Terms-of-Trade Effects, Interdependence and Cross-Country Differences in Price Levels*

Doireann Fitzgerald†

UC-Santa Cruz

This version: May 2003

Abstract

This paper revisits both the theory and the empirics of the classic Balassa-Samuelson productivity model of cross-country differences in price levels. The classic model says that price levels are positively related to productivity in the traded sector and negatively related to productivity in the non-traded sector. I show that once endogenous specialization and costly intra-temporal trade are added to the classic model, this result is modified in two ways. First, the elasticity of relative prices with respect to traded sector productivity depends on the strength of terms-of-trade effects, and may even be negative if terms-of-trade effects are sufficiently strong. Second, the asymmetric trade patterns induced by costly trade mean that the relative price level between a pair of countries depends on productivity in all other countries that these two countries trade with. I simulate the model with trade costs, and show that both of these effects are potentially important. I then use the insight that traded-sector production is specialized to reassess the empirical evidence on productivity models of price level differences. I show that the evidence of other researchers is inconclusive. I estimate the relationship in a way that is consistent with the theoretical model. The empirical evidence is weakly supportive of the interdependence effect and neutral as regards the role of terms-of-trade effects.

*I would like to thank my advisors, Elhanan Helpman, Greg Mankiw and Ken Rogoff. I would also like to thank Manuel Amador, Susanto Basu, Francesco Caselli, Juan Carlos Hallak, Philip Lane, Marc Melitz, David Papell, James Stock, Silvana Tenreyro, Jaume Ventura and seminar participants at Harvard, MIT, Chicago GSB and the Federal Reserve Board of Governors for helpful comments and suggestions. All remaining errors are my own.

†Department of Economics,UC-Santa Cruz, Santa Cruz CA 95064. dfitzger@ucsc.edu. Updates available at http://people.ucsc.edu/~dfitzger/

1 Introduction

In this paper, I revisit the classic Balassa-Samuelson model that relates differential cross-country behavior of aggregate price levels (or real exchange rates) to differences in sectoral productivity. I nest a multi-country model of endogenous specialization and intra-temporal trade in the classic framework yielding two new results. First, when countries specialize and trade intra-temporally, terms-of-trade effects matter. Terms of trade effects mediate the classic Balassa-Samuelson relationship between traded sector productivity and real exchange rates, and have in fact the potential to reverse the classic positive relationship between the two. Second, when trade is costly real exchange rates depend on interdependence between countries. The real exchange rate between two countries depends not just on what happens in that pair of countries, but also on what happens in all the other countries that the two countries trade with. Calibration evidence suggests these two effects are potentially important, though econometric evidence in a small panel is so far less conclusive.

In the first section of the paper, I develop a multi-country model of trade with endogenous intra-industry specialization in differentiated traded goods. Although increasing returns in the production of differentiated goods is the mechanism that generates specialization in the model, I argue that the implications generalize to cases where there is specialization for other reasons. When countries produce different baskets of traded goods, shifts in relative supply (due for example to changes in relative productivity in the traded sector) lead to changes in relative prices within traded goods. This is the terms-of-trade effect, which is not present in the classic Balassa-Samuelson model where all countries produce the same traded good. The magnitude and sign of the terms-of-trade effect depends on the elasticity of demand for a particular country's traded output on world markets. Countries that face elastic demand for their traded output on world markets should experience classic Balassa-Samuelson appreciation of the real exchange rate when their traded-sector productivity rises faster than that of their trading partners. But countries that face inelastic demand for their traded output should experience real depreciation as their traded-sector productivity increases.

The addition of trade costs to the model leads to asymmetric patterns of trade, as countries tend to trade more with partners that are closer and larger - the standard gravity effects. It is not possible to solve for a closed form relationship between real exchange rates and productivity in traded and non-traded sectors. However I demonstrate that the real exchange rate between any two countries depends on traded sector productivity in all countries that these two countries trade with. This result suggests that standard bilateral empirical models of real exchange rates may be flawed in the sense that they omit many important explanatory variables.

In the second section of the paper, I simulate the specialization-augmented model with trade costs using productivity, distance and size data for 10 European countries. I show that the terms-of-trade prediction of the model without trade costs carries over to the version with trade costs, and that the "third-country" effect is important. Estimation of a number of different productivity models of real exchange rates using simulated data suggests that failure to control for this effect will lead to biased and imprecisely estimated coefficients on bilateral traded and non-traded sector productivity.

In the third section of the paper, I re-examine the econometric evidence on productivity models of real exchange rates using the panel of 10 European countries used in the simulation. I demonstrate that previous time-series evidence thought to be favourable to a productivity model of real exchange rates is invalid if there is cross-country specialization of production. I also argue that both single-equation and panel time-series tests of the model should be re-evaluated in the light of asymmetric cross-country interdependence. I describe the results of specialization-consistent tests of the augmented productivity model. There is weak evidence in favor of a relationship between relative prices and productivity in this data. I discuss several reasons why the evidence is so weak, and suggest some fruitful avenues for future empirical exploration of productivity models of price level differences.

2 A trade model of real exchange rates

First, I use a simple multi-country framework to recap the central predictions of the classic Balassa-Samuelson model: Relative price levels are shown to depend positively on relative traded sector productivity and negatively on relative non-traded sector productivity. I then introduce endogenous specialization in the production of differentiated tradeable goods into the framework. This modifies the key prediction of the classic model about the relationship between traded-sector productivity and relative prices. I show that in the presence of specialization, the sign and magnitude of the elasticity of relative prices with respect to relative traded sector productivity depends on the strength of terms-of-of trade effects. I then add trade costs to the model, generating an asymmetric pattern of trade. This leads the real exchange rate between two countries to depend on productivity in "third" countries.

2.1 The classic Balassa-Samuelson predictions

The Balassa-Samuelson model assumes the following: There are two sectors, traded and non-traded. Goods markets are perfectly competitive, and price equals marginal cost for each good. Factor markets are integrated and factors can move instantaneously across sectors within countries. As a result, marginal cost differs across sectors only if productivity and factor input ratios differ. Traded goods produced in different countries are perfect substitutes, so there is no motive for intra-temporal trade. Nevertheless, the fact that trade is possible means that the the law of one price holds for the traded good. Under these assumptions, relative factor returns between any pair of countries depend directly on relative traded sector productivity. Higher traded sector productivity in one country results in higher factor returns in that country relative to others, and other things equal, a higher price of non-traded goods and a higher price level overall. Conversely, higher non-traded sector productivity results in lower prices of non-tradeable goods, and a lower price level overall.

These predictions can be demonstrated using a multi-country model. Assume that there are M countries, indexed $i = 1, \ldots, M$. World labor supply is normalized to one, and country i has share s_i of the world labor force - these shares may differ across countries. Each country produces both the traded good (T) and the non-traded good (N).

