Trade Costs and Real Exchange Rate Volatility*

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Abstract

This paper examines the impact of trade costs on real exchange rate volatility. We model two channels endogenously in a Ricardian framework: (i) nontradability and (ii) heterogeneous suppliers of traded goods. The first channel is examined by constructing a two-country Ricardian model of trade, based on the work of Dornbusch, Fischer and Samuelson (1977), which shows that higher trade costs result in a larger nontradable sector, which in turn leads to higher real exchange rate volatility. The second channel is examined by constructing a multi-country Ricardian model of trade, based on the work of Eaton and Kortum (2002), where bilateral real exchange rate volatility depends on how similar a country pairs' set of suppliers of traded goods is. We provide empirical evidence supporting both channels.

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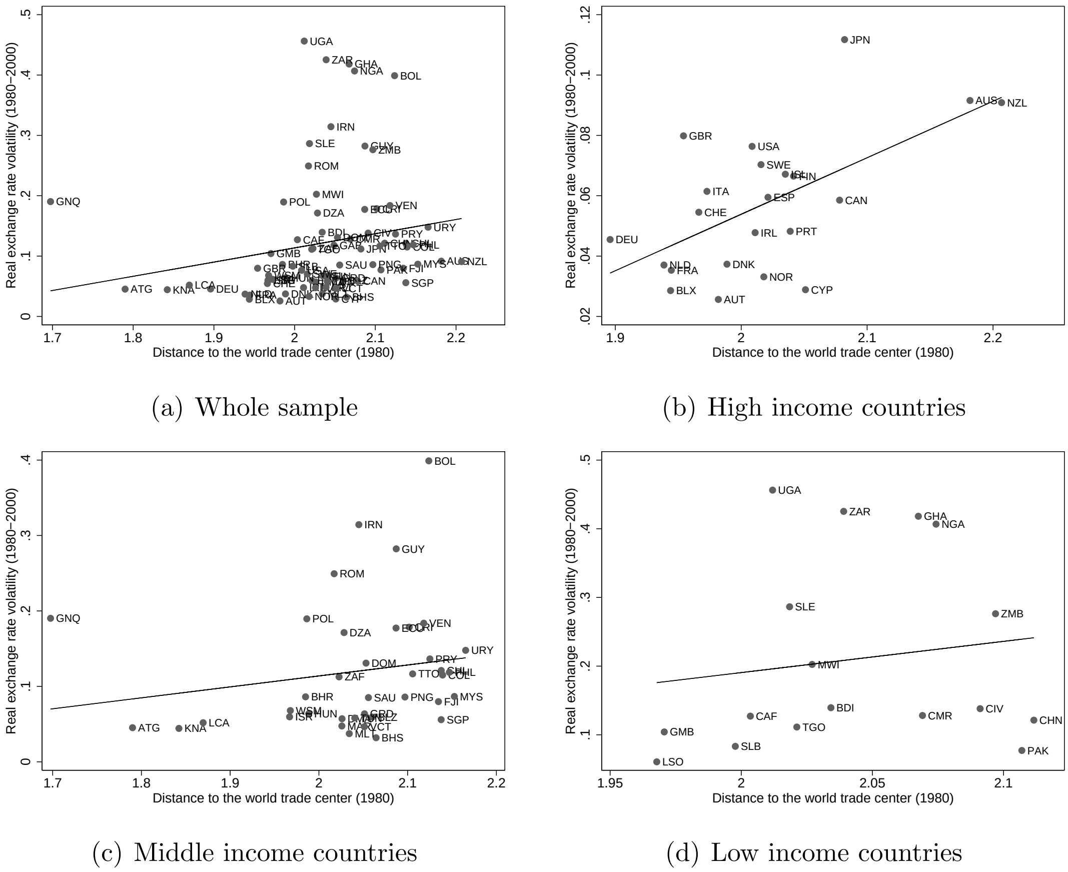
1 Introduction

What impact does globalization have on the international macroeconomy? More specifically, what are the macroeconomic consequences of increased integration in international trade? What is the impact that geography may have on macroeconomic variables? These are large, but important questions to consider given the continuing integration of countries across the world. Furthermore, as Obstfeld and Rogoff (2001) so powerfully show, small trade costs can have large effects on many macroeconomic phenomena. Yet, there is still little rigorous work that examines the channels through which trade imperfections affect macroeconomic variables. In this paper, we provide some simple and intuitive models and tests, which allow us to analyze the impact of trade costs on *long-run* real exchange rate volatility. In particular, we incorporate Ricardian comparative advantage into macroeconomic models to highlight two channels through which trade imperfections impact real exchange rate volatility.

The first channel shows how higher trade costs will lead to a greater range of nontradable goods thereby resulting in a country having higher real exchange rate volatility. Our model builds on the classic work of Dornbusch et al. (1977). In particular, we incorporate uncertainty in the form of productivity shocks. We then present empirical results that support the model. The key intuition for our result is the following. In a Ricardian world without trade costs, productivity shocks will lead to changes in comparative advantage in producing goods across countries. However, the law of one price will continue to hold. Transport costs create a wedge between the prices for some goods that the domestic and foreign economy specialize in. This wedge will result in the production of nontradable goods in both economies, whose prices are independent of the other country's productivity shock. Therefore, relative prices of these goods will not equate across countries given country-shocks, and since a country's overall price index is made up of both tradable and nontradable goods,



(a) Whole sample

(b) High income countries

(c) Middle income countries

(d) Low income countries

Figure 1. Real exchange rate volatility and distance relationship

the real exchange rate will move. Therefore, the greater trade costs – measure as iceberg costs – the higher real exchange rate volatility. We believe that this is a simple point that has not been full explored in the literature. Indeed, Hau (2002) argues that nontradable goods will lead to greater real exchange rate volatility, but models tradability exogenously.[1] Furthermore, as can be seen in Figure 1 our proposed relationship appears to exist in the data.[2]

The second channel we examine is the impact of different suppliers of goods on

[1]Nakdoi (2003) has also examined a similar channel in a dynamic general equilibrium framework. However, her work concentrates on short-run dynamics, whereas we argue that endogenous nontradability should be modeled in a long-run context. Furthermore, we provide direct evidence to test the hypotheses drawn from our model.

[2]However, it is also interesting to note that this relationship appears strongest for high income countries as can be seen in Figure 1(b). We will return to this point below.

real exchange rate volatility. We construct a multi-country model, that builds on the innovative work of Eaton and Kortum (2002). In this world, the distribution of trade is governed by relative technologies and trade costs. Unlike the two-country world that we first examine, the key impact of trade costs is not on tradable/nontradable sectors' relative sizes, but instead on the dissimilarity of the *set* of providers of traded goods that each country has. In particular, there is no longer complete specialization in the production of any given good, so different countries may import the same good from different source countries. Besides providing some interesting examples of how different trade policies may impact bilateral real exchange rate volatility, we believe that our model contributes to a more rigorous modelling of trade on the macroeconomy,[3] as well as complementing the more structural approach that has recently been advocated in the gravity literature in international trade (Anderson and van Wincoop 2003).

Besides providing evidence in support of the theoretical models that we construct, our empirical work complements a large literature that highlights the importance of trade costs (whether they be physical, institutional, or informational) playing a predominant role in causing deviations from the law of one price (LOP) and purchasing price parity (PPP). For example, Engel and Rogers (1996) explicitly control for distance and the border to capture the effects of a myriad of trade costs on price dispersion across the United States and Canada. Furthermore, the existence of trade costs motivate "commodity points" and the use of threshhold autogressive (TAR) models in testing for PPP and LOP relationships (Obstfeld and Taylor 1997). Though most tests in this literature rely on the time series properties of the data, our specifications rely primarily on cross-sectional heterogeneity for identification. That is, we rely on

[3] Some recent work has also taken more seriously the effect of different types of trade and multi-country relationships on the international macroeconomy. For example, see Kraay and Ventura (2001), Bergin and Glick (2003), Broda and Romalis (2004), Fitzgerald (2003), and Ghironi and Melitz (2004). These papers differ substantially from our work both theoretically and empirically.

cross-country (or country-pair) heterogeneity to identity the impact of trade costs on real exchange rate volatility. However, we are able to further exploit time series properties by using panel estimation techniques given the rich nature of the data in the multi-country framework.[4]

Section 2 presents the theoretical model for the two-country case. Section 3 presents the model for the multi-country case. Section 4 presents empirical evidence supporting predictions from the two-country model. Section 5 presents evidence supporting the channel of the multi-country model. Section 6 concludes with a discussion and suggestions for future research.

2 Two-country model

The first model that we build provides a simple illustration of how increases in trade costs can increase real exchange rate volatility by creating a wedge between the tradable and nontradable sectors, so that shocks to not transmit perfectly across countries. The model is setup in a two-country framework, but the foreign country represents the rest of the world. This distinction must be made because an individual country's range of nontradable goods depends on its trade costs with all of its potential trading partners. We also make this distinction in the empirical work by using a country's real effective exchange rate, and proxying overall trade costs by a country's closeness to the world trade center. Furthermore, this and the multi-country model are meant to explain *long-run* real exchange rate volatility. The two-country model borrows heavily from Obstfeld and Rogoff (1996), and makes one central prediction: real exchange rate volatility is increasing in trade costs, and therefore increasing in

[4]Our empirical analysis for the multi-country framwework is in the same spirit as recent work by Rose (2000), though we are not interested in the same relationship that he studies. In particular, Rose's work shows that by entering into a currency union, or decreasing bilateral exchange rate volatility, two countries will increase bilateral trade. Rose addresses the issue of endogeneity between trade and exchange rate volatility. Given that our main regressand of interest is not trade, but a common supplier index (to be defined below), we do not view this endogeneity issue as a major concern.

the distance between one country and its trade partners around the world. Sections 2.1-2.3 outline the model and solves for real exchange rate volatility.

2.1 Consumption

The demand side is modeled using a representative agent who maximizes consumption of a continuum of goods z, which are defined on the line $[0, 1]$. The agent receives only labour income and maximizes the following utility function:

$$U(c) = \exp\left[\int_0^1 \log(c(z))dz\right], \tag{1}$$

which is simply a CES utility function, where the elasticity of substitution is set to one.[5] Taking the good $z = 1$ to be the numéraire, so that the wage rates and commodity prices are expressed in units of good 1, the price index is:

$$P = \exp\left[\int_0^1 \log(p(z))dz\right]. \tag{2}$$

Similarly, the price index for the foreign country is:

$$P^* = \exp\left[\int_0^1 \log(p^*(z))dz\right]. \tag{3}$$

2.2 Production

Production takes place in a "two-country world", where the technology of the producers is stochastic and only requires labour input. Specifically, the home and foreign firms have the following labour requirement to production one unit of good z,

$$\text{Home} : a(z) = \alpha(z) \cdot \exp(\varepsilon)$$

$$\text{Foreign} : a^*(z) = \alpha^*(z) \cdot \exp(\varepsilon^*)$$

[5]In particular, one can show that

$$\underset{\lim \rho \to 1}{U(c)} = \left[\int_0^1 \left(c(z)^{\frac{\rho-1}{\rho}}\right) dz\right]^{\frac{\rho}{\rho-1}} = \exp\left[\int_0^1 \log(c(z))dz\right],$$

where ρ is the elasticity of substitution between goods. The results of the model go through using the more CES general function, but greatly complicate the algebra, so the more specific function is used for clarity sake.

where ε and ε^* are technological shocks that are both distributed i.i.d. $N(0, \sigma^2)$ and are independent of each other.[6]

Firms in each sector at home (and abroad) maximize their profits ex ante conditional on the distribution of these shocks. Given a fixed labour supply in each country, firms in each sector choose labour such that the real wage is equated to the marginal product of labour, so given labour mobility across sectors, this is equivalent to $\frac{w}{p} = \frac{1}{a(z)}$.

