Diversification through Trade

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Abstract

Existing wisdom links increased openness to trade to greater macroeconomic volatility, as trade induces a country to specialize, increasing its exposure to sector-specific shocks. Evidence suggests, however, that country-wide shocks are at least as important as sectoral shocks in shaping volatility patterns. We argue that if country-wide shocks are dominant, the impact of trade on volatility can be negative, because trade becomes a source of diversification. For example, trade allows domestic goods producers to respond to shocks to the domestic supply chain by shifting sourcing abroad. Similarly, when a country has multiple trading partners, a domestic recession or a recession in any one of the trading partners translates into a smaller demand shock for its producers than when trade is more limited. Using a calibrated version of the Eaton-Kortum and Alvarez-Lucas model, we quantitatively assess the impact of lower trade barriers on volatility since the 1970s in a broad group of countries.

I Introduction

An important question of interest to both economists and policymakers is whether openness to trade affects macroeconomic volatility. A widely held view is that international trade leads to higher GDP volatility. This view originates in a large class of theories predicting that openness to trade increases specialization. Because specialization in production increases a country's exposure to shocks specific to the sectors in which the economy concentrates, it is generally inferred that trade increases volatility. In this very influential view, trade entails potentially significant costs in terms of macroeconomic instability, even if it (typically) increases average living standards (the classic theoretical case that "trade leads to volatility" is made by Newbery and Stiglitz, 1984).

This paper revisits the theoretical case for a positive effect of trade on volatility. 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 both developed and developing countries. In other words, macroeconomic volatility is driven more by economy-wide shocks, such as those due to fluctuations in macroeconomic policy, political risk, and other aggregate developments, than by disturbances affecting the particular sectors in which countries tend to specialize.

We argue that the impact of trade on volatility can be remarkably different if country-specific shocks are indeed the dominant source of volatility. The basic idea is simple: when final-good producers in a country can source inputs only from domestic input suppliers, a domestic macroeconomic shock that reduces the supply of inputs will be greatly amplified through its effects on the final good producers. Instead, when final producers can source from suppliers from a variety of countries, shocks to domestic suppliers (or shocks to suppliers based in any individual trading partner) can be more easily absorbed by switching to alternative providers. A similar mechanism operates on the demand side: when a country has multiple trading partners a domestic recession or a recession in any one of the trading partners into a smaller demand shock for its producers than when trade is more limited. The idea is to explore whether and the extent to which openness to trade in goods can operate as a source of macroeconomic diversification. There is an analogy with the role of openness to trade in financial assets, which has long been recognized as a possible source of diversification [Obstfeld and Rogoff (1998)]— the analogous potential role of trade in goods has not been recognized before. The key difference between trade in financial assets and trade in goods is that trade in assets stabilizes consumption, not income or output (in fact, trade in assets can exacerbate income volatility), while trade in goods can stabilize both output and consumption.[1]

To develop the idea, 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 (2006)'s model, hereafter EKAL, augmented to allow for aggregate shocks. Production combines labour and a variety of tradeable inputs that are subject to cost shocks. Some special cases illustrate the idea. If country-specific shocks are independently and identically distributed across countries, a 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 particularly relevant for developing (and hence small in an economic sense) countries, which instead, under the traditional view, are deemed to be the ones that suffer the biggest increases in volatility. However, as the analysis makes clear, 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). In particular, if the variances of and covariances with trading partners' shocks are high enough, a move from autarky to costless free trade causes an increase, rather than a decline, in domestic volatility. Hence, trade can be destabilizing if trading partners are very unstable or if they are buffeted by shocks that are highly correlated with domestic shocks. This might explain why direct evidence on the effect of openness on volatility has been ambiguous at best. Specifically, some studies, including Buch, Dropke, and Strotmann (2006), Donaldson (2009), Bejan (2004) and Cavallo (2005) find that trade reduces volatility, while others, including Rodrik (1998), Easterly, Islam and Stiglitz (2001), Kose, Prasad, and Terrones (2003) and di Giovanni and Levchenko (2009), find that trade increases volatility.

A natural implication of the basic idea is that trade has predictions not only for the volatility of a country's GDP, but also for its tendency to commove with other countries. In the extreme case in which countries move from autarky to costless trade, trade always increases the correlation of a country's GDP with the rest of the world. This is yet again in contrast with the implications of the standard views of the role of trade based on sectoral specialization and is consistent with the findings in Frankel and Rose (1998).

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—conceived of as a shock to the biggest country in the world.

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 assess quantitatively how much of the changes in volatility since the 1970s can be attributed to a decline in overall barriers to trade.

The remainder of the paper is organized as follows. Section II presents the model and solves analytically for two special cases, autarky and costless free trade. Section III presents numerical illustrations. Section IV introduces the data, calibration and quantitative results.

