Trade and Comovement

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Abstract

This paper investigates the relationship between international trade and comovement in real GDP growth. We look at the relationship through the lens of a standard general equilibrium framework that conceptualises the demand and supply linkages among countries. We derive a closed-form formula for bilateral correlations consistent with the model and show that correlation depends on the underlying distribution of *all* country-specific shocks and on trade intensities across all trade partners. This result is at odds with empirical strategies typically employed to study the linkages between trade and comovement, which tend to ignore global trade patterns. Numerical simulations with a calibrated version of the model confirm that these global linkages account for the bulk of bilateral comovement.

1 Introduction

Does trade enhance comovement? This question naturally arises when looking back at the long synchronised upswings and several downswings posted by most developed economies since the beginning of 1990s. For almost simultaneously, the world has been experiencing an unprecedented expansion of global trade, on the back of the increased integration of China, South-East Asia and, somewhat later, Central and Eastern Europe in global production chains. While the jury is still out on whether and in which sense exactly have business cycles become more correlated[1], it is a well established fact that global merchandise trade grew almost three times as fast as global GDP from the 1960's and even faster in the past twenty or thirty years, until the current crisis.

We look at the relationship between across-the-border trade in goods and comovement in real GDP growth through the lens of a standard general equilibrium framework that conceptualises the demand and supply linkages among countries. The model is a variant of Eaton and Kortum (2002) and Alvarez and Lucas (2007) with stochastic country-specific shocks and pair-specific trade shocks. With this model, we set out to investigate whether greater openness to trade affects cross-country correlations and, if so, to examine what determines whether two countries' growth rates will be positively correlated.

The relationship between trade and comovement has been the topic of several theoretical and a long list of empirical studies. To exemplify the former stream of literature, Kose and Yi (2006) study the implications of trade on comovement within a canonical international business cycle model. They conclude, on the basis of empirical work of their own and others, that a standard version of the model fails to replicate the patterns they see in data, for which they coin the term trade-comovement puzzle. In an attempt to resolve the puzzle, Arkolakis and Ramanarayanan (2009) use a framework similar to ours but augmented for vertical specialisation to show that experiments with trade intensity can generate moderate increases in cross-country comovement.

Clearly, multi-country macroeconomic models have predictions about the relationship between trade and comovement so it would be desirable to have a corresponding 'stylized fact' to provide a testing ground for competing theories. A large body of empirical work has already been devoted to the study of effects of trade on comovement, and this is the main stream of literature to which our results speak to. The seminal paper in this field

[1]See, for instance, Cerqueira and Martins (2009) or Bower and Guillemineau (2006) for an affirmative answer, or Heathcote and Perri (2004) and Doyle and Faust (2002) for a more cautious view. Kose, Otrok and Prasad (2012) coin the phrase 'decoupling' for the observed decrease in business cycle correlations between the blocks of industrial and emerging countries but convergence within each block.

is Frankel and Rose (1998), who estimate regressions of the following form

$$Corr(\hat{y}_{i\tau}, \hat{y}_{j\tau}) = \alpha + \beta Trade_{ij\tau} + \epsilon_{ij\tau}$$

where $\hat{y}$ denotes a measure of fluctuations in economic activity in period τ and $Trade_{ij\tau}$ is a measure of trade intensity between countries i and j in the same period. Their estimation uses instrumental variables to control for a bias that arises, as they argue, because countries are likely to stabilise their exchange rates with respect to their main trading partners. The instruments they use are exogenous *bilateral* characteristics that capture the distance of the two countries, existence of a common border etc. Other studies using a similar estimation framework include Baxter and Kouparitsas (2005), Calderon, Chong and Stein (2007) and others[2]. Our reading of the literature is that it typically seeks for measures and/or estimation techniques that would capture omitted variables – *bilaterally* relevant for i and j – that they consider important in driving the bias in the equation above.

To preview our results, we derive closed-form formulas for bilateral correlations consistent with our model and find that direct trade between i and j does expose country i to shocks that affect its trade partner j, buttressing thus their comovement. So far, this is consistent with the estimation strategies above. However, we also find that the direct trade empirically accounts for less than 10% of the observed comovement. What matters more, according to our model, is that country i trades with one or more other countries k. Then, if k tends to receive similar shocks as j, countries i and j are likely to post high bilateral correlations – independently of whether they trade with each other or not. This 'indirect-trade' effect, as we call it, accounts for the bulk of observed correlations, because the relative strength of the 'direct' trade exposure to j is typically substantially smaller than the exposure to all other trade partners. To relate this finding to the above empirical works, our results support the search for identification strategies that control for the exposure to coincident shocks, for instance through the similarity of the industrial structure. However, our results also suggest that the search should focus on the similarity between i's *other trade partners* and j, and vice versa, between j's *other trade partners* and i, rather than on the similarity between i and j bilaterally.

[2]Calderon, Chong and Stein (2007) and also Gruben, Koo, Millis (2002) base their regressions on intra-industry trade to capture the role of industry-specific shocks. Also Fidrmuc (2001) provides evidence that using the total volume of trade is misguided and confine the role of trade in transmitting shocks to intra-industry trade only. Other relevant works include Kose, Prasad and Terrones (2003), Clark and van Wincoop (2001), Otto, Voss and Willard (2001), Anderson, Kwark and Vahid (1999).

2 Model

The model we use here is a version of Eaton-Kortum (2002) and Alvarez-Lucas (2007)'s model with stochastic parameters. Adhering, where possible, to their original notation, the model can be described as follows.

Let us assume that there is a continuum of goods $\omega \in [0,1]$ that can be produced in all n countries in the model at costs (x_1, x_2, ..., x_n). Given this mapping between goods ω and cost combinations $x = (x_1, x_2, \ldots, x_n)$, the model can, without loss of generality, be cast in terms of the cost combinations x. Let $\varphi_i(x_i)$ be the density in country i of cost draw x_i (where i here denotes the i^{th} element of x). Assuming it is exponentially distributed with parameters λ_i, the density of x is

$$\varphi(x) = \prod_{i=1}^{n} \varphi_i(x_i) = \prod_{i=1}^{n} \lambda_i e^{-\lambda_i x_i}$$

Parameter λ_i will play a crucial role in our model; let us therefore state here that higher λ_i increases the density of lower cost draws, which amounts to a positive productivity shock.

Let $q_{f,i}(x)$ denote the per-capita quantity of individual goods x that are bought by consumers for final consumption, and let $q_{f,i}$ denote the bundle of all goods that enters utility

$$q_{f,i} = \left(\int_0^1 q_{f,i}(x)^{\frac{\eta-1}{\eta}} \varphi(x) dx \right)^{\frac{\eta}{\eta-1}}$$

Assuming utility is linear in $q_{f,i}$ and taking domestic prices of good x, $p_i(x)$, as given (there is perfect competition in all markets), cost minimisation implies the following demand functions and price index:

$$q_{f,i}(x) = \left(\frac{p_i}{p_i(x)} \right)^{\eta} q_{f,i}$$

$$p_i = \left(\int_0^{\infty} p_i(x)^{1-\eta} \varphi(x) dx \right)^{\frac{1}{1-\eta}} \quad (1)$$

Let individual purchases of goods $q_i(x_i)$ be produced in i using equipped labour, of which there is L_i in total, and all other goods bundled together in the same CES aggregator as given above. We assume that any individual good can be either directly consumed or used as an intermediate input.

The production function is Cobb-Douglas with β, the share of the unproduced input, being common across countries.

$$q_i(x_i) = {x_i}^{-\theta} L_i(x_i)^{\beta} q_{m,i}(x_i)^{1-\beta}$$

where $q_{m,i}(x_i)$ denotes the quantity of the bundle of intermediate goods that it takes to produce a good with cost level x_i. Notice that cost shocks enter the production function as a productivity parameter ${x_i}^{-\theta}$ and recall that shocks are exponentially distributed. As explained in Eaton and Kortum (2002), the transformation ${x_i}^{-\theta}$ makes productivity shocks distributed according to the Frechet distribution, where θ governs the variance of shocks. With higher θ, productivity shocks become more volatile.

Perfect competition and constant returns imply that price of each individual intermediate good *potentially* produced in the domestic economy at productivity ${x_i}^{-\theta}$ would be

$$p_i(x_i) = B x_i^{\theta} w_i^{\beta} p_i^{1-\beta}$$

where constant $B = \beta^{\beta}(1-\beta)^{1-\beta}$ and w_i is the pay of the unproduced input. When producers have the choice of importing intermediates from abroad, each good $x = (x_1, x_2, \ldots, x_n)$ will be priced at the level of the cheapest supplier

$$p_i(x) = B \min_j \left(\frac{{x_j}^{\theta} {w_j}^{\beta} {p_j}^{1-\beta}}{\kappa_{ij}} \right)$$

where $1/\kappa$ represents physical trade costs. For one unit to arrive from j to i, $1/\kappa_{ij}$ must be shipped and paid for. We assume $0 < \kappa \leq 1$ and that it is always cheaper to transport goods directly than through a third country ($\kappa_{ij} \geq \kappa_{ik}\kappa_{kj}$). Domestic trade is costless, $\kappa_{ii} = 1$ and we further assume that there are no money tariffs.

Given that domestic prices of goods x are a function of stochastic vector x, it is possible to work out the price index p_i as given by (1). Using the properties of the Frechet distribution (along the lines in Eaton-Kortum (2002)), we have

$$p_i = A\,B \left(\sum_{j=1}^{n} \left(\frac{{w_j}^{\beta} {p_j}^{1-\beta}}{\kappa_{ij}} \right)^{-\frac{1}{\theta}} \lambda_j \right)^{-\theta} \tag{2}$$

which is a set of non-linear equations solvable for p as a function of vector w. Constant A is defined as $A = \Gamma\left(1 + \theta\ (1-\eta)\right)^{\frac{1}{1-\eta}}$, which implies a parameter restriction $\theta \leq 1/(\eta - 1)$, assuming $\eta > 1$).

With a continuum of goods x, the fraction of goods that will be purchased in i from country j is given by the probability that, for each good x country j is the minimum-price supplier in country i. Denoting this fraction d_{ij}, we have

$$d_{ij} = Prob\left(\frac{B {x_j}^{\theta} {w_j}^{\beta} {p_j}^{1-\beta}}{\kappa_{ij}} \leq \min_k \left(\frac{B {x_k}^{\theta} {w_k}^{\beta} {p_k}^{1-\beta}}{\kappa_{ik}} \right) \right)$$

for each $k \neq j$. Exploiting the properties of Frechet distribution further, one can show that this is

$$d_{ij} = (AB)^{-\frac{1}{\theta}} \frac{\left(w_j^{\beta} p_j^{1-\beta} \Big/ \kappa_{ij}\right)^{-\frac{1}{\theta}} \lambda_j}{\sum_{k=1}^{n} \left(w_k^{\beta} p_k^{1-\beta} \Big/ \kappa_{ik}\right)^{-\frac{1}{\theta}} \lambda_k}$$

Notice that with prices being functions of the wage of the unproduced input, d_{ij} becomes also a function of wages.

Across-the-border linkages are constrained in the model by imposing that spending on goods (which are all potentially tradable) in country i, $L_i p_i q_i$, is equal to total spending of all countries (including i itself) on goods produced in i. Each country spends fraction d_{ji} of $L_j p_j q_j$ on goods produced in i. With eventual imbalances captured by S_i, we have

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

With exogenous L_i and S_i, and prices and trade shares determined by wages, as shown above, this equation implies that per-capita spending q_i can also be determined as a function of wages.

Domestically, the model is closed by imposing, first, the national accounting identity that states that total income of labour must be equal to total final expenditure: $L_i w_i = L_i p_i q_{f,i} + S_i$, which determines total spending of households on final goods $L_i p_i q_{f,i}$. Furthermore, the Cobb-Douglas production function state above implies that the fraction of each good used as an intermediate input is $q_{m,i}(x) = (1-\beta) q_i(x)$. Multiplying both sides by $L_i p_i(x)$ and integrating over x, the right-hand side gives total spending of firms on intermediate goods, which can be also written as a fraction of total spending in the economy (incl. from abroad): $(1-\beta)(L_i p_i q_i + S_i)$. Adding the expenditure on final and intermediate goods and making them equal to total expenditure on goods $L_i p_i q_i$, gives the relationship

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

which completes the description of the model and can be used to determine the remaining endogenous variable in the model (wages).

For ease of notation, let us make the following substitutions. First, let us denote Z_i the following transformation of the aggregate productivity parameter λ_i:

$$Z_i \equiv L_i^{\frac{\beta}{\theta}} \lambda_i$$

and denote $Lw_i = L_i w_i$. What we gain by these transformations is that we avoid the need to work with a parameter L_i, that does not have a self-evident counterpart in data (recall

that L_i is the unproduced input in the economy – equipped labour – rather than a simple head count). Lw_i, instead, is total income of the factor, which can be easily mapped to national accounts.

Using this notation, we can now collect the key equations. Substituting from (4) for $L_i p_i q_i$ and ignoring trade imbalances, as we do in all subsequent derivations, the trade identity (3) is:

$$Lw_i = \sum_{j=1}^{n} Lw_j d_{ji} \tag{5}$$

which jointly with the definition of d_{ij} with our transformed variables

$$d_{ij} = (AB)^{-\frac{1}{\theta}} \frac{\left(Lw_j^{\beta} p_j^{1-\beta} \Big/ \kappa_{ij}\right)^{-\frac{1}{\theta}} Z_j}{\sum_{k=1}^{n} \left(Lw_k^{\beta} p_k^{1-\beta} \Big/ \kappa_{ik}\right)^{-\frac{1}{\theta}} Z_k} \tag{6}$$

gives a set of equations in prices and aggregate nominal income only. Rewriting the price equation (2) with the new notation, it also becomes a function of prices and aggregate income. Jointly, these two form a set of $2n$ equations in $2n$ variables: aggregate nominal income Lw_i and its price level p_i. As shown in Appendix A.1, trade identities (3) are not linearly independent, so we will be able to solve only for relative prices subject to a numeraire. The key relationships, which are used to solved the model, for both algebraic and numerical purposes, then are

$$Lw_i = \sum_{j=1}^{n} Lw_j \frac{\left(Lw_i^{\beta} p_i^{1-\beta} \Big/ \kappa_{ji}\right)^{-\frac{1}{\theta}} Z_i}{\sum_{k=1}^{n} \left(Lw_k^{\beta} p_k^{1-\beta} \Big/ \kappa_{jk}\right)^{-\frac{1}{\theta}} Z_k}$$

$$p_i = AB \left(\sum_{k=1}^{n} \left(Lw_k^{\beta} p_k^{1-\beta} \Big/ \kappa_{ik}\right)^{-\frac{1}{\theta}} Z_k \right)^{-\theta}$$

2.1 Closed-form solution

The model has a closed-form solution only in the special cases of autarky and zero trade costs. While these are useful to understand the basic relationship between trade and comovement, they are not helpful in terms of pointing at the key channels through which trade impacts comovement in the data. As we show in section 4.1, trade costs are far away from the free-trade assumption among most countries. We therefore proceed to log-linearise the model and describe its solution in terms of log-deviations of shocks around their steady-state values. By doing so, we are able to derive an insightful closed-form solution for covariances and eventually also for correlations between GDP growth rates.