I. Consumers

Preferences over the traded and non-traded goods are identical in each country. They are given by

$$C_i = \frac{C_i^{T\delta} C_i^{N1-\delta}}{\delta^{\delta} (1-\delta)^{1-\delta}} \tag{1}$$

where C_i is total utility from consumption in country i and C_i^T and C_i^N are counsumption of the traded and non-traded goods respectively. The utility-consistent price index is:

$$P_i = P_i^{T\delta} P_i^{N1-\delta} \tag{2}$$

where P_i is the overall price index, and P_i^T and P_i^N are the prices of the traded and non-traded goods. These preferences imply that a constant share of income is devoted to expenditure in each sector[1]: That is, demands for traded and non-traded goods take the form

$$P_i^T C_i^T = \delta P_i C_i \quad \text{and} \quad P_i^N C_i^N = (1-\delta) P_i C_i \tag{3}$$

By analogy with the consumption aggregate and the consumer price index, aggregate output and the producer price index are defined as

$$Y_i = \frac{Y_i^{T\delta} Y_i^{N(1-\delta)}}{\delta^\delta (1-\delta)^{1-\delta}} \quad \text{and} \quad P_i^Y = P_i^{T\delta} P_i^{N(1-\delta)} \tag{4}$$

II. Producers

For simplicity, labor is assumed to be the only factor of production.[2] Let Y^q denote output in sector q. Production functions in the two sectors in the are given by

$$Y_i^T = A_i^T L_i^T \quad \text{and} \quad Y_i^N = A_i^N L_i^N \tag{5}$$

where L_i^T is labor employed in the traded sector and L_i^N is labor employed in the non-traded sector. Assuming perfect competition in goods markets in each country and in each sector, the price of each good equals marginal cost:[3]

$$P_i^T = \frac{W_i}{A_i^N} \quad \text{and} \quad P_i^T = \frac{W_i}{A_i^T} \tag{6}$$

III. Market clearing and law of one price

Labor markets are integrated and perfectly competitive so wages (W_i) are the same in both sectors and the labor market clears:

$$W_i^T = W_i^N = W_i \tag{7}$$

$$s_i = L_i^T + L_i^N \tag{8}$$

[1]This assumption is made for simplicity. Empirically, preferences over traded and non-traded goods appear to be non-homothetic.

[2]Introducing more than one factor leads to additional Heckscher-Ohlin effects on cross-country relative price levels, if factor intensities differ across the traded and non-traded sectors. These effects are discussed by Baghwati (1984).

[3]In an appendix, I show the effect of assuming that non-traded sector prices are a country-varying markup over marginal cost.

where s_i is country i's share of the total world labor force. Although there is no motive for intra-temporal trade, the law of one price holds across countries for the single traded intermediate good. So $P_i^T = P_j^T$

IV. Equilibrium

In this framework, the relative wage between country i and country j depends directly on relative tradeable sector productivities through the fact that each country produces the same traded good, and the law of one price holds:

$$\frac{W_i}{E_{ij}W_j} = \frac{A_i^T}{A_j^T} \tag{9}$$

Using the price index corresponding to the Cobb-Douglas aggregator for consumption, it follows that the relative price level or real exchange rate between country i and country j is given by

$$\frac{P_i}{E_{ij}P_j} = \left[\frac{A_i^T}{A_j^T}\frac{A_j^N}{A_i^N}\right]^{1-\delta} \tag{10}$$

The relative price level is positively related to relative traded sector productivity, negatively related to relative non-traded sector productivity. In fact, the elasticity of relative prices with respect to traded sector productivity is equal in magnitude but opposite in sign to the elasticity of relative prices with respect to non-traded sector productivity. Note is that it is crucial that there be two sectors, one traded and one non-traded. Given the normal negative relationship between prices and productivity, it is very difficult to generate a positive correlation between prices and productivity in a one-sector model.

2.2 Specialization and terms-of-trade effects

I now consider what happens when countries specialize in the production of different baskets of traded goods. I present a model with endogenous specialization in differentiated goods due to the existence of increasing returns. Assume again that there are M countries, indexed $i = 1, \ldots, M$. Again, world labor supply is normalized to one, and country i has share s_i of the world labor force. Each country produces both traded and non-traded goods. There is a potentially infinite number of varieties of the traded good. Because of fixed costs of production of individual varieties, each country specializes in the production of a distinct set of traded goods, the number of which is endogenously determined.

I. Consumers

Preferences are identical in each country. Preferences over traded and non-traded goods are again given by

$$C_i = \frac{C_i^{T\delta} C_i^{N1-\delta}}{\delta^{\delta} (1-\delta)^{1-\delta}} \tag{11}$$

with corresponding price index

$$P_i = P_i^{T\delta} P_i^{N1-\delta} \tag{12}$$

These preferences result in demands for traded and non-traded aggregates of the form

$$P_i^T C_i^T = \delta P_i C_i \quad \text{and} \quad P_i^N C_i^N = (1-\delta) P_i C_i \tag{13}$$

Preferences over varieties of the traded good are of the Dixit-Stiglitz form with elasticity of substitution η. Traded varieties are indexed by j and $C(j)_i^T$ is the consumption of variety j in country i

$$C_i^T = \left[\sum_j C(j)_i^{T\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \tag{14}$$

The corresponding price index is

$$P_i^T = \left[\sum_j P(j)_i^{T1-\eta} \right]^{\frac{1}{1-\eta}} \tag{15}$$

Given these preferences, demands for individual traded goods take the constant price-elasticity form

$$C(j)_i^T = \left(\frac{P(j)_i^T}{P_i^T} \right)^{-\eta} C_i^T \tag{16}$$

II. Producers

Labor is the only factor of production. Within any given country i, TFP may differ across traded and non-traded sectors, but is the same across all traded varieties. Country i produces n_i varieties of the traded good, where the number of varieties is determined endogenously. Traded sector production functions have a fixed cost component in terms of labor (i.e. the fixed cost does not disappear as productivity grows):[4]

$$Y(j)_i^T = A_i^T \left[L(j)_i^T - \alpha \right] \quad \text{and} \quad Y_i^N = A_i^N L_i^N \tag{17}$$

The market for non-traded goods is perfectly competitive, so prices are set equal to marginal cost. Producers of traded goods maximize profits by setting price equal to a markup over marginal cost (where the markup is a function of the elasticity of demand they face). They ignore the externalities from individual firm behavior on the overall price level.

$$P(j)_i^T = \tfrac{\eta}{\eta-1} \tfrac{W_i^T}{A_i^T} \quad \text{and} \quad P_i^N = \tfrac{W_i^N}{A_i^N} \tag{18}$$

With free entry, the zero profit condition for traded-sector firms is

$$\alpha W_i = Y(j)_i^T \left[P(j)_i^T - \frac{W_i}{A_i^T} \right] \tag{19}$$

Together with pricing behavior, this implies the following relationship between output of each variety and productivity:

$$Y(j)_i^T = \alpha(\eta - 1) A_i^T \tag{20}$$

III. Market clearing

Labor markets are integrated and perfectly competitive so wages are the same in both sectors

$$W_i^T = W_i^N = W_i \tag{21}$$

and the labor market clears

$$\sum_j^{n_i} L(j)_i^T + L_i^N = L_i^T + L_i^N = s_i \tag{22}$$

$L(j)_i^T$ is the amount of labor employed in the production of variety j of the traded good. Each country has a balanced current account in each period, i.e. the value of goods produced

[4] This assumption is not innocuous. However, as I argue later, the prediction that terms-of-trade effects mediate the relationship between relative prices and relative traded sector productivity is not specific to this particular assumption.

is equal to the value of goods consumed

$$P_i C_i = P_i^Y Y_i = W_i \left[L_i^T + L_i^N \right] = W_i s_i \tag{23}$$

By analogy with the consumption aggregate and the consumer price index, aggregate output and the producer price index are defined as

$$Y_i = \frac{Y_i^{T\delta} Y_i^{N(1-\delta)}}{\delta^\delta (1-\delta)^{1-\delta}} \quad \text{and} \quad P_i^Y = P_i^{Y^T \delta} P_i^{N(1-\delta)} \tag{24}$$

where P_i^{Ti} is the producer price index for traded goods, distinct from the consumer price index for traded goods, P_i^T.[5] Since the current account is equal to zero at all times, the value of traded goods produced by country i is equal to the value of traded goods consumed:

$$\sum_j^{n_i} P(j)_i^T Y(j)_i^T = \delta P_i C_i \tag{25}$$

IV. Law of one price

The law of one price holds for traded varieties:

$$P(x)_i^T = E_{ij} P(x)_j^T \tag{26}$$

and since preferences are identical, Purchasing Power Parity holds for the traded consumption aggregate:

$$P_i^T = E_{ij} P_j^T \tag{27}$$

V. Equilibrium

A zero current account implies that the wage bill in the traded-goods sector is equal to the value of traded goods consumption, and similarly for the non-traded goods sector

$$W_i L_i^T = \delta P_i C_i \quad \text{and} \quad W_i L_i^N = (1-\delta) P_i C_i \tag{28}$$

[5] In general, when the current account is not constrained to equal zero, the aggregate price level should be negatively correlated with the current account. To maintain a surplus, a country must have a low price of non-traded relative to traded goods.

