Diversification through Trade *

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This draft: November 2017

Abstract

A widely held view is that openness to international trade leads to higher income volatility, as trade increases specialization and hence exposure to sector-specific shocks. Contrary to this common wisdom, we argue that when country-wide shocks are important, openness to international trade can lower income volatility by reducing exposure to domestic shocks, and allowing countries to diversify the sources of demand and supply across countries. Using a quantitative model of trade, we assess the importance of the two mechanisms (sectoral specialization and cross-country diversification) and show that in recent decades international trade has reduced economic volatility for most countries.

*Thanks: Referees, Pol Antras, Costas Arkolakis, Robert Barro, Fernando Broner, Ariel Burstein, Lorenzo Caliendo, Julian DiGiovanni, Bernardo Guimaraes, Nobu Kiyotaki, Pete Klenow, David Laibson, Fabrizio Perri, Steve Redding, Ina Simonovska, Jaume Ventura, Romain Wacziarg, and seminar participants at Bocconi, Birmingham, CREI, Princeton, Penn, Yale, NYU, UCL, LBS, LSE, Toulouse, Warwick, as well as participants at SED, ESSIM, and the Nottingham trade conference. Calin Vlad Demian, Balazs Kertesz, Federico Rossi, and Peter Zsohar provided superb research assistance. Caselli acknowledges financial support from the Luverlhume Fellowship. Koren acknowledges financial support from the European Research Council (ERC) starting grant 313164. Tenreyro acknowledges financial support from the ERC starting grant 240852.
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I Introduction

An important question at the crossroads of macro-development and international economics is whether and how openness to trade affects macroeconomic volatility. A widely held view in academic and policy discussions, which can be traced back at least to Newbery and Stiglitz (1984), is that openness to international trade leads to higher income volatility. The origins of this view are rooted in a large class of theories of international trade predicting that openness to trade increases specialization. Because specialization in production tends to increase a country's exposure to shocks specific to the sectors (or range of products) in which the country specializes, it is generally inferred that trade increases volatility. This view seems present in policy circles, where trade openness is often perceived as posing a trade-off between the first and second moments (i.e., trade causes higher productivity at the cost of higher volatility).[1]

This paper revisits the common wisdom on two conceptual grounds. First, the existing wisdom is strongly predicated on the assumption that sector-specific shocks (hitting a particular sector) are the dominant source of income volatility. The evidence, however, does not support this assumption. Indeed, country-specific shocks (shocks common to all sectors in a given country) are at least as important as sector-specific shocks in shaping countries' volatility patterns (e.g. Stockman, 1988, Costello, 1993, Koren and Tenreyro, 2007).[2] The first contribution of this paper is to show analytically that when country-specific shocks are

[1] See for example the report on "Economic openness and economic prosperity: trade and investment analytical paper" (2011), prepared by the U.K. Department of International Development.

[2] Both Stockman and Costello find that country-specific shocks are more important than sector-specific shocks in shaping volatility patterns in seven (resp., five) industrialized countries. Using a wider sample of countries and a different method, Koren and Tenreyro confirm these results, and find that the relative weight of country-specific shocks is even more relevant in less developed economies.

an important source of volatility, openness to international trade can lower income volatility. In particular, openness reduces a country's exposure to domestic shocks, and allows it to diversify its sources of demand and supply, leading to potentially lower overall volatility. This is true as long as the volatility of shocks affecting trading partners is not too large, or the covariance of shocks across countries is not too large. In other words, we show that the sign and size of the effect of openness on volatility depends on the variances and covariances of shocks across countries.

The paper furthermore questions the mechanical assumption that higher sectorial specialization per se leads to higher volatility. Indeed, whether income volatility increases or decreases with specialization depends on the intrinsic volatility of the sectors in which the economy specializes in, as well as on the covariance among sectorial shocks and between sectorial and country-wide shocks.

We make these points in the context of a quantitative, multi-sector, stochastic model of trade and GDP determination. The model builds on a variation of Eaton and Kortum (2002), Alvarez and Lucas (2007), and Caliendo and Parro (2015), augmented to allow for country-specific and sector-specific shocks.[3] In each sector, production combines equipped labour with a variety of tradable inputs. Producers source tradable inputs from the lowest-cost supplier (where supply costs depend on the supplier's productivity as well as trade costs), after productivity shocks have been realized. This generates the potential for trade

[3] Variations of this model have been used to address a number of questions in international economics. An incomplete list includes Hsieh and Ossa (2011) and di Giovanni, Levchenko, and Zhang (2014), who study the global welfare impact of China's trade integration and technological change; Levchenko and Zhang (2013), who investigate the impact of trade with emerging countries on labour markets; Burstein and Vogel (2016) and Parro (2013), who study the effect of international trade on the skill premium; Caliendo, Parro, Rossi-Hansberg and Sarte (2014), who study the impact of regional productivity changes on the U.S. economy, and so on. None of these applications, however, focuses on the impact of openness to trade on volatility. A partial exception is Burgess and Donaldson (2012), which we discuss below.

to "insure" against shocks, as producers can redirect input demand to countries experiencing positive supply shocks. However, (equipped) labor must be allocated to sectors before productivity shocks are realized. This friction allows us to capture the traditional specialization channel, because it reduces a country's ability to respond to sectorial shocks by reallocating resources to other sectors. An extension of the model allows for ex-post sectorial reallocation of equipped labour in the presence of reallocation costs.

We use the model in conjunction with sector-level production and bilateral trade data for a diverse group of countries to quantitatively assess how changes in trading costs since the early 1970s have affected income volatility.[4] We find that the decline in trade costs since the 1970s has caused sizeable reductions in income volatility in 80 percent of the countries in our sample, while it led to modest increases in volatility in the rest. The range of changes in volatility due to trade varies significantly across countries, with the largest reductions being in excess of 60% and the largest increases in the order of 8%. On average, volatility fell 22% compared to a counterfactual where trade barriers remain at their early-1970s level. The impact of trade on volatility was especially strong in the 1980s and 1990s, whereas it became muted in the first years of this century.

The general decline in volatility due to trade is the net result of the two different mechanisms discussed above: sectorial specialization, and country-wide diversification. The country-wide diversification mechanism contributed to lower volatility in more than 80% of the countries in our sample, consistent with our key idea that trade is a source of diversification of country-wide shocks. The sectoral-specialization mechanism increased volatility

[4]The data are disaggregated into 24 sectors. We stop the analysis in 2007 as our model abstracts from the factors underlying the financial crisis.

in 67% of the countries in the sample, which is what common wisdom suggests – though it's remarkable, but consistent with our theoretical points above, that common wisdom. The crucial point, however, is that the country-wide diversification effect is on average three times as large as the sectoral-specialization effect, so that the net effect is that trade reduces volatility in the overwhelming majority of cases.

We subject our results to a variety of robustness checks and extensions. In the latter, we find that it is important to feature a detailed input-output structure to fully capture the impact of trade on volatility. We also find that the impact of trade on volatility is not driven by the emergence of China, but it is a much more general phenomenon.

The focus of our quantitative evaluation is real income, defined as nominal GDP deflated by a cost of living index. In the model, the cost of living index is a preferenced-based ideal price deflator. In the data counterpart, the cost of living index is the CPI. Hence, we work with a welfare-relevant notion of income.[5] Indeed, we could alternatively have focused on consumption volatility, because, for most countries in the world, income and consumption fluctuations are almost perfectly correlated, and in our model income equals consumption. For the same reason, our model abstracts from trade in financial assets.

The fact that openness to trade has ambiguous predicted effects on volatility might partly explain why direct empirical evidence on the effect of openness on volatility has yielded mixed results. Some studies find that trade decreases volatility [e.g., Bejan (2006), Buch, Döpke and Strotmann (2009), Cavallo (2008), Haddad, Lim and Saborowski (2010),

[5] Kehoe and Ruhl (2008) and Burstein and Cravino (2015) study the theoretical impact of foreign productivity shocks on various measures of domesitc economic activity. In general, foreign productivity shocks (or other sources of change in the terms of trade) have little first-order effects on production-based measures of activity (e.g. GDP deflated by the GDP deflator), while they have first-order effects on welfare-based measures.

Parinduri (2011), Burgess and Donaldson (2012)], while others find that trade increases it [e.g., Rodrik (1998), Easterly, Islam, and Stiglitz (2001), Kose, Prasad, and Terrones (2003), di Giovanni and Levchenko (2009)]. The model-based analysis can circumvent the problem of causal identification faced by many empirical studies, allowing for counterfactual exercises that isolate the effect of trade costs on volatility. Moreover, it can cope with highly heterogenous trade effects across countries.

