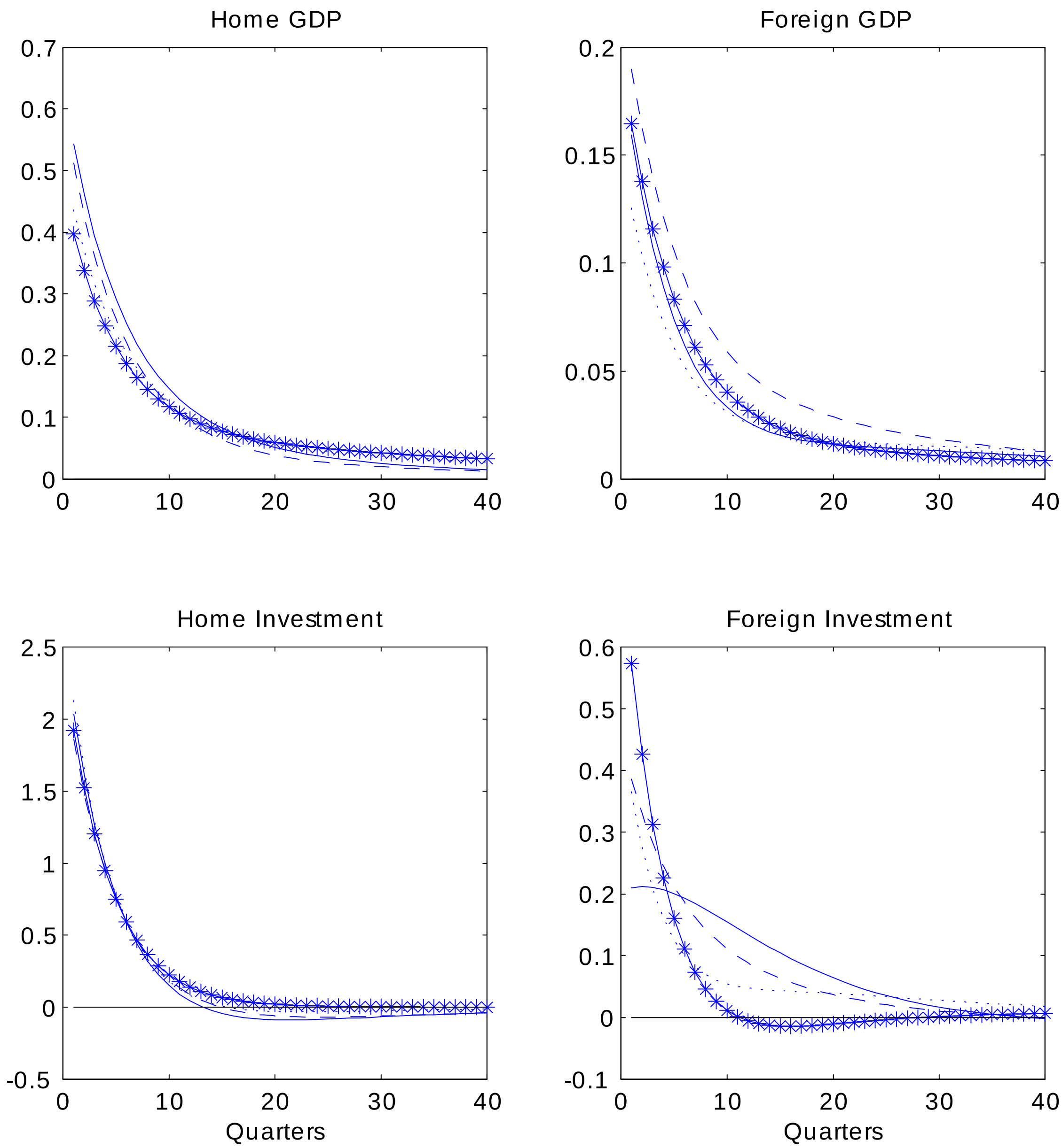

Figure 2: The responses of home and foreign GDP and investment to a positive home TFP shock. In the solid line the structural elasticity is equal to 4 and there is no distribution. In the dashed line the structural elasticity is equal to 0.9 and there is no distribution. In the dotted line the structural elasticity is equal to 8, there is a distribution sector, but distribution capital can be instantaneously reallocated from distribution of domestic goods to the distribution of imports, and vice versa. In the line with stars the structural elasticity is equal to 8, there is a distribution sector, but frictions prevent the reallocation of distribution inputs in the short run.