This implies that the amount of labor employed in each sector is given by:

$$L_i^T = \delta s_i \quad \text{and} \quad L_i^N = (1-\delta)\, s_i \tag{29}$$

A country with traded-sector labor force δs_i will produce n_i traded varieties, where

$$n_i = \frac{L_i^T}{L\,(j)_i^T} = \frac{\delta s_i}{\alpha + Y\,(j)_i^T / A_i^T} = \frac{\delta s_i}{\alpha\eta} \tag{30}$$

Market clearing for each individual traded good says that the amount produced of each variety equals total world demand for that variety.

$$Y\,(j)_i^T = \sum_{k=1}^{M} \delta \left(\frac{P\,(j)_k^T}{P_k^T} \right)^{-\eta} \frac{P_k C_k}{P_k^T} \tag{31}$$

Substituting in and rearranging yields a first relationship between wages, traded sector productivity, and the price of the traded aggregate:

$$W_i^{\eta} A_i^{T1-\eta} = \left[\frac{\eta}{\eta - 1} \right]^{1-\eta} \frac{\delta}{\alpha\eta} \sum_{k=1}^{M} s_k P_k^{T\eta-1} W_k \tag{32}$$

Then, for all countries i and j relative wages depend on relative traded sector productivity, with an elasticity that depends on the elasticity of demand for a country's traded output:

$$\frac{W_i}{W_j} = \left(\frac{A_i^T}{A_j^T} \right)^{\frac{\eta-1}{\eta}} \tag{33}$$

Since PPP holds, the relative price level or real exchange rate between country i and country k is given by

$$\frac{P_i}{P_k} = \left[\frac{P_i^T}{P_k^T} \right]^{\delta} \left[\frac{P_i^N}{P_k^N} \right]^{1-\delta} = \left[\frac{A_k^N}{A_i^N} \frac{W_i}{W_k} \right]^{1-\delta} \tag{34}$$

$$\frac{P_i}{P_k} = \left[\frac{A_k^N}{A_i^N} \left(\frac{A_i^T}{A_k^T} \right)^{\frac{\eta-1}{\eta}} \right]^{1-\delta} \tag{35}$$

Equation (33) says that, in contrast to the classic Balassa-Samuelson prediction, the elasticity of relative wages with respect to relative traded sector productivity need not equal one. In fact, as long as the output of country i is imperfectly substitutable with the output of other countries, the elasticity is less than one. The intuition is that imperfect substitutability leads each individual country to face a downward-sloping demand curve on world markets for its traded output, as captured in equation (31). An increase in traded sector productivity leads to an increase in the supply of traded varieties produced in country i relative to other countries. However, because of the fact that demand is downward sloping, this depresses the relative price of country i's output, i.e. there is a terms-of-trade effect. As a result, demand for labor increases less than in the classic case, so wages are driven up by less than in the classic case. As the intuition suggests, terms-of-trade effects are not specific to this particular model.[6] In fact, in a more general framework, it is possible to envisage that terms-of-trade effects might be sufficiently perverse that an increase in traded-sector productivity could actually lead to a reduction in relative wages.[7]

A corollary of the terms-of-trade effect is that *aggregate* productivity may in fact be *negatively* correlated with relative price levels. Equation (35) says that relative prices are a weighted average of relative traded sector productivity and relative non-traded sector productivity. Due to the terms-of-trade effect, the weight on traded sector productivity is smaller in absolute value than the weight on non-traded sector productivity. Hence, if the gap in traded sector productivity between a pair of countries is small relative to the gap in non-traded sector productivity, the non-traded sector productivity may dominate. This may induce a negative relationship between aggregate productivity (a function of both traded and non-traded sector productivity) and relative prices. To illustrate this, consider the case where in each country, productivity is identical in traded and non-traded sectors. In this case, aggregate productivity A_i is equal to sectoral productivity A_i^T and A_i^N. Substituting A_i and A_j in to (35) yields:

$$\frac{P_i}{P_j} = \left(\frac{A_j}{A_i}\right)^{\frac{1-\delta}{\eta}}$$

This demonstrates that under certain circumstances, more productive countries have lower

[6] The terms-of-trade effect on relative price levels has been noted by Benigno and Thoenissen (2002) and MacDonald and Ricci (2002). It is similar to the terms-of-trade effect in Acemoglu and Ventura (2001), though they examine the results in the context of the world distribution of incomes rather than the distribution of prices.

[7] In this framework, values of η (the parameter governing the elasticity of substitution between traded varieties, and the elasticity of demand for each variety) that are less than one violate equilibrium conditions. With less restrictive preferences, it is possible to envisage an elasticity of demand for a country's output that is less than one.

price levels instead of higher price levels.[8]

2.3 Trade costs and interdependence

Now suppose that everything is as in section 2.2 except that there is an iceberg cost of trade, assumed proportional to the distance between countries. When this cost is non-zero, different countries end up consuming different baskets of goods, because they face different relative prices. They will tend to trade more with countries that are closer to them, and that are large. This gives the model gravity-type features.

With an iceberg trade cost, prices of identical traded goods differ across countries. If good i is produced in country i, then the relationship between the price of the good in country i and any other country k is given by:

$$P\left(i\right)_k^T = \frac{P\left(i\right)_i^T}{1-\tau.d_{ik}} \tag{36}$$

where τ scales all trade costs, and d_{ik} is the distance between country i and country k, assumed greater than or equal to zero. The distance between a country and itself is always equal to zero.

As before, market clearing for each individual traded good says that the amount produced of each variety equals total world demand for that variety. So, taking account of the fact that the amount that is exported is larger than the amount that is imported due to the iceberg trade cost yields:

$$Y\left(j\right)_i^T = \sum_{k=1}^{M} \delta \left(\frac{P\left(j\right)_k^T}{P_k^T} \right)^{-\eta} \frac{P_k C_k}{P_k^T} \frac{1}{1-\tau.d_{ik}} \tag{37}$$

Substituting in and rearranging yields the first equilibrium condition: a relationship between wages, traded sector productivity, and the price of the traded aggregate:

$$W_i^{\eta} A_i^{T1-\eta} = \left[\frac{\eta}{\eta-1}\right]^{1-\eta} \frac{\delta}{\alpha\eta} \sum_{k=1}^{M} \frac{s_k}{\left(1-\tau.d_{ik}\right)^{1-\eta}} P_k^{T\eta-1} W_k \tag{38}$$

Substitution into the traded price index yields the second equilibrium condition: a relation-

[8]Note that one-sector models (or models with uniform within-country productivity) always generate a negative correlation between productivity and prices.

ship beween wages, traded sector productivity and the price of the traded aggregate:

$$P_i^{T1-\eta} = \left[\frac{\eta}{\eta-1}\right]^{1-\eta} \frac{\delta}{\alpha\eta} \sum_{k=1}^{M} \frac{s_k}{(1-\tau.d_{ik})^{1-\eta}} A_k^{T\eta-1} W_k^{1-\eta} \tag{39}$$

Using (39) to substitute into (38) yields a system of equations the solution to which is the vector of relative wages:

$$W_i^{\eta} A_i^{T1-\eta} = \sum_{k=1}^{M} \frac{s_k W_k}{(1-\tau.d_{ik})^{1-\eta}} \left[\sum_{h=1}^{M} \frac{s_h A_h^{T\eta-1} W_h^{1-\eta}}{(1-\tau.d_{kh})^{1-\eta}}\right]^{-1} \tag{40}$$

This model cannot be solved for relative wages in closed form. However, from (40) it is clear that the relative wage between any given pair of countries depends not only on traded sector productivity in that pair of countries, but also on productivity in other countries. This implies that the relative price level between a pair of countries depends on the traded-sector productivity of all other countries. With asymmetric trade, bilateral real exchange rates for different country-pairs are interdependent. Note that (40) is also the equilibrium condition of a model with Armington specialization and perfectly competitive traded-sector firms.