Besides contrasting with assessments of the trade-volatility relationship based on (a simplistic understanding of) the specialization framework, our paper also offers an alternative perspective on openness and volatility to the so-called International Real Business Cycle approach. Backus, Kehoe, and Kydland (1992) show that GDP volatility is higher in the open economy than in the closed economy, as capital inputs are allocated to production in the country with the most favorable technology shock. Hence, income fluctuations are amplified in an open economy. In our multi-country, multi-sector setting, instead, income volatility can—and often does—decrease with openness, as intra-temporal trade in inputs allows countries with less favorable productivity shocks to source inputs from abroad, thus reducing income (as well as consumption) volatility.[6]

A paper that is closely related to ours is Burgess and Donaldson (2012), who use the Eaton-Kortum model in conjunction with data on the expansion of railroads across regions in India to assess whether real income became more or less sensitive to rainfall shocks, as India's regions became more open to trade. The authors find that the decline in transportation costs

[6] Also related is the empirical literature initiated by Frankel and Rose (1998), who documented a strong correlation between bilateral trade flows and GDP comovements between pairs of countries (see also, e.g., Kose and Yi (2001), Arkolakis and Ramanarayanan (2009)). Our main focus in this paper is on the effect of trade on *volatility*—and the channels mediating this effect—but the quantitative approach we follow in our counterfactual exercise can potentially be extended to also identify the effect of trade on bilateral comovement—and indeed, other higher-order moments.

lowered the impact of productivity shocks on real income, implying a reduction in volatility. Our analysis is at a higher level of generality, and highlights that, while a reduction in volatility has been experienced by many countries as they became more open to trade, the size and sign of the trade effect on volatility may be— and indeed has been—different across different countries.[7]

The remainder of the paper is organized as follows. Section II presents the model and solves analytically for two special cases, autarky and costless free trade. Section III introduces the data and calibration. Section IV presents the quantitative results, including robustness checks and extensions. Section V presents concluding remarks. The Appendix contains further derivations and a detailed description of the datasets used in the paper.

II A Model of Trade with Stochastic Shocks

The baseline model builds on a multi-sector variation of Eaton and Kortum (2002), Alvarez and Lucas (2006), and Caliendo and Parro (2015), augmented to allow for stochastic shocks, as well as frictions to the allocation of non-produced (and non-traded) inputs across sectors.

II.A Model Assumptions

The world economy is composed of N countries. In each country n there is a final consumption good. The consumption good is a bundle of sectoral goods produced by J sectors.

[7]See also Donaldson (2015), where the question is also addressed in the context of India's railroad expansion. There is also a growing literature on the effect of globalization on income risk and inequality. We do not focus on distributional effects within countries in this paper, though it is obviously a very important issue, and a natural next step in our research. For theoretical developments in that area, see for example, Anderson (2011) and the references therein.

In turn, each sectoral output is a bundle of sector-specific varieties. Each sectoral variety can be produced domestically or imported. Domestic production of sectoral varieties uses non-produced inputs, to which we refer as "equipped labor," and other sectoral goods acting as intermediates. All markets are perfectly competitive.

The consumption bundle C_{nt} is packaged by a consumption-good producer using the Cobb-Douglas aggregate

$$C_{nt} = \prod_{j=1}^{J} \left(C_{nt}^{j}\right)^{\alpha_t^j}, \tag{1}$$

where C_{nt}^{j} is the quantity of sectoral good j used for consumption, and $\sum_{j=1}^{J} \alpha_t^j = 1$. The αs are allowed to change over time to capture possible changes in tastes.

Sectoral output in sector j, Q_{nt}^{j}, is

$$Q_{nt}^{j} = \left[\int_0^1 q_{nt}(\omega^j)^{\frac{\eta-1}{\eta}} d\omega^j\right]^{\frac{\eta}{\eta-1}}, \tag{2}$$

where $q_{nt}(\omega^j)$ is the quantity of sectoral variety ω^j used in sector j, and $\eta > 0$ is the elasticity of substitution across goods within a given sector. Implicit in this formulation is the assumption that each sector relies on a continuum of sector-specific varieties, ω^j.

The technology for producing good ω^j in country n is

$$x_{nt}(\omega^j) = A_{nt}^{j} z_n(\omega^j) l_{nt}(\omega^j)^{\beta^j} \prod_{k=1}^{J} M_{nt}^{k}(\omega^j)^{\gamma^{kj}}, \tag{3}$$

where $x_{nt}(\omega^j)$ is the output of good ω^j by country n at time t; $M_{nt}^{k}(\omega^j)$ is the amount of sector k output used by country n in the production of good ω^j; $l_{nt}(\omega^j)$ is the corresponding amount of equipped labour; $z_n(\omega^j)$ is a time-invariant variety-specific productivity factor;

and A^j_{nt} is a time-varying productivity shock common to all the varieties in sector j. The exponent γ^{kj} captures the share of sector k in the total production cost of sector j. We assume constant returns to scale, or $\beta^j + \sum_{k=1}^{J} \gamma^{kj} = 1$, for all j. Notice that (3) allows for a rich input-output structure, as the intensity with which each sector's output is used as intermediate by other sectors varies across all sector pairs.

Building on the literature, we assume the productivities $z_n(\omega^j)$ follow a sector-specific, time-invariant Fréchet distribution $F^j_n(z) = \exp(-T^j_n z^{-\theta})$. A higher T^j_n shifts the distribution of productivities to the right, that is leading to probabilistically higher productivities. A higher θ decreases the dispersion of the productivity distribution, and hence reduces the scope for comparative advantage. The z terms are the main determinants of long-term comparative advantage in our model.

The shocks to A^j_{nt} over time are interpreted as standard TFP shocks, and are what make the model stochastic at the aggregate level. We will later decompose them into a country-specific component and a sector-specific component. This decomposition will be used to identify separately the country diversification and the sectoral specialization channels.

The intermediate goods ω^j can be produced locally or imported from other countries. Delivering a good from country n to country m in sector j and time period t results in $0 < \kappa^j_{mnt} \leq 1$ goods arriving at m; we assume that $\kappa^j_{mnt} \geq \kappa^j_{mkt}\kappa^j_{knt} \quad \forall m, n, k, j, t$ and $\kappa^j_{nnt} = 1$. All costs incurred are net losses.[8] Under the assumption of perfect competition, goods are sourced from the lowest-cost producer, after adjusting for transport costs. The sectoral outputs Q^j_{nt} are nontraded.

[8]In the calibration, the κs will reflect all trading costs, including tariffs; so implicitly we adopt the extreme assumption that tariff revenues are wasted—or at least not rebated back to agents in a way that would interact with the allocation of resources in the economy.

At a given point in time t, country n is endowed with L_{nt} units of a primary (non produced) input, which we interpret as equipped labour. At the beginning of each period, before the realization of the shocks A^j_{nt}, a representative consumer decides on the optimal allocation of the primary input L_{nt} across the different sectors, L^j_{nt}. After the shocks to productivity are realized, equipped labour can be reallocated within a sector, but not across sectors. Next, production and consumption take place. Clearly, clearing in the input market within a sector implies

$$L^j_{nt} = \int_0^1 l_{nt}(\omega^j) d\omega^j.$$

The lack of ex-post reallocation across sectors in a given period aims at capturing the idea that in the short run it is costly to reallocate productive factors across sectors. Aside from realism, our main intention in including it is that we wish to nest into our model the traditional view that trade causes volatility by pushing countries to specialize - thus making them overly responsive to sectoral shocks. Without frictions to sectoral reallocation, this mechanism could not arise, as the economy would respond to shocks by moving labor from the negatively-affected sectors to the sectors receiving (relatively) positive shocks. Our model would then feature only our novel mechanism, namely the diversification of country-level shocks.[9]

The representative agent has a per-period utility flow $\log(C_{nt})$.[10] Because there is no (endogenous) intertemporal trade and no capital in the economy, the only decision the rep-

[9] In the quantification, a period will be one year. This amounts to assuming that it takes at least one year for resources to be reallocated across sectors. In Section V we relax the assumption of full rigidity within one period, and allow for ex post sectoral reallocation of equipped labour subject to an adjustment cost, which we calibrate to match sectoral reallocation flows in the data.