Given this condition in each country, a relative labour schedule that regulates comparative advantage may then be defined as:

$$A(z) = \frac{a^*(z)}{a(z)}. \tag{4}$$

This schedule is used to solve for the equilibrium wages, prices, and distribution of production across countries. Furthermore, this schedule holds both before and after the shocks hit the economies.

2.3 Equilibrium

In equilibrium, the range of goods that a country produces or imports depends on productivity differentials and trade costs $\tau > 0$. We assume that the steady-state productive structure is such that there is a zero trade balance in equilibrium given the expected value of the relative productivity schedule A(z) defined by (4). We believe that this is a realistic assumption for the steady-state equilibrium. In particular, home will produce goods ex ante such that:[7]

$$\frac{w}{w^*} < \mathrm{E}\left\{\frac{A(z)}{1-\tau}\right\} = \mathrm{E}\left\{\frac{\alpha^*(z)\cdot\exp(\varepsilon^*)}{(1-\tau)\alpha(z)\cdot\exp(\varepsilon)}\right\},$$

[6]The assumption of independent productivity shocks, i.e., $\mathrm{Cov}(\varepsilon, \varepsilon^*) = 0$, may seem strong. However, the assumption does not alter our main results below except under special circumstances, and will therefore be ignored for simplicity of exposition.

[7]Note that similar conditions will hold ex post.

and foreign will produce goods such that

$$\frac{w}{w^*} > \mathrm{E}\left\{(1-\tau)A(z)\right\} = \mathrm{E}\left\{(1-\tau)\frac{\alpha^*(z)\cdot\exp(\varepsilon^*)}{\alpha(z)\cdot\exp(\varepsilon)}\right\}.$$

Given the trade costs, a range of goods $z \in (z^F, z^H)$ are nontraded, where z^F are foreign goods and z^H are home goods. It is for these goods that prices in the domestic and foreign sector are given by: $p(z) = w \cdot a(z)$ and $p^*(z) = w^* \cdot a^*(z)$. The price of traded goods will not be equated, given trade cost τ that must be paid, across countries (i.e., the law of one price no longer holds). In short, the Ricardian nature of the model implies specialization of each country in a range of tradable goods whose prices differ between countries by a constant factor related to trade costs.

For the sake of tractability and simplicity of exposition we suppose that there are two periods. In the first period, the firms choose the marginal good of production taking the expected value of the comparative advantage and trade is balanced. Up to here this has been the traditional approach in Dornbusch et al. (1977) and Krugman (1987) initial model setups. In a more general context this assumption may be equivalent to rational expectations. The production structure, z^F and z^H, will be determined in the first period, which represents the steady state of the economy. Thus, in the second period when a shock is realized the schedule $A(z)$ shifts only because of the shocks, and given the previously determined z^F, z^H, which we assume remain fixed, wages and prices will adjust, thereby creating a trade imbalance ex post.[8]. We believe that this a reasonable assumption given that countries' production structures change very slowly over time compared to wage and price movements. This in turn implies that the trade balance will no longer necessarily equal zero out of steady-state. We will not go through the whole derivation of equilibrium, but given home and foreign labour supplies, L and L^* respectively, and defining home's trade balance as total income less total consumption: $TB = wL - PC$ (similarly for the foreign

[8]These assumptions allow us to introduce uncertainty in a tractable manner

country), the relative wages can be expressed as:

$$\frac{w}{w^*} = \left\{ \frac{-\left(z^H - z^F\right) TB}{[L^*/a^*(1)]} + z^F \right\} \frac{L^*/L}{(1 - z^H)}. \tag{5}$$

This equation illustrates that once that wages fully adjust due to the shocks the trade balance must adjust to a new level that might be out of the steady-state equilibrium. We now move on to explore the properties of the real exchange rate in more detail.

2.4 Real exchange rate volatility

Given equations (2) and (3), and the discussion on how one can solve for individual goods prices in Section 2.3, the real exchange rate can be written as:

$$\frac{P}{P^*} = \exp\left\{ \int_{z^F}^{z^H} \log\left(\frac{w \cdot \alpha(z)}{w^* \cdot \alpha^*(z)} \cdot \frac{\exp(\varepsilon)}{\exp(\varepsilon^*)} \right) dz + \left[z^F - (1 - z^H) \right] \log(1 - \tau) \right\}, \tag{6}$$

where the relative prices not only depend on the prices of nontradables, but also on the international specialization pattern. To solve for the volatility of the real exchange rate we take the variance of the logarithm of this equation. In doing so, it is only the shocks, ε and ε^*, that drive the volatility of the exchange rate. In particular, the volatility of the real exchange rate can thus be expressed as:

$$\mathrm{Var}\left\{ \log\left(\frac{P}{P^*} \right) \right\} = 2\left(z^H - z^F\right)^2 \sigma^2. \tag{7}$$

See Appendix A for the full derivation. Given this expression the main result of this section can then be stated (and proved) by the following proposition

Proposition 1 *Real exchange rate volatility is increasing in trade costs, and therefore increasing in a country's closeness — due to both natural (e.g., distance) and artificial (e.g., tariffs) barriers to trade — with respect to the rest of the world.*

Proof: $\mathrm{Var}\left\{\log\left(\frac{P}{P^*}\right)\right\} = 2\left(z^H - z^F\right)^2 \sigma^2$ and $z^F = A^{-1}\left(\frac{w}{w^*} \cdot \frac{1}{1-\tau}\right)$ with A^{-1} decreasing given the set up of the problem. Analogously $z^H = A^{-1}\left(\frac{w}{w^*} \cdot [1 - \tau]\right)$. Thus,

$\frac{\partial z^F}{\partial \tau} < 0$ and $\frac{\partial z^H}{\partial \tau} > 0$. Therefore, one has that:

$$\frac{\partial}{\partial \tau}\left(\mathrm{Var}\left\{\int_{z^F}^{z^H}(\varepsilon(z)-\varepsilon^*(z))\partial z\right\}\right)=\frac{\partial}{\partial \tau}\left[2\left(z^H-z^F\right)^2\sigma^2\right]=\frac{\partial z^H}{\partial \tau}-\frac{\partial z^F}{\partial \tau}>0,$$

and then the volatility of the real exchange rate is increasing in trade costs. Further, if trade costs are assumed to increase with distance, as is standard in the trade literature, volatility increases with the degree of a country's geographical and commercial isolation. ■

This completes the theoretical part for the two-country model.[9] Empirical results in Section 4 confirm that Proposition 1 holds. Before examining these results, we present a multi-country model of trade that isolates a different channel through which trade costs affect real exchange rate volatility.

3 Multi-country model

In the previous section we studied the impact of trade costs in a two-country setting that allows for nontradable goods. In that model, the degree to which country-specific shocks are propagated to the real exchange rate depends on size of the nontradable sector, which depends on trade costs. In this section, we study the multi-country case without allowing for the existence of nontradable goods. However, despite this constraint and contrast, trade costs still account for real exchange rate volatility. Specifically, given technological differences and trade barriers, any two countries may have different trading partners for a given good. Therefore, though each country's import basket is composed of the same goods, any good may be provided by a different supplier. As a result, the diffusion of each country's idiosyncratic shocks to other countries' price indexes will be heterogeneous. In this setting we show how geopolitics

[9]Note, that as argued in footnote 6 above, the assumption of independent domestic and foreign shocks does not alter our results. Specifically, given the setup of the model, the solution for real exchange rate volatility, equation (7), would have the additional term $-2\mathrm{Cov}\left(\varepsilon,\varepsilon^*\right)\left(z^H-z^F\right)$. Therefore, volatility will always be increasing in trade costs.

matters for real exchange rate volatility. For that we explore different geographical or political arrangements that will illustrate this new mechanism.

The real exchange rate that we examine theoretically is actually only composed of traded goods, unlike in the two-country model above. We make this simplifying assumption for ease of exposition, and the logic needed to incorporate the tradable/nontradable is identical to the two-country model. However, we do derive a simple price index and real exchange rate, in Appendix B.1, that incorporate the prices of nontradable goods. What is important to remember, though, is that our main results go through when incorporating nontradability.

Before deriving the solution for the real exchange rate volatility, which is based on multi-country Ricardian model of Eaton and Kortum (2002), we present some preliminary information to aid in the derivation. Sections 3.1-3.4 present our key assumptions and derive the equilibrium.[10] The intuition behind the result is quite straightforward, but the simple derivative of volatility with respect to trade costs cannot be signed unambiguously. Therefore, Section 3.5 presents some simple numerical examples to confirm that bilateral real exchange rate volatility increases with trade costs given a reasonable set of parameters.

3.1 Technological shocks

In this section we build our results around the model of Eaton and Kortum (2002), which in turn uses Dornbusch et al. (1977) as a starting point. The particularity of this new model is that it allows for extension of Dornbusch et al.'s model to a multi-country setting through the introduction of uncertainty in country i's efficiency in producing good $j \in [0, 1]$, that we denote $z_i(j)$.

As in Eaton and Kortum we assume that country i's efficiency follows a Fréchet distribution, conditional on idiosyncratic shocks. A key assumption that facilitates

[10] Appendix B.2 discusses some useful statistical theories.

the determinations of each country's price index is that this distribution applies to all goods.

The cost of inputs, c_i, is assumed to be equal across goods in a given country. Therefore, with constant returns to scale, the cost of producing a unit of good j in country i is given by $c_i/z_i(j)$. Trade costs are modeled as an iceberg transport cost between countries i and n, $\tau_{ni} > 1$.[11]

The price of an unit of good j produced in country i and offered in country n is therefore:

$$p_{ni}(j) = \frac{c_i}{z_i(j)} \cdot \tau_{ni}.$$

Given that the same good can come from N countries, shoppers in country n, under conditions of perfect competition, will pay the cheapest price offered in the market. This price is:

$$p_n(j) = min\{p_{ni}(j) : i = 1, ..., N\}$$

On the demand side, we assume that consumers have the following utility function when consuming a quantity of good j, $Q(j)$:

$$U = \left(\int_0^1 Q(j)^{\frac{\rho-1}{\rho}} dj \right)^{\frac{\rho}{\rho-1}} \tag{8}$$

Given the assumptions made concerning production and consumption of tradable goods across countries, a country's exact price index as the solution:[12]

$$p_n = \gamma \Phi_n^{-1/\theta} = \gamma \left(\sum_{i=1}^{N} T_i (c_i \tau_{ni})^{-\theta} \right)^{-1/\theta}, \tag{9}$$

where $\gamma = \left[\Gamma \left(\frac{\theta+1-\rho}{\theta} \right) \right]^{1/(1-\rho)}$, T_i is a country i's state state of technology, c_i is country i's input cost, τ_{ni} is an iceberg transport cost between countries i and n ($\tau_{ni} > 1$ if $n \neq i$ and $= 1$ if $n = i$), and θ regulates comparative advantage across countries.

