Diversification through Trade

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Abstract

This paper investigates the relationship between international trade and volatility of real GDP growth and revisits the theoretical case for a positive effect of trade on volatility. Using one of the canonical models of international trade, we show that trade can act as a channel for the diversification of country-specific shocks and in that way contribute to lower volatility. More generally, the sign and size of the effect depend critically on the variance-covariance of shocks across countries.

1 Introduction

An important question at the crossroads of macro-development and international economics is whether (and how) openness to trade affects macroeconomic volatility. A widely held view in academic and policy discussions is that international trade leads to higher GDP volatility. The origins of this view are rooted in a large class of theories of international trade predicting that openness to trade increases specialization. Because specialization (or lack of diversification) in production tends to increase a country's exposure to shocks specific to the sectors (or range of products) in which the country specializes, it is generally inferred that trade increases volatility.

This paper revisits the theoretical case for a positive effect of trade on volatility. In particular, it begins by pointing out that the existing wisdom is strongly predicated on the assumption that sector-specific shocks are the dominant source of GDP volatility. Koren and Tenreyro (2007), however, find that country-specific shocks (common to all sectors within a country) are at least as important in shaping volatility patterns in developed countries, and more critically so in developing countries. We argue in this paper that the impact of trade on volatility can be remarkably different if imperfectly correlated country-specific shocks are indeed the dominant source of volatility. Concretely, using one of the canonical models of international trade, we show that openness to trade, by reducing exposure to domestic shocks, can lead to lower GDP volatility; this will be true as long as the volatility of trading partners and covariance of shocks across countries are not too big; in other words, trade can act as a channel for the diversification of country-specific shocks and in that way contribute to lower volatility. More generally, the sign and size of the effect depends critically on the variance-covariance of shocks across countries.

To make our point, we study a model of trade and GDP determination in which shocks are country-specific, affecting all sectors in a country. The model builds on a variation of the Eaton and Kortum (2002) and Alvarez and Lucas (2007)'s model[1], augmented to allow for aggregate shocks. Production combines labour and a variety of tradable inputs that are subject to cost shocks. Some of these shocks are idiosyncratic, as in the original EKAL model, and some are aggregate, affecting all sectors in the country. The model delivers the following predictions. If country-specific shocks are *iid* across countries, a multilateral move from autarky to costless free trade unambiguously reduces volatility in all countries. The reduction in volatility is stronger the smaller the country, ceteris paribus. This is because a smaller country trades relatively more (relative to its GDP) and hence can more

[1]Henceafter referred to as the EKAL model or each paper separately as EK or AL.

easily diversify the exposure to its own-country shocks, both on the demand and supply side. Results can be reverted, however, if the variances of and covariances with trading partners' shocks are high enough. The model also shows that a move from autarky to free trade causes the covariance of growth rates across countries with the rest of the world to increase; this increase is smaller for bigger countries, which, by their sheer size will be relatively less affected by the increase in trade openness. (As is common in Ricardian models, the increase in trade due to lower transaction costs will unambiguously increase the level of output in all countries, but more so in smaller countries).

The model is thus capable (at least qualitatively) to reconcile the substantial and widespread increase in trade flows over the past 30 years, together with the substantial decline in macroeconomic volatility during the same period; it is also consistent with the shoot up in volatility in 2008-2010 and the contraction of trade amidst the crisis. As the model makes clear, however, openness to trade does not always lead to lower volatility: The sign and size of the effect can vary substantially across countries (and, critically, with the set of trading partners). This might explain why direct evidence on the effect of openness on volatility has been ambiguous at best. Some studies find that trade decreases volatility (e.g. Buch, Dropke and Strotmann (2006) for Germany and Burgess and Donaldson (2010)'s for India), while others find that trade increases it (Easterly and Kraay (2000)).

The second part of the paper attempts a quantification of the contribution of trade to the observed changes in volatility since 1970 in a large group of countries. Using a calibrated version of the model developed above, we try to answer the question: How much of the changes of volatility since the 1970s can be attributed to a decline in overall barriers to trade?

The paper is organized as follows. Section 2 presents the model and solves analytically for two special cases, autarky and costless free trade. Section 3 presents numerical illustrations. Section 4 introduces the data and calibration and, finally, Section 5 discusses our quantitative results.

2 Model of trade with aggregate shocks

The model is a basic version of EKAL, with aggregate shocks (stochastic λ). There is a continuum of goods $q(x)$ which are produced using equipped labour L (unproduced) and all other produced goods. In particular, each good $q(x)$ is produced by a Cob–Douglas production function in L and a CES bundle of all the intermediate inputs $q(x)$. Aside from being used in the production of other goods, the $q(x)$s can also be directly consumed. As in EK, the utility derived from consumption takes the same CES form in which the $q(x)$s enter the production function. Notice that the $q(x)$s are therefore both intermediate (when used in producing other $q(x)$s) and final goods (when used in consumption). This is consistent with the national accounts where each sector's output can be both used as intermediate by other sectors and as a final good by consumers. All produced goods $q(x)$ are in principle tradable in international markets (though the cost for some could be very big – so big that they may not end up being traded in equilibrium and only produced domestically).

For the sake of exposition, we first discuss the model in autarky and then allow for international trade. All production is subject to constant returns and we conduct the analysis of the closed economy in units of the economy's endowment L_i. For simplicity, we suppress the subindex i in the description of the closed economy.

2.1 Closed economy

Total factor productivity (TFP) varies across intermediate goods; the inverse of TFP levels, x, are modelled as random variables, independent across goods, with common density ϕ. Buyers (who could be final consumers or firms buying intermediate inputs) purchase individual goods $q(x)$ to maximize the CES objective:

$$q = \left(\int_0^\infty q(x)^{\frac{\eta-1}{\eta}} \phi(x) dx \right)^{\frac{\eta}{\eta-1}}$$

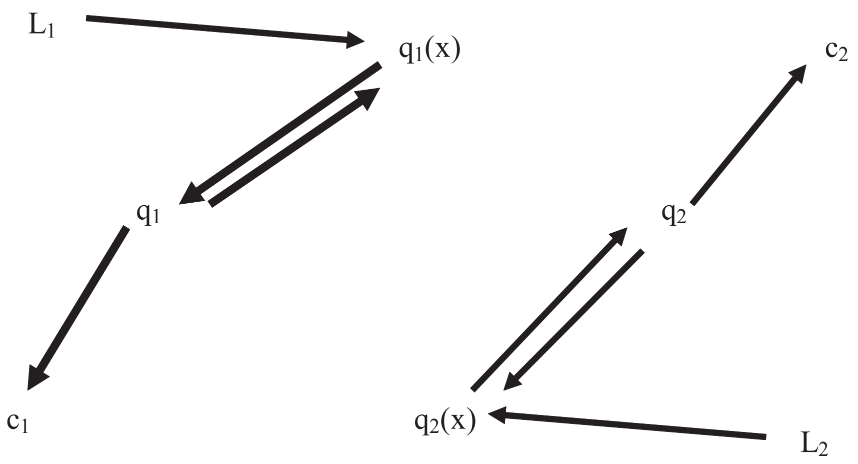
where $\eta > 0$ is the elasticity of substitution across goods. The part of the bundle q that is directly consumed will be denoted c and the part that enters production of $q(x)$ as intermediate inputs q_m. The technology for $q(x)$ is Cobb-Douglas in the effective labour input $s(x)$ and the bundle of intermediate goods q_m defined above:

$$q(x) = x^{-\theta} s(x)^\beta q_m(x)^{1-\beta}$$

The structure of the economy (for two countries that do not trade with each other) is shown in Figure 1. The cost draws x are common to all producers in the economy. Because of constant returns, the number of producers is indeterminate and there is no market power: prices are set at marginal costs; autarky prices of intermediate goods are hence given by:

$$p(x) = Bx^\theta w^\beta p^{1-\beta}$$

Figure 1: Structure of production in autarky (2 countries)



where w is the unit cost of equipped labour, and $B = \beta^{\beta}(1-\beta)^{(1-\beta)}$. Following EKAL, we assume that the density ϕ follows an exponential distribution with parameter λ, $x \sim exp(\lambda)$ and hence the price of q is given by:

$$p = \left(\lambda \int_0^{\infty} p(x)^{1-\eta} e^{-\lambda x} dx\right)^{\frac{1}{1-\eta}}$$

With some algebra, $p(x)$ and p can be written as multiples of w:

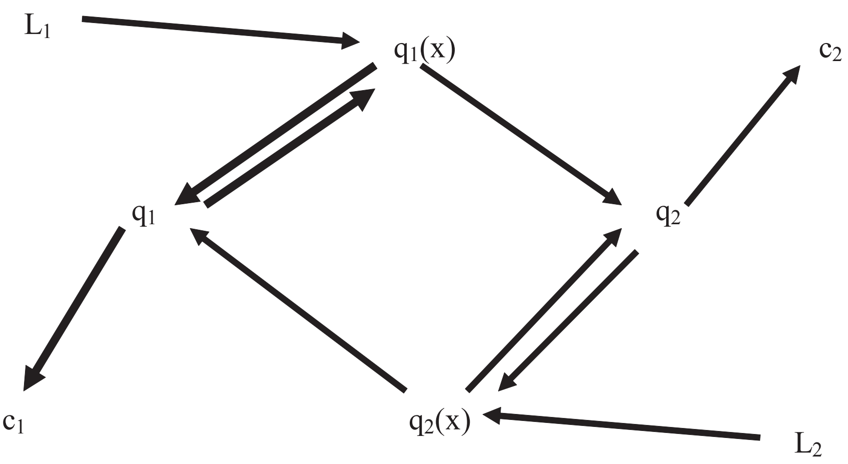
$$p(x) = A^{(1-\beta)/\beta} B^{1/\beta} x^{\theta} \lambda^{\frac{-\theta(1-\beta)}{\beta}} w$$
$$p = (AB)^{1/\beta} \lambda^{-\theta/\beta} w$$

This is a slightly modified version of the EKAL model, which assumes a common distribution of productivity for the whole economy (not just manufacturing, as in EKAL's interpretation); in EKAL, there is a separate non-tradable final good sector (identified with services) with deterministic common technology across all countries. As said, we pose no stark distinction between tradables and non-tradables and rather focus on the average degree of tradability for the whole economy. This modification requires a slightly different interpretation of the empirical counterparts of the model, which we will address at the calibration stage.

2.2 International trade

As in EKAL, we assume that intermediate inputs $q(x)$ can be traded internationally; $\phi(x) = \phi(x_1, ..., x_N)$ is now the joint density of goods that have productivity draws

Figure 2: Structure of production with trade



$x = (x_1, ..., x_N)$ across countries, where the draws are assumed to be independent across countries: $\phi(x) = (\prod \lambda_i) \exp[-\sum \lambda_i x_i]$. The structure of production can be then summarized as shown in Figure 2.

Delivering a tradable good from country j to country i results in $0 < \kappa_{ij} \leq 1$ goods arriving at j; we assume $\kappa_{ij} \geq \kappa_{ik}\kappa_{kj}$ for all i, k, j and $\kappa_{ii} = 1$. All costs incurred are a net loss. In the calibration, the κs will reflect all costs, including tariffs; so implicitly we adopt the extreme assumption that tariffs are all wasted (perhaps in political elections). The intermediate bundle for use in country i is then:

$$q_i = \left(\int_{\mathbf{R}_+^N} q_i(x)^{\frac{\eta-1}{\eta}} \phi(x) dx \right)^{\frac{\eta}{\eta-1}}$$

where $\phi(x)$ is the probability density function of goods with technology x. The price level in country i is now given by:

$$p_i(w) = AB \left(\sum_{j=1}^{N} \left(\frac{w_j^\beta p_j(w)^{1-\beta}}{\kappa_{ij}} \right)^{-1/\theta} \lambda_j \right)^{-\theta}$$

which leads to N equations (p_i) to be solved in terms of $w_i, i = 1, ..., N$. Defining $d_{ij}(w)$ as the fraction of country i's total spending $L_i p_i q_i$ that is spent on goods from country j:

$$d_{ij}(w) = (AB)^{-1/\theta} \left(\frac{w_j^\beta p_j(w)^{1-\beta}}{p_i(w) \kappa_{ij}} \right)^{-1/\theta} \lambda_j \tag{1}$$

The trade identity requires that dollar payments for goods flowing out of country i to the rest of the world must equal payments flowing in country i from the rest of the world.

Allowing for trade imbalance S_i and with $\sum_j d_{ij} = 1$,

$$L_i p_i q_i + S_i = \sum_{j=1}^{N} L_j p_j q_j d_{ji}(w)$$

The Cobb-Douglas assumption and the overall resource constraint for the economy further imply[2]

$$L_i w_i = \beta(L_i p_i q_i + S_i) \tag{2}$$

The trade identity therefore simplifies to

$$\frac{L_i w_i}{\beta} = \sum_{j=1}^{N} \left(\frac{L_j w_j}{\beta} - S_j \right) d_{ji}(w) \tag{3}$$

In the original EKAL model, the productivity parameters λs are deterministic, so GDP per capita is a deterministic constant for each country j. As said, we assume that λs are subject to shocks. In particular, higher realizations of λ_j lead to stochastically lower costs x in country j and higher GDP$_j$. Stochasticity in λ_j thus imparts stochasticity in GDP$_j$. It is instructive to look at two extreme cases: 1) complete autarky and 2) costless international trade.

2.3 Volatility in autarky

We study the volatility of real GDP, $Y_i = \frac{L_i w_i}{p_i}$, measured as the variance of deviations from mean. Autarkic prices and real GDP are given by:

$$p_i = (AB)^{1/\beta} \lambda_i^{-\theta/\beta} w_i$$
$$Y_i = \frac{L_i w_i}{p_i} = (AB)^{-1/\beta} \lambda_i^{\theta/\beta} L_i$$

Call $Z_i = \lambda_i L_i^{\beta_i/\theta}$ the weighted productivity of the economy (weighted by its size). Therefore, $Y_i = (AB)^{-1/\beta} Z_i^{\theta/\beta}$; denoting by $\hat{x} \equiv \frac{\Delta \ln x}{\Delta t}$ and evaluating changes around the mean of Z_i, we obtain:

$$\hat{Y}_i = \frac{\theta}{\beta} \hat{Z}_i$$

And hence volatility is given by:

$$Var(\hat{Y}_i) = \left(\frac{\theta}{\beta} \right)^2 Var(\hat{Z}_i)$$

[2]Derivation of this equation is shown in Appendix.

2.4 Volatility with costless trade

With no impediments to trade, $\kappa_{ij} = 1$ and trade imbalances zero, we have:

$$p_j = p = (AB)^{1/\beta} \left(\sum_{j=1}^{N} w_j^{-\beta/\theta} \lambda_j \right)^{-\theta/\beta} \tag{4}$$

Using this in the formula for trade shares (1), we have

$$d_{ji}(w) = w_i^{-\beta/\theta} \lambda_i \left(\sum_{j=1}^{N} w_j^{-\beta/\theta} \lambda_j \right)^{-1}$$

and from the trade identity (3) we obtain,

$$w_i = \left(\frac{\lambda_i}{L_i} \right)^{\frac{\theta}{\theta+\beta}} M \tag{5}$$

where $M = \left(\sum_{j=1}^{n} \frac{L_j w_j}{\sum_{k=1}^{n} w_k^{-\beta/\theta} \lambda_k} \right)^{\frac{\theta}{\theta+\beta}}$ is common to all countries. Therefore[3]:

$$Y_i = (AB)^{-1/\beta} Z_i^{\frac{\theta}{\beta+\theta}} \left(\sum_{j=1}^{N} Z_j^{\frac{\theta}{\theta+\beta}} \right)^{\theta/\beta}$$

where $Z_i = \lambda_i L_i^{\beta/\theta}$ as before. The log-linear approximation of this is

$$\hat{Y}_i = \frac{\theta}{\beta + \theta} \hat{Z}_i + \frac{\theta^2}{\beta\,(\beta + \theta)} \sum_{j=1}^{N} \gamma_j \hat{Z}_j \tag{6}$$

where $\gamma_j = \frac{\bar{Z}_j^{\frac{\theta}{\beta+\theta}}}{\sum_{j=1}^{N} \bar{Z}_j^{\frac{\theta}{\beta+\theta}}}$ is the country j's share in the sum of weighted productivities of all countries. Rearranging, we have:

$$\hat{Y}_i = \frac{\theta}{\beta} \left(\frac{\beta + \theta\gamma_i}{\beta + \theta} \right) \hat{Z}_i + \frac{\theta^2}{\beta\,(\beta + \theta)} \sum_{j \neq i} \gamma_j \hat{Z}_j \tag{7}$$

And therefore, volatility in free trade is given by:

$$\begin{aligned} Var(\hat{Y}_i) \;\; = \;\; & \left(\frac{\theta}{\beta} \right)^2 \left\{ \left(\frac{\beta + \theta\gamma_i}{\beta + \theta} \right)^2 Var(\hat{Z}_i) + \left[\frac{\theta}{\beta + \theta} \right]^2 \sum_{j \neq i} \gamma_j^2 Var(\hat{Z}_j) \right\} \\ & +2 \left(\frac{\theta}{\beta\,(\beta + \theta)} \right)^2 \theta \frac{\beta + \theta\gamma_i}{(\beta + \theta)} \sum_{j \neq i} \gamma_j Cov(\hat{Z}_j, \hat{Z}_i) \end{aligned} \tag{8}$$

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[3]With (4) and (5), ratio $\frac{w_i}{p_i}$ becomes $(AB)^{-1/\beta} \left(\frac{\lambda_i}{L_i} \right)^{\frac{\theta}{\beta+\theta}} M \left(\sum_{j=1}^{n} \left(\left(\frac{\lambda_j}{Lj} \right)^{\frac{\theta}{\theta+\beta}} M \right)^{-\beta/\theta} \lambda_j \right)^{\theta/\beta}$. Multiplying by L_i and simplifying gives the result.