[10] The log utility assumption gives rise to a particularly intutive and tractable decision rule for the labor allocation.

resentative agent has to take in each period is the allocation of equipped labor across sectors before observing the shock realizations. Since labor can be freely reallocated at the beginning of each period, this is a purely static decision.

Since equipped labor is the only non-produced input, the per period budget constraint in each period is:

$$P_{nt}C_{nt} = \sum_{j=1}^{J} w_{nt}^{j} L_{nt}^{j} \tag{4}$$

where P_{nt} is the price of the consumption good defined in equation (1), and $w_{nt}^{j} L_{nt}^{j}$ is the nominal value-added generated in sector j. This budget constraint assumes that trade is balanced. In Section V we relax this assumption.

Using (4) in the utility function we can solve for the sectoral labor allocation:

$$L_{nt}^{j} = \arg\max E_{t-1} \left[\log \left(\frac{\sum_{j=1}^{J} w_{nt}^{j} L_{nt}^{j}}{P_{nt}} \right) \right], s.t. : \sum_{j=1}^{J} L_{nt}^{j} = L_{nt}, \tag{5}$$

where E_{t-1} indicates that the expectation is taken before the realization of period t shocks.[11]

II.B Model Solution

Conditional on the realization of the country-and-sector specific shocks A_{nt}^{j}, our model is very similar to other general equilibrium, multi-sector versions of the Eaton-Kortum model. The main difference is that equipped labor is pre-allocated across sectors. Hence, we do not offer a detailed derivation of the key equilibrium conditions that are unaffected by the

[11] Implicit in our formulation is the assumption that there is perfect risk-sharing within a country, but no risk-sharing across countries. To motivate the lack of risk-sharing across countries, see our earlier discussion on the high comovement between consumption and output as well as the high correlation between consumption and output volatility.

ex-ante allocation of resources, but merely state them in the following list.

$$d^j_{nmt} = \frac{T^j_m \left(\frac{B^j \left(w^j_{mt}\right)^{\beta^j} \prod_{k=1}^J (P^k_{mt})^{\gamma^{kj}}}{A^j_{mt} \kappa^j_{nmt}} \right)^{-\theta}}{\sum_{i=1}^N T^j_i \left(\frac{B^j \left(w^j_{it}\right)^{\beta^j} \prod_{k=1}^J (P^k_{it})^{\gamma^{kj}}}{A^j_{it} \kappa^j_{nit}} \right)^{-\theta}}, \tag{6}$$

$$P^j_{nt} = \xi \sum_{m=1}^N T^j_m \left(\frac{B^j \left(w^j_{mt}\right)^{\beta^j} \prod_{k=1}^J (P^k_{mt})^{\gamma^{kj}}}{A^j_{mt} \kappa^j_{nmt}} \right), \tag{7}$$

$$P_{nt} = \prod\nolimits_j^J \left(\frac{1}{\alpha^j_n} \right)^{\alpha^j} \left(P^j_{nt}\right)^{\alpha^j}, \tag{8}$$

$$R^j_{nt} = \sum\nolimits_{m=1}^N d^j_{mnt} E^j_{mt}, \tag{9}$$

$$E^j_{nt} = \alpha^j_t P_{nt} C_{nt} + \sum\nolimits_{k=1}^J \gamma^{jk} R^k_{nt}, \tag{10}$$

$$w^j_{nt} L^j_{nt} = \beta^j R^j_{nt}, \tag{11}$$

and the budget constraint (4). In the equations above, d^j_{nmt} is the fraction of country n's total spending on sector-j goods that is imported from country m; P^j_{nt} is the price of sectoral-good j in country n; R^j_{nt} is total revenues accruing to firms operating in sector j in country n; and E^j_{nt} is total expenditure by country n residents (consumers and firms) on sectoral good j. $B^j \equiv \left(\beta^j\right)^{-\beta^j} \prod_{k=1}^{J} \left(\gamma^{k_j}\right)^{-\gamma^{k_j}}$ and $\xi \equiv \left[\Gamma\left(\frac{\theta+1-\eta}{\theta}\right)\right]$, where Γ is the gamma function, are parametric constants. Hence, equation (6) says that country n imports disproportionately from countries m and sectors j that have high productivity draws T^j_m and A^j_{mt}; low wages w^j_{mt} and sectoral prices P^k_{mt}; and low bilateral trading costs, namely high κ_{nmt}s. Equation (7) says that the same factors affect domestic sectoral prices. Equation (8) follows from the final-good producer's profit maximization problem, and shows the price of consumption as an aggregate of the sectoral prices. Equation (9) expresses the total sales of sector j in country n as a function of each country's expenditures on that sector and the share of country n in each country's imports in that sector. Equation (10) states that a country's expenditures in sector j is the sum of final and intermediate uses of sector j goods. Equation (11) simply notes from the Cobb-Douglas formulation that value added from sector j is a share β^j of the gross output of sector j.

To these fairly standard equilibrium conditions we add here the first-order conditions for the allocation of inputs to sectors, i.e. the solution to (5). This turns out to be:

$$\frac{L_{nt}^j}{L_{nt}} = E_{t-1}\left[\frac{w_{nt}^j L_{nt}^j}{\sum_k w_{nt}^k L_{nt}^k}\right], \qquad \forall j, t. \tag{12}$$

The share of resources allocated to a given sector equals its expected share in value added. Note that $1/\sum_k w_{nt}^k L_{nt}^k$ is the marginal utility of consumption in period t; thus, more resources are allocated to higher value-added sectors, after appropriately weighting by marginal utility.[12]

The model can conceptually be solved backwards in two steps. First, for any given set of values for L_{nt}^j, equations (6)-(11) can be solved for P_{nt}, w_{nt}^j, P_{nt}^j, d_{nmt}^j, E_{nt}^j, R_{nt}^j, and C_{nt} as functions of the κ_{mnt}^js, the T_{nt}^js, the A_{nt}^js, and of course the L_{nt}^js. For calibration purposes it turns out to be both possible and convenient to express the dependence of these solutions

[12] Compared to the allocation in a determinisitc model, in our stochastic application sectors whose productivity is negatively correlated with aggregate productivity (that is, they have high value added when the rest of the economy has low value added) are allocated a disproportionate share of resources. In states of the world in which overall income is low, the marginal utility of consumption $1/\sum_k w_{nt}^k L_{nt}^k$ will be high and hence the optimal allocation entails allocating more resources to this sector.

on T_n^j, A_{nt}^j, and L_{nt}^j in terms of the *augmented productivity factors*

$$Z_{nt}^j \equiv T_n^j \left(A_{nt}^j\right)^\theta \left(L_{nt}\right)^{\beta^j \theta} \tag{13}$$

and the sectoral employment shares $\frac{L_{nt}^j}{L_{nt}}$. The augmented productivity factors capture the joint influence of all the exogenous processes (whether deterministic or stochastic) that impinge on the country and sector overall productive capacity.

The second stage of the solution uses (12) to find the ex-ante shares L_{nt}^j/L_{nt}. Our solution method identifies the expectation in (12) with the trend value of the expression in brackets. In particular, we begin with a choice of a candidate time series for L_{nt}^j, and compute the solution for the time series of w_{nt}^j given that candidate time series as well as the realized values of the exogenous processes κ_{nmt}^j and Z_{nt}^j. We then compute the trend of the expression in brackets in (12), and if this is (close enough to being) equal to L_{nt}^j/L_{nt} we stop. Otherwise, the next iteration sets L_{nt}^j/L_{nt} equal to the trend value resulting from the previous iteration. A more detailed explanation is provided in the Appendix.

In identifying the expectations operator in (12) with a trend operator we introduce some small approximation error, but we regard this as preferable to having to impose an arbitrary structure on all the shock processes (of which we have many) – which would be needed if we were to compute the full rational expectations solution.

The key theoretical outcome we are interested in is aggregate income volatility, which we measure as the variance (or standard deviation, where indicated), of real income deviations from country-specific trends. In turn, real income in the model is given by total value added deflated by the optimal expenditure-based price index, or $Y_{nt} = \frac{w_{nt} L_{nt}}{P_{nt}}$. As discussed in the Introduction, these welfare-relevant measures of income are expected to show first-order responses to changes in the terms of trade, and hence in foreign productivities, endowments, or trade costs.