[11] Note that this expression of trade costs is different from Section 2, but helps for expositional purposes.

[12] See Eaton and Kortum (2002) for the full derivation.

We are interested in determining the volatility of two countries' bilateral real exchange rate given idiosyncratic technological shocks. Therefore, we are interested in shocks to T_i. We therefore assume that these technological shocks are lognormal. In particular,

$$\begin{aligned} T_i &= \tilde{T}_i \exp(\varepsilon_i), \text{ with} \\ \varepsilon_i &\sim n\left(0, \sigma_\varepsilon^2\right), \end{aligned} \tag{10}$$

where $\tilde{T}_i > 1$, and may also $= T > 1 \; \forall \; i$. This assumption essential posits that the steady-state/long-run technological level of countries may or may not differ. Furthermore, it is assumed that $\text{Cov}\{\varepsilon_i, \varepsilon_j\} = 0 \; \forall \; i \neq j$.[13]

3.2 Real exchange rate volatility

It is not possible solve for an exact closed-form of solution real exchange rate volatility in the multi-country model, but we are able to find a closed-form solution by using a first-order Taylor approximation around the steady-state. The derivation is not too complicated, but long, so it is relegated to Appendix B, which shows that:

$$\begin{aligned} \text{Var}\left\{\log\left[\frac{p_1}{p_2}\right]\right\} \approx \Upsilon & \left(\underbrace{\frac{\sum_{i=1}^N \tilde{T}_i^2 (c_i\tau_{1i})^{-2\theta}}{\left[\sum_{i=1}^N \tilde{T}_i (c_i\tau_{1i})^{-\theta}\right]^2}}_{[1]} + \underbrace{\frac{\sum_{i=1}^N \tilde{T}_i^2 (c_i\tau_{2i})^{-2\theta}}{\left[\sum_{i=1}^N \tilde{T}_i (c_i\tau_{2i})^{-\theta}\right]^2}}_{[2]} \right) \\ & - 2\Upsilon \left(\underbrace{\frac{\sum_{i=1}^N \tilde{T}_i^2 (c_i^2\tau_{1i}\tau_{2i})^{-\theta}}{\sum_{i=1}^N \tilde{T}_i (c_i\tau_{1i})^{-\theta} \sum_{i=1}^N \tilde{T}_i (c_i\tau_{2i})^{-\theta}}}_{[3]} \right), \end{aligned} \tag{11}$$

where $\Upsilon = \left(\frac{e^{\sigma_\varepsilon^2}\left[e^{\sigma_\varepsilon^2} - 1\right]}{\theta}\right) > 0$.

One can easily take the derivative of the real exchange rate variance in (11) with respect to bilateral trade costs $\tau_{12} = \tau_{21}$. However, signing this derivative is not

[13]This assumption may be again be considered extreme, but greatly simplifies the analysis. Furthermore, empirical results support the main conclusions of the model.

straightforward given that the derivative generally has an inflection point. Therefore, Section 3.5 will present some numerical examples that show that this derivative is in fact usually negative. However, it is worthwhile to first give a description of the three components of the variance term in equation (11).

The first (second) term [1] ([2]) is a weighting that reflects the composition of country 1's (country 2's) consumption of goods from the rest of the world. In particular, by inspection it is easy to see that as τ_{1i} (τ_{2i}) approaches 1, that [1] ([2]) will only depend on relative technological and cost differentials (i.e., as world of frictionless trade), which in turn will imply that the shocks to other countries will pass directly to country 1's (country 2's) price index one-for-one. Therefore, term [1] ([2]) will increase as trade costs increase. This in turn implies an increase in bilateral real exchange rate volatility. The third term [3] reflects (dis)similarities between countries 1 and 2 consumption baskets. The more similar these baskets are, the larger [3] will be, which in turn will reduce bilateral real exchange rate volatility. Therefore, it is possible to have two countries on the opposite side of the world, and hence large bilateral (physical) trade cost, but with similar consumption baskets, which in turn might lead to very small bilateral real exchange rate volatility.

3.3 Link to factor costs

One can relate real exchange rate volatility, equation (11), to the underlying wages of each country. In particular, Eaton and Kortum assume that a country's production function depends on (1) labour input, and (2) intermediate goods. Therefore, the cost of the input bundle of country i is thus:

$$c_i = w_i^{\beta} p_i^{1-\beta},$$

where β is the constant share of labour in production, and w_i is the wage in country i. This formulation then leads to an equilibrium for input costs. To make things more transparent in our model, we will assume that $\beta = 1$; that is, labour is the only input for production. This assumption, will (1) simplify our analysis, and (2) allow us to draw an analogy to our two-country model. Therefore, we define our input cost to be:

$$c_i = w_i. \tag{12}$$

Therefore, (11) may simply be re-written as:

$$\begin{aligned} \text{Var}\left(\log\left[\frac{p_1}{p_2}\right]\right) \approx \Upsilon \left(\frac{\sum_{i=1}^{N} \tilde{T}_i^2 (w_i \tau_{1i})^{-2\theta}}{\left[\sum_{i=1}^{N} \tilde{T}_i (w_i \tau_{1i})^{-\theta}\right]^2} + \frac{\sum_{i=1}^{N} \tilde{T}_i^2 (w_i \tau_{2i})^{-2\theta}}{\left[\sum_{i=1}^{N} \tilde{T}_i (w_i \tau_{2i})^{-\theta}\right]^2} \right) \\ - 2\Upsilon \left(\frac{\sum_{i=1}^{N} \tilde{T}_i^2 (w_i^2 \tau_{1i} \tau_{2i})^{-\theta}}{\sum_{i=1}^{N} \tilde{T}_i (w_i \tau_{1i})^{-\theta} \sum_{i=1}^{N} \tilde{T}_i (w_i \tau_{2i})^{-\theta}} \right). \end{aligned} \tag{13}$$

3.4 General equilibrium

To close the model both the goods and labour market have to be in equilibrium. In particular, depending on the structure of the model, countries' prices and wages may be interdependent. Indeed, this case does arise in Eaton and Kortum (2002), and would complicate the solution for the real exchange rate volatility considerably. However, if we assume that labour is mobile between the tradable and nontradable sectors, then wages are determined exogenously by productivity in the nontradable sector. Therefore, (13) still holds, and we can solve for tradable labour supply from the equation:

$$L_i = \frac{\sum_{n=1}^{N} \pi_{ni} \alpha Y_n,}{w_i}$$

where $\pi_{ni} = \frac{T_i (w_i \tau_{ni})^{-\theta}}{\phi_n}$ is the probability that country i provides a good at the lowest price to country n, and Y_n is total income and is exogenous. See Appendix B.1 for more details concerning equilibrium in the nontradable sector.

3.5 Examples

This section will present some numerical examples that will allow us to explore the impact of changes in different parameters on real exchange rate volatility. In particular, we will concentrate on changes in bilateral trade costs. Besides enabling the signing of the derivative of equation (13), these exercises examine a potential macroeconomic impact — i.e., the impact on real exchange rate volatility — of different forms of trade agreements.

Example 1 considers the impact of a very specific customs union on bilateral real exchange rate volatility. In particular we will simulate the bilateral exchange rate between a country that does not belong to the free trade area and another country that belongs to it. This simulation allows us to study the impact of a reduction in trade costs linked to a fall in the tariffs that the country external to the custom unions faces at the time of signing the trade agreement. The reduction in trade cost can be gradual as is the case in most of the trade agreements, until reaching zero trade costs, which in this particular example are linked to tariffs. The results from this simulation can be also interpreted as a measure of the volatility facing countries, subject to different trade costs, relative to a country that joins a trade union.

Example 2 considers the impact of a country joining a free trade agreement on bilateral real exchange rate volatility. In this example we study what happens to the the bilateral volatility between a country that joins a free trade agreement and a country that belongs to a set of countries excluded from the free trade area. The simulations show the effect of a gradual reduction in tariffs between the free trade area and its new member. As in the previous simulation, this example can be also interpreted as a measure of the volatility facing countries, subject to different trade costs, relative to a country belonging to the free trade area. The two examples provide realistic situations and we try to choose parameter values that best match previous findings.[14]

Example 1 (Custom union 1) This example examines the impact of trade costs

[14]The parameter values used in the simulations will stay as close as possible to those that Eaton and Kortum estimate/use.

and other parameters on the volatility of the real exchange rate of country 1 and country 2, where country 2 is part of a customs union and country 1 is not. In particular, we define this world as N countries as follows for our simulation purposes:

- Country 1 is not in the customs union. Countries $2, \ldots, N$ are in the customs union and identical, $N \geq 30$.
- $\theta = 8.26$, $\sigma_\varepsilon \geq 0.1$.
- Technologies:
  - $T_1 = 2$.
  - $T_2 = (1 + \Delta T)T_1$, $\Delta T > 0.1$, $T_i = T_2$ for $i = 2, \ldots, N$.
- Costs:
  - $c_1 = 0.5$.
  - $c_2 = (1 + \Delta c)c_1$, $\Delta c > 0.1$, $c_i = c_2$ for $i = 2, \ldots, N$.
- Trade costs:
  - $\tau_{1i} = \tau_{i1} = \tau \geq 1$ for $i = 2, \ldots, N$.
  - $\tau_{2i} = \tau_{i2} = 1$ for $i = 2, \ldots, N$.

Given this selection of parameters, Figure 4 examines the impact of trade costs on real exchange rate volatility examines the impact of trade costs on real exchange rate volatility. Figure 4(a) examines the impact of changing trade costs, τ, for differing values in the variance of the productivity shocks. In all cases, we assume that $N = 150$, $T_1 = 2$,$\Delta T = 0$, $c_1 = 1$, and $\Delta c = 0$. The technological and costs gap are referred to the customs union with respect to country 1. The real exchange rate volatility is increasing in bilateral trade costs for all σ_ε. The other fact to notice is that a rise in the volatility of productivity shocks (σ_ε) has an increasing effect on real exchange rate volatility as σ_ε grows.