We seek a solution in terms of real GDP $Y_i = Lw_i/p_i$, let us therefore transform the last two equations from the previous section once more, to have them in terms of Y_i and p_i:

$$Y_i\, p_i = \sum_{j=1}^{n} Y_j\, p_j \frac{\left(Y_i^{\beta} p_i \Big/ \kappa_{ji}\right)^{-\frac{1}{\theta}} Z_i}{\sum_{k=1}^{n} \left(Y_k^{\beta} p_k \Big/ \kappa_{jk}\right)^{-\frac{1}{\theta}} Z_k} \tag{7}$$

$$p_i = AB \left(\sum_{k=1}^{n} \left(Y_k^{\beta} p_k \Big/ \kappa_{ik}\right)^{-\frac{1}{\theta}} Z_k \right)^{-\theta} \tag{8}$$

Log-linearising both equations and using steady-state trade shares $\overline{d}_{ij}$ as defined in (6), we obtain the following relationships[3]:

$$\begin{aligned}
\overline{Y}_i\, \overline{p}_i\, (\hat{y}_i + \hat{p}_i) = \sum_{j=1}^{n} & \overline{Y}_j\, \overline{p}_j\, \overline{d}_{ji} \\
& \left(\hat{y}_j + \hat{p}_j - \frac{\beta \hat{y}_i + \hat{p}_i - \hat{\kappa}_{ji}}{\theta} + \hat{z}_i - \sum_{k=1}^{n} \overline{d}_{jk} \left(- \frac{\beta \hat{y}_k + \hat{p}_k - \hat{\kappa}_{jk}}{\theta} + \hat{z}_k \right) \right) \\
\hat{p}_i = \sum_{k=1}^{n} & \overline{d}_{ik}\, (\beta \hat{y}_k + \hat{p}_k - \hat{\kappa}_{ik} - \theta \hat{z}_k)
\end{aligned}$$

Notice that the latter equation implicitly defines a weighted average of relative prices $\sum_{k=1}^{n} \overline{d}_{ik}\, (\hat{p}_k - \hat{p}_i)$, which could help us eliminate relative prices from the former equation. However, there is an important caveat. For each country i, all terms in the price equation are summed over k, which is the second subscript in d_{ik}, while the first summation in the trade identity above is over the first subscript of d_{ji}. Nevertheless, there is a useful relationship that will allow us to proceed with solving both log-linearised equations simultaneously. Namely, let us impose

$$Lw_i d_{ij} = Lw_j d_{ji} \quad \text{or, equivalently} \quad Y_i\, p_i\, d_{ij} = Y_j\, p_j\, d_{ji} \tag{9}$$

which states that the value of goods produced by country j used in country i's production equals the value of goods produced by i used in j's output.

The relationship follows from the assumption of symmetric trade costs: $\kappa_{ij} = \kappa_{ji}$, which is also the cornerstone of the strategy we follow to identify trade costs from data; see section 4.1 below. Let us explain why (9) holds because it is not straightforward.

[3]In what follows, variables with a bar denote steady-state values, while a hat indicates a log-deviation from the steady state.

Notice that without making any assumptions on trade costs κ, trade shares (6) can be used to write

$$\frac{d_{ij}}{d_{ji}}\frac{d_{jk}}{d_{kj}} = \left(\frac{Lw_j^{\beta}p_j^{2-\beta}\kappa_{ji}}{Lw_i^{\beta}p_i^{2-\beta}\kappa_{ij}}\right)^{-\frac{1}{\theta}}\frac{Z_j}{Z_i}\left(\frac{Lw_k^{\beta}p_k^{2-\beta}\kappa_{kj}}{Lw_j^{\beta}p_j^{2-\beta}\kappa_{jk}}\right)^{-\frac{1}{\theta}}\frac{Z_k}{Z_j}$$

Now, assuming symmetry, $\kappa_{ij} = \kappa_{ji}$ and $\kappa_{jk} = \kappa_{kj}$ gives

$$\frac{d_{ij}}{d_{ji}}\frac{d_{jk}}{d_{kj}} = \left(\frac{Lw_k^{\beta}p_k^{2-\beta}}{Lw_i^{\beta}p_i^{2-\beta}}\right)^{-\frac{1}{\theta}}\frac{Z_k}{Z_i}$$

which, for $\kappa_{ik} = \kappa_{ki}$, equals d_{ik}/d_{ki}. We therefore obtain the relationship

$$\frac{d_{ij}d_{jk}}{d_{ji}d_{kj}} = \frac{d_{ik}}{d_{ki}}$$

which can be arbitrarily expanded, as long the number of countries allows, according to the following the pattern. Note that country labels a, b, etc. can represent any country; what matters is that the circular link $d_{*f}\,d_{f*}$ between any two countries is obeyed.

$$\frac{d_{\mathbf{a}b}\,d_{bc}\,d_{c*}\ldots d_{*y}\,d_{y\mathbf{z}}}{d_{ba}\,d_{cb}\,d_{*c}\ldots d_{y*}\,d_{zy}} = \frac{d_{\mathbf{az}}}{d_{za}}$$

This powerful condition says that the share of country z goods in a's output relative to the share of a's goods in z's output must hold for trade that takes place directly between a and z, the right-hand side of the expression, as well as for the relative contents of goods in any other country's (or countries') exports to the pair, i.e. the left-hand side. If, for instance, trade costs and the country-specific shocks are such that country z's share in a's output is five times larger than a's share in z's output, the content of z's good in a's imports from a third country j will be also five times larger than the content of a's goods in z' exports from j. This is because costs of trade via j: $\kappa_{aj}\kappa_{jz}$ and $\kappa_{zj}\kappa_{ja}$, are identical for both countries. When trade costs are symmetric, there is no reason why the relative shares of goods traded directly or indirectly should differ. Naturally, the amount of goods traded between both countries directly and indirectly, via output of other countries, will be very different, depending on how costly trade with j is for both countries and how big j is (both relative to all other countries).

What ever parameter values drive the fact that a's and z's goods account for the relative share $\frac{d_{az}}{d_{za}}$ in each other's production, given the universal symmetry and zero trade imbalances, the same drivers will then substantiate that z's nominal output will be $\frac{d_{az}}{d_{za}}$ times larger than that of a. Notice that equation (9) is stricter than the trade identity (5) but it is consistent with it (to see it, sum over j, making use of $\sum_{j=1}^{n} d_{ij} = 1$).

Mathematically, the derivation of (9) uses $(n-1)$ independent equations from the trade identity (5), successively eliminating trade shares of other countries.

Having established that $Y_i\, p_i\, d_{ij} = Y_j\, p_j\, d_{ji}$, our log-linearised model becomes

$$\hat{y}_i + \hat{p}_i = \sum_{j=1}^{n} \overline{d}_{ij} \left(\hat{y}_j + \hat{p}_j - \frac{\beta \hat{y}_i + \hat{p}_i - \hat{\kappa}_{ji}}{\theta} + \hat{z}_i - \sum_{k=1}^{n} \overline{d}_{jk} \left(- \frac{\beta \hat{y}_k + \hat{p}_k - \hat{\kappa}_{jk}}{\theta} + \hat{z}_k \right) \right)$$

$$\hat{p}_i = \sum_{k=1}^{n} \overline{d}_{ik} \left(\beta \hat{y}_k + \hat{p}_k - \hat{\kappa}_{ik} - \theta \hat{z}_k \right)$$

Substituting $\sum_{k=1}^{n} \overline{d}_{ik} \left(\hat{p}_k - \hat{p}_i \right)$ from the price equation to corresponding expressions in the trade equation and simple algebra then lead to the following expression for GDP growth rates:

$$(\beta + \theta)\, \hat{y}_i = \theta \hat{z}_i + \sum_{j=1}^{n} \overline{d}_{ij} \left((2+\theta)\, \hat{\kappa}_{ij} + (1+\theta)\, \theta \hat{z}_j \right) + (\theta - \beta\,(1+\theta)) \sum_{j=1}^{n} \overline{d}_{ij} \hat{y}_j \qquad (10)$$

where we separate the sums on the right-hand side to motivate the next step, which is to solve the set of i linear equations above by means of matrix algebra. Let us define the following matrices:

$$\mathbf{I} \ldots i \,\mathrm{x}\, i \,\text{identity matrix}$$

$$\mathbf{y} \ldots i \,\mathrm{x}\, 1 \,\text{vector of}\ \hat{y}_i$$

$$\mathbf{D} \ldots i \,\mathrm{x}\, i \,\text{matrix of}\ \overline{d}_{ij}$$

$$\mathbf{K} \ldots i \,\mathrm{x}\, i \,\text{matrix of}\ \hat{\kappa}_{ij}$$

$$\mathbf{z} \ldots i \,\mathrm{x}\, 1 \,\text{vector of}\ \hat{z}_i$$

With this notation, the equation becomes

$$(\beta + \theta) \left(\mathbf{I} - \frac{\theta - \beta\,(1+\theta)}{\beta + \theta} \mathbf{D} \right) \mathbf{y} = (2+\theta) \sum_{j=1}^{n} \left(\overline{d} \circ \hat{\kappa} \right)_{ij} + \theta \left(\mathbf{I} + (1+\theta)\, \mathbf{D} \right) \mathbf{z}$$

where $\left(\overline{d} \circ \hat{\kappa} \right)_{ij}$ stands for the ij element of the Hadamard (element-by-element) product of $\overline{d}_{ij}$ and $\hat{\kappa}_{ij}$. For square matrices and symmetric $\mathbf{K}$, the following expression holds (Styan, 1973):

$$\sum_{j=1}^{n} \left(\overline{d} \circ \hat{\kappa} \right)_{ij} = (\mathbf{D}\, \mathbf{K})_{ii}$$

which states that the row-sum of an element-by-element product of two square matrices equals the diagonal of their matrix product. Alternatively, the same result can be achieved by $\mathbf{D_L}\, \mathrm{vec}(\mathbf{K})$, where $\mathbf{D_L}$ represents an n-by-n^2 matrix, which is created by stacking n

matrices each of the size of $\mathbf{D}$ next to each other (row-wise), where the r^{th} submatrix carries the r^{th} row from the original matrix $\mathbf{D}$ and has all other elements equal to zero. For illustration, for $n = 3$, it would have the following shape

$$\mathbf{D_L} = \begin{bmatrix} d_{11} & d_{12} & d_{13} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & d_{21} & d_{22} & d_{23} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & d_{31} & d_{32} & d_{33} \end{bmatrix}$$

The *vec* operator reshapes an n-by-n matrix into an n^2-by-1 column vector. Because of the symmetry in trade costs, we do not need to transpose matrix $\mathbf{K}$ beforehand.

With these preliminary definitions, and denoting $\mathbf{M}(\mathbf{D})$ the invertible matrix

$$\mathbf{M}(\mathbf{D}) = \mathbf{I} - \frac{\theta - \beta\,(1+\theta)}{\beta + \theta}\mathbf{D}$$

the solution to the log-linearised model is given by

$$\mathbf{y} = \frac{1}{\beta+\theta}\,\mathbf{M}(\mathbf{D})^{-1}\left[\,(2+\theta)\,(\mathbf{D}\,\mathbf{K})_{ii} + \theta\;(\mathbf{I} + (1+\theta)\,\mathbf{D})\,\mathbf{z}\right]$$

or alternatively

$$\mathbf{y} = \frac{1}{\beta+\theta}\,\mathbf{M}(\mathbf{D})^{-1}\left[\,(2+\theta)\,\mathbf{D_L}\,\mathrm{vec}(\mathbf{K}) + \theta\;(\mathbf{I} + (1+\theta)\,\mathbf{D})\,\mathbf{z}\right] \tag{11}$$

which defines the log-deviations of real GDP as a function of shocks that affect bilateral trade costs and country-specific productivity. The expression is sufficiently simple to derive the moments of real GDP growth rate based on the properties of exogenous shocks. Notice the way shocks are transmitted across countries – the strength of cross-country relationships is governed by the matrix of steady-state trade-shares.

What can we say about the impact of shocks on GDP growth rates? Country specific shocks $\hat{z}_i$ affect GDP growth rates in two ways[4]. First, directly through $\mathbf{I}\,\mathbf{z}$ and secondly indirectly through $(1+\theta)\,\mathbf{D}\mathbf{z}$. Recall that higher $\hat{z}_i$ (a positive productivity shock to i), on average, increases productivities of i's individual firms. Other things equal, other countries therefore end up purchasing a wider range of goods from i, which makes i richer. This is where the direct effect comes from. The indirect effect then reflects the role of relative prices on the growth rate of i's real GDP, where prices of i are always measured relative to the weighted average of prices of all countries (weighted by the trade shares $\mathbf{D}$). They play a double role; first, they matter because nominal GDP is divided by the price

[4]Let us note that the individual channels we describe here are only hypothetical because, in equilibrium, all of them will work simultaneously, reinforcing or counterbalancing each other. We do so, nonetheless, in belief that this explanation will ease the understanding of the model.

level and, secondly, they reinforce demand of other countries for i's goods. Regarding the latter, it carries weight θ because, in our model, higher θ rises the variance of individual productivity draws, making higher productivity shocks asymmetrically more likely.

Next, shocks to trade costs κ, say a positive shock that makes i's goods cheaper in other countries through higher $\hat{\kappa}_{ji}$, affect GDP in a similar way as the country-specific shocks. First, there is the direct demand effect – all countries buy more from i when trade costs are lower. Secondly, lower trade costs also make i's prices relatively cheaper, which again works through the $(1+\theta)$ effect described in the previous paragraph. Since trade costs are always relative, the trade-share matrix $\mathbf{D}$ now premultiplies both terms. Should trade costs not be symmetric, the former demand channel would depend on how costly it would be for other countries to import goods from i ($\hat{\kappa}_{ji}$) while the relative-price channel on i's cost of importing goods from countries j ($\hat{\kappa}_{ij}$). However, trade costs are symmetric in our model and therefore both effects are indistinguishable.

Finally, let us reflect on the role of the $\mathbf{M}(\mathbf{D})$ inverse in the solution. The purpose of the (slightly cumbersome) notation we introduced above though which we eliminated the coefficients at the identity matrix was to motivate the following step. Namely, writing $\mathbf{M}$ as a difference $\mathbf{I} - c_m\mathbf{D}$ allows using the power series expansion for approximating the inverse as follows[5]

$$(\mathbf{I} - c_m\mathbf{D})^{-1} \simeq \sum_{k=0}^{\infty} c_m^k \mathbf{D}^k = \mathbf{I} + c_m\mathbf{D} + c_m^2\mathbf{D}^2 + \dots$$

Intuitively, what this operation does is that it takes into account the direct impact of shocks described above (through the identity matrix) as well as the indirect impact that carries through via trade. To see it, note that the i^{th} element of the product $\mathbf{M}(\mathbf{D})^{-1}\mathbf{z}$ would be approximately equal to

$$\hat{z}_i + c_m \sum_{a=1}^{n} \overline{d}_{ia}\hat{z}_a + c_m^2 \sum_{a=1}^{n}\sum_{b=1}^{n} \overline{d}_{ib}\overline{d}_{ba}\hat{z}_a + c_m^3 \sum_{a=1}^{n}\sum_{b=1}^{n}\sum_{c=1}^{n} \overline{d}_{ic}\overline{d}_{cb}\overline{d}_{ba}\hat{z}_a + \dots$$

where the first element is the direct impact of own productivity shock; the second element captures shocks to all countries a (including i itself) as carried through trading with countries a; the third element captures the impact in i of country a's shocks on i's direct trade partner b (where the degree with which it is felt in i depends on i's openness to b

[5]The infinite sum converges. Note that c_m can be alternatively written as $-\frac{\theta(\beta-1)+\beta}{\theta+\beta}$, which makes it clear that $|c_m| < 1$ because β, the share of the intermediate input in production, is always $0 < \beta < 1$. Furthermore, $\mathbf{D}$ is a matrix of trade shares (all elements between zero and one), which become smaller after successive multiplications. In the extreme case of autarky, $\mathbf{D}$ is an identity matrix, for which the sum converges because $|c_m| < 1$.

and b's openness to a); the fourth element is again the impact in i of a's shocks on i's direct trade partner c as transmitted through c's trade with b (where the impact depends on $\overline{d}_{ic}\overline{d}_{cb}\overline{d}_{ba}$), etc. etc. The inverse therefore takes care of transmitting the shocks via both direct- and indirect-trade channels so that all shocks are felt in each country via all thinkable trade relationships that exist in the equilibrium.