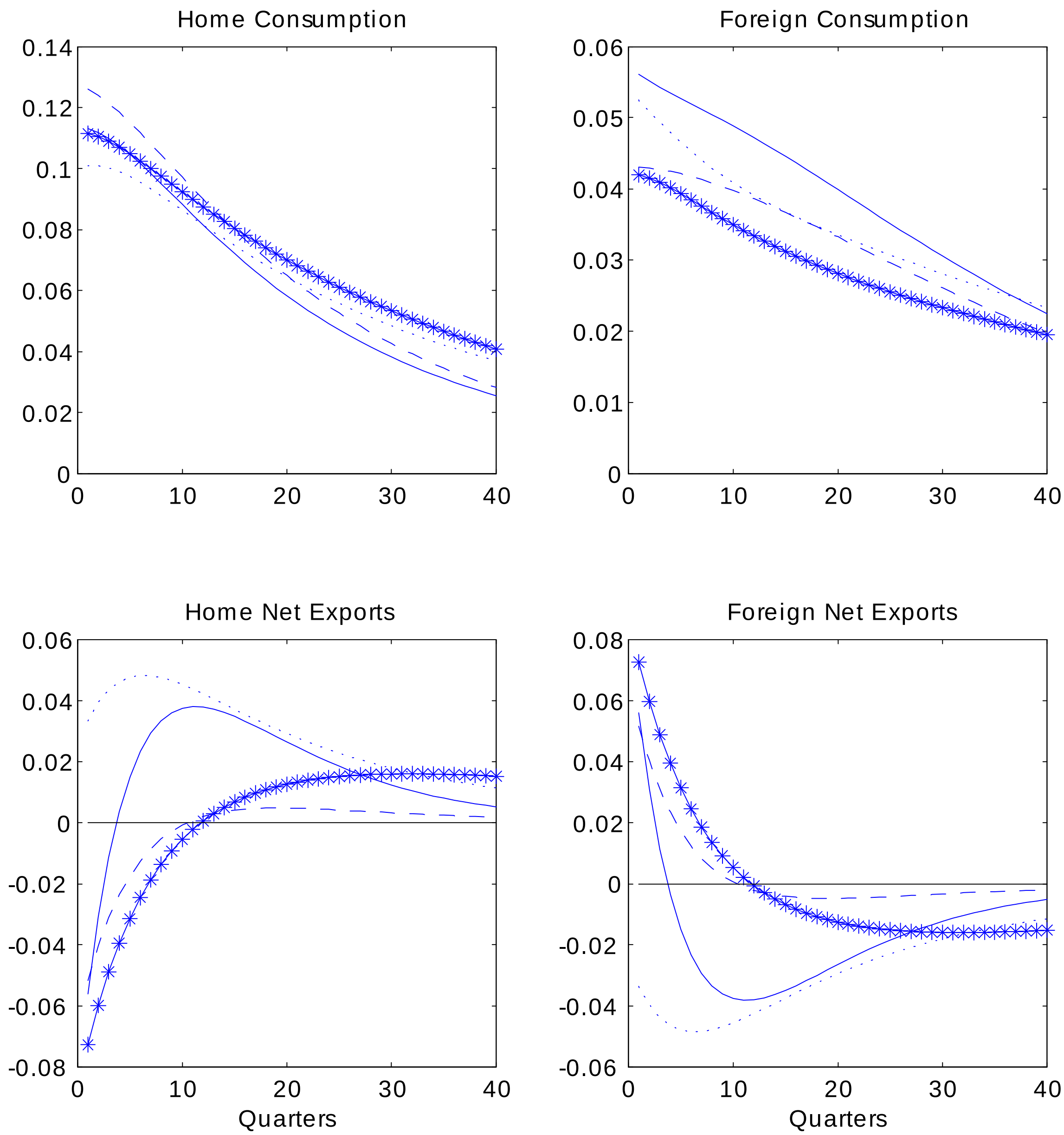

Figure 3: The responses of home and foreign consumption and net exports to a positive home TFP shock. In the solid line the structural elasticity is equal to 4 and there is no distribution. In the dashed line the structural elasticity is equal to 0.9 and there is no distribution. In the dotted line the structural elasticity is equal to 8, there is a distribution sector, but distribution capital can be instantaneously reallocated from distribution of domestic goods to the distribution of imports, and vice versa. In the line with stars the structural elasticity is equal to 8, there is a distribution sector, but frictions prevent the reallocation of distribution inputs in the short run.