Figure 4(b) examines the impact of changes in τ for different ranges of technological gaps between countries 1 and and the custom union. In all cases, we assume that $\sigma_\varepsilon = 0.5$, $N = 150$, $T_1 = 2$, $c_1 = 1$, and $\Delta c = 0$. The real exchange rate volatility is increasing in bilateral trade costs for all ΔT. Moreover, the difference in the impact of changes in the technological gap is not great for all ranges of trade costs. However, and increase in the technological gap reduces volatility.

Figure 4(c) examines the impact changes in τ for different ranges of cost gaps between countries 1 and the customs union. In all cases, we assume that $\sigma_\varepsilon = 0.5$, $N = 150$, $T_1 = 2$, $\Delta T = 0$, and $c_1 = 1$. The real exchange rate volatility is increasing in bilateral trade costs for all Δc. However, as one can see in the figure, this rate of increase is not monotonic. It is also interesting to note that, unlike changes in the technological gap, changes in the cost gap has increasing and quite large impacts on real exchange rate volatility, and its response to changes in trade costs.

Figure 4(d) examines the impact changes in τ for different sizes of the customs union ($N - 1$). In all cases, we assume that $\sigma_\varepsilon = 0.5$, $T_1 = 2$, $\Delta T = 0$, $c_1 = 1$, and $\Delta c = 0$. The real exchange rate volatility is increasing in bilateral trade costs for all N. The most interesting feature of this experiment is that real exchange rate volatility *decreases* as the custom union size *increases*. This finding reflects the impact of diversification: as the custom union's size grows, countries 1 and 2 have more common suppliers of goods (as long as there is trade), which implies that countries 1 and 2's price indices will be subject to more common shocks.

Example 2 (Free trade agreement) This example constructs a simple representation of what could potentially occur to bilateral real exchange rate volatility when one country joins a (bilateral) free trade agreement with a group of countries and another country does not. Country 1 signs a free trade agreement with a group of countries (Group 3), and Country 2 belongs to another group of countries (Group 4). Initially Country 1 faces the same trade costs with respect to both groups of countries ($\tau = 3$). And the trade costs between both groups of countries is the same as the one between Country 1 and any of the two groups (i.e.,$\tau = 3$). The geometric representation of this policy experiment is as follows: think initially of an equilateral triangle of side 3 (τ), with Country 1 on the top and Group 3 at bottom left and Group 4 at the bottom right. Once country one moves towards Group 3 (by signing a free trade agreement) it describes a semicircle. The arc of this semi-circle is sixty degrees. In this manner we keep distance between Group 4 and Country 1 constant (and hence with respect to Country 2) and the distance between both groups of countries constant. Recall that we compute the real exchange rate volatility between Country 1 and Country 2, which belongs to Group 4. A simple geometric representation is shown in Figure 2.

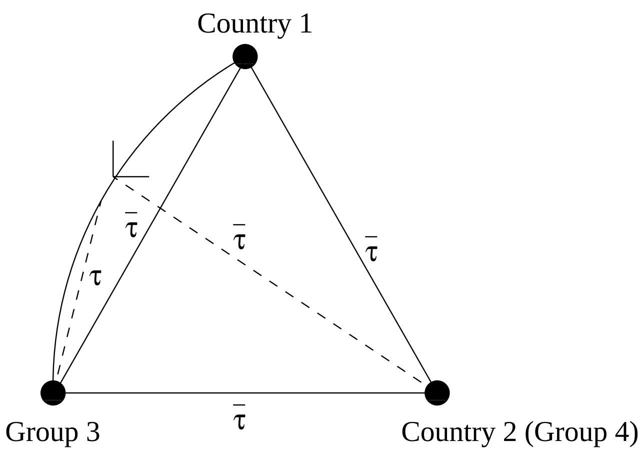


Figure 2. Free trade agreement between Country 1 and Group 3

This configuration can be used to simulate what happens to bilateral real exchange rate volatility. In particular, the key parameter that varies is trade cost τ between Country 1 and Group 3, which in turn will alter relative trade costs for country 1.

- There are N countries. Groups 1 and 2 each have $(N-2)/2$ countries.

- $\theta = 8.26$, $\sigma_\varepsilon = 0.5$.
- Technologies:
  - $T_1 = 2$, $T_2 = T_4$.
  - $T_3 = T_4(1 + \Delta T)$, $T_4 = 2$.
- Costs:
  - $c_1 = 1$, $c_2 = c_4$.
  - $c_3 = c_4(1 + \Delta c)$, $c_4 = 1$.
- Trade costs:
  - $\tau_{12} = \tau_{21} = 3$.
  - $\tau_{13} = \tau_{31} = \tau$
  - $\tau_{i4} = \tau_{4i} = 3$, $i = 1, 3$.
  - $\tau_{23} = \tau_{32} = 3$.
  - $\tau_{24} = \tau_{42} = 1$.

Given this selection of parameters, Figure 5 examines the impact of trade costs on real exchange rate volatility.

Figure 5(a) examines the impact of increasing trade costs, τ, for differing values of the *volatility of the productivity shocks*. In all cases, we assume that $N = 150$, $T_1 = 2$, $T_4 = 2$, $\Delta T = 0$, $c_1 = 1$, $c_4 = 1$, and $\Delta c = 0$. The real exchange rate volatility is increasing in bilateral trade costs for all σ_ε. Again, a rise in the volatility of productivity shocks (σ_ε) has an increasing effect on real exchange rate volatility as σ_ε grows.

Figure 5(b) examines the impact changes in τ for different ranges of technological gaps between Groups 3 and 4. In all cases, we assume that $\sigma_\varepsilon = 0.5$, $N = 150$, $T_1 = 2$,

$T_4 = 2$, $c_1 = 1$, $\Delta c = 0$, $c_4 = 1$. The real exchange rate volatility is increasing in the trade costs between groups for all ΔT. A greater technological gap implies slightly smaller volatility.

Figure 5(c) examines the impact changes in τ for different ranges of cost gaps between between groups 3 and 4. In all cases, we assume that $\sigma_\varepsilon = 0.5$, $N = 150$, $T_1 = 2$, $T_4 = 2$, $\Delta T = 0$, $c_1 = 1$, $c_4 = 1$. The real exchange rate volatility is increasing in trade costs for all Δc. A greater cost gap increases volatility. However, as one can see in the figure, this rate of increase is not monotonic.

Figure 5(d) examines the impact changes in τ for different sizes of Group 3 ($(N-1)/2$). In all cases, we assume that $\sigma_\varepsilon = 0.5$, $c_1 = 1$, $c_4 = 1$, $\Delta c = 0$,$T_1 = 2$, $T_4 = 2$, $\Delta T = 0$. The real exchange rate volatility is increasing in trade costs for all N. The most interesting feature of this experiment is that real exchange rate volatility *decreases* as the size of Group 3 (and hence Group 4) *increases*. This finding again reflects the impact of diversification.

These examples confirm the multi-country's model prediction that trade costs increase bilateral real exchange rate volatility, as well as providing some interesting examples related trade agreements. However, it is also important to examine whether a model's prediction stands up to the data. The following two sections do exactly this by testing for the importance of the channels highlighted in the two-country and multi-country models.

4 Two-country empirical results

According to the model in Section 2, we expect that a country's real exchange rate volatility increases with transport costs. Given that we do not have a direct measure of transport costs, we use a distance proxy (to be discussed below). We therefore estimate the following empirical model:

$$\sigma_{i,t}^{RER} = \beta_0 + \beta_1 \log\left(\text{Remoteness}_{i,t-1}\right) + \gamma \mathbf{X} + \nu_{i,t}, \tag{14}$$

where σ_i^{RER} is the measure of country i's real exchange rate volatility, which is calculated over the periods $t-1$ and t. The methodology used to calculate this measure is discussed in Section 4.1. Remoteness$_{i,t-1}$ is country i's transport cost proxy at the beginning of the time period, and $\mathbf{X}$ includes country i's (log) real GDP per capita at $t-1$, and a decade dummy variable for the panel estimation. Income per capita is included to capture other potential country characteristics that are correlated with exchanger rate and general macroeconomic volatility. Indeed, there is empirical and theoretical literature that relates a country's income level to its macroeconomic volatility (e.g., Acemoglu and Zilibotti 1997).

Equation (14) is estimated both cross-sectionally, over the time period 1980-2000, and over a "mini-panel" for the time periods 1980-89, and 1990-2000. We choose starting of period exogenous values to deal with potential endogeneity problems. Our model is meant to explain a long-run relationship, so we do not expect results to vary greatly over different specifications. Furthermore, we estimate this model for the whole sample, as well as splitting the countries into three income groups: (i) high, (ii) middle, and (iii) low.

4.1 Data

Given that the empirical specification is for a country with respect to the rest of the world, we must measure a country's real exchange rate relative to the rest of the world. As a first pass at the data, we therefore use the monthly real effective exchange rate found in the International Financial Statistics (IFS) database. The volatility measure is calculated by first taking the annual real exchange rate change (in log differences) each month; e.g., we take the change between Feb94-Feb95, and then Mar94-Mar95, and so on (i.e., a "rolling window" of annual real exchange rate changes).[15] We then compute the standard deviation of these annual changes over different time periods (i.e., between $t-1$ and t, which is either the whole sample period or by decade) as our measure of long-run volatility.[16]

The crucial variable that we construct is Remoteness. Specifically, this variable is defined as the distance from country i to the world trade center. This measure captures a country's trade remoteness viz. the rest of the world. We use this measure rather the size of the nontradable sector for several reasons. First, remoteness captures the strength of a country's commercial ties with the rest of the world, which plays an important role in defining the size of the nontradable sector. This point follows from the fact that it is not a country's distance to its closest economic pole that defines the nontradable sector since each country has different comparative advantages. Second, Remoteness is easy to measure homogeneously across countries. Third, trying to explicitly measure a country's tradable and nontradable sector is inherently difficult given that this nexus is not obvious. For example, the price of tradable goods incorporate nontradable components due to the distribution channel within a country, and similarly nontradable goods often incorporate traded inputs. Fourth, given the previous two points and other issues, the Remoteness measure is most probably subject to less measurement error than other potential covariates. Following Frankel and Romer (1999) and Wei (2000), we define Remoteness from country i to the world trade center as follows:

$$\text{Remoteness}_i = \sum_{j \neq i} \pi_j \cdot \log(\text{distance}_{i,j}),$$

[15] Taking the volatility of the log change has two advantages over taking the volatility of the log level: (i) the resulting measure is in invariant to the country, and (ii) the measure allows us to interpret the coefficients in the regressions as essentially elasticities.