Before we proceed further, we briefly note that the solution can be easily specialised for the extreme cases of autarky and cost-less trade. In autarky, trade shares $\mathbf{D}$ is an identity matrix and trade costs $\mathbf{K}$ are zero. Therefore matrix $\mathbf{M}$ becomes a constant $(2+\theta)\,\beta/\,(\beta+\theta)$ and $\mathbf{y}^{Aut} = \frac{\theta}{\beta}\mathbf{z}$ or $\hat{y}_i^{Aut} = \frac{\theta}{\beta}\hat{z}_i$. Of course, when countries are closed and the only source of volatility are own productivity shocks, GDP growth mimics the behaviour of these shocks. A corresponding formula with costless trade, realising that dk_{ij} are still zero, is the following:

$$\mathbf{y}^F = \frac{\theta}{\beta+\theta}\,\mathbf{M}\big(\mathbf{D}^F\big)^{-1}\left[\mathbf{z} + (1+\theta)\,\mathbf{D}^F\mathbf{z}\right]$$

Without matrices, the same relationship derived from (10) would be

$$\hat{y}_i^F = \frac{\theta}{\beta+\theta}\hat{z}_i + \frac{(1+\theta)\,\theta}{\beta+\theta}\sum_{j=1}^{n}\overline{d}_{*j}\hat{z}_j + \frac{\theta-\beta\,(1+\theta)}{\beta+\theta}\sum_{j=1}^{n}\overline{d}_{*j}\hat{y}_j^F$$

where the notation d_{*j} for an element in the j^{th} column of $\mathbf{D}^F$ refers to the fact that with $\kappa_{ij}^F = 1$ and equal prices everywhere (because of free trade), d_{ij} does not depend on i any longer, i.e. all countries import the same fraction of goods from j. Notice that the last term is common for all countries and functions as a common scaling constant, amplifying or moderating the response of all countries to shocks. We conclude that the dynamics of GDP growth with cost-less trade is determined not only by own productivity shocks $\hat{z}_i$, as was the case in autarky, but also by other countries' productivity shocks, transmitted through trade.

3 Sources of comovement

The point of this section is to investigate the mechanics of the model and study how trade linkages across countries induce comovement. We start with stating the general formula for *covariance* between $\hat{y}_i$ and $\hat{y}_j$. Subsequently, we make several simplifying assumptions that allow us to derive an approximate, yet tractable closed-form solution for *correlations* between GDP growth rates of any two countries. Finally, we present several illustrations that document how various linkages in the model drive comovement.

Let us start with solution (11) we obtained in the previous section. The covariance matrix of $\mathbf{y}$, $Cov(\mathbf{y}) = \mathbb{E}\big(\mathbf{y}\mathbf{y}^T\big)$[6] is given by the following expression

$$\begin{aligned} Cov(\mathbf{y}) = \frac{1}{(\beta+\theta)^2}\,\mathbf{M}(\mathbf{D})^{-1}\Big[\,&(2+\theta)^2\,\mathbf{D_L}\,\mathbb{E}\Big(\mathrm{vec}(\mathbf{K})\,\mathrm{vec}(\mathbf{K})^T\Big)\;\mathbf{D_L}^T \\ &+\theta\;(2+\theta)\,\mathbf{D_L}\,\mathbb{E}\Big(\mathrm{vec}(\mathbf{K})\,\mathbf{z}^T\Big)\Big(\mathbf{I}+(1+\theta)\,\mathbf{D}^T\Big) \\ &+\theta\;(2+\theta)\,\Big(\mathbf{I}+(1+\theta)\,\mathbf{D}\Big)\,\mathbb{E}\Big(\mathbf{z}\,\mathrm{vec}(\mathbf{K})^T\Big)\,\mathbf{D_L}^T \\ &+\theta^2\,\Big(\mathbf{I}+(1+\theta)\,\mathbf{D}\Big)\mathbb{E}\big(\mathbf{z}\,\mathbf{z}^T\big)\,\Big(\mathbf{I}+(1+\theta)\,\mathbf{D}^T\Big)\Big]\,\big(\mathbf{M}(\mathbf{D})^{-1}\big)^T \end{aligned} \tag{12}$$

which relates covariances of GDP growth rates to covariances of trade shocks, covariances of country-specific shocks and their cross-covariances.

3.1 Trade and country-specific shocks

For the sake of clarity, let us now abstract from any volatility in trade costs and focus instead on how country-specific shocks are transmitted through trade. While trade shocks, as we document in section 4.1, play an important role in cross-country comovement, we are more interested in the role of trade as a channel for transmission of country-specific (or aggregate) shocks, to which the trade shocks add an additional layer of disturbances. Under the assumption of fixed trade costs and a general covariance matrix of $\hat{z}$, which we label $\mathbf{\Omega}_z$, the formula above collapses to

$$Cov(\mathbf{y}) = \frac{\theta^2}{(\beta+\theta)^2}\,\mathbf{M}(\mathbf{D})^{-1}\Big[\Big(\mathbf{I}+(1+\theta)\,\mathbf{D}\Big)\mathbf{\Omega}_z\Big(\mathbf{I}+(1+\theta)\,\mathbf{D}^T\Big)\Big]\,\big(\mathbf{M}(\mathbf{D})^{-1}\big)^T$$

Notice that in autarky[7], this is equal to $\frac{\theta^2}{\beta^2}\mathbf{\Omega}_z$, which is consistent with our solution for $\hat{y}_i^{Aut} = \frac{\theta}{\beta}\hat{z}_i$. Clearly, with no covariance in underlying shocks, there is no mechanism in the model that would make growth rates correlated.

More interestingly, this formula shows that even if shocks are uncorrelated, trade induces non-zero cross-covariances[8]. We illustrate below in detail what gives rise to non-

[6] Log-deviations from steady-state values have zero mean.

[7] Matrix $\mathbf{D}$ is an identity matrix and therefore $\mathbf{M} = \frac{\beta(2+\theta)}{\beta+\theta}$.

[8] Replace $\mathbf{\Omega}_z$ with an identity matrix to see that the off-diagonal elements of the covariance matrix are nonzero. Notice that we cannot conclude that the changes in covariances induced by trade will be positive for all parameter values and trade shares. While all elements within the square brackets are by definition positive when $\mathbf{\Omega}_z$ is an identity matrix, the same cannot be said about the inverse that pre- and post-multiplies the bracket. Matrix $\mathbf{M}(\mathbf{D})$ is defined as $\mathbf{I} - c_m\mathbf{D}$, where $c_m = \frac{\theta-\beta(1+\theta)}{\beta+\theta}$ can be positive or negative. Its inverse can have both positive and negative elements. Note that even positive definiteness of matrix $\mathbf{M}$, which could be guaranteed under certain parameter restrictions, would not necessarily result in positive elements in the covariance matrix.

zero covariances and whether they also translate in non-zero correlations in several specific environments but the general point is that trade exposes each country to shocks that affect its trade partners and possibly also other countries, not directly connected through trade, which may however tend to receive similar shocks as one of the direct trade partners.

To make our point and illustrate how trade generates comovement, let us write the formula above in a more intuitive way. Expanding the terms inside of the brackets, we have

$$\Big[\dots\Big] = \mathbf{\Omega}_z + (1+\theta)\,\mathbf{\Omega}_z\mathbf{D}^T + (1+\theta)\,\mathbf{D}\mathbf{\Omega}_z + (1+\theta)^2\,\mathbf{D}\mathbf{\Omega}_z\mathbf{D}^T$$

Next, approximation of the inverses as shown in the previous section gives

$$\begin{aligned} Cov(\mathbf{y}) &\simeq \frac{\theta^2}{(\beta+\theta)^2}\sum_{k=0}^{\infty}\sum_{l=0}^{\infty} c_m^{k+l}\mathbf{D}^k\Big[\dots\Big]\left(\mathbf{D}^l\right)^T \\ &\simeq \frac{\theta^2}{(\beta+\theta)^2}\Big[\mathbf{\Omega}_z + (1+c_m+\theta)\left(\mathbf{D}\mathbf{\Omega}_z + \mathbf{\Omega}_z\mathbf{D}^T\right) \\ &+ (1+c_m+\theta)^2\,\mathbf{D}\mathbf{\Omega}_z\mathbf{D}^T + c_m\,(1+c_m+\theta)\left(\mathbf{D}^2\mathbf{\Omega}_z + \mathbf{\Omega}_z\left(\mathbf{D}^T\right)^2\right) + \dots\Big] \end{aligned} \tag{13}$$

As said, successive multiplications by $\mathbf{D}$ represent the pass-through of shocks via trade partners of trade partners etc. With realistic values of $\mathbf{D}$, the off-diagonal elements are typically of the order of 1/100, hence their cross-products have a minimal effect on the final outcome, compared to the first-order terms. Let us therefore abstract from the second- and higher order terms and deliver the intuition with a simplified version of the function. A comparison of the effects we obtain in this way with the results generated with a full version of the formula presented in the following section confirms that the loss of generality makes only little difference to the key results.

The first-order terms in the covariance matrix are given by the middle line in (13). The ij^{th} element of the matrix is

$$Cov(\hat{y}_i,\hat{y}_j) \simeq \frac{\theta^2}{(\beta+\theta)^2}\Big[\omega_{ij} + (1+c_m+\theta)\Big(\sum_{k=1}^{n}\overline{d}_{ik}\,\omega_{kj} + \sum_{k=1}^{n}\overline{d}_{jk}\,\omega_{ik}\Big)\Big]$$

where ω_{ij} is the ij element of $\mathbf{\Omega}_z$, i.e. covariance between countries i and j's shocks. Denoting the constant

$$c_d = 1 + c_m + \theta = 1 + \frac{\theta - \beta\,(1+\theta)}{\beta+\theta} + \theta = \frac{\theta\,(2+\theta)}{\beta+\theta}$$

and extracting relevant covariances from the sums, we have

$$Cov(\hat{y}_i, \hat{y}_j) \simeq \frac{\theta^2}{(\beta+\theta)^2} \Bigg\{ \Big(1 + c_d \left(\overline{d}_{ii} + \overline{d}_{jj}\right) \Big)\omega_{ij} + c_d \Big(\overline{d}_{ij}\, \omega_{jj} + \overline{d}_{ji}\, \omega_{ii}\Big) + c_d \sum_{k \neq i,j} \Big(\overline{d}_{ik}\, \omega_{kj} + \overline{d}_{jk}\, \omega_{ik}\Big) \Bigg\}$$

What does the formula tell about the (first-order) effects of trade on covariances? The way we wrote it suggests there are three factors to consider; with the first and second one closely related because they concern the bilateral characteristics of i and j. The first term reflects how the underlying covariance between i and j's shocks decreases when countries open to trade; $\overline{d}_{ii}$ reaches maximum in autarky and falls as country i starts trading with other countries (trade shares sum to 1). Therefore, as both countries become more open, the less it matters how the underlying $i - j$ shocks comove and the greater is the importance of the other terms in the formula. Notice that the term would decrease also if the two countries trade only with each other. Then, and this is the second term in the formula, their covariance would increasingly capture the pass-through of each others' shocks (ω_{jj} stands for variance of j's shocks). If i and j trade only with each other and are equally volatile, this term would dominate the first one because variances ω_{ii} are larger than covariances ω_{ij}.

What if trade costs (and other parameters) are such that there is no direct trade between i and j but both i and j trade with other countries? Then covariance between i and j's growth would become increasingly determined by the last factor in the formula, which describes how exposed country i is – through trade linkages $\overline{d}_{ik}$ – to shocks that tend to affect (assuming $\omega_{ik} > 0$) both i's trade partners and j; and vice versa, how exposed j is – through shares $\overline{d}_{jk}$ – to shocks that affect j's trade partners and i. Together, these are weighted covariances between own trade partners and the other country in the pair. The term will rise when, say, country i trades with countries, whose shocks comove with j. Notice that it does not require that j also trades with these countries, it only considers their underlying covariances. In other words, covariance of GDP growth between i and j depends on how j comoves with countries i trades with and vice versa. If j tends to get similar shocks as a third country m, then through i's exposure to m the shocks i implicitly gets are those that affect j as well.

This result sheds light on the specification strategy for an empirical investigation of trade and comovement. As discussed in the introductory part of the paper, the typical

approach is to relate a measure of comovement between a pair of countries to a set of bilateral characteristics, including a measure bilateral trade intensity. The model, however, suggests that there is a need for controlling for the underlying covariances among *all* countries one of the pair trades with, for otherwise the last term in the equation above generates a systematic 'error' in the association of trade between two countries and their comovement. This error arises because the covariance between i and j's growth is systematically affected by each of the countries' trade with others that comove with its counterpart in the pair. The strength of this link is pair-specific and therefore it will not be treated with country-specific dummies. We will inspect the quantitative significance of this channel in the empirical part of this paper.

Until now, we have described the channels through which covariances are affected by trade in our model. By doing so, we have implicitly assumed that trade has no effect on countries' volatility, which meant that covariances were directly comparable. However, as trade can decrease or increase variances, depending on the particular characteristics of a country's trade partners so the changes in covariances induced by trade could, in principle, we amplified or counterbalance by the effect of trade on volatility. Let us now therefore extend the analysis to a more general case and see what would be the impact of trade on correlations – a dimensionless measure of linear comovement. The results described so far remain relevant because correlations are covariances scaled by the product of standard deviations.

Variance of i's GDP growth in our model is as follows

$$Var(\hat{y}_i) = Cov(\hat{y}_i, \hat{y}_i) \simeq \frac{\theta^2}{(\beta+\theta)^2} \left\{ \omega_{ii} + 2\, c_d \sum_{k=1}^{n} \overline{d}_{ik}\, \omega_{ik} \right\}$$

which is variance of own shocks plus a weighted average of covariances that i imports through trade (including from itself). If i and its trade partners tend to be hit by similar shocks, i's volatility will be higher compared with what it would have been otherwise. As said, correlation is covariance between i and j over the product of i and j's standard deviations. Notice therefore that the product in the denominator will be high if both i and j are trading with countries that tend to get similar shocks as i and j, respectively, increasing thus their volatility.

Combine the results for covariance and variances (the numerator and denominator of

the expression below) gives the following formula for correlation between i and j's growth:

$$Cor(\hat{y}_i, \hat{y}_j) \simeq \frac{\left(1 + c_d\left(\overline{d}_{ii} + \overline{d}_{jj}\right)\right)\omega_{ij} + c_d\left(\overline{d}_{ij}\,\omega_{jj} + \overline{d}_{ji}\,\omega_{ii}\right) + c_d \sum_{k\neq i,j}\left(\overline{d}_{ik}\,\omega_{kj} + \overline{d}_{jk}\,\omega_{ik}\right)}{\left(\omega_{ii} + 2\,c_d \sum_{k=1}^{n} \overline{d}_{ik}\,\omega_{ik}\right)^{1/2}\left(\omega_{jj} + 2\,c_d \sum_{k=1}^{n} \overline{d}_{jk}\,\omega_{jk}\right)^{1/2}}$$

With this formula at hand, we can conjecture about the relative roles of the direct- and indirect-trade channel on correlations. First, let us summarise the results for bilateral trade intensities $\overline{d}_{ij}$ (direct trade between i and j). If i and j trade only with each other, are symmetric in every respect, and $\mathbf{\Omega}_z$ is an identity matrix, correlation between i and j simplifies to

$$\frac{2\,c_d\,\overline{d}_{12}}{1 + 2\,c_d\,(1 - \overline{d}_{12})}$$

The derivative of this expression with respect to $\overline{d}_{12} = \overline{d}_{21}$ is clearly positive. Direct trade, in this stylized setting, increases bilateral correlation because it makes countries exposed to each others' shocks, while simultaneously decreasing their volatility (trade with a country whose shocks are uncorrelated with the domestic ones works as a hedge against own shocks).