II A Model of Trade with Aggregate Shocks

The model is a basic version of EKAL, with country-specific aggregate shocks (stochastic λs). In each country $n = 1, 2, ...N$, there is a continuum of goods indexed by their (inverse) technology $x \in (0, \infty)$ which are produced using equipped labor L_n and a composite bundles of all other produced inputs. Aside from being used as intermediates in the production of other goods, produced goods can also be directly consumed. As in EK, the utility derived from consumption takes the same functional form in which the intermediate goods enter the production function.[2] Countries differ in the efficiency with which goods are produced and in the size of L_n. All produced goods are in principle tradeable in international markets (though the cost could be very big—so big that they may not end up being traded in equilibrium and only produced domestically). In the calibration exercise we also allow for trade imbalances.

For the sake of exposition, we first discuss the model in autarky and then allow for international trade. We supress the subindex n in the description of the closed economy. All production is subject to constant returns and we conduct the analysis of the closed economy in units of the economy's endowment L. In a given country, the only parameter that varies across goods is the inverse efficiencies x, which are modeled as random variables, independent across goods, with common density ϕ. Buyers (who could be final consumers or firms buying intermediate inputs) purchase individual goods to maximize the CES objective:

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

where $\eta > 0$ is the elasticity of substitution across goods. The technology for producing $q(x)$ is Cobb-Douglas in the effective labour input and the bundle of intermediate goods defined above:

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

where $q_m(x)$ is the amount of the composite good used in the production of good x, and $s(x)$ is the fraction of total input L allocated to the production of good x. 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:

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

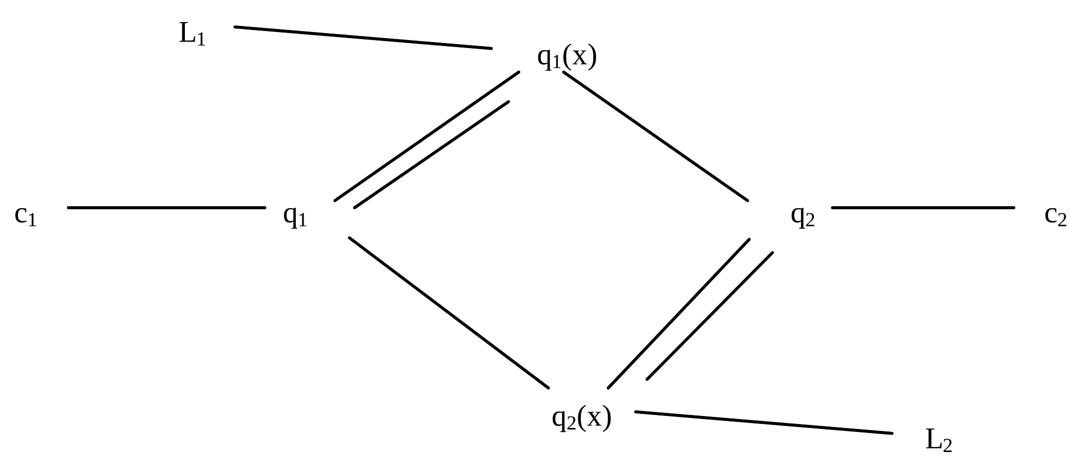
where w is the unit cost of L, $B = \beta^{-\beta}(1-\beta)^{-1+\beta}$. We assume that the density ϕ follows an exponential distribution with parameter λ, $x \sim exp(\lambda)$ and hence the price of q is given by:

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

This is a slightly modified version of the EKAL model; it assumes a common distribution of productivity shocks for all goods in the economy (not just manufacturing, as in EKAL's interpretation).

International Trade As in EKAL, we assume that intermediate inputs x can be traded internationally; $\phi(x) = \phi(x_1, ..., x_N)$ is now the joint density of goods that have productivity draws $x = (x_1, ..., x_N)$ across countries, where the draws are assumed to be independent across countries: $\phi(x) = \left(\prod \lambda_n\right) \exp\left[-\sum \lambda_n x_n\right]$. The structure of production can be then summarized as follows (1 in this case indexes one country and 2 the rest of the world):

Figure 2: Structure of Production



Delivering a tradable good from country j to country i results in $0 < \kappa_{ij} \leq 1$ goods arriving at j $(= 1$ if $i = j)$; with $\kappa_{ij} \geq \kappa_{ik}\kappa_{kj} \nabla i, k, j$ 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. 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 pdf 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, we obtain:

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

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 $\sum_j d_{ij} = 1$,

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

which under the Cobb-Douglas assumption simplifies to

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

In the original EKAL model, the productivity parameters $\lambda_j's$ are deterministic, so GDP per capita is a deterministic constant for each country j. As said, we assume that $\lambda_j's$ 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.

Volatility in Two Special Cases We study the volatility of real GDP, $Y_i = \frac{L_i w_i}{p_i}$, measured as the variance of deviations from mean.