3 Simulation of the model

3.1 Data and parameters

The model with trade costs presented in the previous section, and summarized in equation (40) cannot be solved in closed form, but it is relatively parsimonious in terms of parameters. The solution depends on just three global parameters: δ, the value share of traded goods in consumption; η, the elasticity of demand for traded output on world markets and τ, the iceberg cost of trade. It also depends on the size distribution of countries (where size refers to the size of the labor force), bilateral distances, and of course on productivity in traded and non-traded goods sectors. All of these are relatively easy to measure for developed countries. I construct measures of traded and non-traded sector TFP levels for a set of 10 European countries: Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Sweden and the UK.These countries trade a good deal with each other, but relatively little with countries outside the group, which is consistent with the model.

Price data are necessary for econometric evaluation of the model. Estimates of the relative price levels of absorbtion (Private consumption, C plus government consumption G plus investment I) are taken from the Penn World Tables, Version 6.1. The relative price I use is labelled P in the database.[9] Total absorbtion is the most appropriate empirical counterpart to the model concept C, since G and I are not modelled. Although the benchmark studies on which price level comparisons are based are carried out only at 5-year intervals, the authors of the PWT use data from national accounts to interpolate price comparisons between benchmark studies. Common weights are used to make the relative price comparisons. This contrasts with the model, where the price level P is an index that corresponds exactly to a utility function, which allows the weights to vary with relative prices. In practice, since the countries under consideration are all developed countries, price-appropriate weights are unlikely to differ much across the sample. Therefore it is unlikely that the assumption of identical weights biases the results substantially.

Section 2 presents a one-factor model, where TFP and labor productivity are identical. In the real world there are many factors. Simple models with multiple factors suggest that the appropriate measure of productivity is total factor productivity. Total factor productivity comparisons are often made using value added, because sectoral production and input use time series are not available. As explained by Caves, Christensen and Diewert (1982), if the value added function is Cobb-Douglas in capital and labor, with exponent α on labor, a superlative,[10] transitive TFP comparison is given by

$$\frac{TFP_c^j}{TFP_d^j} = \frac{Y_c^j}{Y_d^j}\frac{L_d^{j\alpha} K_d^{j1-\alpha}}{L_c^{j\alpha} K_c^{j1-\alpha}} \tag{41}$$

This is the method used to construct the productivity estimates.

The OECD Intersectoral Database gives data on sectoral employment, capital stocks, value added and labor share in domestic currency, current and constant prices, for all of the sample countries from 1970 to the mid-1990s. I update the database using OECD and national statistical sources as described in the data appendix. I define Agriculture, Mining and Manufacturing as traded sectors, and all the remaining sectors as non-traded. Over

[9] Consumer prices and expenditure weights are used to construct the relative price P reported in the Penn World Tables. This suggests that it is more appropriate to think of it as a price of absorbtion rather than a price of output in an open economy context.

[10] i.e. exact for the flexible translog value added function.

time, changes in the costs of trade have naturally altered the range of goods and services that can be and are traded. However, a finer and potentially time-varying classification of traded and non-traded would reduce the sample size, as many countries do not report all variables at a sufficiently fine level of disaggregation.[11]

Constant-price data on aggregate value added are converted to international dollars using the Summers-Heston PPP for absorbtion for the base year (1990). Traded sector constant-price value added is converted to international dollars using the base-year exchange rate. This is consistent with the assumption in the model that the law of one price holds for tradeables. Non-traded sector constant-price value added is converted to international dollars using a PPP for the non-traded sector, constructed using Summers-Heston benchmark data for the base year.[12] Aggregate and sectoral constant-price capital stocks are converted to international dollars using the base year PPP for investment (P_i in the Summers-Heston notation). Further details on the construction of the productivity data can be found in the data appendix.

Population, taken from the Penn World Tables, is used as the measure of size. Bilateral distance is the distance in kilometres from capital city to capital city. Bonn is assumed to be the capital city of Germany throughout the period 1970-99.

In order for the simulation to make sense, baseline values of the parameters must have some connection to reality. The value share of traded goods in total consumption, δ is tricky to estimate, but for the countries under consideration, the value share of traded goods in production can be easily calculated from the OECD Intersectoral database. Where the current account is relatively small as a fraction of total output, the two should be similar. The value share of traded goods in total output has in fact fallen steadily over the past 30 years in almost all OECD countries, from a high of 0.5 to a low of 0.2 in some countries. This indicates misspecification of the Cobb-Douglas aggregator over tradeables and non-tradeables, but at this time, I do not deal with the issue.[13] I set $\delta = 0.5$ throughout.

Although I present a model where η is a global parameter, there are strong reasons to believe that the elasticity of export demand actually differs across countries. In particular,

[11] De Gregorio, Giovannini and Wolf (1994) use the ratio of sectoral exports to production to classify sectors as traded or non-traded. They classify Transportation services as traded. In the 1990s, services made up 15 to 20 percent of trade for the countries in my sample

[12] Details of the construction of this PPP are available on request.

[13] Non-homotheticities are assumed by De Gregorio et al. (1994) to match the evolution of relative quantities and relative prices of traded and non-traded goods.

it is likely to depend on country size, the degree of specialization of the economy and market structure in the sectors in which the country specializes. The size of this particular parameter is of great interest to policy-makers, because it governs the response of exports to a devaluation. Several studies attempt to estimate it for a wide variety of countries. The consensus is that the price elasticity of export demand differs across countries, that it is larger in the long run than the short run, and that in the long run, it lies somewhere between 0 and 4, being concentrated in the neighborhood of 1.[14] Although the theoretical model makes sense only when $\eta \geq 1$, there is no clear prediction on whether the long run elasticity is systematically greater than 1 or less than 1. Hence, it may be empirically relevant to consider the case of terms-of-trade reversals. I examine the effects of assuming elasticities that range from 0.5 to 4.

The parameter τ governs the strength of trade costs. It must be greater than or equal to zero. The maximum value of τ is dictated by the restriction that all countries in the sample trade with each other at least to some extent. Hence $1 \geq \tau.d_{\max}$ where $d_{\max}$ is the maximum bilateral distance between country-pairs in the sample. Trade costs probably fall over the period 1970 to 1999, and falling trade costs should generate convergence in price levels for a given distribution of relative productivities.

3.2 Simulation results

I explore the properties of the simulated model as follows: The data and parameters described above are used to construct model-consistent price series. This synthetic data, along with the actual data on traded and non-traded sector productivity is used to estimate a number of different reduced form approximations to the nonlinear model with trade costs.

First, I investigate the performance of the estimating equation suggested by the model without trade costs. Taking logs of

$$\frac{P_i}{P_k} = \left[\frac{A_k^N}{A_i^N} \left(\frac{A_i^T}{A_k^T} \right)^{\frac{\eta-1}{\eta}} \right]^{1-\delta} \tag{42}$$

[14] See, for example the survey of Goldstein and Khan (1985) and for a more up-to-date example Senhadji and Montenegro (1998).

and adding an error term to allow for the fact that the approximation is not perfect yields:

$$\ln \frac{P_{it}}{E_{ijt} P_{jt}} = \beta_0 + \beta_1 \ln \frac{A^T_{it}}{A^T_{jt}} + \beta_2 \ln \frac{A^N_{it}}{A^N_{jt}} + \varepsilon_{ijt} \tag{43}$$

Table 1 reports the results from estimating this equation using data sets constructed under several different configurations of the trade cost, τ, and the elasticity of demand for country exports, η. Values of η that are less than one are considered. This is inconsistent with specialization due to increasing returns and monopolistic competition, but is not inconsistent with Armington specialization, for example. The results in Table 1 indicate that the relationship between relative prices and relative non-traded sector productivity is indeed negative in the model with trade costs. It indicates that the relationship between relative prices and relative traded sector productivity depends on the elasticity of demand for country exports in the direction predicted: The closer to one is the elasticity of demand, the smaller is the elasticity of relative prices with respect to relative traded sector productivity. In fact, if demand is inelastic ($\eta < 1$) there is a negative relationship between relative prices and traded sector productivity. The results further suggest that when trade costs are large, extracting evidence of a significant relationship between prices and productivity may be difficult, as the coefficients of the reduced form are not likely to be estimated with precision.