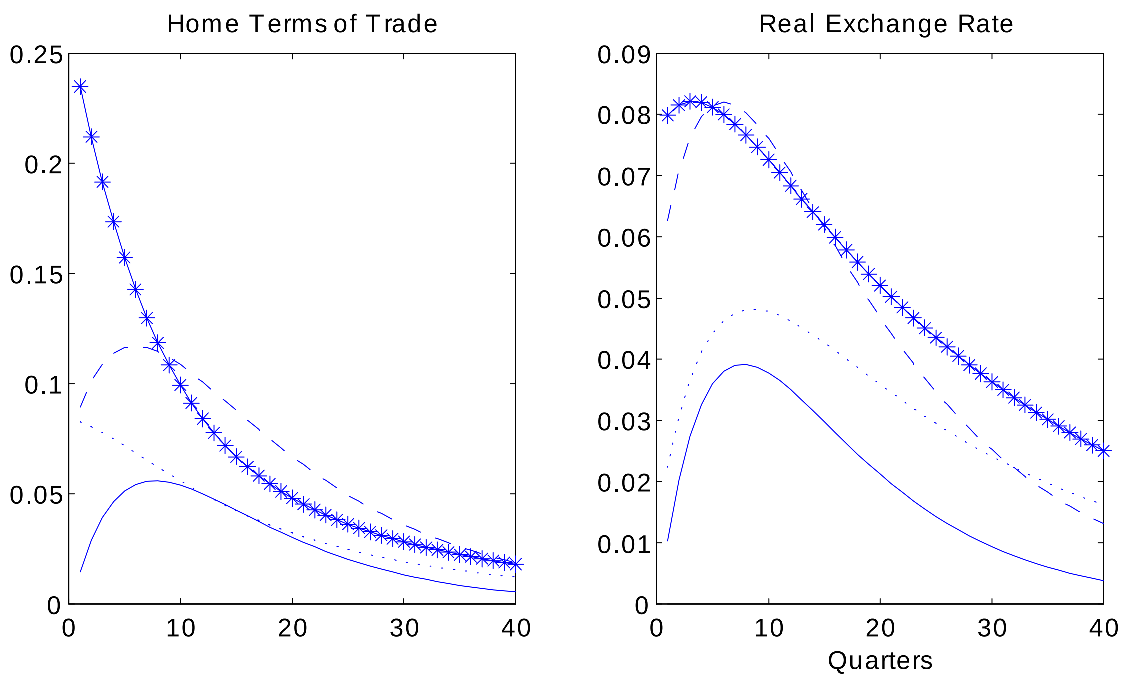

Figure 4: The response of the home country terms of trade and the real exchange rate to a positive home TFP shock. In the solid line the structural elasticity is equal to 4 and there is no distribution. In the dashed line the structural elasticity is equal to 0.9 and there is no distribution. In the dotted line the structural elasticity is equal to 8, there is a distribution sector, but distribution capital can be instantaneously reallocated from distribution of domestic goods to the distribution of imports, and vice versa. In the line with stars the structural elasticity is equal to 8, there is a distribution sector, but frictions prevent the reallocation of distribution inputs in the short run.