Compared with the variance in autarky, $Var(\hat{Y}_i) = \left(\frac{\theta}{\beta}\right)^2 Var(\hat{Z}_i)$, it is clear that the volatility due to domestic productivity fluctuations, $Var(\hat{Z}_i)$, now receives a smaller weight because $\left[\frac{\beta+\theta\gamma_i}{\beta+\theta}\right] < 1$ since $\gamma_i < 1$. The smaller the country in terms of its presence in international trade, the smaller the impact of domestic volatility of shocks, $\hat{Z}_i$, on its GDP, relative to autarky. Openness to trade, however, exposes the country to other countries' productivity shocks and these contribute positively to volatility. The question is then whether the gain in diversification (given by lower exposure to domestic productivity) is bigger than the increased exposure to new shocks. The answer depends on the relative sizes of the countries and the variance-covariance matrix of shocks across them. If all countries have the same variance $Var(\hat{Z}_j) = \sigma$ and the $\hat{Z}_j$ are uncorrelated, the volatility of the country in free trade (8) becomes:

$$Var(\hat{Y}_i) = \left(\frac{\theta}{\beta}\right)^2 \left\{ \left[\frac{\beta+\theta\gamma_i}{\beta+\theta}\right]^2 + \left[\frac{\theta}{\beta+\theta}\right]^2 \sum_{j\neq i} \gamma_j^2 \right\} \sigma$$

which is lower than the volatility in autarky if an only if:

$$\left[\frac{\beta+\theta\gamma_i}{\beta+\theta}\right]^2 + \left[\frac{\theta}{\beta+\theta}\right]^2 \sum_{j\neq i} \gamma_j^2 < 1$$

Or, put differently, iff[4]:

$$2\beta\theta(\gamma_i - 1) + \theta^2 \left[\sum_j \gamma_j^2 - 1\right] < 0 \qquad (9)$$

which is always true (recall $\gamma_j < 1$) and $\sum_{j=1}^{N} \gamma_j^2 \leq 1$. Of course, if other countries have higher variances or the covariance terms are important, then the weights countries receive matter and the resulting change in volatility cannot be signed.

3 Numerical illustrations

We simulate the model for many periods (or realizations of λ_j) and obtain simulated time series of $\text{GDP}_{t,j}$ for different degrees of openness, gauged by trade costs κ. This exercise is aimed at confirming the intuition on the qualitative mechanism; later on we attempt a more realistic calibration. We then compute volatility of each country's GDP. The qualitative exercise consists of drawing $\lambda = (\lambda_1 ... \lambda_n)$ each period from a normal distribution with fixed mean and std deviation (matching average values in the sample);

[4]See Appendix for proof.

we choose θ, α, and β as in AL. We then explore the following (qualitative) experiments: 1) Widespread decrease in international trade barriers, 2) A Big Country joins the World, and 3) A crisis hits a big country.

3.1 Widespread decrease in international trade barriers

We set $L_n = 1$ and $\kappa_{ijt} = \kappa_t$ increases uniformly over time from the case of autarky ($\kappa = 0$) to free trade ($\kappa = 1$) for $i \neq j$, with $\kappa_{iit} = 1$. The upper panel of Figure 3 shows that as κ_t increases, that is, as trading costs decrease, volatility decreases; countries are able to diversify uncorrelated country-specific shocks.

If the size of countries is modified to allow for some big countries, $L_n = (1, 1, 1, 3, 3)$, and all else stays as before, the lower panel of Figure 3 clearly show that the decline in volatility is smaller for big countries.

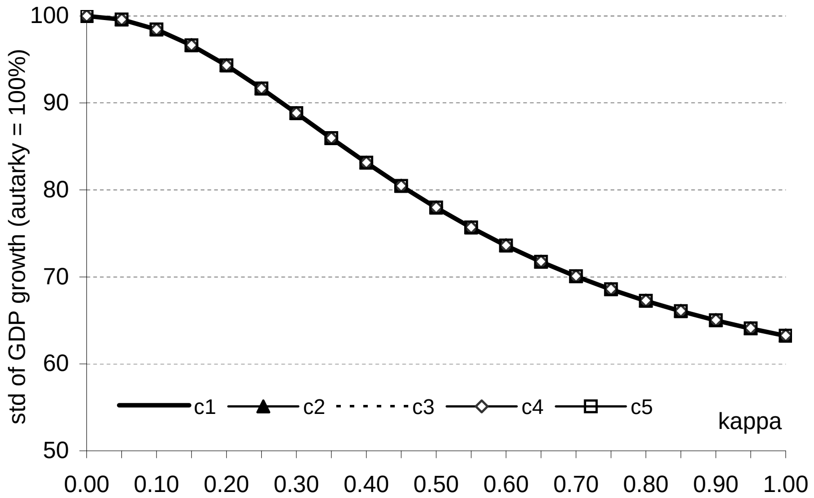
3.2 Big country joins the world

We keep all parameters as before, with $L_n = (1, 1, 1, 3, 3)$ but assume that four countries are open to trade with each other (constant $\kappa_{ij} = 0.3$ for $i, j \neq 5$, $\kappa_{ii} = 1$) and one of the big countries moves from autarky to free trade with the remaining countries ($\kappa_{i5t} = \kappa_{5jt}$ for $i, j \neq 5$ increases uniformly). The country that joins experiences a significant decline in volatility, in line with the conclusions of the above simulations (see Figure 4). Other countries also see some decline in volatility as their trading costs against big country 5 fall; the decrease is smaller than in previous simulations because their mutual trading barriers do not change. This simulations suggest that an increase in openness vis-à-vis one big country is also consistent with an overall decrease in volatility.

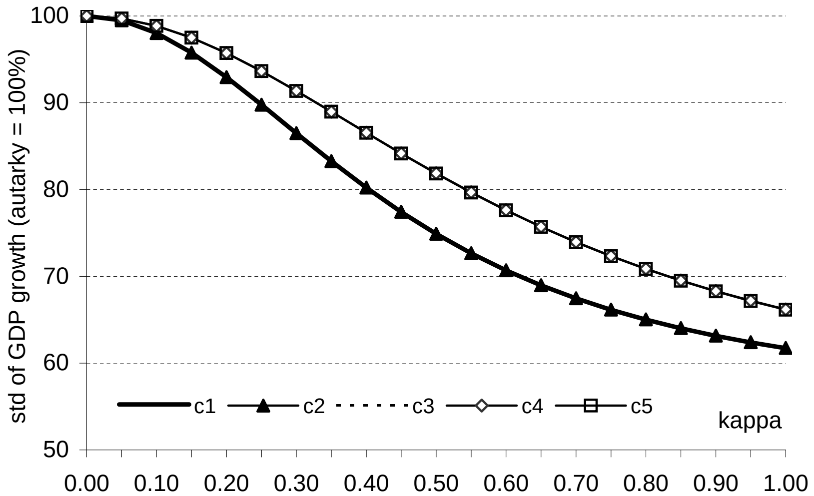
3.3 Crisis hits a big country

We keep the parameters as before, $L_n = (1, 1, 1, 3, 3)$, with κ_{ij} increases uniformly over time from autarky to free trade and explore what happens to GDP if one of the big countries (country 5) experiences a 10% fall in λ. The more open to trade countries are, the more the countries that were not hit by the shock suffer the impact the contraction in the big country. (When countries are completely close, of course they experience no change in GDP). Conversely, for the country that suffered the shock, higher openness helps mitigate the impact. The more open the country is, the lower the fall in its own GDP. See Figure 5 for illustration. The model is therefore consistent with the notion that

Figure 3: Volatility: uniform decrease in trade barriers



Note: Figure shows standard deviation of GDP (in log-deviations) relative to standard deviation computed when $\kappa = 0$ (case of autarky).