[16] We also experimented by detrending the data using Hodrick-Prescott filters with low frequency smoothing parameters (e.g., 500,000; 1,000,000; or 1,500,000), and then calculating the variance of these series. Results do not vary greatly using these data instead of the annual changes.

where j is an index for all countries in the world, and with

$$\pi_j = \frac{\text{Trade}_j}{\sum_k \text{Trade}_k},$$

where each country j is one of i's trading partners, k represents all countries in the world, and Trade is defined as the sum of Exports and Imports. The term π_j is a weighting that captures how much total trade country j does compared to total world trade. Therefore, if country j is very close to country i and country j also trades a lot, the $\pi_j \cdot \log(\text{distance}_{i,j})$ term will be larger, which implies that the index Remoteness$_i$ is larger, and country i is thus closer to the world trade center (i.e., less remote). The intuition behind this index is that the closer a country is to countries that trade a lot, the more likely the country is to be more open/have lower trade costs. The advantage of using this index rather than an openness measure is that it does not include country i's actual trade, and therefore reduces any simultaneity concerns. The trade data are from the IMF's Direction of Trade Database, and the distance between country capitals' are taken from the CIA. Income per capita data are primarily taken from the Penn World Tables (Heston, Summers and Aten 2002), with holes filled in from the World Development Indicators (WDI) and the IFS. Country income groups are taken from the WDI.

4.2 Empirical results

The main results are presented in Table 1 for the whole sample, while Tables 2-4 presents the breakdown by income groups. We present two main specifications: one with only the distance measure, and the other controlling for income per capita. Each table presents cross-sectional results and the two decade panels.

The results in Table 1 supports the two-country's model main prediction. First, turning to the cross-sectional results (1980-2000), the measure of transport costs, Remoteness, is positive and significant as expected in specification (1). The point estimate for this measure decreases, but increases in significance when including income per capita in specification (2). The negative coefficient on the income variable supports the hypothesis that richer countries also exhibit less economic volatility. Turning to the panel results (1980-89/1990-2000), the estimates are similar to the cross-sectional regressions, but are more highly significant. Moreover, real exchange rate volatility decreased on average over the 1990s relative to the 1980s.[17]

It is also interesting to examine sub-samples of data conditional on income per capita. There are two main reasons for doing this. The first is simply to see whether the results are robust to smaller samples of more similar country groups. Though the inclusion of income per capita in the regressions in Table 1 should help deal with this issue, it is evident from Figures 1(b)-1(d), that the strength of the relationship between volatility and trade costs varies across income groups. Second, the channel that we are testing for the impact of trade costs on exchange rate volatility — i.e., the degree of nontradability — is most probably more apparent for more developed countries. Specifically, these economies are subject to less imperfections than developing ones, and have very diverse and dynamic industrial structures across different sectors of the economy. Therefore, the impact of the switch between nontradable and tradable goods will be more apparent in these economies.

The results reported in Tables 2-4 support this logic. First, the Remoteness coefficient is positive and very significant for high income countries in Table 2. The income per capita coefficients are now actually positive and significant — this result is puzzling and may be explained by the fact that the higher income countries in the sample include the United States, Japan and Canada, while the rest of the high country sub-sample are primarily European countries, which trade a lot with each other

[17] Note the coefficient for the Remoteness variable interacted with the decade dummy is negative and significant. However, the correlation between this interacted variable and the decade variable is approximately 0.99. Therefore, given this high correlation and the use of only two time periods, we choose not to place much weight on this result, though it would be interesting to examine the impact of increasing trade liberalization on relative price movements.

and were part of exchange rate stabilization mechanisms during the sample period. Second, the significance of the Remoteness coefficient more or less disappears for the middle and low income countries in Tables 3 and 4, though the coefficient is significant (at the 10% level) for the panel regressions for the middle income countries. However, the income per capita coefficients are negative and significant for the groups. A final fact to note is that the relative contribution of the Remoteness variable to the R^2 of the high income regressions is almost two-thirds for both the cross-sectional and panel regressions, but extremely small for the low income countries.

5 Multi-country empirical results

The central prediction from the multi-country model in Section 3 is that, *ceteris paribus*, countries that have more common suppliers of traded goods should also experience lower bilateral real exchange rate volatility. This result arises because the more common the suppliers of goods, the more will the two countries' price indices move together given shocks to these suppliers. This section attempts to operationalize this concept, in a reduced form, as well as test for its validity using a large sample of data.

We construct a common supplier index using bilateral trade data. One would ideally like to use a weighted measure of prices for traded goods, but these data are not available. Therefore, we construct and index based on the relative value of goods that any two countries import from a common country. Given the model, it would be ideal to do this at the most disaggregated level (i.e., the good level) as possible. Unfortunately, as will be discussed in Section 5.1 we must rely on more aggregated data.

The index is constructed as follows. Consider a world with N countries, M sectors/goods, and X_{rsm} is exports of good m from country r to country s. Then, the index of common suppliers for countries i and j can be written as:

$$CS_{ij} = \frac{\sum_{k\neq(i \text{ or } j)}^{N} \sum_{m=1}^{M} \mathbf{1}\left(X_{kim} > 0, X_{kjm} > 0\right)\left[X_{kim} + X_{kjm}\right]}{\sum_{k\neq(i \text{ or } j)}^{N} \sum_{m=1}^{M} \left(X_{kim} + X_{kjm}\right)}, \tag{15}$$

where $\mathbf{1}$ is the indicator function. The numerator captures the value of imports from common suppliers for countries i and j, while the denominator uses countries i and j's total trade with the world (except with each other) as a normalization. This normalization helps to deal with the effect of country size — i.e., the probability of two large countries importing a larger amount of a good from a given country is higher than that for two smaller countries, *ceteris paribus*, simply because of sheer size of the countries (and not, for example, trade costs). Moreover, the normalization bounds the index between 0 and 1.

Given this indicator, we estimate the following regression for bilateral real exchange rate volatility:

$$\sigma_{ij,t}^{RER} = \beta_0 + \beta_1 CS_{ij,t-1} + \gamma\mathbf{X} + \zeta_{ij,t}, \tag{16}$$

where $\mathbf{X}$ is a matrix of controls, which include distance, an indicator of a common border, the countries' income level and the countries' income per capita. This equation is estimated in five year panels, and we therefore include time period dummies as well as country-pair or country-specific (i and j) fixed effects. The inclusion of the geographical variables captures potential trade frictions, which in turn may result in the failure of the law of one price. Furthermore, the inclusion of income variables also captures potential determinants of bilateral trade, and are motivated by the "gravity" specification from the empirical trade literature. Finally, equation (16) is also estimated for sub-samples, which are dependent on the country-pair level of development: (i) developed-developed, (ii) developed-developing, and (iii) developing-developing.

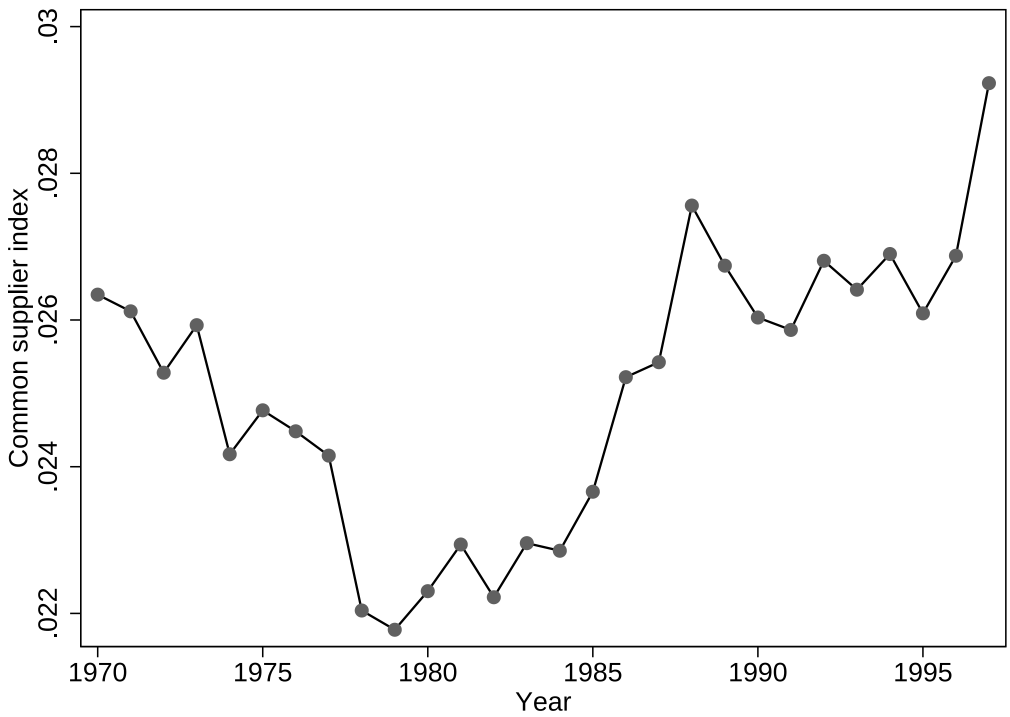


Figure 3. Annual world average of common supplier index

5.1 Data

The greatest challenge in collecting data is to obtain the necessary series to construct (15). As discussed above, the more disaggregated these data, the better. Hummels and Klenow (2002) exploit some very disaggregated trade data produced by UNCTAD. Unfortunately, (1) these data are not available for a very long time series (only the past few recent years), and (2) are very expensive. The lack of the time series component is not trivial. Unlike the Remoteness measure used in testing the two-country model in Section 4, the common supplier index (as calculated) does vary quite a bit over the period that we are examining. See Figure 3 for the annual world average of the calculated index.

Furthermore, an additional reason to believe that there might be some interesting time series variation is how the nature of trade has changed over time. For example, Yi (2003) highlights how small changes in tariffs over time have increased trade substantially due to "vertical specialization"; i.e., stages of production being globalized, with intermediate goods being shipped through several countries during production.

Therefore, we exploit the World Trade Database for 1970-1997. This database provides worldwide annual bilateral trade flows, which are disaggregated at the 4-digit SITC level.[18] This is still quite a high level of aggregation, but yields both intertemporal variation, as witnessed in Figure 3, as well as cross-sectional variation. We therefore construct the common supplier index for countries that actually have some bilateral trade in the database. The means and standard deviations of the index for the observations that we use in the estimations are 0.040 and 0.045, respectively.[19]

The bilateral real exchange variable is constructed using nominal exchange rate and CPI data from Global Financial Database in order to maximize country-pairs. We calculate the standard deviation of annual exchange rate changes over five years, where we again employ a rolling twelve month window to calculate annual real exchange rate changes as described in Section 4.[20] Furthermore, to eliminate some obvious outliers, we restrict our analysis to volatilities of one-hundred percent or less.[21] Our other control variables come from the same sources as discussed in Section 4.1, where we group middle and low income countries into developing countries.

[18]We also experimented with cruder cuts at the data; i.e., at 2- and 3-digit SITC levels. However, given the model's prediction, we did not expect these indices to perform as well in the regressions, which was indeed the case.

[19]Note that the average of this index is in general quite small. This partly reflects the fact that we do not consider direct trade between countries, and given asymmetries, this in turn may lead to some very small numbers even for countries that are quite close to each other. For example, almost 80% of Canadian trade is with the U.S., but the same is not the case for the U.S., which in turn will lead to a small index since the denominator of the index includes U.S. trade with the rest of the world.

[20]We also examined filtered data as in Section 4, but our results did not vary greatly.