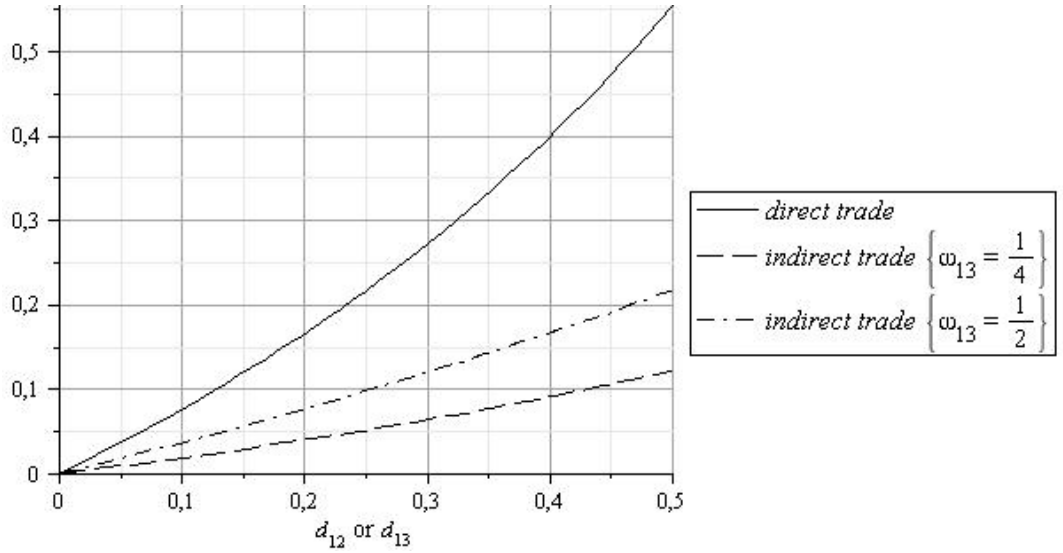
Secondly, consider the case with **no direct trade between i and j** but non-zero trade with a third country. Assuming the same kind of symmetry as above, correlation between i and j is

$$\frac{2\,c_d\,\overline{d}_{13}\omega_{13}}{1 + 2\,c_d\,(1 - \overline{d}_{13}) + 2\,c_d\,\overline{d}_{13}\omega_{13}}$$

which shows that trade with the third country matters, to the first-order approximation, only if it has non-zero covariance with one country in the pair. For $\omega_{13} > 0$, there will be a positive effect on i and j's covariances because the country they trade with tends to get similar shocks as the two countries. Variance is affected as well; first because there is lower exposure to domestic shocks and secondly, trade with the third country brings another opportunity for diversification of shocks. With equal variances of shocks, the former will always dominate the latter and variance of GDP growth unambiguously decreases. We have thus established that indirect trade with a country that tends to get similar shocks as i or b gives rise to positive correlation between i and j even if there is no trade between i and j directly. The size of the effect rises with the intensity of trade with the third country and with the magnitude of cross-covariances ω_{13}.

However, the relative force of the third-country channel will, other things equal, be smaller than of the direct-trade channel above because the same factor that drives positive covariances (correlated shocks between i/j and the third country) will, at the same

Figure 1: Correlation between i and j's GDP growth: Move from autarky to trade



Note: The figure shows the change in $Cor(\hat{y}_i, \hat{y}_j)$ as countries move from autarky to trade. There are three countries i, j, and k of equal size, for different values of trade intensity. The full line is a case with direct trade between i and j but no trade with k, symmetric trade costs and $\mathbf{\Omega}_z = Cov(\mathbf{Z})$ an identity matrix. The two other lines show the same correlation when there is no direct trade but both i and j trade (symmetrically again) with k. $\mathbf{\Omega}_z$ is a diagonal matrix with nonzero $\omega_{i3} = \omega_{j3}$, taking values as shown in the figure.

time, limit the possibility for diversification of shocks. Figure 1 compares the impact on correlation between i and j when countries move from autarky to a) direct trade (full line) and b) to trade with a third country (dashed lines). As argued, the quantitative impact of direct trade on correlation is larger than the effect of the indirect trade (in this stylised setting). However, the latter is by no means insignificant and depends on the magnitude of covariance between shocks.

3.2 Sensitivity analysis

We now return to the general formula for covariances (12) and present several experiments that assess the robustness of the results we have presented so far to other parameters in the model. In order to make the analysis tractable, we need to make assumptions about the structure of the terms in expected values in (12): covariances of trade shocks, covariances of country-specific shocks and their cross covariances[9].

Regarding trade shocks, let us denote σ_κ the variance of trade shocks $\hat{\kappa}_{ij}$ and $\sigma_{\kappa\kappa}$ the covariance between trade shocks across pairs. Let these be the same for all country

[9]The matrix of cross-covariances of trade and country-specific shocks is the expression in the second and third line in (12). The sum of the two lines is a symmetric square matrix.

pairs. The symmetry in $\hat{\kappa}$s and the fact that $\kappa_{iit} = 1$ (and therefore $\hat{\kappa}_{iit} = 0$) implies a particular form of the covariance matrix $\mathbf{\Omega}_\kappa$. Appendix A.2 gives an example of how this matrix looks like for three countries. As before, we denote $\mathbf{\Omega}_z$ the covariance matrix of country specific shocks with elements ω_{ij}. Cross-terms $\mathbf{\Omega}_{\kappa z}$ capturing covariances between country-specific shocks and trade shocks are assumed fixed at $\sigma_{\kappa z}$, except for those with $\hat{\kappa}_{iit} = 0$, where they will be zero. With this notation, covariance of GDP growth rates is

$$\begin{aligned} Cov(\mathbf{y}) = \frac{1}{(\beta+\theta)^2}\,\mathbf{M}(\mathbf{D})^{-1}\Big[\,&(2+\theta)^2\,\mathbf{D_L}\,\mathbf{\Omega}_\kappa\,\mathbf{D_L}^T \\ &+\theta\,(2+\theta)\,\mathbf{D_L}\,\mathbf{\Omega}_{\kappa z}\Big(\mathbf{I}+(1+\theta)\,\mathbf{D}^T\Big) \\ &+\theta\,(2+\theta)\,\Big(\mathbf{I}+(1+\theta)\,\mathbf{D}\Big)\,\mathbf{\Omega}_{\kappa z}^T\mathbf{D_L}^T \\ &+\theta^2\,\Big(\mathbf{I}+(1+\theta)\,\mathbf{D}\Big)\mathbf{\Omega}_z\Big(\mathbf{I}+(1+\theta)\,\mathbf{D}^T\Big)\Big]\,\Big(\mathbf{M}(\mathbf{D})^{-1}\Big)^T \end{aligned}$$

Within this framework, we carry out several simulations:

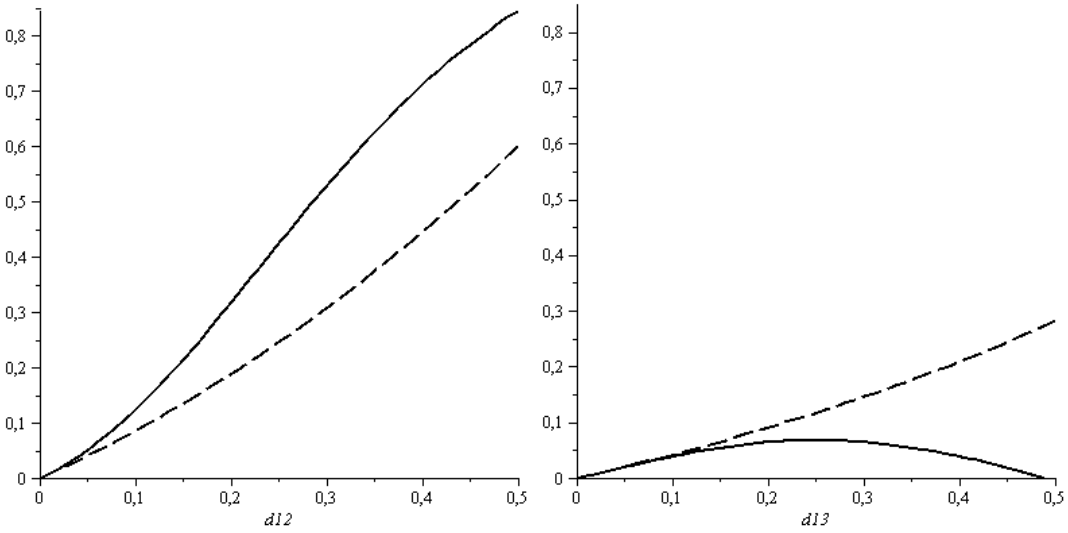
Volatile trade shocks: When trade shocks are allowed to vary, each country pair receives an additional source of perfectly correlated shocks (correlated within the pair), where the latter follows from our assumption of symmetric trade costs. Not surprisingly, this makes bilateral correlations increase for countries that directly trade with each other. Mathematically, the term $\mathbf{D_L}\,\mathbf{\Omega}_\kappa\,\mathbf{D_L}^T$ within the covariance matrix adds the additional variance (weighted with direct trade shares) and covariances that may affect each of the pair via its trade partners:

$$ij \text{ element of } \mathbf{D_L}\,\mathbf{\Omega}_\kappa\,\mathbf{D_L}^T = \overline{d}_{ij}\overline{d}_{ij}\sigma_\kappa + \sum_{k\neq j}\sum_{l\neq i}\overline{d}_{ik}\overline{d}_{jl}\sigma_{\kappa\kappa}$$

If the two countries trade with a third country but no with each other and if covariance among trade shocks are zero across pairs, covariance of their growth rates will not be affected because they do not benefit from the additional source of perfectly correlated shocks, unlike in the case with direct trade. However, since each of the countries will now become exposed to this new source of shocks through its trade with the third country, their volatility will rise. Therefore, correlation between their GDP growth rates offsets the indirect-trade channel described above so that, as trade with the third country increases, correlations start falling again. See Figure 2 for an illustration.

Volatile, correlated trade shocks: When trade shocks are correlated across country pairs, then it increases comovement because trade partners in the pair become subject to more similar shocks. Naturally, for a pair that trades solely with each other, this makes

Figure 2: Correlation of GDP growth: Volatile trade costs

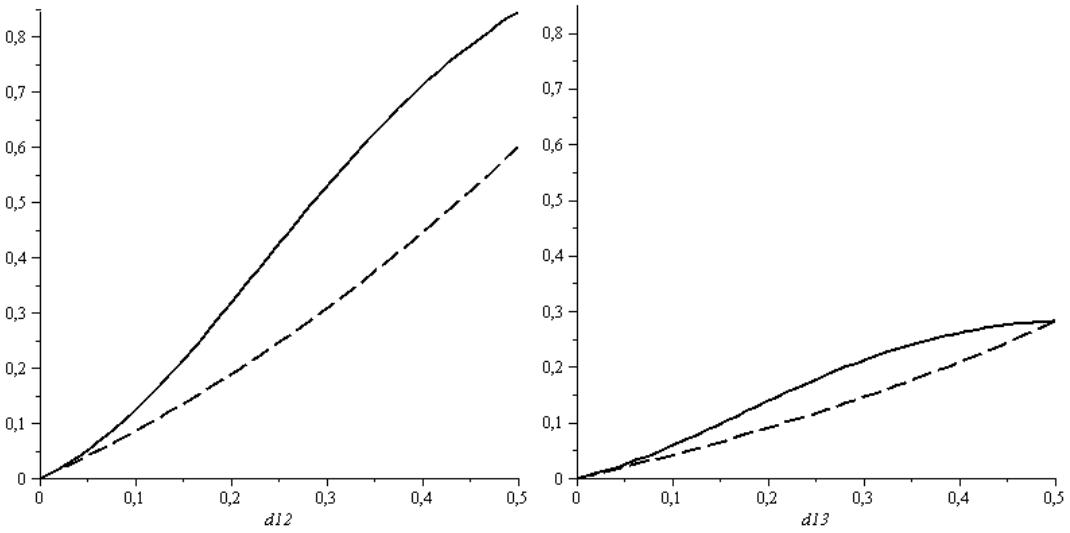


Note: The figure shows the change in $Cor(\hat{y}_1, \hat{y}_2)$ compared with autarky. *Dashed line = Baseline*: $d_{12} = d_{21}$ (left panel) or $d_{13} = d_{23} = d_{31} = d_{13}$ (right panel), no trade otherwise, $\mathbf{\Omega}_z = \mathbf{I}$ (left panel) or $\omega_{13} = \omega_{23} = 1/2$ (right panel), $\mathbf{\Omega}_k = \mathbf{0}$, $\mathbf{\Omega}_{zk} = \mathbf{0}$. *Solid line*: $\mathbf{\Omega}_k$ with $\sigma_\kappa = 1$ and $\sigma_{\kappa\kappa} = 0$.

no difference (the left panel of Figure 3 is indistinguishable from the one in 2). In the opposite case, for countries that do not trade with each other, the fact that they tend to get coincident trade shocks makes them more correlated. In the formula above, this would be captured with nonzero terms $\sigma_{\kappa\kappa}$.

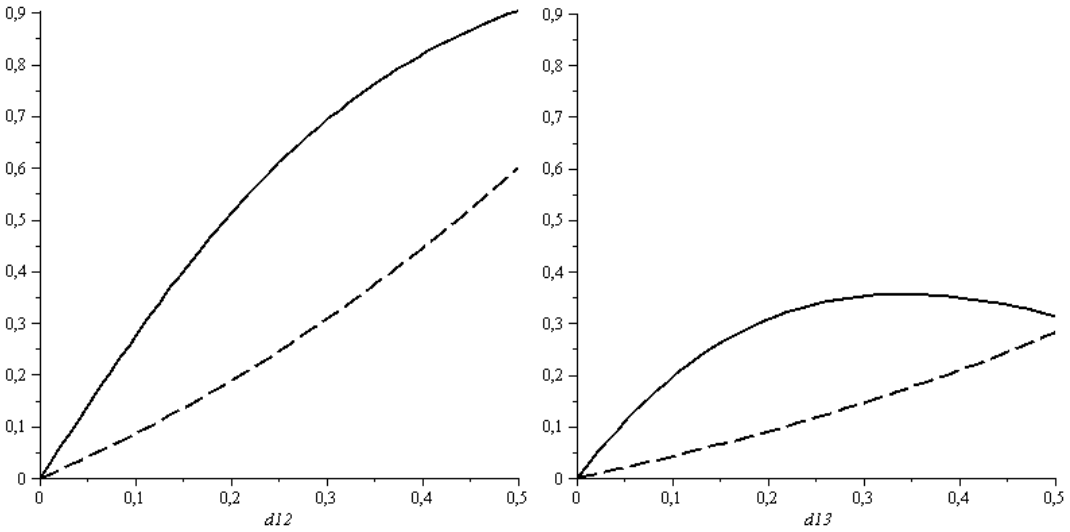
Volatile trade shocks correlated with country-specific shocks: If κs tend to be high (a positive trade shock) when country-specific productivity shocks are high, their joined effect is more pronounced and countries become more correlated. The intuition is similar as for the previous case but the effect is stronger for both scenarios. In the one with direct trade, not only are trade shocks perfectly correlated within the pair (by the symmetry) but they now also tend to comove with both shocks. Because of the symmetry, they amplify bilaterally-good or bilaterally-bad shocks and moderate the opposite ones, which strengthens the diversification nature of trade. In the scenario with indirect trade only, the additional comovement is generated through an identical mechanism but this time with respect to the third country.

Figure 3: Correlation of GDP growth: Volatile, correlated trade costs



Note: The figure shows the change in $Cor(\hat{y}_1, \hat{y}_2)$ compared with autarky. *Dashed line*: Baseline, see Figure 2 for details. *Solid line*: $\mathbf{\Omega}_k$ with $\sigma_\kappa = 1$ and $\sigma_{\kappa\kappa} = 1/2$.

Figure 4: Correlation of GDP growth: Volatile trade shocks correlated with $\hat{z}$



Note: The figure shows the change in $Cor(\hat{y}_1, \hat{y}_2)$ compared with autarky. *Dashed line*: Baseline, see Figure 2 for details. *Solid line*: $\mathbf{\Omega}_k$ with $\sigma_\kappa = 1$ and $\sigma_{\kappa z} = 1/2$.