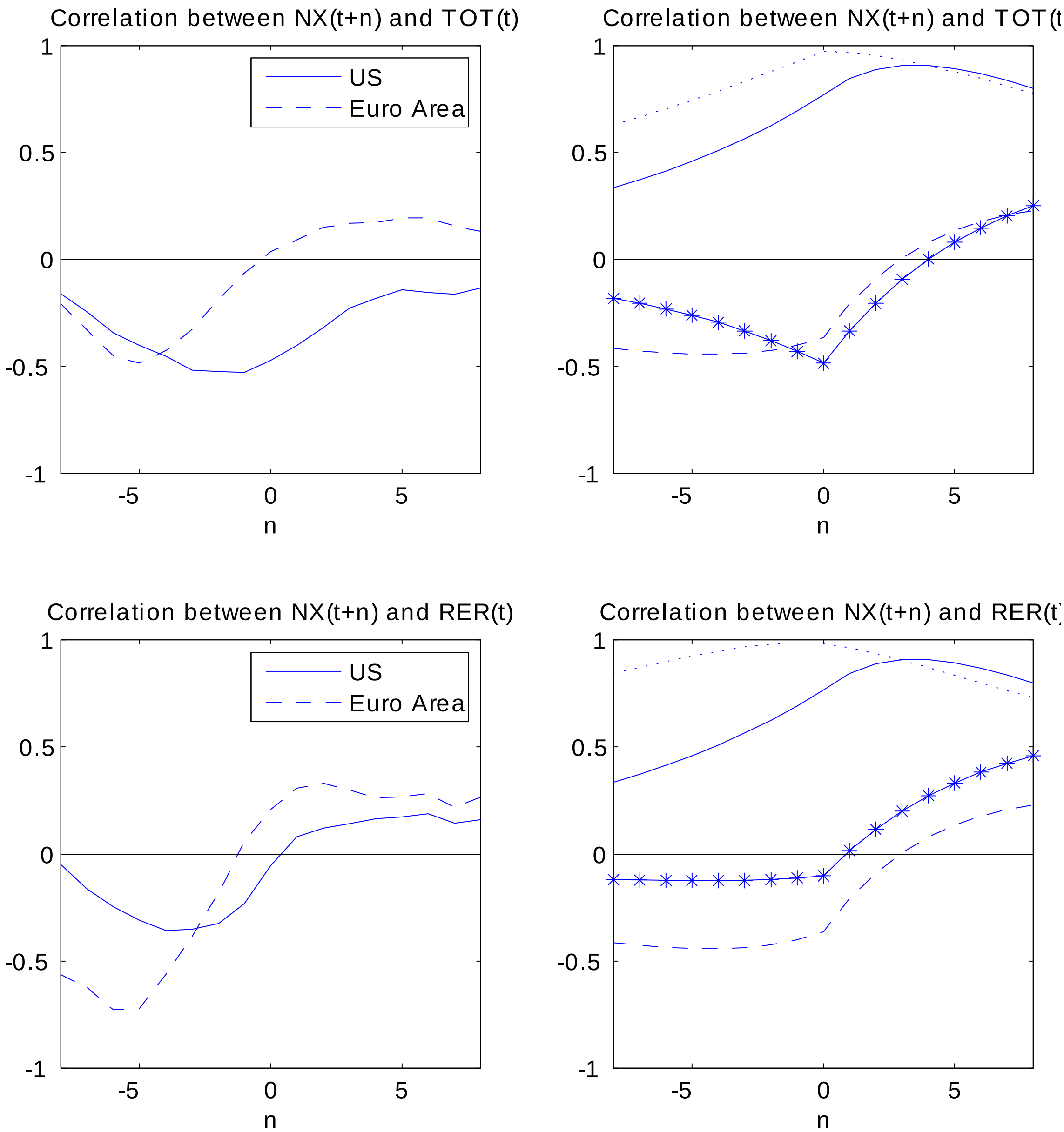

Figure 5: The correlation between relative prices and lagged values of net exports. In the solid line the structural elasticity is equal to 4 and there is no distribution. In the dashed line the structural elasticity is equal to 0.9 and there is no distribution. In the dotted line the structural elasticity is equal to 8, there is a distribution sector, but distribution capital can be instantaneously reallocated from distribution of domestic goods to the distribution of imports, and vice versa. In the line with stars the structural elasticity is equal to 8, there is a distribution sector, but frictions prevent the reallocation of distribution inputs in the short run.

Table 2: The price data used to calibrate the distribution parameter values under various detrending methods.

Remove nominal trend:		Use Time dummy			Remove CPI			Do nothing		
Additional filtering:		HP	Diff	None	HP	Diff	None	HP	Diff	None
St. Dev.	$\hat{w}_t$	12.12	12.10	22.35	12.07	11.87	22.88	12.07	11.98	22.80
St. Dev. relative	$\hat{p}_{it}$	0.69	0.84	19.81	0.56	0.65	17.85	0.56	0.66	16.88
to $\hat{w}_t$	$\hat{c}_{it}$	0.65	0.72	0.69	0.70	0.82	0.72	0.70	0.82	0.72
Autocorrelation	$\hat{w}_t$	0.90	0.80	0.96	0.91	0.79	0.96	0.91	0.80	0.96
	$\hat{p}_{it}$	0.82	0.16	0.95	0.81	0.45	0.96	0.80	0.66	0.95