[21]This restriction decreases the point estimate of the common supplier index, but improves its precision.

5.2 Empirical results

Table 5 presents regressions for the whole sample by pooling the data. Five specifications are run, each including country-pair income fixed effects and period dummies. The first specification only includes the common supplier index, whose point estimate is found to be negative and statistically significant. According to this estimation, a one standard deviation increase in the index (i.e., 4.5%) will decrease bilateral real exchange rate volatility by 1.04% (over a five-year period). Therefore, as two countries increase their trade integration (similarly) with the rest of the world, this will result in more similar consumption baskets of imported goods, which in turn leads to less relative price volatility. However, this specification ignores other potentially important bilateral links that may explain real exchange rate volatility. Therefore, columns (1) and (2) consider geographic and income variables. These variables are meant to proxy other trade and information frictions, as well as correlates to how well the economies are "managed" economically (this is also why the income pair fixed effects are included). Furthermore, the geographical variables may also capture the degree to which business cycles are correlated across countries.

The first (surprising) fact to note is that the distance and border coefficients are not statistically significant. Given previous literature (Engel and Rogers 1996) one would expect that these variables should have strong effects on real exchange rate volatility. Indeed, it is quite possible that the constructed supplier index dominates their effects. However, as will be discussed shortly, direct trade still has an impact on volatility, so in as much as the border and distance proxy for trade costs, this explanation is not a perfect one. It would be interesting to further explore this puzzling finding in future work. The income variables in the third column are significant. As expected, the product of the two countries' income per capita is negatively correlated with volatility. Therefore, more developed countries generally experience less exchange rate volatility. It is also interesting to note that the actual measures of income per capita are significant even when including the income country-pair effects, so this relationship appears to be a continuous one. The coefficient for real income is just significant, but positively signed. This sign is surprising given that one might expect that since larger countries tent to trade more that they would also experience less exchange rate volatility. However, larger economies might also have more complex internal distribution chains, which in turn yields greater frictions in prices. It is also interesting to note that the inclusion of the income variable decreases the common supplier index quite a bit (by about one-half), whereas the inclusion of distance and the border does not. Therefore, the relative wealth of two countries also appears to be positively correlated with their common import behaviour, which proxies for their similarities in trade costs and technology viz. the rest of the world.

Finally, columns (4) and (5) include actual bilateral trade. If countries that trade more with each other also import from similar suppliers, then one would expect that including trade would in fact reduce the coefficient on the common supplier index. This is indeed the case. In fact, simply including trade in column (4) more than halves the coefficient on the common supplier index. However, the index is still very significant. Turning to column (5), including the other covariates further reduces the impact of the index, but it remains significant. One further interesting fact to note is that the coefficient on the real income variable is now larger (and more significant) than in column (3). This finding supports the notion that larger countries may experience less exchange rate volatility because they trade more with each other.

Table 6 estimates the specifications using country-pair fixed effects. The use of fixed effects allows us to control for potential (time-invariant) effects that may be correlated with the common supplier index, and that were not captured by the time-invariant variables included in the pooled regressions of Table 5. Four specifications are run in total: two without trade and two with trade. In general, results are similar to the pooled estimations. The coefficient for the common supplier index is smaller in the baseline specification (1) compared to the pooled specification (1). However, the size of the coefficient does not vary greatly across different specifications for the fixed effects regressions. In particular, a one standard deviation increase in the index will result in a decrease of volatility between the range of 0.58%-0.77% across the four specifications. As before, volatility is decreasing the level of developed (as measure by income per capita), but now volatility is robustly and positively correlated with the two countries' income.

This section has presented reduced form results that confirm the main prediction of the multi-country model of Section 3. That is, two countries' bilateral real exchange rate volatility is smaller if they share a more similar import basket. This result is robust, and most interestingly remains so when including bilateral trade. A natural extension to this work would be to estimate a more structural model, where we control directly for two countries' relative trade costs with trading partners as well as relative technological differences.

6 Conclusion

This paper examines the impact of trade costs on real exchange rate volatility. In particular, we highlight two distinct channels through which these costs affect volatility. First, the size of the nontradable sector determined by trade costs and the non diffusion of idiosyncratic shocks between countries reflected in the dissimilarities of their price indexes. Second, the impact of trade costs determined by geography and geopolitical forces on the heterogeneity of the set of suppliers of traded goods between countries. We endogenize both these channels using simple Ricardian models of trade, in both a two-country and a multi-country setting.Finally, we take the models to the data and directly test our theoretical predictions, which are indeed supported.

We view this paper has a good starting point to more formally analyze the impact of trade and its determinants on macroeconomic volatility and other international macroeconomic issues. We believe that examining such phenomena are important given that research on trade liberalization has mostly focused on microeconomic issues. However, as this paper has shown, there are other important macroeconomic variables to consider.

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Appendix A Two-country real exchange rate volatility

The variance of the real exchange rate can be expressed as follows:

$$\begin{aligned}
\mathrm{Var}\left\{\log\left(\frac{P}{P^*}\right)\right\} &= \mathrm{Var}\left\{\int_{z^F}^{z^H} \log\left(\frac{w\cdot a(z)}{w^*\cdot a^*(z)}\cdot\frac{\exp(\varepsilon)}{\exp(\varepsilon^*)}\right)_{TB=0} dz\right\} \\
&= \mathrm{Var}\left\{\int_{z^F}^{z^H} \log\left(\frac{w\cdot a(z)}{w^*\cdot a^*(z)}\right)_{TB=0} dz\right\} \\
&+ \mathrm{Var}\left\{\int_{z^F}^{z^H} \log\left(\frac{\exp(\varepsilon)}{\exp(\varepsilon^*)}\right) dz\right\} \\
&= \mathrm{Var}\left\{\int_{z^F}^{z^H} (\varepsilon-\varepsilon^*) dz\right\} \\
&= 2\left(z^H - z^F\right)^2 \sigma^2.
\end{aligned} \tag{A.1}$$

where we have used the fact that only ε and ε^* are stochastic, and that (z^F and z^H remain fixed after shocks are realized.

Appendix B Multi-country real exchange rate volatility

B.1 Nontradable sector equilibrium and the real exchange rate

The following is a simple model of aggregate consumption of traded and nontraded goods that will yield the real exchange rate. The problem is symmetric for home and foreign, therefore we only present home's problem.

First, a representative agent maximizes consumption over traded and nontraded goods, where utility takes a Cobbs-Douglas form:

$$U(C_T, C_N) = C_T^{\eta} C_N^{1-\eta}, \tag{B.1}$$

where C_T is the aggregate consumption of traded goods and corresponds to equation (8), while we assume that there is a single nontraded good.[22]

[22]Note that we could similarly assume that there there is a bundle of differentiated nontradable

Production in the the nontraded sector is competitive, exhibits constant returns to scale and only requires labour inputs. In particular, the representative firm has the following linear production function:

$$y_N = \frac{l_N}{a_N}, \tag{B.2}$$

where a_N is the labour requirment in the nontraded sectors, and l_N is labour. Firms therefore choose labour to maximize profits, which in turn implies that the real wage equals the marginal product of labour:

$$\frac{w}{P_N} = \frac{1}{a_N}. \tag{B.3}$$

The price can be normalized to solve for w, and as discussed in Section (3.3), given labour mobility across sectors, this wage also holds in the tradable sector.

Finally, it is possible to show that setting the aggregate consumption basket (B.1) to one implies and minimizing the representative agent's expenditures yields the following aggregate price index:

$$P = \frac{P_T^{\eta} P_N^{1-\eta}}{\eta^{\eta}(1-\eta)^{1-\eta}}, \tag{B.4}$$

where P_T corresponds to p_n in (9). Taking the logarithm of the ratio of P and P^*, where we assume that the preference parameter $\eta = \eta^*$, one has the log real exchange rate:

$$q = p - p^* = \eta(p_T - p_T^*) + (1-\eta)(p_N - p_N^*), \tag{B.5}$$

where q is the log real exchange rate, and lower case p represents the log price level. This model essentially reflects the decomposition in Engel (1999). The model presented in Section 3 describes how greater trade costs can lead to higher volatility of the first term in (B.5); i.e., of the traded goods basket. It is obvious that domestic

consumption goods as in the tradable sector. However, it is simpler to examine a single good to show more explicitly the relationship between wages, prices and labour in the nontraded sector.

shocks will also lead to volatility in the prices of nontraded goods, and given the intuition described for two-country model in Section 2, this component will be larger for any country given higher trade costs. Therefore, except for some extreme conditions (i.e., the volatility of the relative price of tradables decreasing with trade costs), the volatility of the overall real exchange rate, q, increases with trade costs.

B.2 Statistical theorems

The following statistical identities/theorems are found in Casella and Berger (2002) — C&B hereafter — and will be applied below. To make things as clear as possible, we will write the given mathematics as they are found in C&B. In particular, a first-order Taylor approximation is used to solve for real exchange rate volatility. First, note:

Theorem 1 (Taylor, Theorem 5.5.21, C&B, p.241) *If $g^{(r)}(a) = \frac{d^r}{dx^r} g(x)|_{x=a}$ exists, then*

$$\lim_{x \to a} \frac{g(x) - T_r(x)}{(x-a)^r} = 0$$

where, $g(x)$ is the log of the real exchange rate. Since we are interested in approximating this value, we can ignore any remainders in estimating this function. There are many explicit forms that one can use to estimate the function. For the present purposes, the following is useful:

$$g(x) - T_r(x) = \int_a^x \frac{g^{r+1}(t)}{r!}(x-t)^r dt.$$

For the statistical application of Taylor's Theorem, we are most concerned with the *first-order* Taylor series, that is, an approximation using just the derivative (i.e., $r = 1$ in the above formulae). Furthermore, we will also examine multivariate Taylor series, where the above logic applies similarly.

Let $T_1, \ldots, T_k$ be random variables with means $\theta_1, \ldots, \theta_k$, and define $\mathbf{T} = (T_1, \ldots, T_k)$ and $\theta = (\theta_1, \ldots, \theta_k)$. Suppose there is a differentiable function $g(\mathbf{T})$ (an estimator of some parameter) for which we want an approximate estimate of variance. Define

$$g_i'(\theta) = \frac{\partial}{\partial t_i} g(\mathbf{t})|_{t_1=\theta_1,\ldots,t_k=\theta_k}.$$

The first-order Taylor series expansion of g about θ is

$$g(\mathbf{t}) = g(\theta) + \sum_{i=1}^{k} g_i'(\theta)(t_i - \theta_i) + \text{Remainder}.$$

For our statistical approximation we forget about the remainder and write

$$g(\mathbf{t}) \approx g(\theta) + \sum_{i=1}^{k} g_i'(\theta)(t_i - \theta_i). \tag{B.6}$$

Now, take expectations on both sides of (B.6) to get

$$\begin{aligned} \mathrm{E}_\theta g(\mathbf{T}) &\approx g(\theta) + \sum_{i=1}^{k} g_i'(\theta)\mathrm{E}_\theta\{T_i - \theta_i\} \\ &= g(\theta). \end{aligned} \tag{B.7}$$

We can now approximate the variance of $g(\mathbf{T})$ by

$$\begin{aligned} \mathrm{Var}_\theta g(\mathbf{T}) &\approx \mathrm{E}_\theta\left\{[g(\mathbf{T}) - g(\theta)]^2\right\} && \text{(using (B.7))} \\ &\approx \mathrm{E}_\theta\left\{\left(\sum_{i=1}^{k} g_i'(\theta)(T_i - \theta_i)\right)^2\right\} && \text{(using (B.6))} \\ &= \sum_{i=1}^{k} [g_i'(\theta)]^2 \mathrm{Var}_\theta T_i + 2\sum_{i>j} g_i'(\theta) g_j'(\theta) \mathrm{Cov}_\theta\{T_i, T_j\}, && \text{(B.8)} \end{aligned}$$

where the last equality comes from expanding the square and using the definition of variance and covariance. Approximation (B.8) is very useful because it gives us a variance formula for a general function, using only simple variance and covariances.