Second, I investigate the prediction that for a given country-pair, relative prices depend on traded sector productivity in all countries and not just on productivity in that pair. This is done by estimating the reduced-form approximation

$$\ln \frac{P_{it}}{E_{ijt} P_{jt}} = \beta_0 + \beta_1 \ln \frac{A^T_{it}}{A^T_{jt}} + \beta_2 \ln \frac{A^N_{it}}{A^N_{jt}} + \sum_{k \neq i,j}^{M} \phi_{ijk} \ln A^T_{kt} + \varepsilon_{ijt} \tag{44}$$

on a country-by-country basis. For each of the 9 country-pairs with France, synthetic relative prices are regressed on actual relative traded and non-traded sector productivity, and on traded-sector productivity in each of the remaining 8 countries. The results from this exercise are reported in Table 2, with the coefficients ϕ_{ijk} not recorded. The results indicate that relative prices depend on third-country productivity, and that once dependence on third-country productivity is controlled for, the relationship between bilateral relative prices and bilateral traded and non-traded sector productivity is remarkably similar to the relationship in the model without trade costs. In fact, once third-country productivity is controlled for, the bilateral relationship between relative price levels and productivity is precisely estimated. This implies that the failure to control for interdependence may lead to strongly biased and imprecise estimates of the relationship between relative price levels and relative traded sector productivity.

4 Econometric evaluation

First, I show that if production is in fact specialized as in the models in sections 2.2 and 2.3 then some classic tests of the productivity model of real exchange rates are badly misspecified. I also argue that panel cointegration tests as implemented by many researchers in this field are likely to give misleading results if trade is asymmetric and third country effects on bilateral real exchange rates are important. I implement specialization-consistent tests of the productivity model using the sample of 10 European countries described in section 3. The results are not strongly conclusive, though they are not inconsistent with the productivity model of real exchange rates outlined in 2.3.

4.1 Panel evidence

4.1.1 Time-series tests of the productivity model

In a number of influential papers, researchers have used time-series data to test an "intermediate" prediction of the Balassa-Samuelson framework: that the price of traded relative to non-traded goods depends on the ratio of productivity in the traded and non-traded sectors. In order to do so, they use data on production deflators to capture the evolution of tradeables prices relative to non-tradeables prices.[15] In the notation of this paper, they regress $P_t^{Y^T}/P_t^N$ or its difference on A_t^T/A_t^N or its difference. In a world where there is only one homogeneous tradeable good, this makes perfect sense. But when different countries produce different tradeable goods, the test is flawed. As the exposition of the model with specialization demonstrates, the intellectual capital of the Balassa-Samuelson model is staked on a correlation between P^T/P^N and A^T/A^N, not on a correlation between P^{Y^T}/P^N and A^T/A^N. These papers provide robust evidence of a correlation between P^{Y^T}/P^N and A^T/A^N, but

[15] This test is implemented by Asea and Mendoza (1994), De Gregorio et al. (1994) and Canzoneri, Cumby and Diba (1999).

this is not, as they claim, evidence in favor of the Balassa-Samuelson model. If price is a function of marginal cost (an assumption not specifict to the Balassa-Samuelson model) relative prices and the ratio of marginal costs should be correlated even in a perfectly closed economy, for any two sectors arbitrarily defined.

The other approach to testing the productivity model of real exchange rates involves testing for the existence of a long-run relationship between bilateral real exchange rates and bilateral sectoral productivity using time-series data, and estimating the coefficients of this relationship (i.e. (43)). This is an appropriately specified test of the model. However, the results from these tests are almost uniformly unsupportive. Evidence of the predicted cointegrating relationship between prices and productivity on a country-by-country basis is weak. The coefficients on traded and non-traded sector productivity are not estimated precisely, are unstable, and frequently have the "wrong" sign.[16] The explanatory power of sectoral productivity is very low, both in levels and in differences. The evidence in section (3) suggests one reason why this might be the case. When the pattern of trade across countries is asymmetric (as it is), the failure to control for third-country traded-sector productivity may lead to biased and imprecise estimates of the relationship between relative price levels and sectoral productivity.

Chinn and Johnston (1996) and Chinn (1997) obtain what they view as stronger evidence of cointegration between real exchange rates and productivity using panel-cointegration tests. However, the existence of asymmetric interdependence relationships between countries invalidates the use of panel time-series tests for the existence of a long-run relationship between prices and productivity. This is because asymmetric interdependence is likely to induce cross-group cointegrating relationships between relative price levels, i.e. the relative price level between a given pair of countries is cointegrated with the relative price levels of all other country-pairs drawn from the original pair's trading partners. As demonstrated by Banerjee et al (2000, 2001), this results in an empirical size of panel unit root tests that is considerably higher than the nominal level.

[16] See Asea and Mendoza (1994), Chinn and Johnston (1996) and Chinn (1997).

4.1.2 New evidence from a panel of 10 European countries

In testing the productivity model of real exchange rates using my sample of 10 European countries 1970-99 I attempt to improve on the previous literature by controlling for asymmetric interdependence. When there are no costs of trade, the model outlined in section 2.2 suggests a log-linear specification for the relationship between relative prices and sectoral productivity. The simulation evidence suggests that when trade costs are non-zero, the relationship is approximately log-linear, once it is augmented to control for third-country traded-sector productivity. This leads me to propose the estimating equation

$$\ln \frac{P_{it}}{E_{ijt}P_{jt}} = \beta_1 \ln \frac{A^T_{it}}{A^T_{jt}} + \beta_2 \ln \frac{A^N_{it}}{A^N_{jt}} + \lambda \tilde{\boldsymbol{\phi}}_{ij} \ln \mathbf{A}^T_{-ijt} + \varepsilon_{ijt} \tag{45}$$

where $\mathbf{A}^T_{-ijt}$ is the vector of traded sector productivity in countries other than i and j and $\lambda\tilde{\boldsymbol{\phi}}_{ij}$ is a vector of weights on these third-country productivities that is specific to the pair i and j. The element $\lambda\phi_{ijk}$ of this vector is the elasticity of the real exchange rate between country i and country j with respect to traded sector productivity in country k. Note that $\lambda\phi_{ijk}$ is not constrained equal to $\lambda\phi_{kji}$. Unrestricted estimation of $\lambda\tilde{\boldsymbol{\phi}}_{ij}$ by non-linear least squares is feasible if the number of countries included is significantly smaller than the number of time-series observations. However, it greatly reduces the degrees of freedom in the case under consideration. In an appendix available on request, I show that the effects of third-country productivity depend on bilateral import and export shares. This suggests using OECD data on average relative trade shares to calibrate the interdependence parameters up to the order of a constant, λ. Let α_{ik} denote the share of country k in country i's total within-sample trade, and α_{jk} the share of country k in country j's total within-sample trade. I construct

$$\tilde{\boldsymbol{\phi}}_i = \begin{bmatrix} (\alpha_{j1} - \alpha_{i1}) & \cdots & (\alpha_{jN} - \alpha_{iN}) \end{bmatrix}'$$

Given the way in which $\tilde{\boldsymbol{\phi}}_i$ is constructed, λ should be positive as long as the direct effect of changes in A^T_k on prices in countries i and j, together with the substitution effect in country k, outweigh income effects in country k.