Autarky Autarkic prices and real GDP are given by:

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

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

Defining $Z_i = \lambda_i^{\theta/\beta_i} L_i$ as the weighted non produced input of the economy (weighted by its productivity) and denoting by $\hat{x} \equiv \frac{\Delta \ln x}{\Delta t}$ the changes around the mean of Z_i, we obtain:

$$\hat{Y}_i = \hat{Z}_i$$

And hence volatility is given by:

$$Var(\hat{Y}_i) = Var(\hat{Z}_i)$$

and the covariance of output across two autarkic economies is:

$$Cov(\hat{Y}_i, \hat{Y}_j) = Cov\left(\hat{Z}_i, \hat{Z}_j\right)$$

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

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

Hence[3] $d_{ji}(w) = w_i^{-\beta/\theta}\lambda_i\left(\sum_{j=1}^{N} w_j^{-\beta/\theta}\lambda_j\right)^{-1}$ and from $L_i w_i = \sum_{j=1}^{N} L_j w_j \cdot d_{ji}(w)$, we have[4],

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

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[5]:

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

where $Z_i = \lambda_i^{\theta/\beta_i} L_i$ as before. Therefore, volatility under free trade is given by:

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

where $\gamma_j = \frac{\bar{Z}_j^{\frac{\beta}{\theta+\beta}}}{\sum_{j=1}^{N} \bar{Z}_j^{\frac{\beta}{\theta+\beta}}}$ is the relative weight of country j's change in weighted productivity on country i's real GDP evaluated at the mean of $Z_j s$. Compared to the variance in autarky, $Var(\hat{Y}_i) = Var(\hat{Z}_i)$, 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, when compared 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 (**??**) becomes:

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

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[6]:

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

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.

In similar fashion, it is easy to derive the formula for the covariance between country i and j's GDP. For the sake of brevity, denote $\Theta = \frac{\theta}{\beta+\theta}$ and $\Gamma_i = \frac{\beta+\theta\gamma_i}{\beta+\theta}$ so that the formula for $\hat{Y}_i$ reads as

$$\hat{Y}_i = \Gamma_i \hat{Z}_i + \Theta \sum_{j \neq i} \gamma_j \hat{Z}_j$$

Then, the covariance between i and j, $i \neq j$, is given by

$$Cov(\hat{Y}_i, \hat{Y}_j) = \left\{ \begin{array}{c} \Gamma_i \Gamma_j Cov\left(\hat{Z}_i, \hat{Z}_j\right) + \Theta \Gamma_i Cov\left(\hat{Z}_i, \sum_{k \neq j} \gamma_k \hat{Z}_k\right) \\ +\Theta \Gamma_j Cov\left(\hat{Z}_j, \sum_{k \neq i} \gamma_k \hat{Z}_k\right) + \Theta^2 Cov\left(\sum_{k \neq i} \gamma_k \hat{Z}_k, \sum_{k \neq j} \gamma_k \hat{Z}_k\right) \end{array} \right\}$$

The first term captures the influence of covariances between shocks in i and j that would prevail also under autarky, with a lower weight under costless trade $\Gamma_i \Gamma_j < 1$. Under costless trade, however, the diversification brought about by trade makes the bilateral covariance also a function of covariances of country i's shocks with all other countries apart from j, covariances of j's shocks with other countries' apart from i, and finally, the bilateral covariances among the third countries. In the case of uncorrelated shocks and identical variances of shocks across countries, we obtain

$$Cov(\hat{Y}_i, \hat{Y}_j) = \sigma \Theta \left\{ \Gamma_i \gamma_i + \Gamma_j \gamma_j + \Theta \sum_{k \neq i,j} \gamma_k^2 \right\} = \sigma \frac{\theta}{\beta} \frac{1}{(\beta+\theta)^2} \left\{ \gamma_i + \gamma_j + \frac{\theta}{\beta} \sum_{k=1}^{N} \gamma_k^2 \right\}.$$

Under these assumptions, trade in our model has the power to create comovement across countries (covariance would be zero under autarky). The relationship is stronger the bigger is the scope for relative comparative advantage (θ), the bigger is the share of traded intermediates in the production function (the smaller is β) and the bigger is the i and j relative to the rest of the world.

III Some Numerical Illustrations

We simulate the model for many periods (or realizations of $\lambda_j s$) and obtain simulated time series of GDP_{tj} for different degrees of openness, gauged by the 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 and covariances between each country's GDP and the rest of the world. The qualitative exercise consists of drawing $\lambda = (\lambda_1 ... \lambda_n)$ each period from a log-normal distribution with fixed mean and std deviation; we choose θ, α, β as in AL. Graphically,

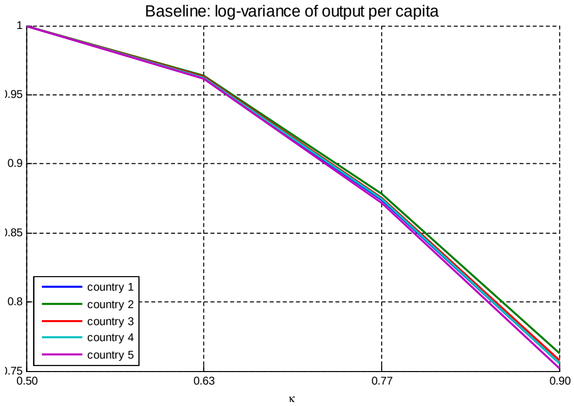
Time series, volatility and covariance:

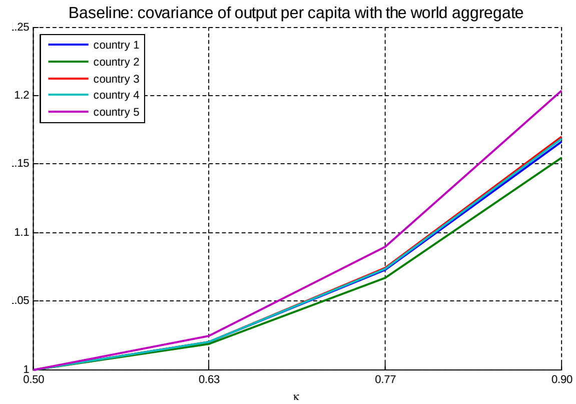
country/period	1	2	3	...	T	*vol*	*cov*	
country 1	y_{1_1}	y_{1_2}	y_{1_3}	$\cdots$	y_{1_T}	σ_{y_1}	$\sigma_{y_1,W}$	
country 2	y_{2_1}	y_{2_2}	y_{2_3}	$\cdots$	y_{2_T}	σ_{y_2}	$\sigma_{y_2,W}$	for given κ
...	...	...	...	...	...	...	...	
country n	y_{n_1}	y_{n_2}	y_{n_3}	$\cdots$	y_{n_T}	σ_{y_n}	$\sigma_{y_n,W}$	

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

1. **Widespread decrease in international trade barriers**

We set $L_n = 1$ and $\kappa_{ijt} = \kappa_t$ increases over time for $i \neq j$, with $\kappa_{iit} = 1$ (κ_{ij} increases uniformly over time from 0.5 to 0.9)

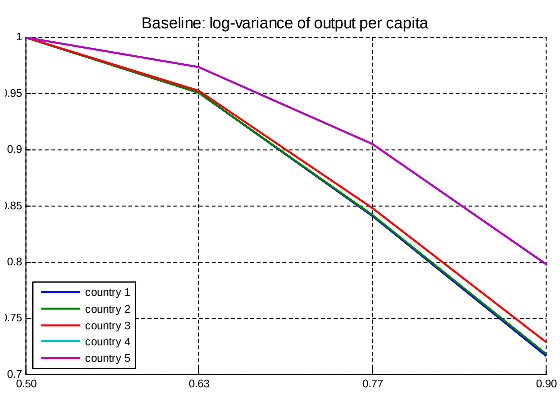


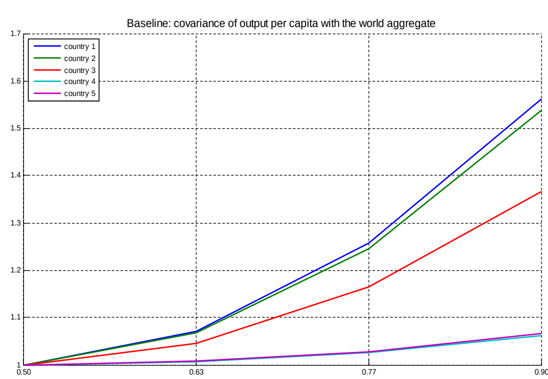


Volatility change Covariance change

The plot on the left shows that, as κ_t increases, that is, as trading costs increase, volatility decreases; countries are able to diversify uncorrelated country-specific shocks. The right hand side plot shows that the higher is κ_t,the more correlated the GDP of countries are.

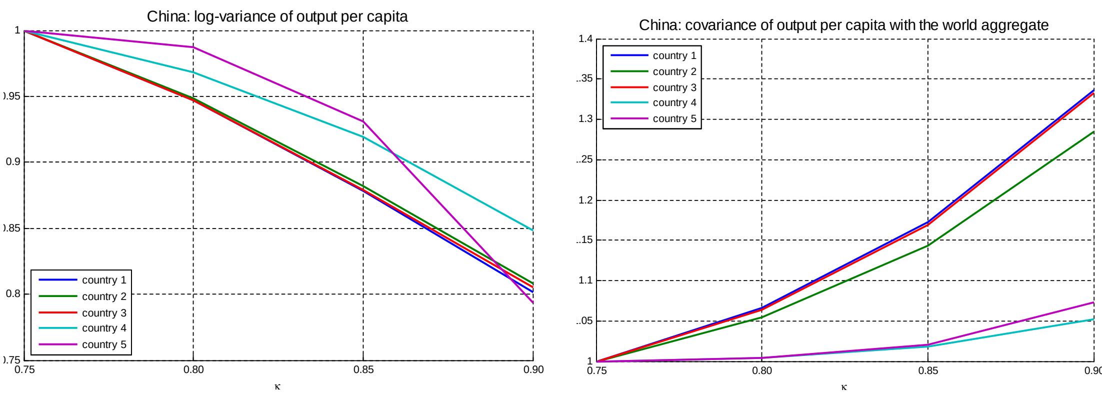
If the size of countries is modified to allow for some big countries, $L_n = (1, 1, 1, 3, 3)$, all else as before, the plots clearly show that the decline in volatility is smaller for big countries; similarly, the increase in covariance is smaller for big countries.