	$\hat{c}_{it}$	0.82	0.66	0.93	0.82	0.64	0.93	0.82	0.65	0.93
Correlation	$\hat{p}_{it}, \hat{w}_t$	−0.27	−0.15	0.33	−0.44	−0.36	−0.20	−0.42	−0.21	−0.26
	$\hat{c}_{it}, \hat{w}_t$	0.34	0.25	0.30	0.74	0.69	0.72	0.74	0.68	0.72
	$\hat{p}_{it}, \hat{c}_{it}$	−0.44	−0.32	−0.01	−0.36	−0.30	−0.15	−0.35	−0.21	−0.19

Table 3: Calibrating the value of the parameters used in distribution

		Data	$\gamma = .02$	$\gamma = .2$	$\gamma = .4$	$\gamma = .6$	$\gamma = .8$	$\alpha_d = .16$	$\alpha_d = .26$	$\alpha_d = .36$	$\alpha_d = .46$	$\alpha_d = .56$
St. Dev.	$\hat{w}_t$	12.12	0.58	0.59	0.60	0.61	0.61	0.59	0.58	0.58	0.58	0.59
St. Dev. relative	$\hat{p}_{it}$	0.69	0.69	0.57	0.50	0.44	0.40	0.87	0.78	0.69	0.60	0.52
to $\hat{w}_t$	$\hat{c}_{it}$	0.65	0.65	0.52	0.44	0.39	0.34	0.84	0.75	0.65	0.55	0.45
Autocorrelation	$\hat{w}_t$	0.90	0.96	0.96	0.95	0.95	0.95	0.98	0.97	0.96	0.95	0.94
	$\hat{p}_{it}$	0.82	0.86	0.88	0.89	0.90	0.90	0.85	0.85	0.86	0.87	0.90
	$\hat{c}_{it}$	0.82	0.86	0.87	0.89	0.90	0.90	0.84	0.85	0.86	0.87	0.89
Correlation	$\hat{p}_{it}, \hat{w}_t$	−0.27	−0.32	−0.33	−0.33	−0.32	−0.31	−0.06	−0.19	−0.32	−0.46	−0.59
	$\hat{c}_{it}, \hat{w}_t$	0.34	0.29	0.29	0.28	0.26	0.25	0.04	0.16	0.29	0.42	0.56
	$\hat{p}_{it}, \hat{c}_{it}$	−0.44	−0.99	−0.99	−0.98	−0.98	−0.98	−0.99	−0.99	−0.99	−0.99	−0.98