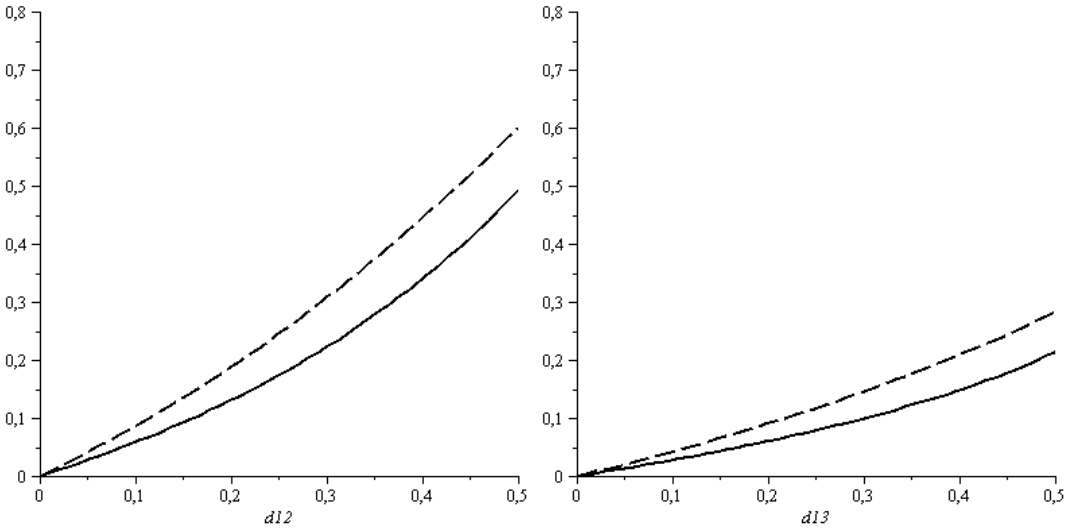
Greater θ: The final exercise we present is to verify that our main conclusions presented so far are robust to different values on θ[10]. This parameter determines the shape of the distribution from which productivity shocks are drawn. As said, higher θ means that shocks are more volatile. Recall that when we described the solution to our model in section 2.1, we argued that shocks affect the model economy through several channels, with one of them operating through changes in relative prices. This mechanism was shown to be positive related to θ in the log-linear approximation of the model. Higher θ therefore makes prices, relative demands for goods and hence also output more sensitive to shocks, increasing thus the potential for exploiting the country's comparative advantage. This is to say that production processes become less similar across countries and therefore their covariance decreases. Likewise, volatility should increase, which leads to an overall fall in correlations and smaller power of trade to generate comovement. Figure 5 quantifies this mechanism for the two special cases of openness and for $\theta = 0.5$ versus $\theta = 0.7$. The effect, while significant, is quantitatively smaller than the effects of the above reported exercises and importantly, it does not change the conclusions qualitatively.

4 Quantitative exercises with data

In this section we look at the relationship between trade and GDP correlations, as observed in data, through the optic of the model we studied in the preceding sections. To accommodate the range of parameters we obtain from data, we work with the fully-fledged (not linearised) version of the model and use numerical techniques to compute its solution. The model allows us to investigate various aspects of data to judge the quantitative significance of the competing theoretical factors. Our strategy therefore is to experiment with the pattern of empirical trade linkages, compute alternative GDP growth rates for all countries and years, obtain bilateral correlations Cor_{ij}^{ex} and compare them with those in the baseline. The baseline scenario is based on country-specific shocks $\hat{z}_{it}$ and trade shocks $\hat{\kappa}_{ijt}$ exactly as found in data. Shocks $\hat{z}_{it}$ are taken as exogenous and do not vary across simulations. Trade imbalances are used in the mapping of observables to parameters used

[10]We do not report a similar exercise with respect to parameter β because it has a clear counterpart in data. Let us only note that changes of β of the same magnitude as we make to θ produce similar changes to our figures – but of the opposite sign. Recall that β is the share of the unproduced input in our model (equipped labour); higher β therefore decreases the share of traded intermediates, which mutes the response of output to shocks, both foreign and domestic (see (11)) and makes countries more correlated.

Figure 5: Correlation of GDP growth: Role of θ



Note: The figure shows the change in $Cor(\hat{y}_1, \hat{y}_2)$ compared with autarky. *Dashed line*: Baseline with $\theta = 0.5$, see Figure 2 for details. *Solid line*: $\theta = 0.7$.

in the model but are ignored in the quantitative simulations (they are not explained by the model).

The road map for our work is as follows:

1. We start with a description of our sample and of the data we use in the model. We also provide a check that the baseline, to which we compare all subsequent simulations, matches the correlations found in data.

2. The first question we investigate is the quantitative power of trade to generate comovement. We do so by comparing the results of the model with baseline trade costs and to the volatility that would prevail in autarky.

3. We further examine the properties of trade costs and test whether it is the average level of trade costs, their trend changes over time or their volatility (trade shocks) that drive the results.

4. We then move to study several candidate mechanisms through which trade could play a role as a channel for transmission of country-specific shocks. Namely, we ask:

    - What part of bilateral correlations can be accounted for by *direct* trade within each pair of countries and what is due to the *indirect* trade with all other countries?

- If the indirect-trade channel turns out important, then which countries matter? Big common trade partners? Big global players overall? Can theory guide us in pointing out to countries that account for most of the effect of the indirect trade?

4.1 Parametrisation of the model

Our sample consists of $n = 69$ countries and an additional aggregate for the rest of the world (ROW). Out of the biggest 30 countries in the world only Russia (together with other post-Soviet republics) is merged in the ROW[11]. The 69 sample countries accounted jointly for 95% world nominal GDP in 2005. Our focus is on annual data from the period 1989-2011; with this choice we mean to take into account the changes in trade linkages brought about by the overall expansion in trade that started to gather pace from 1980s and also take into account the fall of the iron curtain. The length of the sample period is also dictated by sufficient availability of trade data for the large number of country pairs we work with.

There is n^2 parameters in the model we need to identify for every year of data: $n-1$ trade shares d_{ij} for every country i and n productivities Z_i. Starting with trade shares, d_{ij} is the share of goods produced in country j in total demand for goods in country i. Its definition in the model is

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

with d_{ii} implied from the restriction $\sum_j d_{ij} = 1$. We take imports I_{ij} and trade imbalances S_i from IMF Direction of Trade Statistics (see Appendix A.3 for a more detailed description of all variables). Variable $GNO_i \equiv \int p_i(x) q_i(x) d\Phi(x)$ is the value of total production, or gross output.

Collecting reliable data for gross output is a challenging task because adequately long time series are available only for a handful of countries (more or less those covered in EU KLEMS). However, the study of comovement requires a large sample of countries otherwise the residual ROW aggregate quickly starts dominating the comovement patterns for the majority of countries[12].

[11] Other important countries (ordered here according to their 2005 nominal GDP in US$) treated as the ROW include Iran, Hong-Kong (China), the Czech Republic, Singapore, Slovakia, Vietnam, Croatia and Libya. See Appendix A.5 for a list of countries and country codes.

[12] Even with 69 largest countries in our sample, the ROW still accounts for 5% of world GDP and is the 5^{th} largest economy in the model.

We therefore by-pass the need to use (or even estimate) gross output data for a large selection of countries and make a pragmatic assumption that output is a fixed multiple of GDP: $GNO_i = GDP_i/\beta$, where $\beta = 1/2$. This assumption is consistent with our model because gross output *data* (even if statisticians were able to estimate it with a high degree of reliability) are affected by processes that are not captured in the model. Namely, gross output crucially depends on the degree of integration of production processes, which may differ across countries and, more fundamentally for our needs, within a country over time. This is largely relevant for the transition economies included in our sample (most notably China) but it is of some importance also for developed countries, where the organisation of production processes may for instance respond to changes in tax or accounting laws. However, whether a company produces a part of a machine in-house or sublets the task to another domestic company may be irrelevant for the amount of goods the economy trades externally. Yet, it would affect the gross output series and therefore our measures of openness and trade costs. Added to this, the effort statisticians put to constructing a consistent series of gross output is also typically lower than is the case of other key aggregates. Based on this, our trade shares are identified as

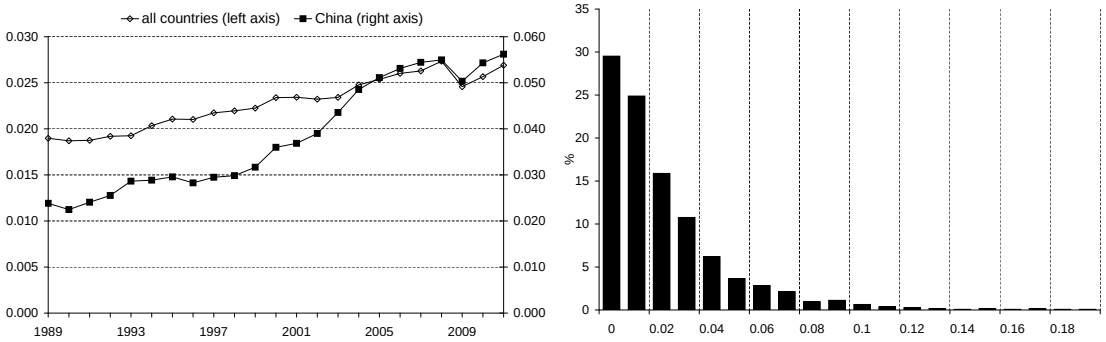
$$d_{ij} = \frac{I_{ij}}{GDP_i/\beta - S_i}$$

With a measure of d_{ij} and assuming symmetric trade costs $\kappa_{ij} = \kappa_{ji}$, as we do consistently throughout this paper, equation (6) implies

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

which means that trade costs are completely determined by the trade shares defined above. This procedure gives a point estimate of trade costs for each of the more than 2000 country pairs every year. Annual averages of trade costs are shown on the left panel of Figure 6. Notice that they are enormous: the average value of κ_{ij} overall is 0.03 (median 0.02), where $\kappa_{ij} = 0$ ensures zero trade between i and j and $\kappa = 1$ is a situation where across-the-border trade is equally costly as domestic trade. Highest values of κ are recorded between Belgium and the Netherlands (0.23), the U.S. and Canada (0.18), and further among Germany and the Netherlands/Belgium/Austria, Belgium and France, and the U.S. and Mexico. A longer list of country pairs with lowest bilateral trade costs is reported in Figure 14. Also note that κs grow over time: average κ increase from 0.019 to 0.027 in our sample period, where the trend is much more pronounced for some countries. For instance, average trade costs of all countries with China rise from 0.02 to 0.06 over the same period. The distribution of average trade costs (per country pair over time) is shown on the right panel of Figure 6.

Figure 6: Average trade costs and distribution of κ_{ijt} in 1989-2011



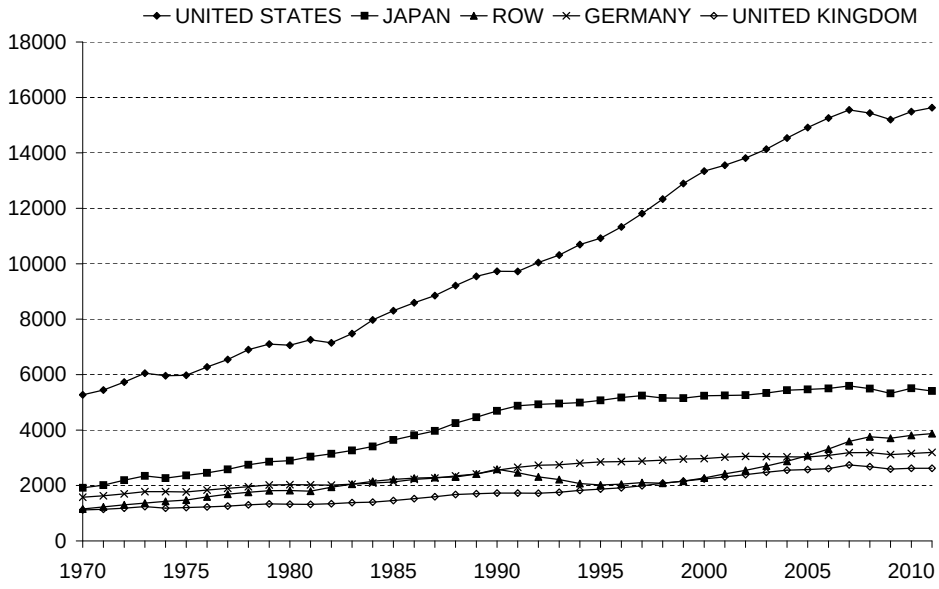
Turning to the productivity measure Z_i, equation (6) again can be used to express real aggregate GDP as:

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

from which we can obtain a measure of shocks Z_i. As the focus of our work is at the comovement of GDP fluctuations, we base our results on constant-price GDP growth rates computed with local-currency GDP data and anchor the series to the 2005 levels of GDP expressed in USD. For the baseline, we favour using GDP levels converted by actual exchange rates rather than PPPs because PPPs reflect domestic purchasing power (in comparable terms) rather than actual purchasing power abroad that is key for the transmission of demand shocks. Shocks Z_{it} for 10 biggest countries in the model are shown in Figure 7. Finally, we choose $\theta = 1/2$. Simulations reported in the previous section confirmed that both our qualitative conclusions and broadly also the quantitative estimates we make are robust to different values of this parameter.

How good is the fit of our model? We would expect the fit be quite good overall because the same variables that we use to identify the model parameters are those that we expect to get from the model. However, we do not aspire to match individual bilateral correlations because there are two sources of discrepancy that are going to worsen the pair-by-pair fit of the model: the model (1) imposes symmetry on trade costs, and (2) ignores trade imbalances. A comparison of correlation matrices is not straightforward because it involves checking of $\frac{n(n-1)}{2}$ entries; with 70 countries this is 2415 bilateral correlations of GDP growth rates. The first check we do is plotting all bilateral correlations in a scatter plot that shows, pair-by-pair, how successful the model is in matching correlations found in the data, i.e. in generating the same type of comovement. This is the left panel of Figure 8. We interpret the figure as giving quite strong support to the model. Obviously, there is a significant amount of mismatch but only few correlations that were significantly

Figure 7: Shocks Z for 10 biggest countries



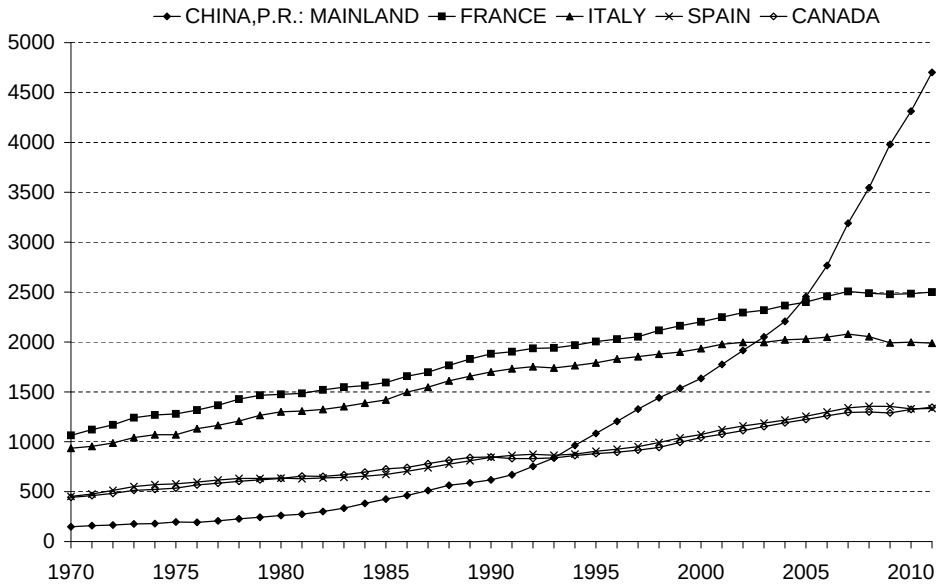
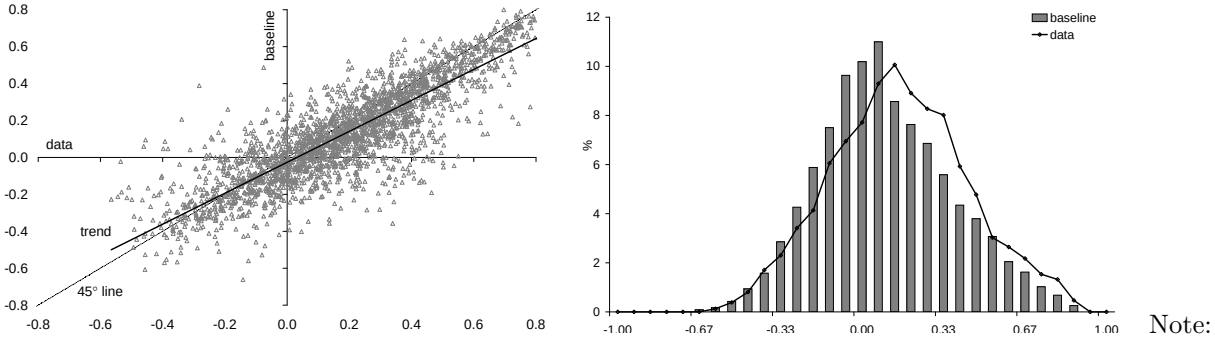


Figure 8: Model v Data



Note: The scatter plot shows correlations of GDP growth rates in data (horizontal axis) and as computed by our model and the histogram plots their respective distributions.