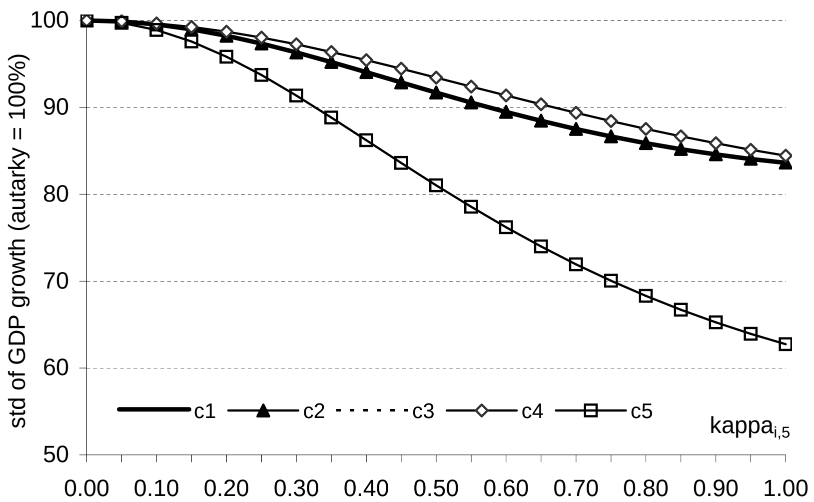
Note: As above. Countries 4 and 5 are big.

with greater trade openness, a large shock to a particular country (e.g. US), can be more strongly transmitted to other countries through stronger demand linkages.

4 Mapping model into data

To identify the key variables from our model with their counterparts in data we will stick to the convention introduced earlier in this paper and identify the weighted shocks $Z_i = \lambda_i L_i^{\beta/\theta}$ rather than shocks λ_i and the size of the economy L_i separately. Allowing

Figure 4: Big country joins the world



Note: Trade costs are fixed for countries 1-4 but uniformly decrease for their trade with country 5. See Figure 3 for further description.

for this modifications, we get the following modified equilibrium conditions:

$$d_{ij} = (AB)^{-1/\theta} \left(\frac{(L_j w_j)^{\beta} \, p_j{}^{1-\beta}}{p_i \kappa_{ij}} \right)^{-1/\theta} Z_j \tag{10}$$

$$p_i = AB \left(\sum_{j=1}^{n} \left(\frac{(L_j w_j)^{\beta} \, p_j^{1-\beta}}{\kappa_{ij}} \right)^{-\frac{1}{\theta}} Z_j \right)^{-\theta} \tag{11}$$

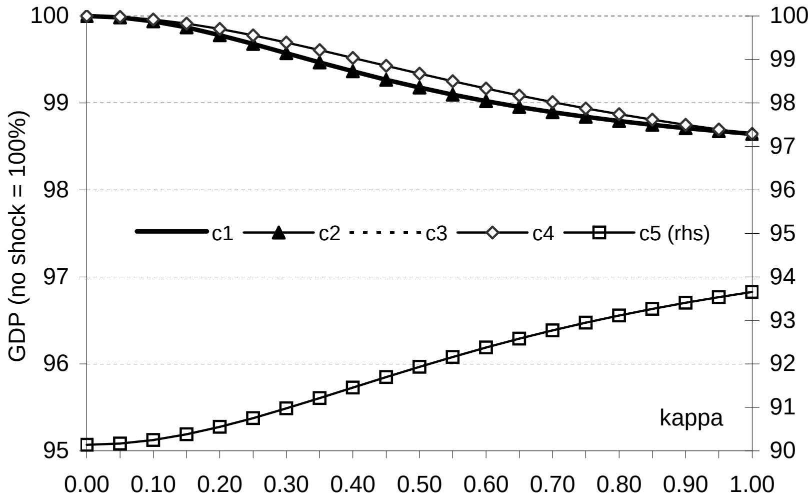
$$\frac{L_i w_i}{\beta} = \sum_{j=1}^{N} \left(\frac{L_j w_j}{\beta} - S_j \right) d_{ji} \tag{12}$$

where $B = \beta^{\beta} (1 - \beta)^{1-\beta}$ and $A = \left[\int_0^{\infty} e^{-z} z^{\theta(1-\eta)} dz \right]^{1/(1-\eta)}$.

It is of some importance to be clear about the meaning of the words 'imports' and 'exports', which will play a key role in our measurement exercise. The quantity flowing from country i to j could be evaluated as the quantity leaving country i, or as the country reaching country j. Similarly, this quantity could be valued at country i prices, or at country j prices. We adopt the convention that 'imports' are quantities arriving evaluated at receiving-country prices, while 'exports' are quantities departing evaluated at sending country prices. With this convention, if $q_{ij}(x)$ is the quantity of good x leaving country j for country i we have

$$I_{ij} = \int p_i(x) \kappa_{ij} q_{ij}(x)$$

Figure 5: Shock to big country



Note: Figure shows the % change in GDP that follows after country 5 is hit by a 10% shock to λ. Trade costs decrease uniformly for all countries; countries 4 and 5 are big compared with 1-3.

whereas the exports from country j to country i are

$$E_{ij} = \int p_j(x)q_{ij}(x)$$

Notice that for a good shipped from j to i we have $p_i(x)\kappa_{ij} = p_j(x)$ so our definitions imply that $I_{ij} = E_{ij}$. This latter point explains why equation (12) holds. While the left-hand-side describes production in country i, and the right-hand-side described uses of country i's output, it is not immediately clear why this is written in terms of other country's imports. The answer is that with our convention the value of other countries imports from i equals the value of country i exports to them.

For our purposes, it is important that we interpret q_i not as *a good* but as a shorthand for the value of the bundle of goods $q(x)$ (some produced domestically, some imported) that are used in domestic production or consumed. Further, p_i is a price index for this basket. Note that there are only $N - 1$ linearly independent equations in (12) so one of the endogenous variables in the system has to be normalized.

4.1 Identifying the observables

There are four objects in the model that have a fairly clear mapping into observable data. These are: real GDP (in PPP), gross output, imports, and exports. In turn, these can be combined to compute measures of $L_ip_iq_i$, S_i, d_{ij} and that of β. Starting with real GDP, L_iw_i is the value of payments received by the unproduced input, i.e. nominal GDP.

$L_i w_i / p_i$ are nominal payments deflated by the price index, or a measure of real GDP. We show in Appendix that the PWT series of constant-price GDP expressed in PPP maps well to our measure of $L_i w_i / p_i$.

$L_i p_i q_i$ is the value of all purchases by domestic agents. It is therefore equal to gross output of the economy plus imports minus exports:

$$L_i p_i q_i = GNO_i - S_i$$

S_i is exports minus imports, both evaluated at domestic dollar prices. Formally, this is

$$S_i = \sum_k E_{ki} - \sum_k M_{ik}$$

GNO_i is the value of total production, or gross output. In the model it is the quantity $GNO_i \equiv \int p_i(x) q_i(x) d\Phi(x)$. The countries for which we can construct this series account for 91 percent of world GDP and for 84 percent of world exports in 2000. For countries for which we are unable to find estimates of total gross output we estimate the series using data on gross output in industry, value added, population and year dummies. More details in the appendix.

d_{ij} is the share of goods produced in country j in total demand for goods in country i. This is defined as

$$d_{ij} = \frac{I_{ij}}{L_i p_i q_i} = \frac{I_{ij}}{GNO_i - S_i}$$

with d_{ii} implied from the restriction $\sum_j d_{ij} = 1$.