Useful properties of the lognormal distribution

If X is a random variable whose logarithm is normally distributed (that is $\log X \sim n(\mu, \sigma^2)$ then one can solve for its moments and variance exactly. Specifically, given that the variable $Y \equiv \log X$ has the moment generating function $M_Y(t) = \exp(\mu t +$

$\sigma^2 t^2/2)$, one has that:

$$\begin{aligned} \mathrm{E}\{X\} &= \mathrm{E}\{\exp[\log X]\} \\ &= \mathrm{E}\{\exp[Y]\} \\ &= M_Y(1) \\ &= \exp(\mu + \sigma^2/2) \end{aligned} \tag{B.9}$$

$$\begin{aligned} \mathrm{E}\left\{X^2\right\} &= \mathrm{E}\{\exp[2\log X]\} \\ &= \mathrm{E}\{\exp[2Y]\} \\ &= M_Y(2) \\ &= \exp[2(\mu + \sigma^2)] \end{aligned} \tag{B.10}$$

$$\begin{aligned} \mathrm{Var}\{X\} &= \mathrm{E}\left\{X^2\right\} - \mathrm{E}^2\{X\} \\ &= \exp[2(\mu + \sigma^2)] - \exp(2\mu + \sigma^2) \end{aligned} \tag{B.11}$$

B.3 Volatility solution

First, define the variance of the natural logarithm of the bilateral real exchange rate between countries 1 and 2 as[23]:

$$\begin{aligned} \mathrm{Var}\left\{\log\left[\frac{p_1}{p_2}\right]\right\} &= \mathrm{Var}\left\{\log\left[\frac{\Phi_1}{\Phi_2}\right]^{-1/\theta}\right\} \\ &= \mathrm{Var}\left\{\log\left[\frac{\sum_{i=1}^{N} T_i(c_i\tau_{1i})^{-\theta}}{\sum_{i=1}^{N} T_i(c_i\tau_{2i})^{-\theta}}\right]^{-1/\theta}\right\} \end{aligned} \tag{B.12}$$

Step 1: Mean and Variance of T_i

To solve for these values, we may use equations (B.9)-(B.11) and (10). Specifically,

[23]It is important to note that we are actually calculating a conditional/hierarchical variance. In particular, we are interested in the variances of the price indices, which are dependent on a parameter, T_i, which in turn we treat as a random variable. Therefore, in thinking about the conditional variance, one may use the identity: $\mathrm{Var}X = \mathrm{E}\{\mathrm{Var}\{X|Y\}\} + \mathrm{Var}\{\mathrm{E}\{X|Y\}\}$ (Theorem 4.4.7, C&B, p. 167). In our example, p_n is X and is T_i is Y. Now, given the definition of the price index p_n, its variance conditional on T_i will be zero, therefore the first term of the conditional variance identity is zero. Meanwhile, the expected price index is as defined in (9), as shown by Eaton and Kortum (2002).

this yields the following:

$$\mathrm{E}\left\{T_i\right\} = \mathrm{E}\{\exp[\log T_i]\} = \exp\left[\log \tilde{T}_i + \sigma_\varepsilon^2/2\right] = \tilde{T}_i e^{\sigma_\varepsilon^2/2} \tag{B.13}$$

$$\mathrm{E}\left\{T_i^2\right\} = \mathrm{E}\{\exp[2\log T_i]\} = \exp\left[2\log \tilde{T}_i + 2\sigma_\varepsilon^2/2\right] = \tilde{T}_i^2 e^{2\sigma_\varepsilon^2} \tag{B.14}$$

$$\mathrm{Var}\left\{T_i\right\} = \mathrm{E}\left\{T_i^2\right\} - \mathrm{E}^2\left\{T_i\right\} = \tilde{T}_i^2 e^{\sigma_\varepsilon^2}\left(e^{\sigma_\varepsilon^2} - 1\right), \tag{B.15}$$

where we have used the fact that $\mathrm{E}\left\{\log T_i\right\} = \log \tilde{T}_i$.

Step 2: Expectation of Φ_i's definition

It is helpful to define the following two terms to simplify notation later:

$$\mu_1 \equiv \mathrm{E}\{\Phi_1\} = e^{\sigma_\varepsilon^2/2} \sum_{i=1}^{N} \tilde{T}_i (c_i \tau_{1i})^{-\theta}$$

$$\mu_2 \equiv \mathrm{E}\{\Phi_2\} = e^{\sigma_\varepsilon^2/2} \sum_{i=1}^{N} \tilde{T}_i (c_i \tau_{2i})^{-\theta}$$

In particular, we will apply Theorem 1 to solve for (B.12) around (μ_1, μ_2).

Step 3: Solving the variance of the log of the real exchange rate around (μ_1, μ_2)

We may solve (approximately) for (B.12) by applying equation (B.8) in using Theorem 1, where in this case $g(\mu_1, \mu_2) \equiv \log(p_1/p_2)$. In particular, begin by noting that

$$\frac{\partial}{\partial \mu_1} g(\mu_1, \mu_2) = \frac{1}{\mu_1} \qquad \frac{\partial}{\partial \mu_2} g(\mu_1, \mu_2) = \frac{1}{\mu_2}$$

One may then simply use these partial derivatives and apply (B.8) to find that:

$$
\begin{aligned}
\mathrm{Var}\left\{\log\left[\frac{p_1}{p_2}\right]\right\} &\approx \left(\frac{1}{\theta^2}\right)\left[\left(\frac{1}{\mu_1}\right)^2\mathrm{Var}\{\Phi_1\}+\left(\frac{1}{\mu_2}\right)^2\mathrm{Var}\{\Phi_2\}-\frac{2}{\mu_1\mu_2}\mathrm{Cov}\{\Phi_1,\Phi_2\}\right]\\
&= \left(\frac{1}{\theta^2}\right)\left[\left(\frac{1}{\mu_1}\right)^2\sum_{i=1}^{N}\mathrm{Var}\{T_i\}(c_i\tau_{1i})^{-2\theta}+\left(\frac{1}{\mu_2}\right)^2\sum_{i=1}^{N}\mathrm{Var}\{T_i\}(c_i\tau_{2i})^{-2\theta}\right]\\
&\quad \left(\frac{1}{\theta^2}\right)\left[\frac{2}{\mu_1\mu_2}\mathrm{Cov}\left\{\sum_{i=1}^{N}T_i(c_i\tau_{1i})^{-\theta},\sum_{i=1}^{N}T_i(c_i\tau_{2i})^{-\theta}\right\}\right]\\
&= \Upsilon\left[\left(\frac{1}{\mu_1}\right)^2\sum_{i=1}^{N}\tilde{T}_i^2(c_i\tau_{1i})^{-2\theta}+\left(\frac{1}{\mu_2}\right)^2\sum_{i=1}^{N}\tilde{T}_i^2(c_i\tau_{2i})^{-2\theta}\right]\\
&\quad -2\Upsilon\left[\left(\frac{1}{\mu_1\mu_2}\right)\sum_{i=1}^{N}\tilde{T}_i^2(c_i^2\tau_{1i}\tau_{2i})^{-\theta}\right]\\
&= \Upsilon\left(\underbrace{\frac{\sum_{i=1}^{N}\tilde{T}_i^2(c_i\tau_{1i})^{-2\theta}}{\left[\sum_{i=1}^{N}\tilde{T}_i(c_i\tau_{1i})^{-\theta}\right]^2}}_{[1]}+\underbrace{\frac{\sum_{i=1}^{N}\tilde{T}_i^2(c_i\tau_{2i})^{-2\theta}}{\left[\sum_{i=1}^{N}\tilde{T}_i(c_i\tau_{2i})^{-\theta}\right]^2}}_{[2]}\right)\\
&\quad -2\Upsilon\left(\underbrace{\frac{\sum_{i=1}^{N}\tilde{T}_i^2(c_i^2\tau_{1i}\tau_{2i})^{-\theta}}{\sum_{i=1}^{N}\tilde{T}_i(c_i\tau_{1i})^{-\theta}\sum_{i=1}^{N}\tilde{T}_i(c_i\tau_{2i})^{-\theta}}}_{[3]}\right),
\end{aligned}
\tag{B.16}
$$

where $\Upsilon = \left(\frac{e^{\sigma_\varepsilon^2}\left[e^{\sigma_\varepsilon^2}-1\right]}{\theta}\right) > 0$. The $\mathrm{Cov}\{\cdot\}$ term is found by noting that $\mathrm{E}\{T_iT_j\} = \tilde{T}_i\tilde{T}_j e^{\sigma_\varepsilon^2}$ if $i \neq j$, and that $\mathrm{E}\left(T_i^2\right)$ is (B.14).

Table 1. Determinants of real exchange rate volatility: Whole sample.

	1980-2000		1980-89/1990-2000	
	(1)	(2)	(1)	(2)
Log(Remoteness)	0.235^{+}	0.195*	0.288**	0.164*
	(0.123)	(0.090)	(0.104)	(0.066)
Log(Y/L)		-0.059**		-0.054**
		(0.012)		(0.011)
Decade			-0.044**	-0.034*
			(0.014)	(0.013)
Observations	78	78	156	156
R^2	0.04	0.37	0.07	0.30

Exchange rate volatilities are calculated using rolling twelve month log exchange rate changes over specified time period. All other variables are beginning of period. Robust clustered standard errors in parentheses; $^{+}$ significant at 10%; * significant at 5%; ** significant at 1%.

Table 2. Determinants of real exchange rate volatility: High income countries.

	1980-2000		1980-89/1990-2000	
	(1)	(2)	(1)	(2)
Log(Remoteness)	0.187**	0.199**	0.176**	0.193**
	(0.040)	(0.042)	(0.040)	(0.041)
Log(Y/L)		0.025*		0.034*
		(0.011)		(0.014)
Decade			-0.004	-0.012+
			(0.005)	(0.006)
Observations	22	22	44	44
R^2	0.36	0.44	0.27	0.36

Exchange rate volatilities are calculated using rolling twelve month log exchange rate changes over specified time period. All other variables are beginning of period. Robust clustered standard errors in parentheses; $^{+}$ significant at 10%; * significant at 5%; ** significant at 1%.