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

		Data	$\eta = .10$	$\eta = .25$	$\eta = .40$	$\eta = .55$	$\eta = .70$	$\chi = 0$	$\chi = .09$	$\chi = .18$	$\chi = .27$	$\chi = .36$
St. Dev.	$\hat{w}_t$	12.12	0.56	0.57	0.58	0.59	0.59	0.64	0.60	0.58	0.56	0.55
St. Dev. relative	$\hat{p}_{it}$	0.69	0.90	0.77	0.69	0.63	0.58	0.43	0.62	0.69	0.74	0.77
to $\hat{w}_t$	$\hat{c}_{it}$	0.65	0.86	0.73	0.65	0.58	0.53	0.37	0.57	0.65	0.69	0.73
Autocorrelation	$\hat{w}_t$	0.90	0.98	0.97	0.96	0.95	0.95	0.97	0.97	0.96	0.96	0.95
	$\hat{p}_{it}$	0.82	0.82	0.84	0.86	0.88	0.89	0.46	0.83	0.86	0.88	0.89
	$\hat{c}_{it}$	0.82	0.82	0.84	0.86	0.87	0.89	0.39	0.82	0.86	0.87	0.88
Correlation	$\hat{p}_{it}, \hat{w}_t$	−0.27	−0.21	−0.28	−0.32	−0.36	−0.39	0.15	−0.21	−0.32	−0.40	−0.45
	$\hat{c}_{it}, \hat{w}_t$	0.34	0.19	0.25	0.29	0.32	0.35	−0.23	0.16	0.29	0.37	0.43
	$\hat{p}_{it}, \hat{c}_{it}$	−0.44	−0.99	−0.99	−0.99	−0.99	−0.99	−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.

				Model - 1				Model - 2			
			Distribution	No	No	Yes	Yes	No	No	Yes	Yes
			Elasticity	4	0.9	8	8	4	0.9	8	8
		Data	Frictions	N/A	N/A	No	Yes	N/A	N/A	No	Yes
St. Dev.	GDP	0.92		1.07	0.97	0.89	0.82	1.10	1.02	0.91	0.86
	NX	0.28		0.30	0.16	0.15	0.12	0.34	0.16	0.19	0.11
Volatility	C	0.89		0.42	0.49	0.52	0.59	0.41	0.47	0.51	0.57
Relative	I	3.14		3.16	3.22	3.88	3.83	3.09	3.06	3.80	3.65
to GDP	N	0.85		0.49	0.45	0.39	0.27	0.48	0.43	0.38	0.26
	Ex	3.86		1.31	1.00	1.49	1.21	1.31	0.97	1.58	1.15
	Im	3.37		1.13	1.12	1.12	1.27	1.27	0.96	1.55	1.15
	Tot	2.14		0.33	0.81	0.52	1.16	0.32	0.77	0.51	1.11
	Q	4.14		0.23	0.57	0.42	0.73	0.22	0.54	0.41	0.70
Co-movement	C	0.84		0.80	0.82	0.81	0.86	0.80	0.84	0.80	0.85
with	I	0.91		0.89	0.94	0.90	0.91	0.88	0.93	0.90	0.91
GDP	NX	−0.41		0.10	−0.47	0.52	−0.24	0.19	−0.13	0.56	0.10
	N	0.81		0.94	0.90	0.92	0.94	0.94	0.89	0.93	0.93
	Ex	0.54		0.58	0.59	0.78	0.41	0.60	0.62	0.86	0.64
	Im	0.82		0.51	0.99	−0.03	0.76	0.30	0.77	−0.11	0.50
	Tot	0.29		0.48	0.39	0.59	0.54	0.51	0.48	0.61	0.60
	Q	−0.02		0.48	0.39	0.46	0.49	0.51	0.48	0.49	0.55
Cross-country	GDP	0.52		0.23	0.48	0.24	0.44	0.17	0.34	0.19	0.31
co-movement	C	0.76		0.76	0.54	0.69	0.50	0.76	0.54	0.69	0.50
	I	0.67		−0.03	0.14	0.01	0.21	−0.03	0.14	0.01	0.21
	N	0.47		0.05	0.47	−0.38	0.47	0.05	0.47	−0.38	0.47
	Ex	0.63		−0.28	0.46	−0.65	−0.39	−0.32	0.41	−0.52	−0.02
Correlation	Tot,NX	−0.13		0.77	−0.36	0.97	−0.48	0.83	0.38	0.98	0.13
	Q,NX	−0.05		0.77	−0.36	0.99	−0.10	0.83	0.38	0.98	0.50