For any set of N countries there can be at most $N-1$ independent bilateral observations on relative prices. Therefore, it is usual to choose a numeraire country and write all variables relative to the numeraire. I choose France as the numeraire. Specification (45) has the convenient property that if the constant term is set to zero, transitivity of price ratios is imposed in pooled estimation.[17] I do not in fact impose this restriction, but in most cases, it is clear that the data would not reject it.

The results from estimating equation (45) using pooled OLS, Between effects and Fixed effects are reported in Table 3. An AR(1) correction is implemented in the pooled OLS and Fixed effects estimates in an attempt to control for persistence. There are four important points to note about these results. First, within this group of developed countries, there is a negative cross-sectional relationship between price levels and aggregate productivity. This is entirely consistent with the specialization-augmented model. Second, the coefficients on relative traded and non-traded sector productivity are in general imprecisely estimated. In particular, the sign of the coefficient on traded-sector productivity is not robust across specifications. This is consistent with biases from imperfect controls for third-country productivity. However the third point to note is that a negative coefficient on traded-sector productivity is not inconsistent with the model, though it requires terms-of-trade effects to be perverse. Finally, including a weighted average of third-country productivity greatly increases the explanatory power of the model, and its sign is robustly positive. This is consistent with the predictions of the model including trade costs. In order to demonstrate that these results are not at odds with the theoretical model, in Table 4, I report the results of estimating pooled OLS, Between effects and Fixed effects using simulated instead of actual price data. To summarize, the panel estimation is not strongly supportive of the augmented productivity model of relative price levels, but it is not inconsistent with it.

Of course, given that the data appears to be strongly persistent it is also appropriate to ask whether there is evidence of a cointegrating relationship between relative prices and relative sectoral productivity. The results from testing for unit roots in the data on a country-by-country basis using the DF-GLS test are reported in Table 5.[18] In general, it is not possible to reject the null hypothesis of a unit root for these countries and these series, though the low power of the test in a short series of 30 observations suggests caution. Accordingly, I proceed to test for cointegration on a country-by-country basis, using the ADF-GLS test described by Perron and Rodriguez (2001). The results are reported in Table

[17] This would not be the case if the equation were written in terms of ratios of A^T to A^N, as is common in the literature.

[18] As already explained, it is likely that the panel unit root tests that currently exist are inappropriate in this context.

6. It is not possible to reject the null hypothesis of no cointegration. That is, using this data and this test, there is no evidence of a robust long-run relationship between relative prices and sectoral productivity.

There are several possible explanations for this failure. First, the test has low power in short samples. In an earlier version of this paper, I perform a Monte Carlo experiment to investigate this hypothesis. The conclusion from this exercise is that low power alone is probably not the reason for the failure to reject the no-cointegration null. Second, measurement error is pervasive in this situation. We measure productivity badly within countries, especially non-traded sector productivity, and cross-country comparisons of prices and productivity are even more fraught with problems. Since variation in the independent variables over time is small for this sample of developed countries (no country experiences a productivity transition) it is all the more likely that measurement error will make the true relationships hard to uncover. As the evidence in section 3 demonstrates, controlling properly for third-country productivity is important, and it may not be appropriately dealt with using the calibrated weighted average $\tilde{\boldsymbol{\phi}}_{ij} \ln \mathbf{A}^T_{-ijt}$. Third, the model on which the estimating equation is based leaves out potentially relevant features of empirical economies. It does not allow for cross-country differences in competition.[19] It assumes that the law of one price holds for traded goods, when there is substantial evidence to the contrary. All of these factors could potentially explain why the evidence of a time-series relationship between price levels and sectoral productivity is weak. More work is necessary to establish whether this requires a modification of the model, or a more powerful empirical approach.

5 Conclusion

The main contribution of this paper is theoretical. I demonstrate that trade models have an important contribution to make to the literature on real exchange rate determination. Once a motive for intra-temporal trade is introduced into the classic Balassa-Samuelson model through specialization of production, it is clear that terms-of-trade effects modify the relationship between relative prices and traded-sector productivity. Terms-of-trade effects reduce the elasticity of relative prices with respect to traded sector productivity, and may even reverse the sign of the relationship. Further, explicit consideration of specialization combined

[19] In an earlier version of the paper, I provide some evidence that this may be important.

with costs of trade suggests that relative price levels between a given pair of countries depend not just on sectoral productivity in that pair, but also on traded-sector productivity of the countries that they trade with. Simulation of the model using data on 10 European countries suggests that the magnitude of both of these effects is likely to be empirically important. I use the data-set on price levels and productivity levels for 10 European countries from 1970 to 1999 to implement a model-consistent test of the relationship between real exchange rates and sectoral productivity. The results are not conclusive. I discuss some reasons for this, and suggest some fruitful avenues for future reasearch on the question.

References

[1] Acemoglu, D. and J. Ventura (2002), "The World Income Distribution," *Quarterly Journal of Economics* 117 (2), 659-694.

[2] Asea, P. and E. Mendoza (1994), "The Balassa-Samuelson Model: A General Equilibrium Appraisal," *Review of International Economics* 2 (3), 191-200.

[3] Banerjee, A., M. Marcellino and C. Osbat (2000), "Some Cautions on the Use of Panel Methods for Integrated Series of Macro-Economic Data," mimeo, European University Institute.

[4] Banerjee, A., M. Marcellino and C. Osbat (2001), "Testing for PPP: Should We Use Panel Methods?" mimeo, European University Institute.

[5] Benigno, G. and C. Thoenissen (2002), "Equilibrium Exchange Rates and Supply Side Performance," Bank of England Working Paper 156.

[6] Bergstrand, J. (1991), "Structural Determinants of Real Exchange Rates and National Price Levels: Some Empirical Evidence," American Economic Review 81 (1), 325-334.

[7] Bhagwati, J. (1984), "Why Are Services Cheaper in Poor Countries?" *Economic Journal* 94 (374), 279-86.

[8] Canzoneri, M., R. Cumby and B.Diba (1999), "Relative Labor Productivity and the Real Exchange Rate in the Long Run: Evidence for a Panel of OECD Countries," Journal of International Economics 47 (2), 245-266.

[9] Caves, D., L. Christensen and W. Diewert (1982), "Multilateral Comparisons of Output, Input and Productivity Using Superlative Index Numbers," *Economic Journal* 92, 73-86.

[10] Chinn, M. and L. Johnston (1996), "Real Exchange Rate Levels, Productivity and Demand Shocks: Evidence From a Panel of 14 Countries," NBER Working Paper 5709.

[11] Chinn, M. (1997), "Sectoral Productivity, Government Spending and Real Exchange Rates: Empirical Evidence For OECD Countries," NBER Working Paper 6017.

[12] De Gregorio, J., A. Giovannini and H. Wolf (1994), "International Evidence on Tradeables and Nontradeables Inflation," *European Economic Review* 38, 1225-1244.

[13] Dornbusch, R., S. Fisher and P. Samuelson (1977), "Comparative Advantage, Trade, and Payments in a Ricardian Model with a Continuum of Goods," American Economic Review 67 (5), 823-839.

[14] Elliott, G., T. Rothenberg and J. Stock (1996), "Efficient Tests for an Autoregressive Unit Root," *Econometrica* 64 (4), 813-836.

[15] Engel, C. (1999), "Accounting for US Real Exchange Rate Changes," *Journal of Political Economy* 107 (3), 507-537.

[16] Fitzgerald, D. and J-C. Hallak (2002), "Specialization, Factor Accumulation and Development," mimeo, Harvard University

[17] Goldstein, M. and M. Khan (1985), "Income and Price Effects in Foreign Trade," in *Handbook of International Economics*, Vol 1., R. Jones and P. Kenen (eds.), North-Holland, 1042-99

[18] Heston, A., R. Summers and B. Aten (2002), *Penn World Table Version 6.1*, Center for International Comparisons at the University of Pennsylvania (CICUP).