II.C Two Illustrative Cases: Autarky and Costless Trade

To illustrate our novel mechanism of diversification through trade, we begin by analyzing a one-sector version of the model (that is, the original Eaton-Kortum model) under two extreme cases for which we have closed-form analytical solutions for GDP: autarky ($\kappa_{nmt} = 0$ for all $n \neq m, t$) and costless trade ($\kappa_{nmt} = 1$ for all n, m, t). We accordingly drop the sector subscripts. The final good is still used as an intermediate. Note that in both cases we can set $P_n = 1$ for all n. In the autarky case this is an innocuous normalization. In the costless-trade case this is due to the fact that prices are equalized across countries.

II.C.1 Volatility under Autarky

Under complete autarky, it can be easily shown that value added in the one-sector economy is a function of augmented productivity:

$$Y_{nt} \propto (Z_{nt})^{\frac{1}{\beta\theta}}$$

where, recall, $Z_{nt} \equiv T_n \left(L_{nt} A_{nt}^{1/\beta}\right)^{\beta\theta}$. Defining $\hat{Z}_{nt}$ ($\hat{Y}_{nt}$) as the log-deviation of Z_{nt} (Y_{nt}) from its deterministic trend, we thus have $\hat{Y}_{nt} = \frac{1}{\beta\theta}\hat{Z}_{nt}$. Hence, much as in a RBC model, in the one-sector economy under autarky shocks to value added are driven exclusively by domestic shocks to the productive capacity of the economy, $\hat{Z}_{nt}$. The variance of income,

$Var(\hat{Y}_{nt})$ thus depends on the variance of the shocks $Var(\hat{Z}_{nt})$:

$$Var(\hat{Y}_{nt}) = \frac{1}{(\beta\theta)^2} Var(\hat{Z}_{nt}).$$

II.C.2 Volatility under Costless International Trade

Under costless international trade ($\kappa_{nmt} = 1$) in the one-sector economy income per capita is:[13]

$$Y_{nt} = (\xi B)^{1/\beta} Z_{nt}^{\frac{1}{1+\beta\theta}} \left(\sum_{m=1}^{N} Z_{mt}^{\frac{1}{1+\beta\theta}} \right)^{\frac{1}{\beta\theta}}$$

and hence GDP fluctuations are given by:

$$\hat{Y}_{nt} = \frac{1}{1+\beta\theta} \left[\hat{Z}_n + \frac{1}{\beta\theta} \sum_{m=1}^{N} \gamma_m \hat{Z}_m \right]$$

where $\gamma_m = \frac{\bar{Z}_m^{\frac{1}{1+\beta\theta}}}{\sum_{i=1}^{N} \bar{Z}_i^{\frac{1}{1+\beta\theta}}}$ is the relative size of country j evaluated at the mean of $Z_j s$. Rearranging, we obtain $\hat{Y}_{nt} = \frac{1}{\beta\theta} \left[\frac{\gamma_n + \beta\theta}{1+\beta\theta} \hat{Z}_n + \frac{1}{1+\beta\theta} \sum_{m \neq n}^{N} \gamma_m \hat{Z}_m \right]$. Volatility under free trade is hence given by:

$$Var(\hat{Y}_{nt}) = \left(\frac{1}{\beta\theta} \right)^2 \left\{ \begin{array}{c} \left(\frac{\gamma_n + \beta\theta}{1+\beta\theta} \right)^2 Var(\hat{Z}_{nt}) + \left[\frac{1}{1+\beta\theta} \right]^2 \sum_{m \neq i} \gamma_m^2 Var(\hat{Z}_{mt}) \\ 2 \frac{\gamma_n + \beta\theta}{1+\beta\theta} \frac{1}{1+\beta\theta} \sum_{m \neq n} \gamma_m Cov(\hat{Z}_m, \hat{Z}_n) \end{array} \right\}$$

Compared to the variance in autarky, $\frac{1}{(\beta\theta)^2} V(\hat{Z}_{nt})$, it is clear that the volatility due to domestic productivity fluctuations, $Var(\hat{Z}_{nt})$, now receives a smaller loading, as $\left(\frac{\gamma_n + \beta\theta}{1+\beta\theta} \right)^2 < 1$ since $\gamma_n < 1$. The smaller the country (as gauged by its share γ_n), the smaller the impact

[13] See derivations in the Appendix. With costless international trade, the aggregate production function exhibits decreasing returns in the domestic equipped labour L_{nt}, a result that goes back to Acemoglu and Ventura (2002).

of domestic volatility of shocks, $\hat{Z}_n$, on its GDP, when compared to autarky. Openness to trade, however, exposes the economy to other countries' productivity shocks, which will also contribute to the country's overall volatility.

Whether or not the gain in diversification (given by lower exposure to domestic productivity) is bigger than the increased exposure to new shocks depends on the variance-covariance matrix of shocks across countries. If all countries have the same constant variance $Var(\hat{Z}_{nt}) = \sigma$, and the $\hat{Z}_{nt}$ are uncorrelated, volatility under free trade becomes:

$$Var(\hat{Y}_{nt}) = \left(\frac{1}{\beta\theta}\right)^2 \left\{ \left(\frac{\gamma_n + \beta\theta}{1+\beta\theta}\right)^2 + \left[\frac{1}{1+\beta\theta}\right]^2 \sum_{m \neq i} \gamma_m^2 \right\} \sigma$$

which is unambiguously lower than the volatility under autarky.[14] Of course, if other countries have higher variances or the covariance terms are important, then the weights countries receive matter and the resulting change in volatility cannot be unambiguously signed.

Aside from the over-simplified variance and covariance structure, these examples abstract from the traditional channel thought to link trade to increased volatility, namely sectoral specialization. In order to evaluate the relative importance of country diversification and sectoral specialization, as well as to base the analysis on a more realistic stochastic environment based on the data, and to evaluate infra-marginal changes in trade costs, the rest of the paper focuses on the full multi-sector model with frictions to the reallocation of labor following the realization of shocks.

[14] To see this note that $2\beta\theta\gamma_n + \sum_{j=1}\gamma_j^2 < 2\beta\theta + 1$ since $\gamma_m \leq 1$ for every m, and so $(\beta\theta)^2 + 2\beta\theta\gamma_n + \sum_{j=1}\gamma_j^2 < (1+\beta\theta)^2$. This means that the expression in curly brackets is less than 1.

III Quantification

Our goal is to quantitatively assess the effect of historical changes in trade barriers on income volatility for as large a sample of countries and as fine a level of sectoral disaggregation as available data allows. It turns out that the necessary data are available for a sample of 24 core countries, and an aggregate of the remaining countries, to which we refer to as "rest of the world" (ROW). The country coverage is good, in the sense that the countries included account for an overwhelming share of world GDP and trade. In terms of sectoral breakdown, we are able to consider 24 sectors: agriculture, 22 manufacturing sectors, and services. It would clearly have been desirable to access an even finer breakdown. Among other things, a finer breakdown would have potentially implied greater effective rigidity in the allocation of labor across sectors, allowing us to test the robustness of our conclusions on the importance of the specialization channel. Nevertheless, 24 sectors is at the top end of the level of disaggregation usually achieved in applications of the Eaton-Kortum framework.[15]

In order to solve the model numerically, we need to estimate the values of the exogenous trading costs κ^j_{nmt} and the augmented productivity processes Z^j_{nt}. We also need to calibrate the parameters α^j_t, β^j, γ^{kj}, θ, and η.

III.A Exogenous Processes

As has become standard in empirical applications of the Eaton and Kortum framework, we back out realized paths of both trade costs κ^j_{nmt} and augmented productivities Z^j_{nt} from (ver-

[15] While in this paper the focus is on country-wide shocks and sectoral shocks, future work could even extend to "granular" shocks. See, e.g. di Giovanni and Levchenko (2012) for a discussion of trade and volatility with granular shocks and di Giovanni, Levchenko and Mejean (2014) for a country-level application.

sions of) the gravity equation (6) [e.g. Costinot, Donaldson, Komunjer (2012), Levchenko and Zhang (2014, 2016)]. Allen, Arkolakis, and Takahashi (2017) discuss the identification issues involved in this inference problem, whose solution generally requires additional information on trade costs. In our case, we impose additional restrictions on the patterns of bilateral trade costs, which allow us to back out the full matrix of bilateral trade costs κ^j_{nmt} independently from the Z^j_{nt}s. We can then plug the estimated κ^j_{nmt}s back into (6) to back out the Z^j_{nt}s.[16]

III.A.1 Trade Costs

In order to back out the κ^j_{nmt}s independently of the other variables in the gravity equation we follow Head and Ries (2001) and assume that $\kappa^j_{nmt} = 1$ for $n = m$, and that $\kappa^j_{nmt} = \kappa^j_{mnt}$ for all n, m, and j. With these assumptions, equation (6) can be manipulated to yield:

$$\frac{d^j_{nmt} d^j_{mnt}}{d^j_{mmt} d^j_{nnt}} = \left(\kappa^j_{nmt}\right)^{2\theta}. \tag{14}$$

Recall that d^j_{nmt} is the fraction of country n's total spending on sector-j goods that is imported from country m. Imports are directly observable and spending can be constructed from available data as gross sectoral output plus sectoral imports minus sectoral exports. Hence, for a given value of θ (see below for the calibration of this parameter), we can obtain the time series of trading costs by sector and country-pairs $\left\{\kappa^j_{nmt}\right\}$.