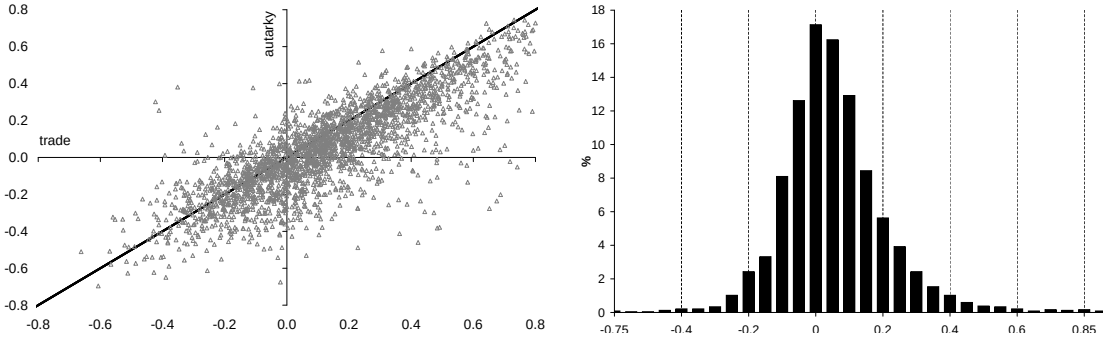
positive or negative in the data take the opposite sign in the model. Correlation between the data and model series is positive and high (0.86) and the slope of the trend line we fit through the data is lower but close to the 45° line.

The right panel of the figure report histograms of the bilateral correlations from the model (bars) and from the data (line). The point of plotting distributions is to contrast the level of dispersion and other characteristics of both series. In this particular case, the mean of correlations computed from the model is lower than found in the data (0.13 v 0.18) and the difference is more pronounced for the median of the distribution (0.11 v 0.18). To put it differently, the model-generated distribution is more skewed to the right (skewness of 0.27 v 0.09). This is not surprising; the symmetry imposed by the model makes it generate correlations centred closer to zero because trade costs within the pair, averaged by the symmetry, will be generally closer to zero except for the cases when the underlying trade intensities we use to compute κs were high for both countries in the pair. Finally, let us note that there is about the same level of variance in both distributions (0.27 v 0.28). Overall, both the scatter plot and the distributions buttress our confidence that the model is capable to replicate the data we put in in both the qualitative and quantitative sense.

4.2 Autarky versus baseline

Having discussed the choice of parameters and the fit of the model, the first question we investigate is the quantitative power of trade to generate comovement. We do so by comparing the baseline results from the model with correlations that we obtain by assuming complete autarky. In this case, $\kappa_{ijt} = 0$ for all $i \neq j$ and $\kappa_{ijt} = 1$ for $i = j$. We have shown above that since the only source of volatility in autarky are the country-

Figure 9: Trade v Autarky



Note: The scatter plot shows bilateral correlations with trade costs as in the data (horizontal axis) against correlations in autarky. The histogram plots the distribution of the absolute change in bilateral correlations induced by trade.

specific shocks Z_{it}, comovement in GDP growth rates is bound to mimic the correlations in productivity shocks. Should trade have only a marginal effect on correlations, we would expect that baseline correlations be close to those in autarky, i.e. close to the 45° line in the scatter plot Figure 9. However, we observe a lot of variation around the diagonal line. Since these two scenarios differ only with κs, we conclude that trade does significantly affect bilateral correlations.

What can we say about the direction of the effect? Observations below the 45° line in the figure are the bilateral correlations that have increased with trade compared with their values in autarky; the strength of the effect rises with the distance to the 45° line. This is the case for 71% pair-wise correlations while for the remaining 29% pairs, trade makes bilateral correlations lower than would be the case in autarky. The histogram of trade-induced changes in correlations (absolute differences to autarky correlations) is depicted on the right panel of the figure. The (unweighted) average of the distribution is 0.08 and median 0.06 but there is a significant amount of variability in the effects on particular correlations (standard deviation is 0.15) and the distribution is strongly skewed to the right. The point me take from this exercise is that trade has a significant effect on bilateral comovement, which is on average positive but the particular outcome depends on how much and with whom a country trades (this is consistent with the theoretical formulas derived in Section 3.1).

4.3 Role of trade costs

The question is then whether the change in comovement due to trade is driven primarily by the *level* of trade costs or rather by the additional volatility brought about by changes

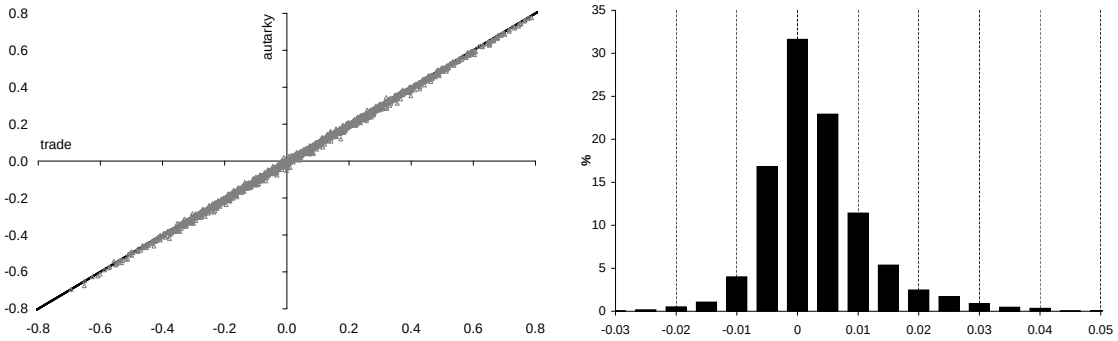
in κ_{ijt}. According to the simulations presented in this section, the answer is that the 'level' effect (of average trade costs) has a relatively small impact on correlations in our sample. The fact that trade costs change over time but also that they are inherently volatile, account for a larger part of the overall effect.

First, we test the 'level' effect by asking what would the change in bilateral correlations (compared with autarky) be had trade costs been fixed over time at the bilateral averages: $\kappa_{ijt} = \overline{\kappa_{ijt}} \geq 0$. Figure 10 shows the scatter plot and histogram analogous to the case with actual κ_{ijt} presented above (notice the difference in scale in the histogram here relative to Figure 9). Clearly, correlations differ only marginally from those experienced in autarky; the mean and median change in correlations is 0.01 with standard deviation less than 0.01. Why is it the case?

Part of the explanation for the small effect of the *level* of openness is that moves in κ from zero (autarky) to $\overline{\kappa_{ijt}}$ generally do not map one-to-one to changes in correlations; the correlation coefficient between average trade costs, i.e. $\overline{\kappa_{ijt}} - 0$, and the changes in correlations generated by them is only 0.5. However, the small average size of κ also plays a role. The right panel of Figure 11 presents the histograms of changes in bilateral correlations (compared with autarky) computed with $\kappa^{*}_{ijt} = 2 \cdot \overline{\kappa_{ijt}}$ and $\kappa^{**}_{ijt} = 3 \cdot \overline{\kappa_{ijt}}$, i.e. with still zero trade shocks but twice and three-times higher levels of κs (smaller trade costs). For the sake of comparison, also shown are the previously discussed distributions obtained with $\overline{\kappa_{ijt}}$ (full line) and the baseline distribution with trade shocks κ_{ijt} (with markers), and a scatter plot of correlations with $\kappa^{**}_{ijt} = 3 \cdot \overline{\kappa_{ijt}}$ against autarky. Both figures suggest that the level of trade costs has, in principle, the power to generate a quantitatively significant change in correlations. However, the average level of trade costs in our sample is too small to do so. On a 0-1 scale, with 0 being autarky and 1 costless trade, the average value of κ_{ij} is only 0.03 (median 0.02) with maximum of 0.23 recorded between Belgium and the Netherlands (see Figure 6 for the distribution of κs). When $\overline{\kappa_{ijt}}$ doubles and triples, the mean change in correlations (v autarky) rises from 0.01 to 0.02 (median 0.02) and to 0.04 (median 0.03), respectively.

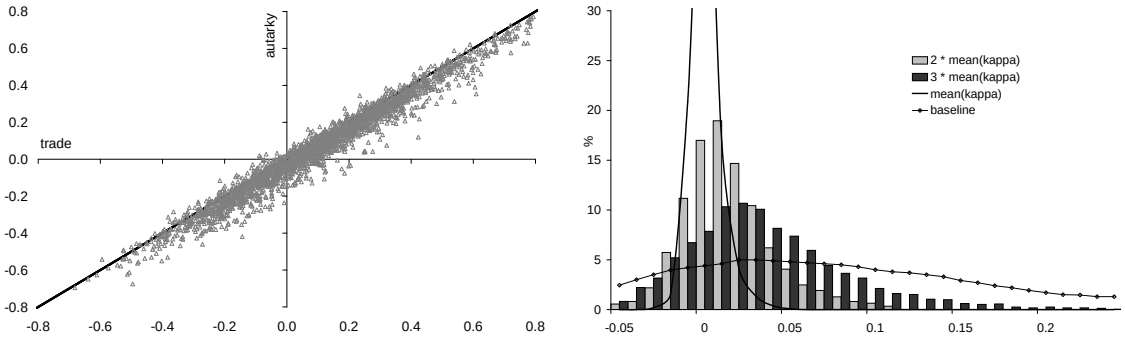
Having discussed why the 'level' effect of lowering trade costs is quantitatively small in our sample, the next question is what other factors are behind the large effects of trade overall, as shown in Figure 9. They could be due to strong trends in κ_{ijt}, the volatility around the trends (pure trade shocks), or both. We have illustrated in Figure 6 that κs do grow over time and for some countries, especially those that experienced a rapid integration into world trade channels in the sample period, the trend in κs is enormous. Cheaper and faster means of transport make the case of a synchronous downward trend

Figure 10: Correlations with trade and in autarky – with constant trade costs



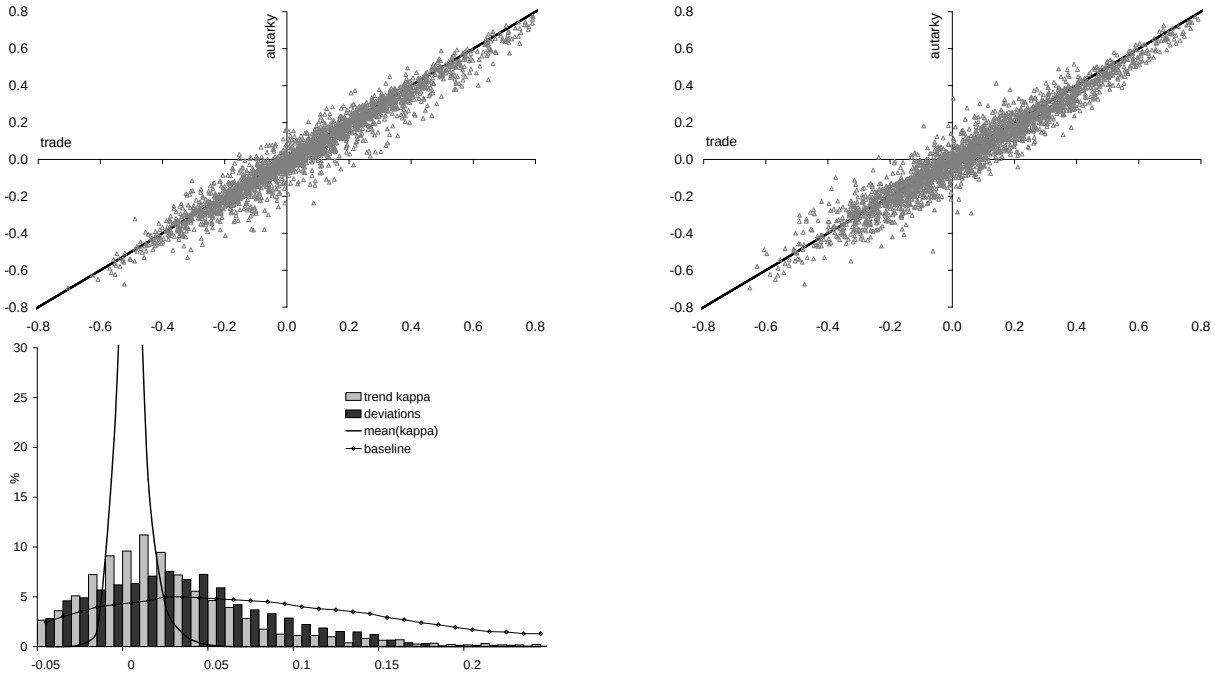
Note: The scatter plot shows bilateral correlations without trade shocks (horizontal axis) against correlations in autarky. The histogram plots the distribution of the absolute change in bilateral correlations induced by the *level*-change in trade costs.

Figure 11: Histogram of correlations with constant trade costs – larger κ



Note: The scatter plot shows bilateral correlations with constant $\kappa_{ijt}^{**} = 3 \cdot \overline{\kappa_{ijt}}$ (horizontal axis) against correlations in autarky. The histogram plots the corresponding distributions of changes in bilateral correlations (compared with autarky).

Figure 12: Histogram of correlations with smoothed and detrended trade costs



Note: The scatter plots shows bilateral correlations with smoothed κ_{ijt} (top left panel) and detrended κ_{ijt} (top right panel) against correlations in autarky (vertical axis). The histogram plots the corresponding distributions of changes in bilateral correlations (compared with autarky).

in trade costs intuitively appealing. We therefore ask whether synchronised trends in κ could explain the observed change in bilateral correlations.

We examine this question by using, first, trends extracted from κ_{ijt} with an HP filter[13], and secondly, relative trade shocks applied to the sample and cross-country average $\kappa = 0.03$. Results are presented in Figure 12. What we learn from this figure is that both trend changes in κ_{ijt} and shocks to trade costs matter more for comovement than the average level of κ_{ijt}. The distributions of changes in correlations computed in these scenarios are closer to the baseline than those computed with constant κs. Means and medians of both distributions are still small 0.02 (compared with 0.08 in the baseline) but standard deviations rise to 0.06 and 0.07, respective (compared to 0.15 in the baseline).

To summarise the findings of the exercises presented so far, we have shown that trade matters for cross-country correlations. Opening to trade makes correlations between GDP growth rates increase 0.08 points on average and generates a significant level of dispersion (for half of the country pairs the changes in correlations are either negative and lower than -0.01 or more positive and larger than 0.15 – these are the lower and upper quartiles

[13]We use smoothing parameter 6.25, in line with Ravn (2001).

of the distribution). We have further shown that the main driving force behind the effects of trade on correlations seems to be the movements in trade costs over time; both their (possibly synchronised) trends and fluctuations around trends are important factors in accounting for the dispersion and, to a lesser extent, for the magnitude of the effects of trade on comovement. The average level of trade costs has, on the other hand, had only a little impact so far but could become more significant in the future, if trade costs continue falling.

4.4 Direct versus indirect trade

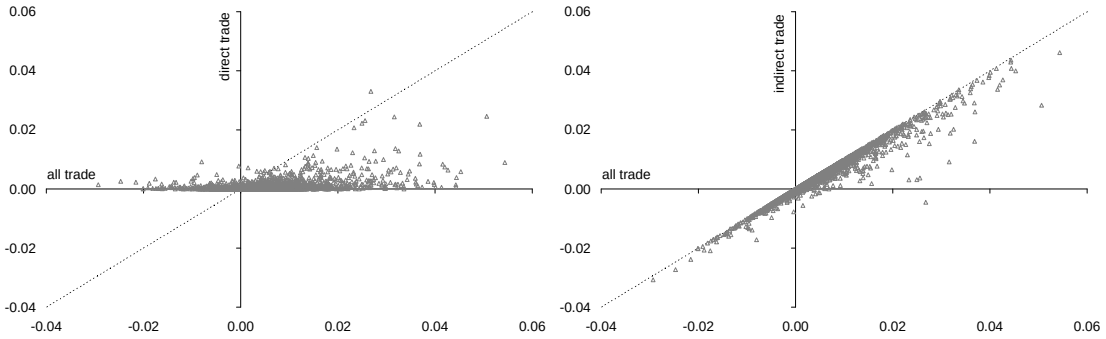
In the exercises that follow, we concentrate on the role of trade in transmitting country-specific shocks. Our aim is to assess the quantitative importance of the two competing channels we have identified in the theoretical section: the role of direct trade linkages between i and j, and the role of indirect trade between i or j with third countries. We have seen above that in a stylised setting with three countries, identical volatilities and full symmetry in trade relationship, the effect of direct trade on bilateral correlations between i and j is relatively larger that that of trade with third countries, in particular if the shocks affecting the third country are not strongly correlated with those hitting i or j. In this section we therefore test to what extent is this stylised setting representative of the patterns in actual data. In order to isolate the transmission role of trade from the effects of falling trade cost or their volatility, we freeze κ_{ij}s at their average pair-specific values.