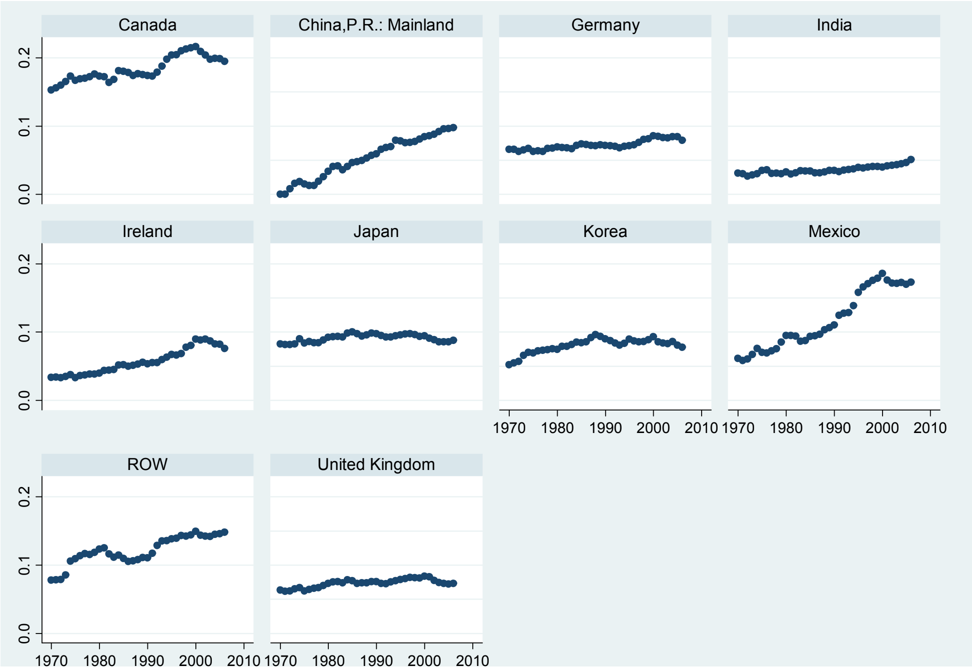
The share of unproduced input in the production of intermediates β_i follows from equation (2)

$$\beta_i = \frac{L_i w_i}{L_i p_i q_i + S_i} = \frac{GDP_i}{GNO_i}$$

In the exercises we report, we use a constant value $\beta = 0.5$ for all countries and years, which is the average found in data.

Finally, we use a value of $\theta = 0.5$. In the model, higher θ implies higher variance of productivity shocks and increases the potential to exploit comparative advantage of each country. There is no clear empirical counterpart to this in existing empirical work. Typically, that work is based on estimates of the elasticity of trade shares with respect to trading costs, where the latter are proxied as the maximum difference between prices in two countries (see EK). This is not really the case for our model, in which many goods are not traded in equilibrium and for which the difference in trading costs cannot be observed. But along the arguments of Simonovska and Waugh (2009), our point is that existing estimates of trade elasticities in current empirical work, underestimate the θ in our model.

Figure 6: Trade costs of USA and selected trade partners



4.2 Computing the unobservables

This section discusses our identification strategy regarding trade costs κ and shocks $Z_i = \lambda_i L_i^{\beta/\theta}$. We begin by assuming symmetric trade costs $\kappa_{ij} = \kappa_{ji}$ for all i, j. From equation (10), we have

$$\frac{d_{ji}}{d_{ii}} = \left(\frac{p_j \kappa_{ji}}{p_i}\right)^{1/\theta} \quad \text{and} \quad \frac{d_{ij}}{d_{jj}} = \left(\frac{p_i \kappa_{ij}}{p_j}\right)^{1/\theta}$$

Applying $\kappa_{ij} = \kappa_{ji}$, we obtain a formula that relates trade costs *entirely* to the trade shares defined above.

$$\kappa_{ji} = \left(\frac{d_{ij}}{d_{jj}} \frac{d_{ji}}{d_{ii}}\right)^{\theta/2}$$

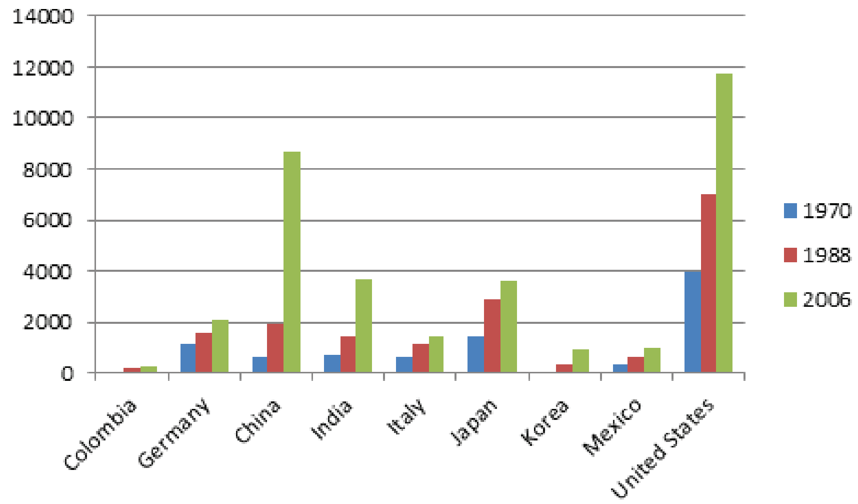
For illustration, Figure 6 plots the values of κ_{ijt} for $i = US$ and selected trade partners j.

Next, for $i = j$, equation (10) can again be used to write real aggregate GDP as:

$$\frac{w_i L_i}{p_i} = (AB)^{-\frac{1}{\beta}} \left(\frac{Z_i}{d_{ii}}\right)^{\theta/\beta} \tag{13}$$

Therefore, with a measure of $\frac{w_i L_i}{p_i}$, we can retrieve the exogenous process Z_i. Selected series of Z_{it} are reported in Figure 7. As we show in Appendix, the measure of constant-price GDP in international dollars of the PWT corresponds in our model to the quantity $\mu \frac{w_{i,t} L_{i,t}}{p_{i,t}}$ so using this in the above expression we are able to retrieve the composite measure of shocks up to a positive constant μ common across countries and periods. Once we have

Figure 7: Shocks Z for selected countries and years



the values for Z_i and κ_{ij}, we can solve the model and we can then ask what fraction of the decline in volatility can be attributed to openness to trade or the process for Z_i. We give a preliminary answer to the question in the following section, where we remain agnostic about the properties of trade costs κ. Results using a full parameterisation of the model are then presented in section 5.

4.3 Minimalist counterfactual

Having identified real GDP, $Y_i = L_i w_i / p_i$, and trade shares d_{ij}, we can use the equilibrium equation (13) in a logarithmic form to get a sense of the contribution of trade to the change in volatility. Let us denote by z_{it} the natural logarithm of shocks Z_{it} and y_{it} the log of total (not per capita) real GDP of country i in year t:

$$y_{it} = \text{const} + \frac{\theta}{\beta} \left(z_{it} - \ln d_{ii,t} \right)$$

We can then decompose GDP volatility as

$$\underbrace{\text{Var}\left(\tilde{y}_i\right)}_{(2)} = \left(\frac{\theta}{\beta}\right)^2 \left[\underbrace{\text{Var}(\tilde{z}_i)}_{(3)} + \underbrace{\text{Var}(\ln \tilde{d}_{ii})}_{(4)} \underbrace{-2\,\text{Cov}(\tilde{z}_i, \ln \tilde{d}_{ii})}_{(5)} \right] \tag{14}$$

where the tildes indicate growth rates and the numbers below the expressions link each term with the corresponding column in Table 1.

Trade policy can change the last two terms in the brackets, but not the first (at least not directly). We estimate each of the three terms before and after the mid 1980s, and

Table 1: Minimalist counterfactual: Change in volatility from 1970-1984

	% change in Std(y_i)	Absolute Difference				% share of (2) accounted for by (4+5)
		Var(yi)	Var(zi)	Var(dii)	Cov	
	(1)	(2)	(3)	(4)	(5)	(4+5)/(2)x100
Australia	-34	-3.74	-6.09	-0.49	2.84	-63
Austria	-61	-8.80	-6.14	-0.12	-2.55	30
Belgium	-47	-6.25	-1.58	4.59	-9.26	75
Canada	-25	-3.28	0.00	-0.11	-3.17	100
China	-20	-3.23	-2.39	0.42	-1.26	26
Colombia	-15	-1.37	-1.26	0.25	-0.36	8
Denmark	-29	-4.78	-5.76	0.05	0.93	-21
Finland	37	8.78	13.58	0.62	-5.42	-55
France	-34	-3.39	-2.36	-0.42	-0.60	30
Germany	-26	-2.41	-2.58	0.89	-0.72	-7
Greece	-55	-21.45	-23.08	0.62	1.01	-8
India	-6	-0.84	-2.17	0.25	1.08	-160
Ireland	-8	-2.38	1.21	-1.26	-2.33	151
Italy	-60	-10.10	-4.63	-0.54	-4.93	54
Japan	-8	-0.96	-2.74	-0.32	2.11	-185
Korea	14	7.07	7.38	-0.57	0.25	-4
Mexico	-22	-9.48	-1.81	1.02	-8.69	81
Netherlands	-29	-2.44	1.35	3.22	-7.01	155
Norway	-1	-0.09	0.46	-1.10	0.55	605
Portugal	-55	-31.05	-27.14	-0.63	-3.28	13
Spain	-35	-5.52	-4.64	-0.05	-0.82	16
Sweden	12	0.98	2.17	0.58	-1.77	-122
UK	-38	-4.66	-3.45	-0.76	-0.46	26
USA	-55	-8.82	-8.56	-0.08	-0.18	3