[19] Ito, T., P. Isard and S. Symansky (1999), "Economic Growth and Real Exchange Rates: An Overview of the Balassa-Samuelson Hypothesis in Asia," in T. Isard and A. Krueger (eds.), *Changes in Exchange Rates in Rapidly Developing Countries: Theory, Practice, and Policy Issues*, The University of Chicago Press, 109-130.

[20] Keller, W (2001), "International Technology Diffusion," NBER Working Paper 8573.

[21] Kravis, I. and R. Lipsey (1983), *Toward an Explanation of National Price Levels*, Princeton Studies in International Finance No. 52

[22] Kravis, I. and R. Lipsey (1988), "National Price Levels and the Price of Tradeables and Nontradeables," *American Economic Review* 78 (2), 474-478.

[23] MacDonald, R. and L. Ricci (2002), "Purchasing Power Parity and New Trade Theory," IMF Working Paper 02/32.

[24] Maddala, G. and I. Kim (1998), *Unit Roots, Cointegration and Structural Change*, Cambridge University Press

[25] Obstfeld, M. and K. Rogoff (2001) "Perspectives on OECD Capital Market Integration: Implications for U.S. Current Account Adjustment," in Federal Reserve Bank of Kansas City Global Economic Integration: Opportunities and Challenges, 169-208.

[26] O'Connell, P. (1998), "The Overvaluation of Purchasing Power Parity," *Journal of International Economics* 44, 1-19

[27] OECD (2001), Intersectoral Database, contained in *OECD Statistical Compendium.*

[28] Papell, D. (1997), "Searching For Stationarity: Purchasing Power Parity Under the Current Float," *Journal of International Economics* 43, 313-332

[29] Perron, P. and G. Rodríguez (2001), "Residual Based Tests for Cointegration with GLS Detrended Data," mimeo, Boston University.

[30] Senhadji, A. and C. Montenegro (1998), "Time Series Analysis of Export Demand Equations: A Cross-Country Analysis," IMF Working Paper 98/149

A Data construction

Employment, Capital and Output are taken mainly from the OECD Intersectoral Database (now discontinued). This database covers the 10 sample countries from 1970 until the mid-1990s and gives employment, capital, output and the labor share by sector. The sectors Agriculture, Mining and Manufacturing are defined as traded. All other sectors are defined as non-traded. This classification is chosen to maximize the sample size and consistency of the data. The coverage of the Intersectoral Database in terms of years depends on the country and on the series. Where necessary, the database was updated to 1999. The main source for the updating was OECD National Accounts. For some countries data from national statistical institutes was also required. Where there was a discontinuity between the Intersectoral Database series and the series used to update, only the time-series variation in the series used to update was integrated into the database. This required at least one overlapping year between the two series. The capital stock was updated using a different procedure from that used in the construction of the Intersectoral Database. The perpetual inventory method was used, with the depreciation rate being set equal to the average depreciation rate for that sector, backed out using the Intersectoral Database capital and gross fixed capital accumulation data for the 5 years prior to the last capital observation in the Intersectoral Database. The updated capital stock series were not sensitive to the choice of depreciation rate. Further details of the updating are available on request.

A.1 Capital comparisons

The OECD Intersectoral Database supplies an estimate of the sectoral capital stock, valued at 1990 local prices, and converted into 1990 international dollars using the PPP for capital in 1990 given in the PWT. The same PPP is applied to capital in all sectors in a given country. The capital employed in country c, sector j in year t valued at 1990 international prices is thus calculated as

$$P^K_{w,1990} K^j_{c,t} = \frac{P^K_{w,1990}}{P^K_{c,1990}} P^K_{c,1990} K^j_{c,t}$$

where the w subscript refers to world prices and the c subscript refers to domestic prices.

A.2 Output comparisons

The OECD Intersectoral Database supplies sectoral output data valued at 1990 domestic prices and at current domestic prices. Price deflators vary across sectors, as relative prices can change over time. Total output valued at 1990 domestic prices is converted to total output valued at 1990 international prices by multiplying by the PPP for output in 1990 taken from the PWT:

$$P^Y_{w,1990}Y_{c,t} = \frac{1}{E_{c,1990}}\frac{P^Y_{w,1990}}{P^Y_{c,1990}}P^Y_{c,1990}Y_{c,t}$$

Shares of output in the tradeable and non-tradeable sectors are calculated valued at 1990 domestic prices:

$$sh_{c,t,j} = \frac{P^j_{c,1990}Y^j_{c,t}}{P^Y_{c,1990}Y_{c,t}}$$

Non-tradeable output valued at world prices is calculated using:

$$P^N_{w,1990}Y^N_{c,t} = \frac{1}{E_{c,1990}}\frac{P^N_{w,1990}}{P^N_{c,1990}}.\frac{P^N_{c,1990}Y^N_{c,t}}{P^Y_{c,1990}Y_{c,t}}P^Y_{c,1990}Y_{c,t}$$

where the non-traded sector PPP in 1990 is calculated from the Summers-Heston benchmark data for 1990. Details of this calculation are available on request. According to the model, which assumes that the law of one price holds for tradeable output:

$$P^T_{c,1990} = E_{c,1990}P^T_{w,1990}$$

it is appropriate to use the nominal exchange rate to convert tradeable output to world prices. Since in any case, constructing output PPPs for the tradeable sector raises both conceptual and practical difficulties, I follow the guidance of the model:

$$P^T_{w,1990}Y^T_{c,t} = \frac{1}{E_{c,1990}}.\frac{P^T_{c,1990}Y^T_{c,t}}{P^Y_{c,1990}Y_{c,t}}P^Y_{c,1990}Y_{c,t}$$

A.3 TFP comparisons

The formula I use to calculate TFP is described in the text. Due to lack of data availability, I do not control for hours worked, capital utilization or other factors besides capital and labor. Nor do I control for deviations from perfect competition. The production function for sectoral value added is assumed to be

$$Y_{c,t}^{j} = A_{c,t}^{j}\left(K_{c,t}^{j}\right)^{1-\alpha_{j}}\left(L_{c,t}^{j}\right)^{\alpha_{j}}$$

The exponents on capital and labor are allowed to differ across sectors, but are assumed constant over time and across countries. The value chosen for α_j is the average across sample countries and sample years of the labor share of output in that sector. This labor share is constructed using data from the OECD Intersectoral database. It is calculated using data in current domestic currency. TFP levels are calculated as

$$\hat{A}_{c,t}^{j} = \frac{P_{w,1990}^{j} Y_{c,t}^{j}}{\left(P_{w,1990}^{K} K_{c,t}^{j}\right)^{1-\alpha_{j}}\left(L_{c,t}^{j}\right)^{\alpha_{j}}}$$

A.4 Labor productivity

Sectoral labor productivity is calculated by taking the simple ratio of sectoral output, weighted by the world price of output in that sector in 1990, and employment in that sector:

$$Q_{c,t}^{j} = \frac{P_{w,1990}^{j} Y_{c,t}^{j}}{L_{c,t}^{j}}$$

A.5 Other data

In calibrating the parameters of a multi-country asymmetric version of the model, I use bilateral trade data from the OECD. I also use input-output tables from the OECD. Population from the PWT is the measure of size.