1. **A Big Country joins the World**

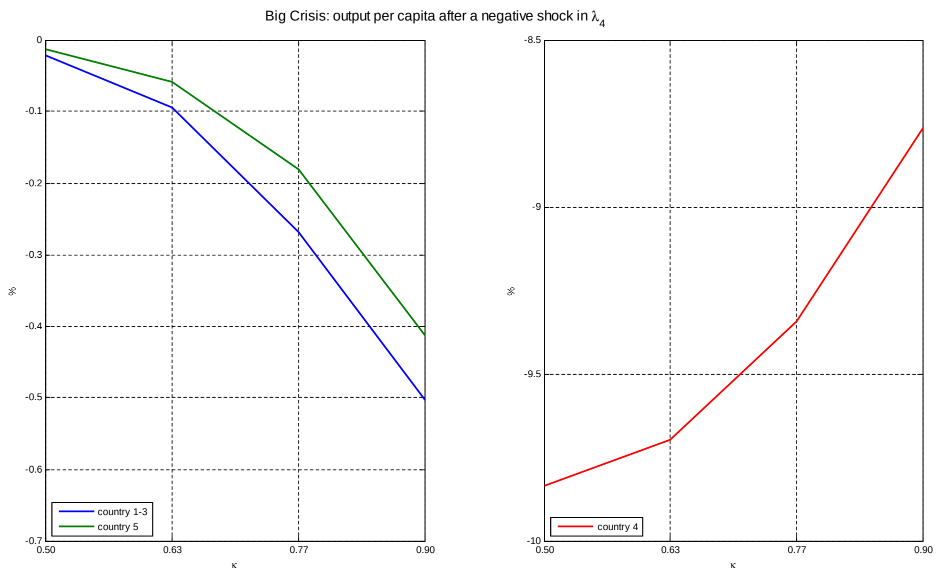
We keep all parameters as before, with $L_n = (1, 1, 1, 3, 3)$ but assume that four countries start up more open (κ_{ij} increases uniformly from 0.75 to 0.9) and one of the big countries starts with higher costs and $\kappa_{i5t} = \kappa_{5jt} < \kappa_{ijt}$, $j \neq 1$ at $t = 1$ (κ_{ij} increases uniformly from 0.4 to 0.9).



The country that joins experiences a more significant decline in volatility, when compared to the other big country, as trading costs fall more rapidly. The smaller countries see a substantial decline in volatility, comparable to the one seen in the previous graph (even though they start up more open on average).

2. **Shock to Big country**

We keep the parameters as before, $L_n = (1, 1, 1, 3, 3)$, with κ_{ij} increases uniformly over time from 0.5 to 0.9 and explore what happens to GDP if one of the big countries experiences a fall in λ. The fall in output for the countries that did not suffer the shock is depicted in the left panel. The more open to trade countries are, the more they suffer the impact the shock to the big country. (If countries were completely close, of course they would 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; the fall in output for this country is depicted in the right-hand side panel.



IV 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 $Z_i = \lambda_i L_i^{\beta_i/\theta}$ rather than shocks λ_i and the size of the economy L_i separately. Allowing for these modifications, we get the following modified equilibrium conditions:

$$d_{ij} = A^{-1/\theta} \left(\frac{B_j \left(L_j w_j\right)^{\beta_j} {p_j}^{1-\beta_j}}{p_i \kappa_{ij}} \right)^{-1/\theta} Z_j \tag{2}$$

$$L_i p_i q_i + S_i = \sum_{j=1}^{N} L_j p_j q_j d_{ji} \tag{3}$$

$$L_i w_i = \beta_j (L_i p_i q_i + S_i) \tag{4}$$

where $B_j = \beta_j^{\beta_j}\left(1-\beta_j\right)^{1-\beta_j}$, and $A = \left[\int_0^\infty e^{-z} z^{\theta(1-\eta)} dz\right]^{1/(1-\eta)}$. A derivation of equation (4) is in the appendix.

It is important for the calibration 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

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

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 (3) 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 (3) so one of the endogenous variables in the system has to be normalized (see the appendix)

A 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 $L_i p_i q_i$, S_i, d_{ij} and that of β_i. Starting with real GDP, Lw_i is the value of payments received by the unproduced input, i.e. nominal GDP. Lw_i/p_i are nominal payments deflated by the price index, or a measure of real GDP. We show in the appendix that the PWT series of constant-price GDP expressed in PPP maps well to our measure of Lw_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 (4)

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

As a first pass in the exercises we report, we use $\beta = 0.5$, which is the average over all countries and periods.

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 advantages. 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 approach would fail in 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. We think $\theta = 0.5$ is a reasonable benchmark to start.