Note: The table presents a decomposition of the volatility of GDP growth into terms related to unobservable shocks and terms related to trade policy. It shows how the respective terms changed between two periods 1970-1984 and 1985-2006. The last column gives the share of the change in volatility that can broadly be accounted for by terms related to trade. See equation (14).

study how they contributed to the decline in volatility in different countries. This is a decomposition, so all volatility will be accounted for – the residual Var(z_i) will pick up all the slack. Table 1 summarizes the results. The last column of the table gives the relative importance of the joint contribution of the change in $Var(\ln \tilde{d}_{ii})$ and $Cov(\tilde{z}_i, \ln \tilde{d}_{ii})$ in the total change in $Var(\tilde{y}_i)$.

There are two lessons to take from this exercise. First, the change in volatility of variables associated with trade has in most cases contributed to greater stability of economic output. Secondly, the impact has varied widely among countries and has been especially strong in small open economies like Belgium, Ireland and the Netherlands. Large developed countries, with the exception of Japan, have benefited less because their reliance on trade is substantially smaller. We will seek to confirm these preliminary findings in the following section.

5 Counterfactual simulations

Suppose the level of openness from 1970-1984 had not changed in the post 1985 period. How would have volatility changed, given the lower degree of openness in the latter period? In this exercise, we use the series of shocks Z_{it} and trade costs κ_{ijt} as measured above and simulate two scenarios. In the baseline, we let the properties of shocks and the level of openness to evolve as in the data while in the counterfactual exercise the level of openness stays at the pre-1984 level (shocks are as in the baseline).

In order for our results not to be driven by a particular realization of shocks we compute this exercise with artificially generated series of shocks and do so many times (5000). Disturbances Z_{it} are modelled as an AR(1) process in log deviations around country-specific trends (HP trends). The latter are taken as given in all simulations. What differs across simulations are the stationary innovations around trends, which are bootstrapped from Z_{it} computed in the previous section. We thus preserve the stochastic properties of our detrended series of Z_{it} in each period (1970-1984 and 1985-2006)[5]. We have experimented with preserving the contemporaneous covariance structure in shocks across countries but this distinction has not proved quantitatively important.

Our trade costs κ are derived from bilateral trade data. Since our point is to show how a general increase in trade openness could have affected volatility of GDP growth, we abstract from the observed volatility in the series of κ and take a representative value for each pair ij and each period (1970 for the first and 2000 for the latter) and keep these values constant within periods. In the counterfactual exercise we keep the 1970 value constant both within and between periods. When the 1970 value of trade costs was missing for a particular pair of countries because of the lack of bilateral trade data, we

[5] The problem of initial values was addressed by simulating long series for each period and removing the redundant years at the beginning of the series.

Table 2: Change in volatility 70-84 v 85-06, counterfactual and baseline

	% change in volatility		absolute difference	relative to baseline (%)
	counterfact.	baseline		
	(1)	**(2)**	**|(1-2)|**	**|(1-2)/(2)|**
Australia	-35.4	-35.5	**0.1**	**0.2**
Austria	-45.9	-47.9	**1.9**	**4.1**
Belgium	-18.3	-22.5	**4.2**	**18.6**
Canada	5.5	3.6	**1.8**	**51.1**
China	2.1	-0.9	**3.0**	**330.8**
Colombia	1.9	0.8	**1.1**	**137.3**
Denmark	-38.8	-40.0	**1.3**	**3.2**
Finland	67.5	62.8	**4.7**	**7.5**
France	-31.6	-33.1	**1.5**	**4.6**
Germany	-52.2	-53.8	**1.6**	**3.0**
Greece	-65.0	-65.7	**0.7**	**1.1**
India	-8.3	-9.2	**0.8**	**9.0**
Ireland	-9.7	-17.5	**7.8**	**44.7**
Italy	-51.7	-52.6	**0.9**	**1.7**
Japan	-51.2	-51.6	**0.4**	**0.8**
Korea	-7.8	-12.6	**4.7**	**37.7**
Mexico	1.8	-1.8	**3.7**	**198.7**
Netherlands	-17.6	-21.4	**3.9**	**18.0**
Norway	12.4	11.0	**1.4**	**12.6**
Portugal	-63.3	-64.1	**0.8**	**1.3**
Spain	-20.1	-22.5	**2.3**	**10.4**
Sweden	19.1	17.3	**1.8**	**10.2**
UK	-34.1	-35.4	**1.3**	**3.6**
USA	-56.2	-57.1	**0.9**	**1.6**

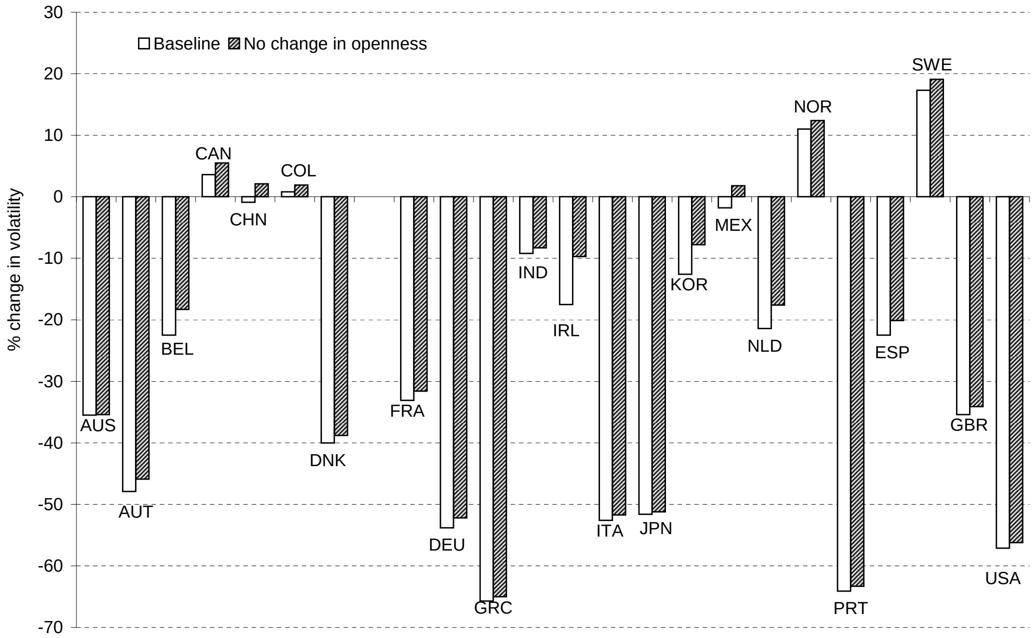
Note: The table shows changes in volatility of GDP growth rates between the two periods. In the baseline, trade costs κ are allowed to change between periods (they take fixed values in each period), while in the other scenario ('counterfactual') trade costs in 1985-2006 are kept at their 1970-1984 values.

used the earliest recorded value instead. Trade imbalances are treated as exogenous in the original EKAL model and we therefore ignore them in the simulations below.

With a newly generated series of Z_{it} and the representative values of κ_{ijt} we solve the model and compute the new series for GDP, detrend it by using the HP filter (separately for each period) and compute the relative change in volatility between the first and second period.

Table 2 summarizes our results. The first column in the table shows the change in volatility that would have prevailed under the counterfactual exercise (trade costs are kept at the 1970 level) and the second column reports the results of the baseline exercise, when the representative value of trade costs changes between periods. For illustration,

Figure 8: Change in volatility 70-84 v 85-06, counterfactual and baseline



Note: The figure shows the change in volatility of GDP growth rate between the two periods with (baseline) and without (counterfactual) changes in trade costs between periods. Country codes refer to countries listed in Table 2. Finland is not shown due to a different scale.

these values are also shown in Figure 8. A comparison of these two exercises shown in the last two columns of the table gives the contribution of trade costs (the only variable that differs between the two reported scenarios) to volatility. The main finding is that in *all* countries lower trade costs, i.e. increased trade, contributed to lower volatility than it would have been otherwise.