We proceed as follows: for a country pair a, b, we keep the pair-specific average κ_{ab} as found in data[14] while cancelling all other trade linkages between countries a and b and the rest of the world, as well as among all other countries[15]. In other words, except for trade between a and b there is no other trade taking place globally. With this pattern of trade costs, the model generates a new solution for GDP with a new correlation matrix of growth among all countries. We record the impact on the coefficient of correlation between the concerned country pair and repeat the exercise for another pair. In total, we carry out $n(n-1)/2$ simulations and obtain a matrix of cor^D_{ij} with each element representing correlation between i and j when the only trade these country engage in is trade between them.

[14]For ease of notation, we now ignore bars that in the previous section denoted averages.

[15]To compute cor^D_{ab}, we set $\kappa^D_{ijt} = \kappa_{ijt}$ for $i = a, j = b$ and $i = b, j = a$ (trade costs are symmetric in our model), $\kappa^D_{iit} = 1$ as always for all i, and $\kappa^D_{ijt} = 0$ otherwise.

Figure 13: Effects of direct and indirect trade on comovement



Note: The variables shown in these scatter plots measure changes correlations induced by certain type of trade relative to autarky. In the left panel, we compare the scenario with direct (and no other) trade between two countries to the baseline with all trade, while the right panel compares the scenario with no direct trade. Always with no volatility in trade costs.

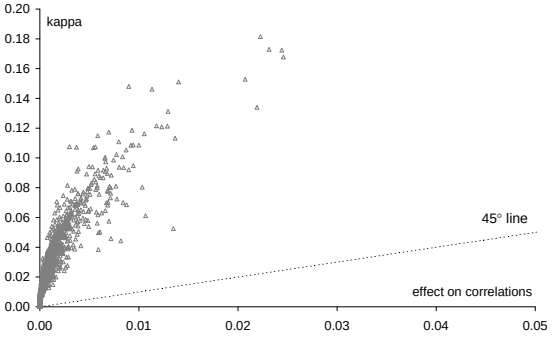
An alternative way of testing the importance of direct trade linkages is to start from the baseline (when all trade costs are at their averages as measured in data) and cancel only the direct pair-specific links between a and b. Recording the bilateral terms computed in this manner in cor_{ij}^{noD} and repeating the simulations for all country pairs, we obtain bilateral correlations that would prevail without any 'direct' trade between a given pair of countries. Figure 13 reports how the scenarios with and without direct trade perform in terms of replicating the changes in correlations obtained with both types of trade (compared always with autarky).

We contrast the changes in correlations obtained in both exercises ($cor_{ij}^{D} - cor_{ij}^{A}$ and $cor_{ij}^{noD} - cor_{ij}^{A}$) with those with both types of trade allowed (baseline with fixed trade costs). Visual inspection of scatter plots presented in Figure 13 suggests that the direct-trade channel performs relatively poorly compared with the indirect one. With only the direct trade, all changes in correlations are positive, which is in line with the conclusions of our theoretical analysis. However, only in few cases is the direct channel able to move correlations substantially towards those computed with both channels 'on'. Viewed from another perspective, closing the direct channel while keeping all the indirect trade is very close to the solution with both channels 'on'.

To quantify the relative role of the two channels, let us decompose the variance of the contribution of trade to correlations (always with fixed κs) to parts accounted for by direct trade, indirect trade and a residual term, respectively. To be precise, we use the following identity:

$$\left(cor_{ij} - cor_{ij}^{Aut}\right) = \left(cor_{ij}^{D} - cor_{ij}^{Aut}\right) + \left(cor_{ij}^{noD} - cor_{ij}^{Aut}\right) + (\text{residual}_{ij})$$

Figure 14: Trade costs and the direct-trade channel



		change in cor	kappa
BEL/LUX	NLD	0.033	0.24
CAN	USA	0.022	0.18
NLD	GER	0.023	0.17
BEL/LUX	GER	0.024	0.17
BEL/LUX	FRA	0.025	0.17
AUT	GER	0.021	0.15
MEX	USA	0.014	0.15
IRL	GBR	0.009	0.15
MALAYS.	THA	0.011	0.15
CHE	GER	0.022	0.13
FRA	GER	0.013	0.13

Note: The figure plots bilateral correlations when the only trade any two countries engage in is trade directly between them (horizontal axis) against the level of trade costs κ for the given country-pair (vertical axis). Cases with greatest impact are listed.

or with short-hand notation:

$$c_{ij}^{All} = c_{ij}^{D} + c_{ij}^{noD} + r_{ij}$$

As in Fujita and Ramey (2008), we then compute the contributions of the terms on the right-hand side to the variance of the dependent variable as follows:

$$Var\left(c_{ij}^{All}\right) = Cov\left(c_{ij}^{All}, c_{ij}^{All}\right) = Cov\left(c_{ij}^{All}, c_{ij}^{D}\right) + Cov\left(c_{ij}^{All}, c_{ij}^{noD}\right) + Cov\left(c_{ij}^{All}, r_{ij}\right)$$

where each of the covariance terms gives the amount of variation in the total contribution of trade to comovement that is generated by the variation in the given variable. Dividing by $Var\left(c_{ij}^{All}\right)$ and multiplying by 100, we obtain the % share of variance explained by each variable. The results are the following: variability in correlations due to direct trade accounts for 9.8% of total variance, variability in correlations due to indirect trade for 90.8% and the residual term for the remaining -0.7%. We therefore conclude that the direct-trade channel tends to explain less than 10% of the 'level' effect of trade on bilateral comovement (keeping in mind that we abstract from any volatility in trade costs).

Not surprisingly, the magnitude of the average trade costs is the key determinant of the strength of the direct-trade channel. See Figure 14 for a plot of the relationship and a table of changes in correlations due to the direct channels for countries that encounter large changes in trade costs.

Why is the indirect channel so powerful in data, compared with the analysis in a stylised setting? There are two reasons. First, with many countries, the exposure to the other country in the pair will typically be (much) smaller than the exposure to all the other countries in the world. Also, the underlying shocks are, on average, weakly but positively correlated. We have shown in the theoretical part that the strength of the

indirect channel rises with openness to third countries and with the correlation of their shocks with the other country in the pair. Therefore, both these factors work jointly to increase the role of the indirect channel compared with the direct one.

4.5 Further thoughts about the indirect-trade channel

Given the significance of the indirect trade, a logical question that arises is what are the important 'third countries' that are responsible for driving the overall effect of the indirect-trade channel. We try to answer this question in three ways. The first and second one are groups of countries that almost automatically suggest them selves given their relative importance in trade of most countries: first, we test the importance for correlations of **big common trade partners** for each pair by pair (keeping all else unchanged); secondly, we test whether the openness or closure of **big global players** matters. To preview the answers, we do not find unambiguous support that one of these groups of countries is the dominant factor behind the 'indirect-trade' channel. Finally, we therefore turn to the theory presented in the previous section to guide us in the identification of the relevant countries.

We do the first two exercises as follows. First, for the n big common trade partners, we start with the baseline with all trade linkages (but average trade costs) and for each pair find the n largest common trade partners based on the geometric average of trade intensities in the baseline and impose prohibitive trade costs between these and i and j. Trade costs for all other countries are as in the baseline. Averaging the d_{ij}s geometrically gives importance to similarity, hence when we then take the first n largest $d_{ik}d_{jk}$, we pick those partners k that are important for both i and j. We do this for all the pairs in the model and record every time the ij element of the correlation matrix. Secondly, for the scenario without the big players, we impose that all countries jointly face prohibitive trade costs against (one country each time): (1) the U.S., then against (2) China, (3) Japan, (4) Germany and (5) the rest of the world aggregate ROW. Finally, we impose prohibitive trade costs against (1-5) jointly. Scatter plots are presented in Appendix A.4.

What do we find? Regarding the role of common trade partners, their presence could, in principle, matter for i and j's comovement given that typically they jointly account for a significant share of the pair's trade. Therefore, one could argue, they represent a potentially important channel for the pass-through of shocks from one country in the pair to the other. The more common partners are dropped, each of the pair could start trading with the remaining countries, potentially each with different ones, which could disrupt the overall pattern of correlations. However, Figures 16 – 20 do not provide

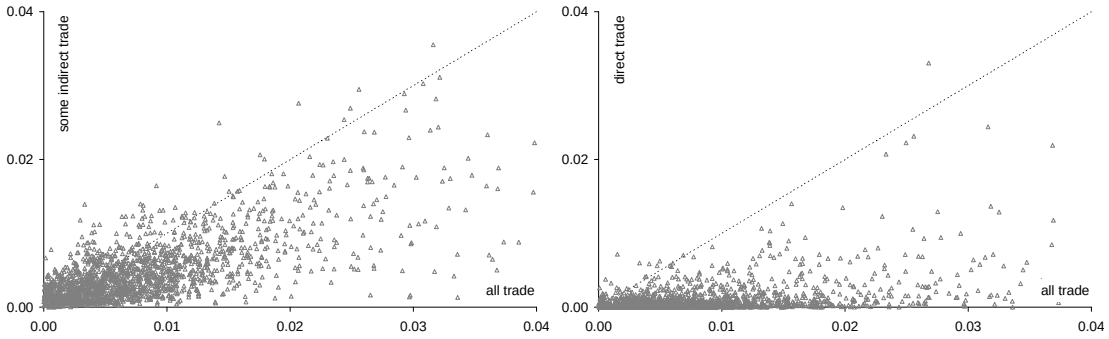
convincing answers. The overall effect of dropping common trade partners does not seem to change correlations in a systematic manner. Those that became high (low) with all trade linkages 'on' compared with autarky typically remain high (low) when common trade partners drop. The majority of observations is still reasonably close to the diagonal line (which plots the baseline changes in correlations). The outliers, for which dropping of common trade partners matters significantly, are relatively scarce, although their number rises as the number of dropped common partners goes up.

Regarding the role of big global players, we do this exercise for the U.S., China, Japan, Germany and the rest-of-the-world aggregate (see Figures 21 – 25). Again, the systematic pattern that was there with all trade seems not to be dramatically affected. We observe the largest effects here in the cases when there is no trade with Germany and the ROW. One could argue that this is because these two countries are strongly integrated (artificially so in the case of the ROW) with a large number of still relatively big countries, playing so the role of a global trade hub. Their collapse (or, better to say, closure) might substantially distort other big countries they trade with, and consequently also the trade patterns of the remaining countries. For Japan and China, the effects are smaller and one could conjecture that this follows from their relatively lower integration with other (larger) countries around the world, so the fact that they disappear from the map of world-wide trade may still disrupt a number of countries (the effect is particularly visible for China), however, the second-order effects are not so damaging as in the case of Germany and the ROW. We would liken them to regional hubs. The U.S. seem to be an intermediate case.

To summarise, the impacts both these groups of countries have on correlations are not as large as one could have expected based on their relative importance (in terms of trade). It seems that the remaining countries, which each pair remains open to, seem powerful enough to deliver a substantial part of correlations between i and j that would be there in the baseline. However, this is not surprising in view of the results we obtained in the theoretical section. We have concluded there that two countries' growth rates will be correlated, among others, if one of the pair trades with another country that tend to be hit by similar shocks as the other country in the pair. To relate this result to the exercises presented here, it suggests that the countries we have dropped (common trade partners or globally big countries) have not fundamentally narrowed the exposure to shocks that *also* affect one of the countries in the pair.

We test whether this conjecture is empirically relevant in the following way. We close all trade (including the direct one between i and j) except five particular trade partners

Figure 15: Direct v indirect trade with a small group of countries



Note: The left scatter plot compares changes in correlations induced by indirect trade with 5 selected countries compared to the baseline with all trade. See main text on how the 5 countries are chosen. The right panel plot similar variable for the case of direct trade only.

of i and five trade partners of j. We illustrate the principle through which we choose them on one of the pair, say country i. First, we require that the chosen trade partners of i get hit by shocks that are positively correlated with j. This ensures that a pass-through of shocks to i that affect also j. Secondly, we require that these countries are negatively correlated with i. We do so in order to provide opportunity for the stabilising effect trade has on volatility. If i trades with someone who tends to get good shocks when i receives bad shocks, both countries become less volatile. Because variance is negatively related to correlations, this factor may also relevant for choosing the 'right' countries. Out of the countries, whose shocks are most correlated with j and least correlated with i, we take five biggest ones. We repeat the same procedure for j. For thus the selected countries k we set κ_{ik} and κ_{jk} equal to their respective averages in data and keep all other (off-diagonal) κs zero.

To see how these 5 countries for i and 5 countries for j matter for i and j's comovement, let us compare changes in correlations we obtain in this exercise (for a lack of a better name, we will refer to it as a **model-based exercise** in what follows) with those for the direct- and indirect-trade channel reported in Figure 13. For greater clarity, we replicate the left panel (direct trade) of the figure together with results of the model-based case in Figure 15, where we change the axis to focus only on cases where trade increases comovement[16].

Based on the results presented in Figure 15, we conclude that the model-based exercise is substantially more successful in matching the baseline correlations than the bilateral

[16]Note that by the setup of the exercise, all correlations will be positive, therefore we do have much to say about the cases where direct or indirect trade leads to negative correlations.

channel. The descriptive statistics for the subsample (65% observations) shown in the figure are as follows: the mean change in correlations (trade v autarky) in the baseline is 0.009; direct trade delivers average change only of 0.001 while the indirect-trade case takes us to 0.008; the model-based case gives 0.005. In terms of volatility, the model-based one generates standard deviations of around two-thirds of the those obtained in the baseline and with indirect trade (0.008 and 0.007 respectively, compared with 0.005 in the theory-guided case), while volatility with direct trade is only 0.002. Overall, the figure suggests that a simple model-based selection of countries is capable to generate the same type of a systematic relationship that we observe in the baseline. For the country pairs where trade with all countries results in positive and high comovement, trade with the few countries selected according to our model gives also systematically higher comovement. The slope of a line fitted through the model exercise is 0.52, compared with 0.87 with all indirect trade and 0.13 with direct trade only. This is in a stark contrast to the cases without several common trade partners and big countries, which were not able to generate systematic departures from the baseline.

5 Conclusions

This paper investigates the relationship between across-the-border trade in goods and comovement in real GDP growth. We use data for a large sample of countries that jointly account for 95% of world GDP. The particular questions we ask are: Does openness to trade affect cross-country correlations? If so, what determines whether two countries' growth rates will be positively correlated?

We look at the relationship through the lens of a standard general equilibrium framework that conceptualises the demand and supply linkages among countries, which then work as a network for transmission of shocks. The model gives an affirmative answer to the first question above. Comparing our baseline scenario (parameterised with trade and real GDP data) to autarky, we find that bilateral correlations in the baseline are, on average, 0.08 higher than what they would have been in autarky. However, there is a large amount of dispersion in the effect going in both directions. We therefore conclude that trade matters for comovement but the magnitude and sign of a particular realisation of the effect depends on with whom and how much countries trade.

To answer the question on *how* trade affects comovement, we show that the main driving force seems to have been the movements in trade costs over time; both their (possibly synchronised) trends and fluctuations around trends are important factors in

accounting for the effects trade has had comovement. Openness itself, i.e. the average level of trade costs, has had only a limited impact so far but we show that if trade costs continue falling, the level of openness gains on importance in the future.

Finally, we investigate the transmission of country-specific shocks through trade. Deriving a closed-form formula for bilateral correlations, we confirm that trade generates comovement as it exposes countries to shocks that affect their direct trade partners. The role of this 'direct' channel has been a topic of many studies estimating the links between comovement and bilateral trade between i and j. However, we also point to another, less well studied channel that generates comovement among countries irrespectively whether they trade with each other or not. The presence of this 'indirect' (or third-country) channel, if not controlled for, could introduce a systematic bias in the relationship between direct trade and comovement.