B Minimalist Counterfactual

The main equilibrium conditions of the model can be used to write real aggregate GDP as:

$$\frac{w_i L_i}{p_i} = \text{const} \cdot L_i \left(\frac{\lambda_i}{d_{ii}}\right)^{\theta/\beta_i}.$$

Suppose that β_i can be observed and is fixed over time for each country. Then the unobserved shocks are L_i and λ_i. Let us denote by z_{it} the natural logarithm of the combination of these shocks,

$$z_{it} = \ln L_{it} + \frac{\theta}{\beta_i} \ln \lambda_{it}.$$

Clearly, even though z_{it} is unobservable, it can be recovered from a simple decomposition,

$$y_{it} = \text{const} + z_{it} - \frac{\theta}{\beta_i} \ln d_{ii,t},$$

where y_{it} is the log of total (not per capita) real GDP of country i in year t.

We can then decompose GDP volatility as

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

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 second and the third terms, but not the first (at least not directly). We estimate each of the three terms before and after the mid 1980s, and study how they contributed to the decline in volatility in different countries. As a first approximation, we assume constant β across all countries (and equal to 0.5). This is a decomposition, so all volatility will be accounted for – the residual Var(z_i) will pick up all the slack. Table ? summarizes the results of the decomposition of the variance of 1-year growth rates. The last column of Table 1 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 learn 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.

C Computing the Unobservables

This section discusses our identification strategy regarding trade costs κ_{ji} and shocks to Z_i. We begin by assuming symmetric trade costs $\kappa_{ij} = \kappa_{ji}$ for all i, j. Then, from equation (2),

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

Using $\kappa_{ij} = \kappa_{ji}$ implies

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

In other words the trade costs are *entirely* pinned down by the trade flows.

Next, always from equation (2)

$$\lambda_i = d_{ii} \left(AB_i\right)^{1/\theta} \left(\frac{w_i}{p_i}\right)^{\beta_i/\theta}$$

Multiplying both sides by $L_i^{\beta_i/\theta}$ we get

$$\lambda_i L_i^{\beta_i/\theta} = d_{ii} \left(AB_i\right)^{1/\theta} \left(\frac{w_i L_i}{p_i}\right)^{\beta_i/\theta},$$

so with a measure of $\frac{w_i L_i}{p_i}$ we can retrieve the exogenous process $Z_i^{\beta_i/\theta} = \lambda_i L_i^{\beta_i/\theta}$. As we show in the 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 expression for $\lambda_i L_i^{\beta_i/\theta}$ we are able to retrieve the composite measure of shocks up to a positive constant μ common across countries and periods. Once we have the values for $\lambda_i L_i^{\beta_i/\theta}$ and κ_{ji}, we can solve the model. By construction, the model will yield the real GDP that we fed in from the data. We can then ask what fraction of the decline in volatility can be attributed to openness to trade or the process for $\lambda_i L_i^{\beta_i/\theta}$.

V Counterfactuals

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 properties of shocks are the same as in data but the level of openness stays at the pre-1984 level. In order for our results not to be driven by a particular realization and interplay of shocks we compute this exercise with artificially generated series of shocks and do so many times (5000). For the ease of interpreting our results, we eliminate trade imbalances in this exercise since they are treated as exogenous in the EKAL model.

The process of shocks is modelled as an AR(1) process in log deviations around country-specific trends (HP trends). The latter are taken as given in all simulations. We then generate counterfactual series of Z_i by bootstrapping stationary innovations from the AR(1) process that have the stochastic properties of our detrended series of Z_{it} in that sub-period (1970-1984 and 1985-2006), respectively, and apply these to the actual trend.[7] We have experimented with preserving the contemporaneous covariance structure in shocks across countries but this distinction has not proved quantitatively important.

As for the trade costs, we take a representative value for each pair ij and each sub-period (1970 for the first and 2000 for the latter) and keep these values constant within sub-periods. In the counterfactual exercise we keep the 1970 value constant both within and between sub-periods. When the 1970 value of trade costs was missing for a particular pair because of the lack of bilateral trade data, we used the earliest recorded value instead.

With this newly generated series of Z_{it} and using the series for κ_{ijt} we solve the model and compute the new series for GDP, detrend it by using the HP filter (separately for each sub-period) and compute the relative change in volatility between the first and second sub-period. The statistics we report below captures the relative change in average volatility across simulations and is defined as

$$\left[\frac{E\left(Var\left(\tilde{y}_{i2}\right)\right)}{E\left(Var\left(\tilde{y}_{i1}\right)\right)}\right]^{\frac{1}{2}}-1$$

where $\tilde{y}_{i1}$ and $\tilde{y}_{i2}$ represent the series of detrended GDP in the first and second sub-period.