Even though the quantitative significance of the diversification channel seems to be small, averaging to about 3 percentage points in fall in volatility, there are large difference across countries. The countries that seem to have benefited most from greater openness were, in that order, Ireland, Belgium, Korea and the Netherlands – all small open economies. At the other end of the spectrum there were larger or less diversified countries Australia, Colombia, India and Japan.

Comparing the relative contribution of openness to volatility, there is strong correlation (0.70) between the contribution of trade to the change in volatility (column $|(1-2)|$) of Table 2 and the change in average trade costs for each country[6], confirming our intuition that countries where trade expanded most have experienced greatest decreases in volatility.

[6]Average trade costs of country i are computed as averages of κ_{ijt} over j in each period.

Returning to the minimalist counterfactual introduced in the previous section, we find negative correlation (-0.44) between the sum of the two channels we ascribed to trade policy (columns 4 and 5 in Table 1) and the change in volatility computed in this exercise, which we take as a sign of consistency between the volatility decomposition exercise and the numerical simulations presented here.

6 Conclusions

This paper revisits a question that keeps coming up in policy discussions of the pros and cons of trade liberalizations, particularly in low income economies: How does openness to trade affect GDP volatility? We develop a general equilibrium quantitative framework to formalise the diversification channel in which trade acts as a hedge against shocks to individual suppliers. The logic of the mechanism we study is as follows. When the production process relies on different inputs that can be sourced from different countries, a shock to a particular supplier (a domestic or foreign one) is easier to accommodate because the pool of potential suppliers is wider and the potential for diversification of cost shocks is greater. The channel is the stronger the lower are trade costs that agents face when trading goods across countries.

We derive formulas for the variance of GDP growth in autarky and free trade and show, first, that trade directly decreases volatility because domestic productivity fluctuations receive smaller weight with free trade than in autarky. Secondly, we show that trade exposes the country to other countries' productivity shocks and these contribute positively to volatility. The overall effect on volatility therefore depends on the relative sizes of the countries and the variance-covariance matrix of shocks across them.

Using data on international trade, GDP and gross output we use the model to quantify the contribution of trade to the changes in volatility since 1970 and find that in all countries lower trade costs generated lower volatility than it would have been otherwise. The quantitative significance of the diversification channel seems to be small on average but its role rises in small open economies, in line with the qualitative predictions of the model. One reason why the channel does not find larger support in data is that costs of across-the-border trade we are able to identify are huge compared with cost-less domestic trade. Stylised illustrations presented in section 3 indicate that greatest gains (in terms of lower volatility) from openness accrue only when trade openness reaches much larger a degree than is currently the case for most economies.

The framework we study in this paper investigates one of the two main mechanisms that can mediate the relationship between trade and volatility. The other mechanism emphasises the role of sectoral shocks and supports the view that as countries becomes specialised in sectors according to their comparative advantage, they become increasingly vulnerable to shocks in that particular sectors. In our future research, we plan to nest the two mechanisms in the framework used here and assess their quantitative importance.

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A Appendix

A.1 Derivation of equation (2)

Equation (2), stating that $L_i w_i = \beta(L_i p_i q_i + S_i)$ can more intuitively be expressed as follows (add $L_i p_i q_i$ and S_i to both sides and rearrange)

$$L_i p_i q_i = (1-\beta)\left(L_i p_i q_i + S_i\right) + L_i w_i - S_i$$

where on the left hand side is the total value of domestic spending on goods, which are partly expended on intermediates and partly in the form of final demand for goods. To add intuition to the first term on the right-hand side (at the cost of loose notation), notice that the total payments to domestic producers of individual goods originate either from domestic or foreign sources. In *per capita* terms we have

$$\int p(x)\, q(x)\, d\Phi(x) = \int_{\text{sold domestically}} p(x)\, q(x)\, d\Phi(x) + \int_{\text{exported}} p(x)\, q(x)\, d\Phi(x)$$

Next, the *per capita* spending on goods $p_i q_i$ accrues partly to domestic producers and partly to foreigners:

$$p_i q_i = \int_{\text{bought domestically}} p(x)\, q(x)\, d\Phi(x) + \int_{\text{imported}} p(x)\, q(x)\, d\Phi(x)$$

Now, obviously, the value of goods sold and bought domestically will be identical in the equilibrium so combining these two lines we arrive in

$$\int p(x)\, q(x)\, d\Phi(x) = p_i q_i + \int_{\text{exported}} p(x)\, q(x)\, d\Phi(x) - \int_{\text{imported}} p(x)\, q(x)\, d\Phi(x)$$

Finally, perfect competition and the Cobb-Douglas formulation implies that $1-\beta$ of this expression accrues to the produced input, i.e. to intermediates. In aggregate terms this becomes $(1-\beta)\left(L_i p_i q_i + S_i\right)$.

A.2 Derivation of equation (9): volatility with free trade

Start with the original condition that shows that GDP under costless trade less is volatile than under autarky.

$$\frac{\left(\beta + \theta\gamma_i\right)^2 + \theta^2 \sum_{j\neq i}^{N} \gamma_j^2}{\left(\beta+\theta\right)^2} < 1$$

The following steps, first, expand the numerator and adds terms; the second line completes the square and collect several terms. Finally, the last line moves $(\theta\gamma_i)^2$ to the expression in square brackets (note the change of the index under the summation sign) and cancels common terms. This inequality holds since $\gamma_i < 1$ for all i.

$$\begin{aligned}
\frac{\beta^2 + (\theta\gamma_i)^2 + 2\beta\theta\gamma_i + \theta^2 - \theta^2 + 2\beta\theta - 2\beta\theta + \theta^2 \sum_{j\neq i}^{N} \gamma_j^2}{(\beta+\theta)^2} &< 1 \\
\frac{(\beta+\theta)^2 + (\theta\gamma_i)^2 + 2\beta\theta(\gamma_i - 1) + \theta^2 \left[\sum_{j\neq i}^{N} \gamma_j^2 - 1\right]}{(\beta+\theta)^2} &< 1 \\
2\beta\theta(\gamma_i - 1) + \theta^2 \left[\sum_{j=i}^{N} \gamma_j^2 - 1\right] &< 0
\end{aligned}$$

A.3 Proof that $L_i w_i / p_i$ maps to constant-price GDP in PPP

It is instructive to start with variable P_i that in the Penn World Tables denotes the price level of GDP, or more precisely the USD value of local expenditures over expenditures evaluated in international prices. While the PWT variables are originally defined (and computed) in terms of expenditures and relative prices, it is possible to cast them in terms of prices and quantities as follows:

$$P_i = \frac{\sum_g p_{g,i}\, q_{g,i}}{\sum_g p_g\, q_{g,i}}$$

with $p_{g,i}$ and $q_{q,i}$ represent the USD price and quantity of good g respectively and p_g is the price of the same good in an international currency. Index g represents spending groups (basic headings in PWT slang), which are constructed in a way that the sum of these expenditure groups adds to total GDP. One of these groups are net exports, valuation of which follows the assumption that

$$p_{nx,i}\, q_{nx,i} = p_{nx}\, q_{nx,i} = S_i$$

where S_i is in USD.

In our model, consumers buy all individual goods $q(x)$ and bundle them using the CES aggregator in a final good q_f. Hence, a PWT statistician would be able to sample only from this one final good in each country and the quantity P_i measured becomes

$$P_{i,t} = \frac{p_{i,t}\, q_{f,i,t}\, L_{i,t} + S_{i,t}}{p_t\, q_{f,i,t}\, L_{i,t} + S_{i,t}}$$

Setting $P_{US,t} = 100$ as is the case in the PWT implies $p_t = p_{US,t}/100$ for all t. The denominator of $P_{i,t}$ is the current-price GDP in international prices

$$CGDP_{i,t} = p_{US,t}\, q_{f,i,t}\, L_{i,t} + S_{i,t}$$

and the real-price (Laspeyres) GDP in international prices is defined as

$$RGDP_{i,t} = p_{US,T}\, q_{f,i,t}\, L_{i,t} + S_{i,t}^T$$

where the last term captures real net exports in year t valued at prices from base year T. Using the income-expenditure identity $L_{i,t}\, w_{i,t} = p_{i,t}\, q_{f,i,t}\, L_{i,t} + S_{i,t}$ and simple algebra we get

$$\begin{aligned}
RGDP_{i,t} &= p_{US,T}\, \frac{(L_{i,t}\, w_{i,t} - S_{i,t})}{p_{i,t}} + S_{i,t}^T \\
&= p_{US,T}\, \frac{L_{i,t}\, w_{i,t}}{p_{i,t}} - \frac{p_{US,T}}{p_{i,t}} S_{i,t} + S_{i,t}^T \\
&= p_{US,T}\, \frac{L_{i,t}\, w_{i,t}}{p_{i,t}} - \frac{p_{US,T}}{p_{i,T}} \frac{p_{i,T}}{p_{i,t}} S_{i,t} + S_{i,t}^T \\
&= p_{US,T}\, \frac{L_{i,t}\, w_{i,t}}{p_{i,t}} + S_{i,t}^T \left(1 - \frac{p_{US,T}}{p_{i,T}}\right) \\
&\approx \mu \frac{L_{i,t}\, w_{i,t}}{p_{i,t}}
\end{aligned}$$

The last equality follows the PWT convention of valuing net exports by the price index of domestic absorption for years other than the base year. By dropping the last term in the approximation we assume that changes in *real* net exports are small for most countries relative to domestic absorption. Given the weight attached to $S_{i,t}^T$ this assumption will be of importance only for countries with price level far off the US one in the base year.