Figure 1 shows the histograms of bilateral κs in manufacturing and agriculture in the first

[16] An alternative to our two-step strategy is to find proxies for the observable determinants of trade costs (e.g. distance, or colonial links) and model the κs explicitly as functions of these determinants. Then equation (6) can be estimated econometrically and the Zs recoverd as (functions of) country-sector fixed effects. See, e.g., Levchenko and Zhang (2014).

and last year of our sample (recall that services are treated as a nontradable sector). In both agriculture and manufacturing trade barriers have declined significantly since the early 1970s. As is typical of estimated trade costs from gravity equations the *levels* of the trade costs are very large. But it is important to remember that the trade barriers do not only reflect transport costs and tariff and non-tariff trade barriers; but also that many manufacturing and, especially, agricultural goods are not fully tradable (e.g. perishable products). They may also pick up a home-bias effect that is not explicitly modelled in Eaton and Kortum.

III.A.2 Productivity in Tradable Sectors

Using again (6), together with (7) and our definition of augmented productivity (13), some algebra yields

$$Z_{nt}^{j} = \underbrace{B^{j\theta}\xi^{\theta} d_{mnt}^{j} \left(y_{n}^{j}\right)^{\theta\beta^{j}} \left(\kappa_{mnt}^{j}\right)^{-\theta} \left(P_{nt}^{\beta^{j}} \prod\nolimits_{k=1}^{J} (P_{nt}^{k})^{\gamma^{kj}}\right)^{\theta} \left(\psi_{nt}^{j}\right)^{-\theta\beta^{j}}}_{\equiv \exp(\zeta_{mnt}^{j})} \left(P_{mt}^{j}\right)^{-\theta}, \qquad (15)$$

where $\psi_{n}^{j} \equiv \frac{L_{n}^{j}}{L_{n}}$ and $y_{n}^{j} \equiv \frac{L_{n}^{j} w_{n}^{j}}{P_{n}}$. This equation holds for all n, m, j, t. It says that, for a given price of sectoral good j in country m, P_{mt}^{j}, and bilateral trading costs κ_{mnt}^{j}, productivity in country n in that sector is inferred to be high if country n exports a lot to country m, or d_{mnt}^{j} is large; if value added y_{n}^{j} is large; or the sectoral input share ψ_{n}^{j} is large.

For all countries, we can directly observe several of the terms collected in the object we have called $\exp(\zeta_{mnt}^{j})$. In particular, data is available for sectoral import shares d_{mnt}^{j} (as already used in the previous subsection), sectoral value added y_{nt}^{j}, and aggregate prices P_{nt}. We do not observe directly the sectoral shares ψ_{nt}^{j}. However, recall from equation (12) that, in our model, equipped labour is allocated across sectors so that the share of employment in each sector equals the *expected* share of that sector's value added in total value added. Hence, to compute the terms ψ^j_{nt} we take the time series of sector j's value added in country n's GDP, and extract its (nonlinear) time trend. We then treat the trend as a proxy for the expected value (as already discussed above), and plug it into (15) as our estimate of ψ^j_{nt}.[17]

This leaves us needing the sector-specific price deflators P^j_{mt} for some benchmark country m. We could easily just plug into (15) the US sectoral price indices and use them to recover the Z^j_{nt}s for all other countries (and the US itself). It turns out, however, that in the next subsection we will need sectoral price deflators for tradable sectors for all countries in order to obtain estimates of the productivity processes for the nontradable sector. As these sectoral price indices are not available for many of the countries in our sample, we develop here a procedure to back out tradeable prices. When we have tradable prices for all countries, we can use (15) more efficiently to estimate productivity processes.

Taking logs and rearranging (15) yields.

$$\theta \log \left(P^j_{mt}\right) = \zeta^j_{mnt} - \log \left(Z^j_{nt}\right).$$

Since this relationship (vis-a-vis) country n must hold for any generic countries m and m', we can write

$$\theta \log \left(P^j_{mt}\right) - \theta \log \left(P^j_{m't}\right) = \zeta^j_{mnt} - \zeta^j_{m'nt}.$$

[17] An alternative procedure would be to take a stand on the equipped-labor aggregate. For example, Levchenko and Zhang (2014) assume it is a Cobb-Douglas aggregate of capital and (raw) labor.

Rearranging this, and averaging over n, we further get

$$\theta \log\left(P_{mt}^{j}\right) = \frac{1}{N}\sum\nolimits_{n=1}^{N}\left(\zeta_{mnt}^{j} - \zeta_{m'nt}^{j}\right) + \theta \log\left(P_{m't}^{j}\right).$$

Recalling that the ζs are observable for all n, this expression tells us that we can recover the sectoral prices for any country m if we have sectoral price indices for at least one country m'. We do have sectoral price indices for the US. We choose units of accounts for each sector so that U.S. nominal sectoral prices are equal to 1 in 1972.

Having thus obtained sectoral price series P_{mt}^{j} for all countries and sectors, we can return to (15) and recover Z_{nt}^{j} from

$$\log(Z_{nt}^{j}) = \frac{1}{N}\sum\nolimits_{m=1}^{N}\left[\zeta_{mnt}^{j} - \theta \log\left(P_{mt}^{j}\right)\right].$$

Note that, in the last two expressions, instead of using the average across a country's trade partners we could have used any individual bilateral relation. Theoretically, either option is valid. However, using the average minimizes the influence of measurement error.

III.A.3 Productivity in Nontradables

The procedure in the previous subsection uses data on trade flows and is thus only applicable to the recovery of augmented productivities in the tradable sectors: agriculture and the various manufacturing industries. To recover the productivity series in the service sector we begin by constructing a time series for the price of services. From equation (8), the price of services $P^s_{n,t}$ can be written as

$$P^s_{nt} = \left(\frac{P_{nt}}{P_{US,t}} P_{US,t}\right)^{\frac{1}{\alpha^s}} \left(\prod_{j=1}^{J} \alpha^{j-\alpha^j}\right)^{-\frac{1}{\alpha^s}} \left[\prod_{j\neq s} \left(P^j_{nt}\right)^{\alpha^j}\right]^{-\frac{1}{\alpha^s}}.$$

We have just described in the previous subsection how to estimate the prices of all the sectors other than services, i.e. the P^j_{nt}s in the last term. From the Penn World Tables we can obtain a general price index for each country n relative to the United States, $\frac{P_{nt}}{P_{US,t}}$. And $P_{US,t}$ is simply the US general price index. With the price series for services at hand, we can construct augmented productivity in services, Z^s_{nt} using again equation (15), for the case $n = m$.[18]

III.A.4 Sectoral versus Aggregate Shocks

Since we are interested in decomposing the overall effect of trade on volatility into the contributions of the two mechanisms, specialization and diversification, we need to separately identify sectoral and aggregate shocks. We resort to a factor model that decomposes augmented productivity shocks into sector- and country-specific components, as described in Koren and Tenreyro (2007). To separate per period shocks from trends we use a band-pass filter to detrend each $\left\{\log Z^j_{nt}\right\}_{t=1}^{T}$ series. Without loss of generality, we decompose the cyclical component, denoted $\hat{Z}^j_{nt}$, as:

$$\hat{Z}^j_{nt} = \lambda^j_t + \mu_{nt} + \epsilon^j_{nt},$$

[18] Implying, therefore, $d^s_{mnt} = \kappa^s_{mnt} = 1$.

where μ_{nt} is the country-specific factor, affecting all sectors within the country; λ_t^j is the global sectoral factor, affecting sector j in all countries; and the residual ϵ_{nt}^j is the idiosyncratic component, specific to the country and sector.[19] In the counterfactual exercises, we can mute the sector- or country-specific factors by setting the corresponding components equal to 0, in order to identify the separate effects of the two trade channels affecting volatility.