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.

Table 6: 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 sectos.

				Model - 1				Model - 2			
			Distribution	No	No	Yes	Yes	No	No	Yes	Yes
			Elasticity	4	0.9	8	8	4	0.9	8	8
		Data	Frictions	N/A	N/A	No	Yes	N/A	N/A	No	Yes
St. Dev.	GDP	0.92		1.07	0.97	0.98	0.85	1.10	1.02	1.03	0.90
	NX	0.28		0.30	0.16	0.49	0.17	0.34	0.16	0.57	0.14
Volatility	C	0.89		0.42	0.49	0.49	0.59	0.41	0.47	0.47	0.56
Relative	I	3.14		3.16	3.22	3.73	3.85	3.09	3.06	3.54	3.64
to GDP	N	0.85		0.49	0.45	0.51	0.57	0.48	0.43	0.48	0.53
	Ex	3.86		1.31	1.00	3.50	1.84	1.31	0.97	3.77	1.37
	Im	3.37		1.13	1.12	3.47	1.81	1.27	0.96	3.75	1.32
	Tot	2.14		0.33	0.81	1.15	3.12	0.32	0.77	1.10	2.94
	Q	4.14		0.23	0.57	0.46	0.73	0.22	0.54	0.44	0.69
Co-movement	C	0.84		0.80	0.82	0.75	0.85	0.80	0.84	0.73	0.82
with	I	0.91		0.89	0.94	0.65	0.78	0.88	0.93	0.62	0.77
GDP	NX	−0.41		0.10	−0.47	0.52	0.00	0.19	−0.13	0.58	0.31
	N	0.81		0.94	0.90	0.53	0.21	0.94	0.89	0.56	0.08
	Ex	0.54		0.58	0.59	0.52	0.11	0.60	0.62	0.70	0.73
	Im	0.82		0.51	0.99	−0.46	0.12	0.30	0.77	−0.43	0.26
	Tot	0.29		0.48	0.39	0.57	0.15	0.51	0.48	0.62	0.36
	Q	−0.02		0.48	0.39	0.36	0.49	0.51	0.48	0.36	0.57
Cross-country	GDP	0.52		0.23	0.48	0.11	0.48	0.17	0.34	0.01	0.32
co-movement	C	0.76		0.76	0.54	0.61	0.47	0.76	0.54	0.61	0.47
	I	0.67		−0.03	0.14	0.29	0.61	−0.03	0.14	0.29	0.61
	N	0.47		0.05	0.47	−0.11	−0.03	0.05	0.47	−0.11	−0.03
	Ex	0.63		−0.28	0.46	−0.82	−0.09	−0.32	0.41	−0.93	−0.25
Correlation	Tot,NX	−0.13		0.77	−0.36	0.99	−0.70	0.83	0.38	0.99	0.57
	Q,NX	−0.05		0.77	−0.36	0.13	−0.03	0.83	0.38	0.14	0.60

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.