This equation allows us to identify real GDP computed from our model with variable $RGDP_{i,t}$ as measured by the PWT, up to a constant common to all countries and all years.

A.4 Data description

Our sample consists from 24 countries, which we call the core countries, for which we were able to collect a sufficient amount of data with none or very little estimation. Other countries, for which less data are available and more estimation was needed, form the rest of the world (ROW). The choice of the core countries was dictated mainly by the availability of data for total gross output; they include: the U.S., Mexico and Canada, Australia, Asia is represented by China, Japan, Korea and India, South America by Colombia, and the rest are advanced European countries: the U.K., a composite of France and its oversee departments, Germany, Italy, Spain, Portugal, a composite of Belgium and Luxembourg, the Netherlands, Finland, Sweden, Norway, Denmark, Greece, Austria and Ireland. While some important countries appear only in our ROW variable (most notably Brazil, Russia, Turkey, Indonesia, Malaysia and oil exporters), the selection of core countries is sufficiently representative in terms of geographic location and the share in the world trade and GDP. The time period we study covers years from 1970 to 2006. We focus on annual data.

The strategy regarding the rest of the world was to use the GDP and population data for those for which we were able to find a full series, look for their individual total output, estimate it when missing and subsequently aggregate. Due to trade data availability, the following groups of countries were merged into a single entity each: former Soviet Union, countries forming the South African Common Customs Area and former Czechoslovakia.

To identify variables in the model three main groups of data were needed. First, we use the PWT variable RGDP to identify real GDP. The series is in international dollars and is available for most countries in the world. Next, we use gross output data, obtained from the EU KLEMS database, the UN database and other sources. Finally, the basis for our trade data is the IMF DOTS database. The rest of the section describes our data sources and estimation methods.

Real GDP: Source is PWT 6.3, variable RGDPL, GDP per capita, international prices, constant prices of 2005, Laspeyres index. Aggregate GDP is a product of RGDPL and variable POP defined below. Real GDP for former USSR and Czechoslovakia required special attention:

- Former Czechoslovakia: for 1990-06 the source is PWT 6.3, sum of the GDP series for the Slovak and Czech Republics; for 1970-89 data are from PWT 5.6 (the growth rate of the data from PWT 5.6 was applied starting with the overlapping year 1990).
- Former USSR: for 1994-2006 the source is PWT 6.3, sum of the GDP series for individual post-soviet republics; for 1989/90-93 when data in PWT 6.3 are missing,

the growth rate of individual countries from the World Bank, WDI (April 2010), GDP in constant 2005 international dollar was used; in 1989 for 5 republics neither the WB data were available so the growth rate of Russia was applied; for 1970-1988 the growth rate from PWT 5.6 was used starting in the overlapping year 1989.

Gross Output: With the exception of India and China, the sources of data for total gross output in core countries are the same that were use to construct output in industry and are defined below. Total output of India (1970-1998) and China (whole series) is not available. We use the available data for output in industry and estimate the missing part, output in services, by regressing output in services for the remaining core countries on their GDP, output in industry, population, CGDP from the PWT, value added in services and a set of year dummies. Output in services and value added in services was obtained as a difference between the respective values for the aggregate economy and industry. The estimation technique was a Poisson regression adapted from Silva and Tenreyro (2006). For India, the missing years were generated using the growth rate of the estimated series.

Gross output data for the rest of the world come from UN Data. Missing values were generated using the growth rate of estimated output (a Poisson regression of total output on GDP and population). Individual country data (after conversion to USD) were then aggregated to the ROW. The series we obtain has a well behaved output/GDP ratio for all years.

Trade Data: We use bilateral imports and exports from 1970 to 2006 from the IMF's Direction of Trade Statistics kindly provided by Julian Di Giovanni. The DOTS reports bilateral gross trade flows. An import data point is I_{ij}, or the dollar value of imports by country i from country j, at country i prices.

There are minor discrepancies between the data and the conventions adopted in the paper, which we do not address. One problem is that imports are evaluated gross of transport costs but not gross of tariffs. Hence we underestimate the quantity $\int p_i(x)q_{ij}(x)d\Phi(x)$ for every $j \neq i$. Another possible problem is that the import data contains re-imports and the export data re-exports.

Auxiliary Data:

- CGDP: GDP per capita, international prices, current prices, PWT 6.3. Converted to aggregate GDP by multiplying by total population.

- GDP in local currency: World Bank, World Development Indicators (April 2010), variable GDP in current LCU. Data for the former Soviet Union and Czechoslovakia come from the UN National Account Main Aggregates Database. Data are available for the currently dissolved entities until 1990 and for their successors states from 1990 onwards. Year 1990 is available for both series. The post-1990 values were computed as a sum of GDP in USD of the successor states and the pre-1990 totals were scaled to match the composite 1990 value.

- Population: PWT 6.3, variable POP.

- Exchange rate: World Bank, World Development Indicators (April 2010), variable Official Exchange Rate defined as LCU per US$, period average. This series was used to convert total output and GDP in local currency units to USD. When currency reported by the WB was not consistent with the series used in the sample, the PWT exchange rate was used.

- Value added in industry and total value added is primarily derived from the EU KLEMS database (November 2009 and March 2008 edition). Industry covers the same sectors as defined in output in industry. When unavailable, other sources were used and linked to the main series by means of growth rates: UN Data (India, Mexico, Norway and Colombia), OECD STAN (Japan), Canadian Statistical Office's, Statistical Yearbooks of China.

- Output in industry is defined as the sum of output in agriculture, hunting, forestry and fishing, mining and quarrying, and manufacturing and is measured in units of local currency. For most countries, the source is the EU KLEMS database (November 2009 and March 2008 editions), variable gross output at current basic prices. When missing, the following sources were used: UN Data (Norway and Colombia), OECD STAN (Japan), Canadian Statistical Office's (Canada), Statistical Yearbooks of China, Statistical Office of India, INEGI (Mexico). Two remarks are due with respect to China and India.

  - Regarding Chinese data, the primary concern was the methodological change initiated around 1998, when China stopped reporting *total* industrial output and limited the coverage to industrial output of firms with annual sales above

5m yuan (USD 625 000). The sectoral coverage remained the same in both series. There were 5 years of overlapping data of both series over which the share of the 5m+ firms on total output decreased from 66 to 57 percent. The chosen approach to align both series was to take the levels of output from the pre-1999 series (output of all firms) and apply the growth rate of output of 5m+ firms in the post-1999 period. This procedure probably exaggerates the level of output in the last seven years and leads to an enormous increase in the output/GDP in industry ratio (from 3.5 in 1999 to 6.0 in 2006). Our conjecture is that the ratio would be less steep if the denominator was value added in industry (unavailable on a comparable basis) because the GDP figure includes net taxes, which might take large negative values. Output in industry of all firms reflects the 1995 adjustment with the latest economic census.

– The Statistical Office of India reports years 1999-2006 on the SNA93 basis. Earlier years were obtained using growth rates of sectoral output as defined in their 'Back Series' database. The main issue with India was the large share of 'unregistered' manufacturing that is reported in the SNA93 series but missing in the pre-1999 data. The 'unregistered' manufacturing covers firms employing less than 10 workers and is also referred to as the informal or unorganized sector. We reconstructed the total manufacturing output using the assumption that the share of registered manufacturing output in total manufacturing output mirrors the share of value added of the registered manufacturing sector in total value added in manufacturing (available from the 'Back Series' database).