III.B Calibration

We set α_t^j so as to match the cross-country average of the share of sector j in total final uses, in each year, using the data on value added described in the Appendix. The β^js are calculated as the average ratios (across time and countries) of value added to total output in each sector, again using the sectoral value added and gross output data from the appendix. And the γ^{kj}s are the average shares of purchases by sector j from sector k from the OECD input-output tables, as a share of total sectoral output.

We allow for a relatively broad parametric range for θ, from $\theta = 2$ to $\theta = 8$, consistent with the estimates in the literature (see Eaton and Kortum, 2002, Donaldson 2015, and Simonovska and Waugh, 2014). We use $\theta = 4$ as the baseline case, and report the results

[19] The three factors, λ, μ, and ϵ are estimated as:

$$\lambda_t^j = N^{-1} \sum_{n=1}^{N} \hat{Z}_{nt}^j$$

$$\mu_{nt} = J^{-1} \sum_{j=1}^{J} \bar{\alpha}^j \left(\hat{Z}_{nt}^j - \lambda_t^j \right)$$

$$\epsilon_{nt}^j = \hat{Z}_{nt}^j - \lambda_t^j - \mu_{nt},$$

where $\bar{\alpha}^j$ is the time average of sectoral expenditure shares α_t^j, and we impose the restriction $\sum_n \mu_n = 0$, implying that the country-specific effect is expressed relative to the world's aggregate. We calculate the country factor as a weighted average of shocks, because the single sector of services takes up 70-80 percent of value added in many economies. This is in contrast to Koren and Tenreyro (2007), who use unweighted average. Their application focuses on manufacturing sectors, which do not differ as much in size.

for other values when discussing the sensitivity of our results. We calibrate the elasticity of substitution across varieties $\eta = 4$, consistent with Broda and Weinstein (2006)'s median estimates. The results are not sensitive to this parametric choice.

IV The Effect of Trade on Volatility

This section uses the framework developed above to quantitatively assess how historical changes in trade costs from the early 1970s have affected volatility patterns in a sample of countries at different levels of development. We first analyze the baseline model's results and then perform a series of sensitivity checks and extensions.

IV.A Baseline Results

Figure 2 starts by comparing the baseline model-generated income volatility with the volatility in the data. The baseline model uses our benchmark calibration, $\theta = 4$, and feeds in the historical time series for the trade costs κ_{mnt}, and for the augmented productivity factors Z_{nt}^{j}. The graph shows the standard deviation of real income deviations from trend. Recall that real income is measured as value added deflated by the expenditure-based price index. The data counterpart is nominal GDP deflated by the CPI index. The correlation between model and data series is 0.99 (0.96 without China) for the standard deviation and 0.99 (0.97 without China) for the variance. The analysis that follows will focus on the variance as a measure of volatility, rather than the standard deviation, because we exploit the additivity properties of the former to separately account for the diversification and sectoral-specialization effects.

Table 1 investigates how the changes in trading costs have affected volatility in the

24 countries in our sample (plus the rest of the world). Column 1 compares our baseline scenario, which uses the estimated time paths of trading costs and productivity processes, to a scenario in which we remove the secular decline in trading costs.[20] In particular, in the counterfactual scenario we keep all the κ^{j}_{nmt}s constant at their 1972 level. The column shows volatility under the counterfactual minus volatility in the baseline, and this difference taken as a percentage of the volatility at constant trading costs. The numbers can be interpreted as the proportional change in volatility caused by the decline in trading costs.

The comparison in Column 1 reveals that volatility is generally higher under the counterfactual scenario with constant trading costs than in the baseline. For 19 countries out of 24 there would have been more volatility under constant trade costs than there has been. For most countries, therefore, the common wisdom which predicts greater volatility following trade integration does not seem to apply.

The biggest declines in volatility caused by trade occurred in Austria, Belgium-Luxemburg, Canada, Denmark, Ireland, and the Netherlands, all of which saw volatility reductions in excess of 50% (meaning their volatility has been 50 percent lower than it would have been had trading costs stayed at their 1972 levels). The biggest increases in volatility due to trade were witnessed by Greece (8 percent increase) and Australia (4 percent). The (unweighted) average country in our sample experienced a 22% decline in volatility thanks to increased openness. But this average effect masks a huge amount of heterogeneity in the quantitative and qualitative effect of trade in volatility, consistent with our discussion of the country-specificity of the trade-volatility relation.

[20] The absolute numbers of the volatilities generated by the scenarios discussed in this Section are reported in Appendix Table 1.

As discussed at several points, openness affects volatility through two channels: a diversification effect and a specialization effect. While neither effect has an unambiguous impact, it is sensible to expect the diversification effect to reduce the impact of country-specific shocks, and hence - in most cases - to reduce volatility; similarly, by exacerbating the impact of sectoral shocks, the specialization effect is generally deemed to increase volatility. In the rest of the table we assess and quantify these predictions.

In order to quantify the impact of the diversification effect, we compare two counterfactual scenarios. As before, the two scenarios differ in the path of trading costs, with one scenario featuring the same decline in trading cost that we back out from the data, and the other having trading costs constant at 1972 levels. However, in these two scenarios the series for Z_{nt}^{j} is replaced by a modified series from which we remove all sectoral shocks (i.e. the shocks λ_t^j and ε_t^j defined in Section III.A.4). In other words we ask what volatility would have been with and without the observed decline in trade costs, if the only shocks to productivity had been the country-wide shocks. Because these two scenarios do not feature sectoral shocks, any differences in volatility must be ascribed to the diversification effect.

The difference is again expressed as a percentage of the volatility under the 1972's trading cost levels and is reported in Column 2. In 20 out of 24 countries volatility at 1972 trade barriers is larger than volatility in the baseline case, confirming that the diversification channel tends overwhelmingly to operate in the direction of lower volatility - as expected.

It is interesting though that there still are countries for which volatility is lower at 1972 trade costs. As discussed, even the diversification channel can amplify volatility, if openness exposes a country to disproportionately large and volatile trading partners, or partners whose shocks are highly correlated with a country's own. Evidently this was the case for these countries. On average, the diversification channel induces a 33% drop in volatility relative to the case where barriers are held at the initial value.

Because of the additive properties of the variance, the specialization effect can be quantified as the difference between the overall change in volatility, and the change due to the diversification effect. This is reported in Column 3. The figures should be interpreted as the change in volatility due to trade integration that would have occurred if only sectoral shocks (global or country specific) had been present. The change is positive for 16 out of 24 countries. Consistent with the standard view, therefore, the specialization channel tends to increase volatility in a majority of cases. Remarkably, however, there is a large number of countries which are pushed to specialize into less volatile sectors, or into sectors that comove negatively (or less positively) with the country's aggregate shocks or other sectoral shocks. On average, the specialization channel implies a decrease in volatility of 10%.

The most important lesson from the comparison of Columns 2 and 3 is about the relative magnitude of the diversification and specialization effects. The average change due to the diversification mechanism is three times as large than the average change due to the specialization mechanism. The specialization effect, on which the policy debate seems centred, is not as important as the diversification effect. We have hinted at the likely reason for this in the Introduction: country-specific shocks are simply much more important quantitatively than sector-specific ones.

In Table 2 we briefly present a dynamic view of how the overall changes seen in Table 1 came about. As Table 1, the table presents comparisons of volatility under different scenarios, but volatility is computed by decade.[21] Not surprisingly, the impact of trade

[21] To calculate decadal volatility, we compute the variance of annual log growth rates in real GDP. It is

(understood as the change in trading costs since 1972) on volatility is modest in the 1970s, as by the end of the 1970s trade costs had not had much time to drift away from the 1972 values. Throughout the 1980s and 1990s, the gap between actual volatility and volatility at 1972 trade costs opens steadily, as the world economy becomes more and more integrated. Interestingly, the gap stops growing in the 2000-2007.

The petering out of the effect of trade on volatility in the last seven years of the sample may possibly reflect some noisiness due to the relative short time span over which volatilities are computed. However, taken at face value, it points to the fact that – consistent with our theory – the impact of trade on volatility is not only heterogenous across countries, but also over time. For example, it could be that country-wide shocks became more correlated in the 2000s, or that trade induced specialization in more volatile sectors. Columns 2 and 3 suggest that the answer is "a bit of both:" the contribution of the diversification effect to lower volatility slowed down in the 2000s compared to the 1990s (Column 2), while the sectoral specialization effect continued to inject increased volatility (column 3).