Baseline and counterfactual percentage change in volatility

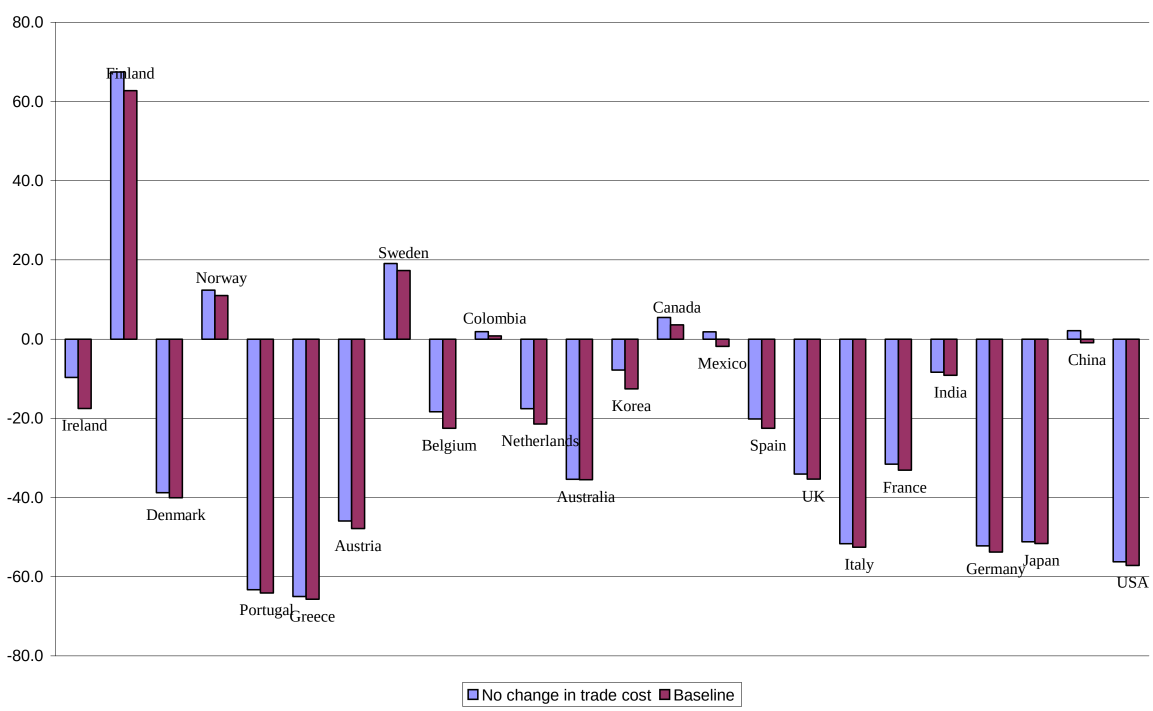


Table 2. Baseline and counterfactual change in volatility

	% 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**

Table 2 summarizes our results. The first column 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. Comparison of these two exercises shows that for all countries the fall in volatility would be smaller (or the increase higher) had trade costs remained at the 1970-84 level. Columns labelled (3) and (4) tell the same story from the perspective of levels of volatility in the second sub-period. Even though on average the quantitative significance of the diversification channel seems to be small, leading to about 3 percent fall in volatility, there are large difference across countries. The countries that seem to have benefited most from openness were, in that order, Ireland, Belgium, Korea and the Netherlands, while at the other end of the spectrum were Australia, Colombia, India and Japan.

It is telling to compare the relative contribution of openness to volatility to the key characteristics of countries in our model. First and most importantly, there is strong correlation (0.70) between the magnitude of the change in volatility and the magnitude of the change in trade costs[8], confirming thus our intuition that countries that opened most have experienced largest falls in volatility. Next, the change in volatility correlates positively (0.41) with the actual level of volatility. In other words, countries that are more volatile than others are, by means of trading, able to import stability from their more stable trading partners. Vice versa, if a country is very stable, opening to trade can lead to higher volatility when partners are highly volatile (or their shocks are positively and significantly correlated with those in the domestic economy). This finding goes in line with the theoretical result derived in (**??**). Finally, there is negative, though somewhat weaker (-0.21) correlation between the fall in volatility and the size of countries reflected by the average of Z_{it} shown in the last but one column of Table 2, which suggest that smaller countries have benefited most from greater openness.

Coming back to the minimalist counterfactual introduced in the previous section, we find a negative correlation of -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 due to openness in this exercise, which we see as a sign of consistency between the volatility decomposition exercise and the numerical simulations.

VI Conclusions

TBW

VII References (incomplete)

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VIII Appendix:

A Derivation of equation (1)

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

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

The first line below expands the numerator and adds terms while the second line collect terms. The last line adds the $(\theta\gamma_i)^2$ term to the expression in square brackets (note the change of the index under the sum). The inequality holds since $\gamma_i < 1$ for all i.