Table 3. Determinants of real exchange rate volatility: Middle income countries.

	1980-2000		1980-89/1990-2000	
	(1)	(2)	(1)	(2)
Log(Remoteness)	0.145	0.175	0.159	0.175^{+}
	(0.139)	(0.119)	(0.118)	(0.088)
Log(Y/L)		-0.047^{+}		-0.041^{*}
		(0.023)		(0.017)
Decade			-0.049^{*}	-0.046^{*}
			(0.020)	(0.020)
Observations	38	38	76	76
R^2	0.03	0.12	0.08	0.14

Exchange rate volatilities are calculated using rolling twelve month log exchange rate changes over specified time period. All other variables are beginning of period. Robust clustered standard errors in parentheses; $^{+}$ significant at 10%; * significant at 5%; ** significant at 1%.

Table 4. Determinants of real exchange rate volatility: Low income countries.

	1980-2000		1980-89/1990-2000	
	(1)	(2)	(1)	(2)
Log(Remoteness)	0.455	0.682	0.732	0.979
	(0.698)	(0.660)	(0.858)	(0.694)
Log(Y/L)		-0.176^{**}		-0.197^{**}
		(0.055)		(0.057)
Decade			-0.098^{+}	-0.100^{+}
			(0.054)	(0.056)
Observations	17	17	34	34
R^2	0.02	0.32	0.07	0.32

Exchange rate volatilities are calculated using rolling twelve month log exchange rate changes over specified time period. All other variables are beginning of period. Robust clustered standard errors in parentheses; $^{+}$ significant at 10%; * significant at 5%; ** significant at 1%.

Table 5. Determinants of bilateral real exchange rate volatility: Whole sample, pooled (1970-97).

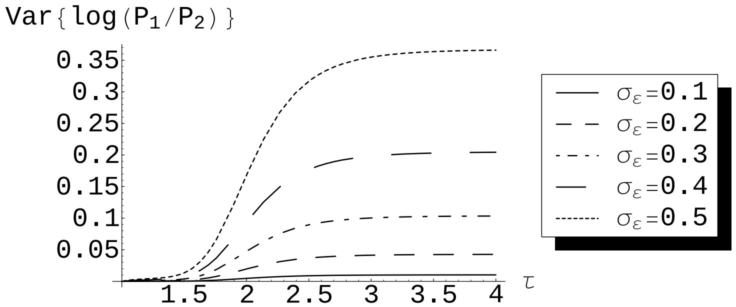
	(1)	(2)	(3)	(4)	(5)
Common supplier index	-0.231**	-0.253**	-0.164**	-0.110**	-0.071*
	(0.027)	(0.030)	(0.032)	(0.032)	(0.034)
Log(Distance)		-0.002	-2.79E-04		-0.004*
		(0.002)	(0.002)		(0.002)
Border		0.007	-6.13E-05		-0.002
		(0.008)	(0.008)		(0.008)
Log($Y_i Y_j$)			0.001+		0.005**
			(0.001)		(0.001)
Log($(Y/L)_i (Y/L)_j$)			-0.018**		-0.015**
			(0.001)		(0.002)
Log(Trade)				-0.004**	-0.006**
				(0.001)	(0.001)
High-high income	-0.069**	-0.069**	-0.025**	-0.060**	-0.026**
	(0.003)	(0.003)	(0.005)	(0.003)	(0.005)
High-low income	-0.014**	-0.013**	0.007*	-0.010**	0.007*
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Constant	0.155**	0.172**	0.425**	0.197**	0.329**
	(0.003)	(0.013)	(0.033)	(0.007)	(0.038)
Observations	13436	13436	13436	13436	13436
R^2	0.08	0.08	0.09	0.08	0.09

Exchange rate volatilities are calculated using rolling twelve month log exchange rate changes over five-year periods. Annual dummies omitted. All other variables are beginning of period. Robust clustered standard errors in parentheses; + significant at 10%; * significant at 5%; ** significant at 1%.

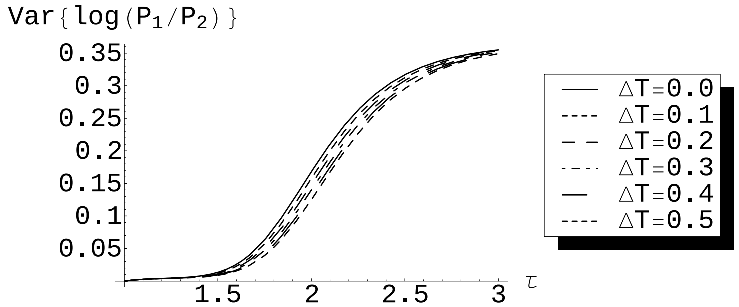
Table 6. Determinants of bilateral real exchange rate volatility: Whole sample, fixed effects (1970-97).

	(1)	(2)	(3)	(4)
Common supplier index	-0.172**	-0.168**	-0.129*	-0.139**
	(0.051)	(0.051)	(0.052)	(0.052)
Log($Y_i Y_j$)		0.032**		0.037**
		(0.009)		(0.009)
Log($(Y/L)_i (Y/L)_j$)		-0.050**		-0.047**
		(0.009)		(0.009)
Log(Trade)			-0.008**	-0.007**
			(0.001)	(0.001)
Observations	13436	13436	13436	13436
Number of groups	2890	2890	2890	2890
R^2	0.09	0.09	0.09	0.09

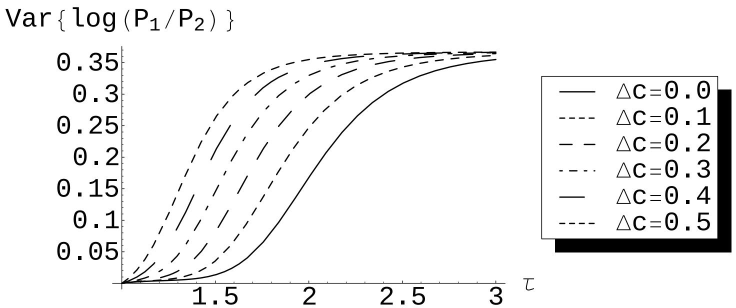
Exchange rate volatilities are calculated using rolling twelve month log exchange rate changes over five-year periods. Constant, country-pair fixed effects, and annual dummies omitted. All other variables are beginning of period. Robust clustered standard errors in parentheses; $^{+}$ significant at 10%; * significant at 5%; ** significant at 1%.



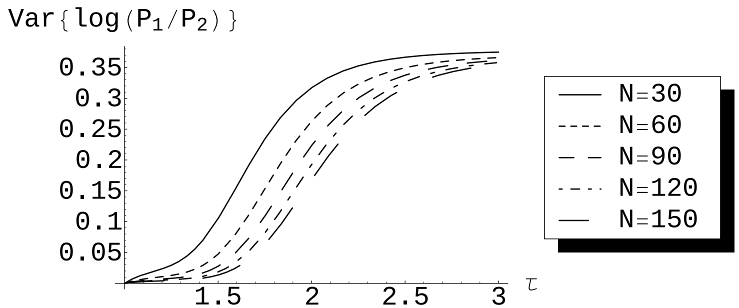
(a) Productivity shock(σ_ε) varying



(b) Technological gap (ΔT) varying

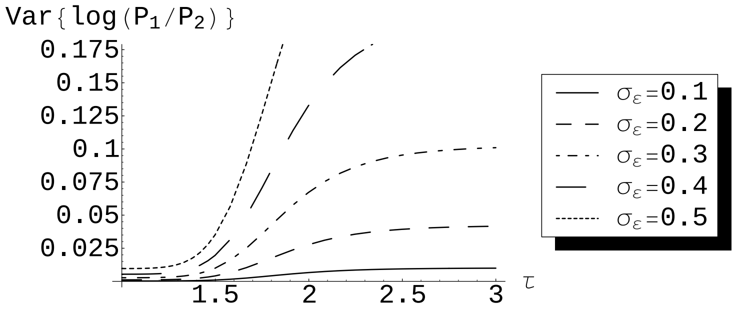


(c) Cost gap (Δc) varying

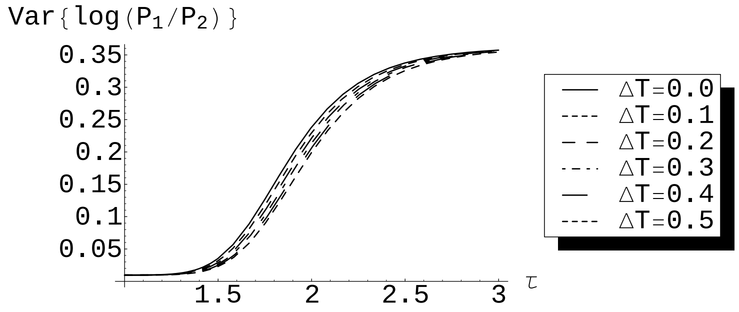


(d) Size of custom union (N) varying

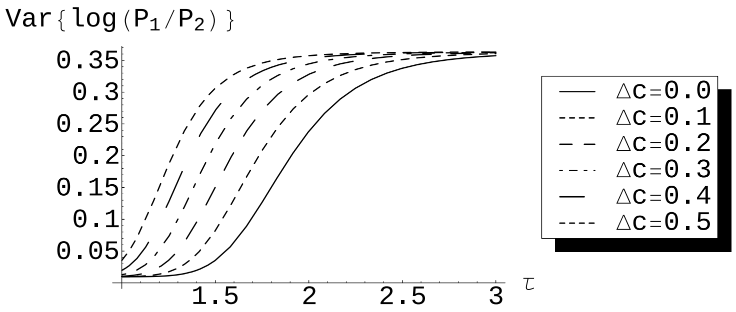
Figure 4. Customs union example



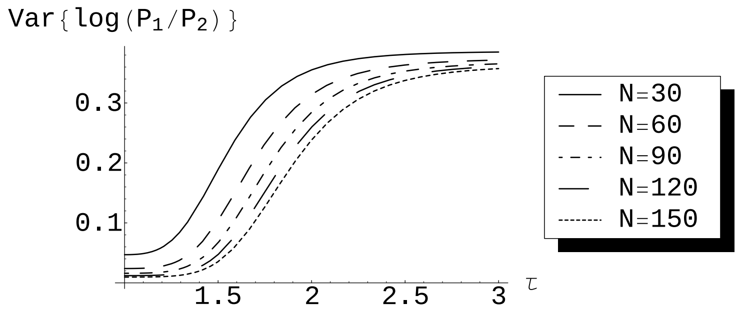
(a) Productivity shock(σ_ε) varying



(b) Technological gap (ΔT) varying



(c) Cost gap (Δc) varying



(d) Size of free trade area (N) varying

Figure 5. Free trade agreement example