Table 1: Prices and productivity in the trade cost model

	elasticity	coeff.	s.e.	R^2	coeff.	s.e.	R^2
$\eta = 4$	$\tau = 0$	$\tau = 0.0002$			$\tau = 0.0004$		
$\ln A_i^T/A_j^T$	0.375	0.34	(0.00)	0.99	0.30	(0.00)	0.94
$\ln A_i^N/A_j^N$	-0.5	-0.51	(0.01)		-0.53	(0.01)	
const.	-	0.00	(0.00)		0.01	(0.00)	
$\eta = 1.5$	$\tau = 0$	$\tau = 0.0002$			$\tau = 0.0004$		
$\ln A_i^T/A_j^T$	0.17	0.06	(0.01)	0.77	-0.14	(0.02)	0.59
$\ln A_i^N/A_j^N$	-0.5	-0.52	(0.02)		-0.58	(0.06)	
const.	-	0.01	(0.00)		0.03	(0.01)	
$\eta = 0.9$	$\tau = 0$	$\tau = 0.0002$			$\tau = 0.0004$		
$\ln A_i^T/A_j^T$	-0.06	-0.23	(0.01)	0.88	-0.59	(0.04)	0.71
$\ln A_i^N/A_j^N$	-0.5	-0.54	(0.03)		-0.67	(0.11)	
const.	-	0.02	(0.00)		0.06	(0.01)	

Note to Table 1: Synthetic price data is constructed using actual data on distance, size and productivity for 10 European countries 1970-99, and the parameters assumed in the table. Table reports estimated coefficients from the regression of the log relative price level (relative to France in each case) on log relative traded and non-traded sector productivity.

Table 2: Third-country productivity in the trade cost model

	$\tau = 0.0002$				$\tau = 0.0004$			
	$\eta = 1.5$				$\eta = 1.5$			
	$\ln \frac{A_i^T}{A_j^T}$	s.e.	$\ln \frac{A_i^N}{A_j^N}$	s.e.	$\ln \frac{A_i^T}{A_j^T}$	s.e.	$\ln \frac{A_i^N}{A_j^N}$	s.e.
Belgium	0.17	(0.00)	-0.50	(0.00)	0.17	(0.00)	-0.50	(0.00)
Denmark	0.17	(0.00)	-0.50	(0.00)	0.17	(0.00)	-0.50	(0.00)
Finland	0.17	(0.00)	-0.50	(0.00)	0.16	(0.00)	-0.49	(0.01)
Germany	0.17	(0.00)	-0.50	(0.00)	0.18	(0.00)	-0.50	(0.01)
Italy	0.16	(0.00)	-0.50	(0.00)	0.15	(0.00)	-0.50	(0.01)
Neth.	0.17	(0.00)	-0.50	(0.00)	0.16	(0.00)	-0.51	(0.00)
Norway	0.16	(0.00)	-0.50	(0.00)	0.15	(0.00)	-0.50	(0.00)
Sweden	0.17	(0.00)	-0.50	(0.00)	0.16	(0.00)	-0.50	(0.00)
UK	0.16	(0.00)	-0.50	(0.00)	0.16	(0.00)	-0.50	(0.00)
$\tau = 0$	0.17		-0.5		0.17		-0.5	

Note to Table 2: Synthetic price data is constructed using actual data on distance, size and productivity for 10 European countries 1970-99, and the parameters assumed in the table. Table reports estimated coefficients from the regression of the log relative price level (relative to France in each case) on log traded and non-traded sector productivity, including the level of traded sector productivity for all other countries in the regression.

Table 3: **Summary statistics: Prices and productivity**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	POLS	POLS	POLS	BE	BE	BE	WI	WI	WI
A	-0.52			-0.48			-0.41		
	(0.16)			0.39			(0.21)		
A^T		-0.13	-0.04		-0.12	0.16		-0.10	-0.06
		(0.08)	(0.09)		(0.35)	(0.45)		(0.11)	(0.10)
A^N		-0.26	-0.18		-0.09	-0.10		-0.40	-0.27
		(0.21)	(0.20)		(1.00)	(1.00)		(0.23)	(0.23)
ϕA^T_{-i}			1.13			1.97			1.15
			(0.50)			(1.95)			(0.61)
cons.	-0.08	0.04	0.02	-0.08	-0.02	0.01			
	(0.04)	(0.03)	(0.02)	(0.08)	(0.07)	(0.08)			
AR(1)	yes	yes	yes	no	no	no	yes	yes	yes

Notes to Table 3: POLS is pooled OLS with correction for AR(1) errors and cross-group error correlation. BE is between effects. WI is within or fixed effects estimation with correction for AR(1) errors and cross-group error correlation. Dependent variable is log of the simulated price level relative to France. A is log aggregate TFP relative to France. A^T and A^N are log traded and non-traded sector TFP relative to France; A^T_{-i} is a weighted average of log traded sector TFP of all third countries; standard errors in parentheses.

Table 4: **Simulated prices and productivity:** $\eta = 1.7$, $\tau = 4 \times 10^{-5}$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	POLS	POLS	POLS	BE	BE	BE	WI	WI	WI
A	-0.39			-0.44			0.18		
	(0.03)			0.16			(0.04)		
A^T		-0.06	0.01		-0.14	-0.03		0.20	0.20
		(0.02)	(0.02)		(0.15)	(0.20)		(0.00)	(0.00)
A^N		-0.57	-0.51		-0.42	-0.43		-0.50	-0.50
		(0.05)	(0.05)		(0.42)	(0.43)		(0.00)	(0.00)
ϕA^T_{-i}			0.65			0.75			0.04
			(0.10)			(0.85)			(0.00)
cons.	0.44	0.03	0.04	0.48	0.03	0.04			
	(0.03)	(0.00)	(0.01)	(0.14)	(0.03)	(0.04)			
R^2	0.42	0.54	0.60	0.53	0.59	0.64	0.92	1.00	1.00

Notes to Table 4: POLS is pooled OLS. BE is between and WI is within or fixed effects estimation. Dependent variable is log of the simulated price level relative to France. A is log aggregate TFP relative to France. A^T and A^N are log traded and non-traded sector TFP relative to France; A^T_{-i} is a weighted average of log traded sector TFP of all third countries; OLS standard errors in parentheses.

Table 5: Unit root tests (DF-GLS)

	P	A	A^T	A^N	A^T_{-i}
Belgium	-2.01	-1.10	-0.50	-1.01	-1.15
Denmark	-1.10	-0.79	-0.24	-0.31	-0.29
Finland	-1.35	-0.98	-1.42	-1.04	-0.32
Germany	-2.52	-2.79	-1.25	-1.21	-1.64
Italy	-2.48	-2.95*	-1.08	-0.27	-0.29
Netherlands	-2.94*	-1.87	0.36	-0.59	-1.13
Norway	-2.55	-1.22	-1.50	-0.51	-0.29
Sweden	-1.93	-1.13	-0.98	-0.77	-1.18
UK	-1.35	-1.31	-2.14	-2.00	-0.86

Note: P is the log of the aggregate price level relative to France; A is the log of aggregate TFP relative to France; A^T is the log of traded sector TFP relative to France; A^N is the log of non-traded sector TFP relative to France; A^T_{-i} is a weighted average of the log of traded sector TFP of all countries except the country in question and France The test is described in Elliott, Rothenberg and Stock (1996). DF-GLS t-statistics are reported. Critical values: 1% -3.77; 5% -3.19; 10% -2.89. * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 6: Cointegration tests (ADF-GLS)

	t-stat.	10%	5%	1%
Belgium	-3.16	-3.85	-4.14	-4.77
Denmark	-2.77	-3.85	-4.14	-4.77
Finland	-2.50	-3.85	-4.14	-4.77
Germany	-3.01	-3.85	-4.14	-4.77
Italy	-3.66	-3.85	-4.14	-4.77
Netherlands	-2.43	-3.85	-4.14	-4.77
Norway	-3.29	-3.85	-4.14	-4.77
Sweden	-1.95	-3.85	-4.14	-4.77
UK	-3.03	-3.85	-4.14	-4.77

Note: This table reports test statistics for null of no cointegration in the regression of P on A^T, A^N and A^T_{-i}. Variable definitions are as in Table 5a. The test is described in Perron and Rodríguez (2001). ADF-GLS t-statistics are reported. The appropriate 10%, 5% and 1% critical values are given in the columns of the table following the test results.