IV.B Sensitivity Analysis

In this section we evaluate the robustness of our baseline results to three alternative implementation choices: (i) allowing for unbalanced trade; (ii) alternative calibration values; (iii) allowing for costly labor reallocation across sectors.

infeasible to estimate a band-pass filter given just 10 years of data. The overall magnitudes of volatility are very similar to those in Table 1.

IV.B.1 Trade Imbalances

Our benchmark model focuses on the balanced trade case. Because we observe significant trade imbalances during the sample period, we begin our robustness checks by allowing countries to run trade surpluses and deficits. We do not attempt to endogenize trade deficits as the computational challenges of adding intertemporal considerations (including issues of default) are formidable. Furthermore, available theoretical models of intertemporal trade are not particularly successful empirically. Hence, as is customary in quantitative applications of the Eaton and Kortum model, we treat the trade surplus an as exogenous process which we take from the data. The required modifications to the baseline model are described in the appendix. As shown in Table 3, the quantitative results with trade imbalances are extremely similar to those in the baseline.

IV.B.2 Scope for Comparative Advantage θ

Table 4 shows the change in volatility due to international trade and its decomposition for two other (extreme) values of θ, $\theta = 2$ and $\theta = 8$. The general message is qualitatively robust: i) the effect of trade on volatility varies across countries; ii) the diversification channel tends to reduce volatility; iii) sectoral specialization tends to reduce volatility; (iv) the diversification channel is much more important than the specialization channel. Having said that, the magnitude of the effects is quite sensitive to changes in θ, with the effect of trade on volatility being stronger for lower values of θ, i.e. when the scope for comparative advantage increases.[22]

[22] This exercise underscores the importance of the parameter θ, and adds to the message of Arkolakis, Costinot, and Rodriguez-Clare (2012): in order to assess the effects of trade on key aggregate variables, the elasticity of trade to trade costs plays a key role.

IV.B.3 Adjustment Costs and Ex Post Sectoral Reallocation

The baseline model assumes that the sectoral allocation of equipped labour is decided one period in advance, before productivity shocks are realized. In this section we relax this stark assumption. We assume that the ex post reallocation of equipped labour is possible, but an adjustment cost is paid in that reallocation. By making sectoral reallocation of labor more flexible we necessarily reduce the importance of the sectoral specialization effect, and magnify the relative importance of our novel diversification mechanism.

We model the cost of labor reallocation in reduced-form fashion. In particular, lifetime utility is given by

$$U_n = \sum_{t=0}^{\infty} \delta^t \left\{ \log(C_{nt}) - \frac{\varrho}{2} \sum_{j=1}^{J} \left[\psi_{nt}^j - \psi_{nt}^{j*} \right]^2 \right\}, \tag{16}$$

where ψ_{nt}^j is now reinterpreted as the *ex-post* share of sector j in equipped labour, and ψ_{nt}^{j*} is the *ex-ante* share, or the allocation before observing the realization of the shocks. A higher value of ϱ implies higher adjustment costs.

The ex-post sectoral input allocation solves:

$$L_{nt}^k = \arg\max \left[\log \left(\frac{\sum_{j=1}^J w_{nt}^j L_{nt}^j}{P_{nt}} \right) - \frac{\varrho}{2} \sum_{j=1}^{J} \left[\psi_{nt}^j - \psi_{nt}^{j*} \right]^2 \right], \ s.t. : \sum_{j=1}^{J} \psi_{nt}^j = \sum_{j=1}^{J} \psi_{nt}^{j*} = 1,$$

and the first-order conditions lead to:

$$\psi_{nt}^k = \psi_{nt}^{k*} + \frac{1}{\varrho} \left[\frac{w_{nt}^k - \frac{1}{J} \sum_{j=1}^J w_{nt}^j}{\sum_{j=1}^J w_{nt}^j L_{nt}^j / L_{nt}} \right]. \tag{17}$$

The ex post input shares ψ_{nt}^k equal the ex-ante optimal shares ψ_{nt}^{k*} plus a fraction of the percentage differential between the sectoral input cost w_{nt}^k and the average equipped labour cost in the economy $\frac{1}{J}\sum_{j=1}^{J} w_{nt}^j$. (Note that the denominator is the average input cost in the economy.) The adjustment cost parameter ϱ determines the semi-elasticity of sectoral adjustment to the cost differential.

Using (**??** in (16) we can solve for the ex-ante allocation, which turns out to be independent of ϱ, and hence it will be the same as in our baseline case, where ϱ is implicitly assumed to be infinite. In other words, ψ_{nt}^{j*} is given by equation (12).

To calibrate ϱ, we use EU KLEMS data on employment and compensation for all countries in the European Union from 1970 to 2007. Using these data, we compute the object in the square bracket in equation (17). We then regress yearly changes in labour shares on yearly changes in the wage differentials to obtain estimates of $\frac{1}{\varrho}$. The estimated regression coefficient is 0.001 (p-value 0.03), implying that labor reallocation is quite unresponsive to wage differentials.[23]

We solve the model and counterfactuals under $\frac{1}{\varrho} = 0.001$ and report the results in Table 5. Given the large estimated value of ϱ, the results are very similar to those in the baseline model. We have experimented with a range of values of $\frac{1}{\varrho}$ (from 0.0005 to 0.002) and the results are virtually identical.

IV.C Additional Insights from the Calibrated Model

In this section we use our model to investigate two further questions about the forces at work in our model and in the data. In particular we ask: (i) What is the quantitative role of

[23] This result is remniniscent of Wacziarg and Wallack (2004), who find small intersectoral labor movements in response to trade liberalizations.

intersectoral input-output linkages in the relationship between trade openness and volatility? (ii) Did the emergence of China as a global trading powerhouse exert a disproportionate effect in other countries' volatility through trade?

IV.C.1 Input-Output Linkages

Our model features input-output linkages as each sector produces goods that can be used as intermediates for other sectors. It is interesting to evaluate the role of these input-output linkages in producing our quantitative results. In principle, we would expect the existence of input-output linkages to provide diversification benefits to sectors, as implicit in such linkages there are possibilities for substitution away from inputs experiencing adverse shocks [e.g., Koren and Tenreyro (2013)]. However, similar to our discussion of the country diversification channel, input-output linkages can also create excessive exposure to particularly volatile suppliers, potentially leading to greater volatility relative to a benchmark where each sector only uses non-produced inputs (or intermediates originating from within the sector). Either way, increased openness to trade should magnify these effects. For example, the more a country can freely trade, the greater the opportunities for a firm to diversify among its input suppliers, and the greater the diversification benefits associates with input-output linkages.

To see if input-output linkages do indeed amplify the impact of trade on income volatility in our model, we compare our baseline results to those of an alternative model without intermediates, i.e. where we set $\gamma^{kj} = 0$ for all j and k. The results from this no-input-output model are presented in Table 6, and should as usual be compared to those of Table 1. While the qualitative findings are similar to those of the full model with input-output linkages, the quantitative impact of trade is considerably reduced in their absence. The average decline in volatility due to trade is only 8% (as usual almost entirely coming from the diversification effect) - against 22% in the full model with input-output linkages. Hence, allowing firms to source inputs from other sectors is crucial to capture the full effects of trade on volatility.

IV.C.2 The Role of China

Our model can be used to generate additional counterfactuals that can shed further light on the sources of changes in income volatility over the last few decades. The emergence of China as a major global trading nation has certainly had a significant effect on the overall openness of other countries. Other authors have already offered evaluations of the impact of China on the first moment of income, i.e. via the classic gains from trade [di Giovanni, Levchenko, and Zhang (2014); Hsieh and Ossa (2016)]; its impact on local labor markets [Autor, Dorn, and Hansen (2013]; and its influence on innovation [Bloom, Daca, and Van Reenen (2016)]. Given China's distinct patterns of comparative advantage and unique cyclical characteristics, it is also interesting to assess its effects on other countries' income volatility.

We assess the role of China with two distinct thought experiments. In the first experiment we imagine a counter-factual world where China does not exists. That is, we perform our usual set of simulations but we drop China from the set of countries. The changes in volatilities we report are therefore the changes in volatility that lower trade costs among the remaining countries would have generated if China had not been participating in world trade. In the second experiment, we imagine a scenario in which China does participate in world trade, but its trading costs are held constant at 1972 levels. The changes in volatility we report are therefore the changes in volatility that lower trade costs among the remaining countries would have generated if China had not experienced any decline in trade costs.