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

B Proof that equations in (3) are not linearly independent

Sum the first $N-1$ equations in the system defined by eq (3)

$$\sum_{i=1}^{N-1}L_ip_iq_i+\sum_{i=1}^{N-1}S_i=\sum_{i=1}^{N-1}\left(\sum_{j=1}^{N}L_jpq_jd_{ji}\right)$$

Impose $\sum_{j=1}^{N} S_i = 0$ and rearrange the right-hand side

$$\sum_{i=1}^{N-1} L_i p_i q_i - S_N = \sum_{j=1}^{N} L_j p_j q_j \left(\sum_{i=1}^{N-1} d_{ji} \right)$$

Apply $\sum_{j=1}^{N} d_{ij} = 1$

$$\sum_{i=1}^{N-1} L_i p_i q_i - S_N = \sum_{j=1}^{N} L_j p_j q_j \left(1 - d_{jN}\right)$$

Cancel terms, rearrange and notice that is exactly the N^{th} equation in (3)

$$L_N p_N q_N + S_N = \sum_{j=1}^{N} L_j p_j q_j d_{jN}$$

C Derivation of equation (4)

Equation (4), stating that $L_i w_i = \beta_i (L_i p_i q_i + S_i)$ can more intuitively be expressed as follows (add $L_i p_i q_i$ and S_i to both sides and rearrange)

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

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 $1-\beta_i$ of this expression accrues to the produced input, i.e. to intermediates. In aggregate terms this becomes $(1-\beta_i)(L_i p_i q_i + S_i)$.

D Proof that Lw_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

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

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

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

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 compared to the role of domestic absorption. Given the weight attached to $S^T_{i,t}$ 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.

E Data sources

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. The choice of the core countries was dictated mainly by the availability of data for total output and they include: the United States, Mexico and Canada, Australia, from Asian countries there is China, Japan, Korea and India, South America is represented by Colombia, and the rest are advanced European countries: the United Kingdom, 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 rest of the word 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.

E.1 Real GDP

Source: 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.

E.2 Gross Output

With the exception of India and China, the sources of data for total gross output in our 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, 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 the 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.

E.3 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. An export data point is E_{ij} or the dollar value of exports by country j to country i, at country j 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.

E.4 Auxiliary Data

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

- GDP: GDP in local currency, World Bank, World Development Indicators (Edition: 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.

- POP: population, PWT 6.3, variable POP.

- ER: exchange rate, World Bank, World Development Indicators (Edition: 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. Two adjustments were needed: (1) To ensure consistency with other data, the exchange rate for Ecuador and El Salvador was set to 1. While most of the WDI data for these countries are in USD, the reported official exchange rate was for their earlier currencies. (2) For Brazil, Iraq and Liberia the PWT exchange rate was used instead because the official exchange rate reported by the WDI would give rise to important inconsistencies.

- Value added in industry and total value added is derived from the EU KLEMS database (November 2009 edition). Industry covers the same sectors as defined in output in industry. When unavailable, other sources used are:

- USA: missing years 1970-76 generated using a growth rate of each sector from EU KLEMS (March 2008 edition).
- China: total value added 1984-06 is from the UN Data, for 1970-1983 the growth rate of GDP from Statistical Yearbooks of China was used. Value added in industry is the sum of GDP in primary industry and GDP in industry from Statistical Yearbooks of China.
- India, Mexico, Norway and Colombia: value added data from the UN Data.
- Japan: data for 1973-06 are from EU KLEMS (November 2009 Edition), for 1970-72 the source is the OECD STAN database (growth rate).
- Canada: 1970-04 EU KLEMS (March 2008 edition), 2005-06 sectoral growth rates from the Canadian Statistical Office's National Economic Accounts (table Gross domestic product at basic prices by industries)
- Germany: the series is EU KLEMS' estimate for both parts of Germany.

• 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 (Australia, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Korea, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the UK), the source is the EU KLEMS database (November 2009 edition), variable gross output at current basic prices. When missing, the following sources were used:

- USA: missing years 1970-76 generated using a growth rate of each sector from EU KLEMS (March 2008 edition).
- Canada: 1970-04 EU KLEMS (March 2008 edition), for 2005-06 sectoral growth rates from the Canadian Statistical Office's National Economic Accounts (table Provincial gross output at basic prices by industries).
- China: data are from the Statistical yearbooks of China. Output in agriculture is defined as gross output value of farming, forestry, animal husbandry and fishery and is available for all years. Mining and manufacturing is reported as a single unit labelled output in industry, which apart from the extraction of natural resources and manufacture of industrial products includes sectors not covered by other countries: water and gas production, electricity generation and supply and repair of industrial products (no adjustment was made). 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.

– India: data are from the Statistical Office of India, National Accounts Statistics. Years 1999-06 are reported on the SNA93 basis. Earlier years were obtained using the 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).

– Mexico: data are from the System of National Accounts published by the INEGI and from the UN National Accounts Database. 2003-06 Sistema de cuentas nacionales, INEGI (NAICS), 1980-03 growth rate from the UN National Accounts Data, 1978-79 growth rate from Sistema de cuentas nacionales, INEGI, 1970-1978 growth rate from System of National Accounts (1981), Volumen I issued by the SPP.

– Japan: data for 1973-06 are from EU KLEMS (November 2009 Edition), for 1970-

72 the source is the OECD STAN database (growth rate).

- Colombia and Norway: data are from the UN National Accounts Database.

- Germany: the series is EU KLEMS' estimate for both parts of Germany.