The condition for the latter to generate comovement between any two countries is *not*, how one could think, that both of them would have to trade with the same third country, which would than act as an intermediary for transmitting their mutual shocks – while this channel may play a role, it is of second-order importance. Our formulas point to a more straightforward way in which the indirect channel matters: it suffices that countries, one of the pair trades with, tend to receive similar shocks as the other in the pair. In other words, trade between i and k, which exposes i to k's shocks, generates comovement also between i and j if k and j tend to be hit by similar shocks.

Contrary to the conventional wisdom, we show that trade intensity between any two countries bilaterally matters little for their comovement. In fact, 90% of comovement (with trade costs fixed over time) is accounted for by trade with third countries, i.e. by the indirect channel. Our findings could help shape the identification strategies used in empirical studies because the formulas we have derived suggest what factors need to be controlled for if one wishes to isolate the influence third countries have on bilateral comovement.

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A Appendix

A.1 Proof that trade identities (3) are not linearly independent

Summing first (n-1) equations in the system defined by equation (3)

$$\sum_{i=1}^{n-1} L_i p_{mi} q_i + \sum_{i=1}^{n-1} S_i = \sum_{i=1}^{n-1} \left(\sum_{j=1}^{n} L_j p_{mj} q_j d_{ji} \right)$$

Using $\sum_{j=1}^{n} S_i = 0$ and rearranging the right-hand side

$$\sum_{i=1}^{n-1} L_i p_{mi} q_i - S_n = \sum_{j=1}^{n} L_j p_{mj} q_j \left(\sum_{i=1}^{n-1} d_{ji} \right)$$

Applying $\sum_{j=1}^{n} d_{ij} = 1$

$$\sum_{i=1}^{n-1} L_i p_{mi} q_i - S_n = \sum_{j=1}^{n} L_j p_{mj} q_j \left(1 - d_{jn}\right)$$

Cancelling terms

$$-S_n = L_n p_{mn} q_n - \sum_{j=1}^{n} L_j p_{mj} q_j d_{jn}$$

Rearranging to get the n-th equation in (3)

$$L_n p_{mn} q_n + S_n = \sum_{j=1}^{n} L_j p_{mj} q_j d_{jn}$$

A.2 Covariance matrix of $\hat{\kappa}$

The matrix below illustrates the covariance matrix $\mathbf{\Omega}_\kappa = \mathbb{E}\Big(\text{vec}(\mathbf{K})\,\text{vec}(\mathbf{K})^T\Big)$ of vectorised trade shocks $\hat{\kappa}$s. We assume constant variances σ_κ and covariances $\sigma_{\kappa\kappa}$ across pairs of countries $ij - kl$. Notice that because $\kappa_{iit} = 1$ and therefore $\hat{\kappa}_{iit} = 0$, the $(ii - ii)^{th}$, some of the elements in the covariance matrix are zero.

$$\mathbf{\Omega}_\kappa = \begin{array}{c|ccccccccc} & \hat{\kappa}_{11} & \hat{\kappa}_{21} & \hat{\kappa}_{31} & \hat{\kappa}_{12} & \hat{\kappa}_{22} & \hat{\kappa}_{32} & \hat{\kappa}_{13} & \hat{\kappa}_{23} & \hat{\kappa}_{33} \\ \hline \hat{\kappa}_{11} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \hat{\kappa}_{21} & 0 & \sigma_\kappa & \sigma_{\kappa\kappa} & \sigma_\kappa & 0 & \sigma_{\kappa\kappa} & \sigma_{\kappa\kappa} & \sigma_{\kappa\kappa} & 0 \\ \hat{\kappa}_{31} & 0 & \sigma_{\kappa\kappa} & \sigma_\kappa & \sigma_{\kappa\kappa} & 0 & \sigma_{\kappa\kappa} & 1 & \sigma_{\kappa\kappa} & 0 \\ \hat{\kappa}_{12} & 0 & \sigma_\kappa & \sigma_{\kappa\kappa} & \sigma_\kappa & 0 & \sigma_{\kappa\kappa} & \sigma_{\kappa\kappa} & \sigma_{\kappa\kappa} & 0 \\ \hat{\kappa}_{22} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \hat{\kappa}_{32} & 0 & \sigma_{\kappa\kappa} & \sigma_{\kappa\kappa} & \sigma_{\kappa\kappa} & 0 & \sigma_\kappa & \sigma_{\kappa\kappa} & \sigma_\kappa & 0 \\ \hat{\kappa}_{13} & 0 & \sigma_{\kappa\kappa} & \sigma_\kappa & \sigma_{\kappa\kappa} & 0 & \sigma_{\kappa\kappa} & \sigma_\kappa & \sigma_{\kappa\kappa} & 0 \\ \hat{\kappa}_{23} & 0 & \sigma_{\kappa\kappa} & \sigma_{\kappa\kappa} & \sigma_{\kappa\kappa} & 0 & \sigma_\kappa & \sigma_{\kappa\kappa} & \sigma_\kappa & 0 \\ \hat{\kappa}_{33} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}$$

A.3 Data sources

The purpose of this section is to document our data sources and transformations we carry out on the data.

Trade Data: We use US$ bilateral imports data, I_{ij}, from 1989 to 2011 from the IMF's Direction of Trade Statistics (DOTS). Based on the treatment of certain trade unions in DOTS, we merge all data for Belgium and Luxembourg, and South Africa and Botswana into their respective aggregates.

GDP in current prices: We take current-price GDP (valued in US$) for 1989-2010 from World Bank, World Development Indicators, variable NY GDP MKTP CD. Supplementary sources for missing observations are UN Data and New Zealand Statistical Office, growth rates for 2011 (and when missing for 2010) are taken from IMF World Economic Outlook (these may be semi-final estimates or IMF's forecasts).

GDP in constant prices: Constant-price GDP is constructed as follows. First we fix the base year using GDP in 2005 denominated in USD (IMF's World Economic Outlook). Other years are linked to the base year by means of growth rates computed on local-currency constant-price data (the source is IMF World Economic Outlook again).

A.4 Figures - scenarios without common / big trade partners

The scatter plots below show changes in correlations induced by certain type of trade relative to autarky. On the horizontal axis (common to all figures) is change in correlations in GDP growth between i and j with all trade costs as in data (average values of trade costs) relative to autarky. Variables shown on the vertical axis differ across figures but always refer to the exercise when i and j stops trading with one or more common trade partners or alternatively, when all countries stop trading with one or more globally big countries, again relative to autarky. Should the dropping of the respective country matter, observations will be further apart from the 45° line. If observations remain close to the diagonal line, trade with the dropped countries is not the key determinant of i and j's mutual correlations.

Figure 16: Change in correlations: 1 largest common trade partner stops trading with i and j

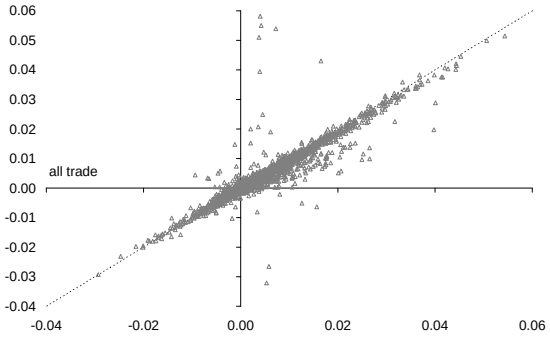


Figure 17: Change in correlations: 2 largest common trade partners stop trading with i and j

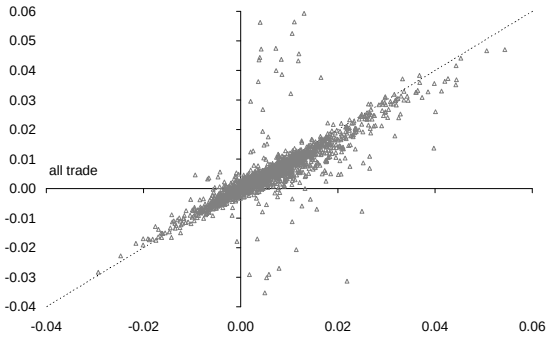


Figure 18: Change in correlations: 3 largest common trade partners stop trading with i and j

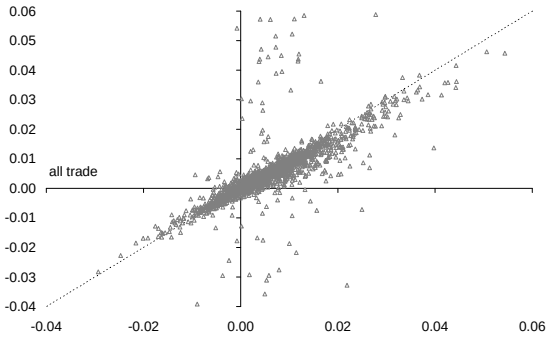


Figure 19: Change in correlations: 4 largest common trade partners stop trading with i and j

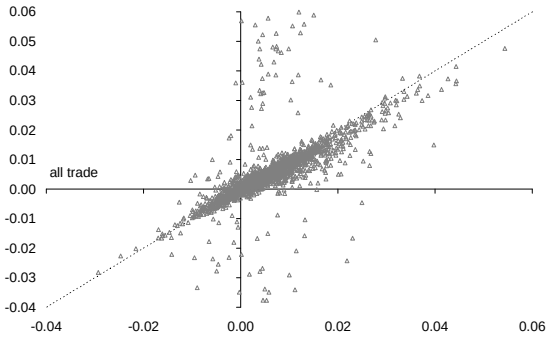


Figure 20: Change in correlations: 5 largest common trade partners stop trading with i and j

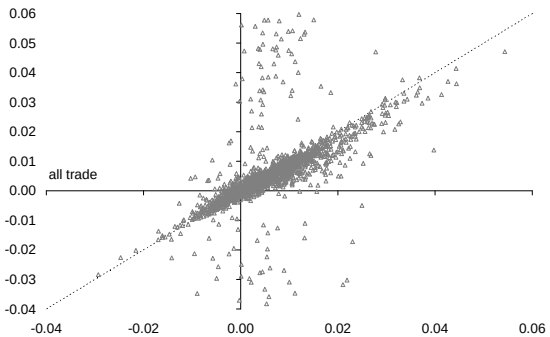


Figure 21: Change in correlations: the U.S. stops trading with all

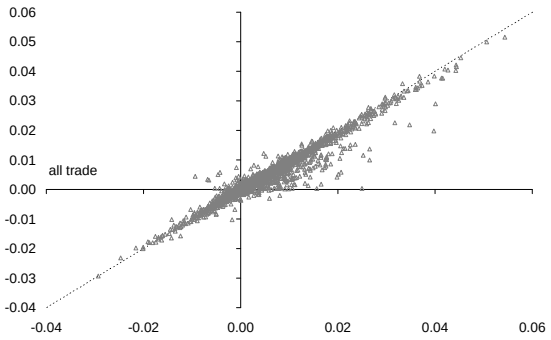


Figure 22: Change in correlations: Japan stops trading with all

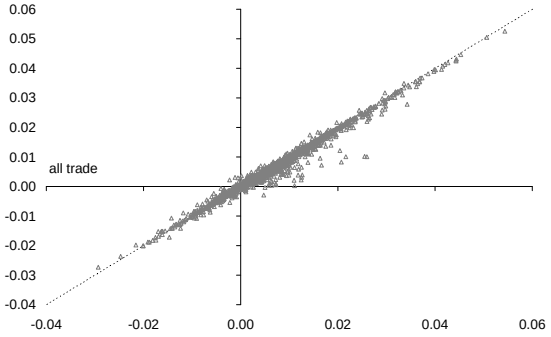


Figure 23: Change in correlations: China stops trading with all

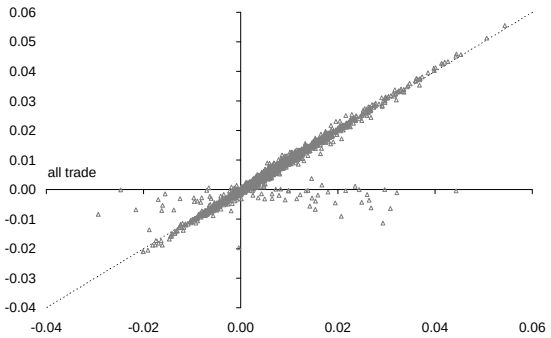


Figure 24: Change in correlations: Germany stops trading with all

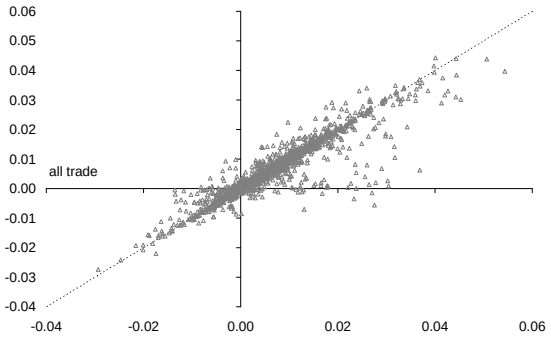


Figure 25: Change in correlations: Rest-of-the-world stops trading with all

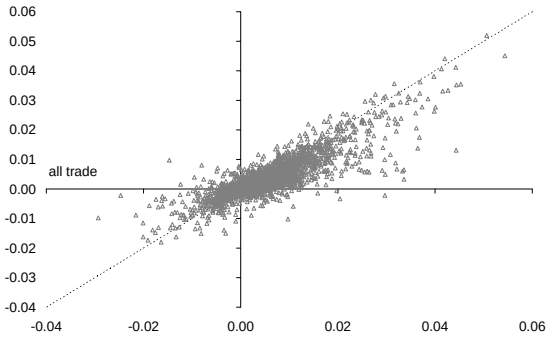
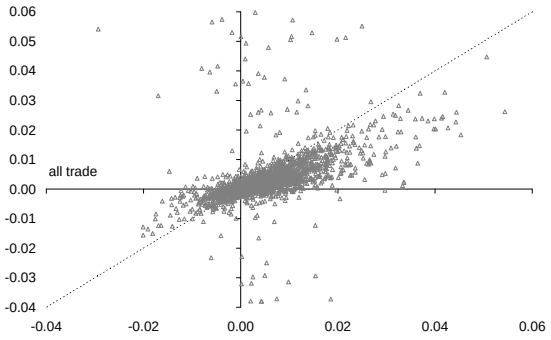


Figure 26: Change in correlations: All 5 biggest countries stop trading with all



A.5 List of countries

ALGERIA	DZA	KOREA	KOR
ARGENTINA	ARG	KUWAIT	KWT
AUSTRALIA	AUS	MADAGASCAR	MDG
AUSTRIA	AUT	MALAYSIA	MYS
BANGLADESH	BGD	MEXICO	MEX
BELGIUM and LUXEMBOURG	BEL	MOROCCO	MAR
BRAZIL	BRA	NETHERLANDS	NLD
BULGARIA	BGR	NEW ZEALAND	NZL
CANADA	CAN	NIGERIA	NGA
COLOMBIA	COL	NORWAY	NOR
COSTA RICA	CRI	OMAN	OMN
COTE D IVOIRE	CIV	PAKISTAN	PAK
CUBA	CUB	PERU	PER
CYPRUS	CYP	PHILIPPINES	PHL
DENMARK	DNK	POLAND	POL
DOMINICAN REPUBLIC	DOM	PORTUGAL	PRT
ECUADOR	ECU	QATAR	QAT
EGYPT	EGY	ROMANIA	ROM
FINLAND	FIN	SOUTH AFRICA	ZAF
FRANCE	FRA	SAUDI ARABIA	SAU
GERMANY	DEU	SPAIN	ESP
GHANA	GHA	SRI LANKA	LKA
GREECE	GRC	SUDAN	SDN
GUATEMALA	GTM	SWEDEN	SWE
HUNGARY	HUN	SWITZERLAND	CHE
CHILE	CHL	SYRIAN ARAB REPUBLIC	SYR
CHINA (MAINLAND)	CHN	THAILAND	THA
INDIA	IND	TUNISIA	TUN
INDONESIA	IDN	TURKEY	TUR
IRELAND	IRL	UNITED ARAB EMIRATES	ARE
ISRAEL	ISR	UNITED KINGDOM	GBR
ITALY	ITA	UNITED STATES	USA
JAMAICA	JAM	URUGUAY	URY
JAPAN	JPN	VENEZUELA	VEN
KENYA	KEN	ROW	ROW