The results from these experiments are presented in Table 7. With only a few exceptions, the impact of trade on volatility without China or when China's trading costs are held constant at 1972 levels are broadly of a similar magnitude. This is not too surprising as China was obviously quite closed in 1972, so holding its trade costs constant limits China's impact on other countries in a similar way as not having China at all.

The most interesting comparison, however, is not between the two scenarios in Table 7, but between the scenarios in Table 7 and our baseline Table 1. The main thing to notice is that the figures in Table 1 are generally quite close to the figures in Table 7. This means that the decline in volatility when all countries experience trade cost declines is quite similar to the decline in volatility when all countries bar China experience trade cost declines, or even when China does not participate in world trade at all. Put crudely, China does not drive our main results.

V Conclusions

How does openness to trade affect GDP volatility? Our study challenges the standard view that trade increases volatility. It highlights a new mechanism (country diversification) whereby trade can lower volatility. It also shows that the standard mechanism of sectoral specialization—usually deemed to increase volatility—can often in practice lead to lower volatility. The analysis indicates that diversification of country-specific shocks has generally led to lower volatility during the period we analyze, and has been quantitatively much more important than the specialization mechanism. The sizeable heterogeneity in the trade effects on volatility can contribute to understand the heterogeneity of results documented by the existing empirical literature.

References

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

[2] Allen, A., C. Arkolakis, and Y. Takahashi (2017) "Universal Gravity," Yale manuscript.

[3] Alvarez, F. and R. E. Lucas (2007), "General Equilibrium Analysis of the Eaton-Kortum Model of International Trade," Journal of Monetary Economics, 54 (6): 1726-1768.

[4] Anderson, J., 2011. "The specific factors continuum model, with implications for globalization and income risk," Journal of International Economics, Elsevier, vol. 85(2): 174-185.

[5] Arkolakis, C., A. Costinot and A. Rodriguez-Clare (2012), "New Trade Models, Same Old Gains?" American Economic Review, 2012, 102(1), p. 94-130.

[6] Arkolakis, C. and A. Ramanarayanan (2009), "Vertical Specialization and International Business Cycle Synchronization," Scandinavian Journal of Economics, 111(4), 655-80.

[7] Autor, David H., David Dorn, and Gordon H. Hanson. 2013. "The China Syndrome: Local Labor Market Effects of Import Competition in the United States." American Economic Review, 103(6): 2121-68.

[8] Backus, D., Patrick J. Kehoe, and F. Kydland (1992), "International Real Business Cycles", Journal of Political Economy 100 (4): 745–775.

[9] Bejan, M. (2006), “Trade Openness and Output Volatility,” manuscript, http://mpra.ub.uni-muenchen.de/2759/.

[10] Bloom, Nicholas; Draca Mirko and John Van Reenen (2016): “Trade Induced Technical Change? The Impact of Chinese Imports on Innovation, IT and Productivity,” *The Review of Economic Studies*, Volume 83, Issue 1, Pages 87–117.

[11] Broda, C. and D. Weinstein (2006), “Globalization and the Gains from Variety,” The Quarterly Journal of Economics, MIT Press, vol. 121(2): 541-585, May.

[12] Burgess, R. and D. Donaldson (2012) “Railroads and the Demise of Famine in Colonial India,” MIT manuscript.

[13] Burstein, A. and J. Vogel (2016), “International trade, technology, and the skill premium,” forthcoming Journal of Political Economy.

[14] Burstein, A. and J. Cravino (2015), “Measured Aggregate Gains from International Trade” with Javier Cravino, American Economic Journal: Macroeconomics, vol 7 (2): 181-218.

[15] Caliendo, L. and F. Parro (2015) “Estimates of the Trade and Welfare Effects of NAFTA,” Review of Economic Studies, 82(1), 1-44.

[16] Caliendo, L., F. Parro, E. Rossi-Hansberg and D. Sarte (2014). "The impact of regional and sectoral productivity changes on the U.S. economy," Princeton and Yale manuscripts.

[17] Cavallo, E. (2008). "Output Volatility and Openess to Trade: a Reassessment," Journal of LACEA Economia, Latin America and Caribbean Economic Association.

[18] Costello, D. (1993) "A Cross-Country, Cross-Industry Comparison of Productivity Growth," Journal of Political Economy, Vol. 101(2): 207-222.

[19] Costinot, A., D. Donaldson, and I. Komunjer (2012): "What Goods Do Countries Trade?A Quantitative Exploration of Ricardo's Ideas," Review of Economic Studies, 79, 581-608.

[20] Department for International Development (2011), "Economic openness and economic prosperity: trade and investment analytical paper" (2011), prepared by the U.K. Department of International Development's Department for Business, Innovation & Skills, February 2011.

[21] di Giovanni, J. and A. Levchenko (2009). "Trade Openness and Volatility," The Review of Economics and Statistics, MIT Press, vol. 91(3): 558-585, August.

[22] di Giovanni, J. and A. Levchenko (2012), "Country Size, International Trade, and Aggregate Fluctuations in Granular Economies," Journal of Political Economy, 120 (6): 1083-1132.

[23] di Giovanni, J, A. Levchenko and I. Mejean (2014), "Firms, Destinations, and Aggregate Fluctuations," Econometrica, 82:4, pages 1303-1340.

[24] di Giovanni, J., A. Levchenko, and J. Zhang (2014). "The Global Welfare Impact of China: Trade Integration and Technological Change," American Economic Journal: Macroeconomics.

[25] Donaldson, D. "Railroads of the Raj: Estimating the Impact of Transportation Infrastructure," (2015) forthcoming, American Economic Review.

[26] Easterly, W., R. Islam, and J. Stiglitz (2001), "Shaken and Stirred: Explaining Growth Volatility," Annual World Bank Conference on Development Economics, p. 191-212. World Bank, July, 2001.

[27] Eaton, J. and S. Kortum (2002), "Technology, Geography and Trade," Econometrica 70: 1741-1780.

[28] Frankel, J. and A. Rose (1998), "The Endogeneity of the Optimum Currency Area Criteria," Economic Journal, Vol. 108, No. 449 (July):. 100-120.

[29] Haddad, M., J. Lim, and C. Saborowski (2013), "Trade Openness Reduces Growth Volatility When Countries Are Well Diversified," Canadian Journal of Economics, 46(2), 765-90.

[30] Head, K. and J. Ries (2001), "Increasing Returns versus National Product Differentiation as an Explanation for the Pattern of U.S.-Canada Trade." American Economic Review 91: 858-876.

[31] Hsieh, C. and Ossa, R. (2011), "A Global View of Productivity Growth in China," *Journal of International Economics* 102: 209-224, September 2016.

[32] Kehoe, T. and K. J. Ruhl (2008), "Are Shocks to the Terms of Trade Shocks to Productivity?," Review of Economic Dynamics, Elsevier for the Society for Economic Dynamics, vol. 11(4): 804-819, October.

[33] Koren, M. and S. Tenreyro (2007), "Volatility and Development," Quarterly Journal of Economics, 122 (1): 243-287.

[34] Koren, M. and S. Tenreyro (2013), "Technological Diversification," The American Economic Review, February 2013, Volume 103(1): 378-414.

[35] Kose, A., E. Prasad, and M. Terrones (2003), "Financial Integration and Macroeconomic Volatility," IMF Staff Papers, Vol 50, Special Issue, p. 119-142.

[36] Kose, A. and K. Yi, (2001), "International Trade and Business Cycles: Is Vertical Specialization the Missing Link?," American Economic Review, vol. 91(2): 371-375, May.

[37] Levchenko, A. and J. Zhang (2013), "The Global Labor Market Impact of Emerging Giants: a Quantitative Assessment," IMF Economic Review, 61:3 (August 2013), 479-519.

[38] Levchenko, A. and J. Zhang (2014), "Ricardian Productivity Differences and the Gains from Trade," European Economic Review, 65 (January 2014), 45-65.

[39] Levchenko, A. and J. Zhang (2016), "The Evolution of Comparative Advantage: Measurement and Welfare Implications," Journal of Monetary Economics, 78, 96-111

[40] Newbery, D. and J. Stiglitz, (1984), "Pareto Inferior Trade," Review of Economic Studies, Wiley Blackwell, vol. 51(1): 1-12, January.

[41] Parinduri, R. (2011), "Growth Volatility and Trade: Evidence from the 1967-1975 Closure of the Suez Canal," manuscript University of Nottingham.

[42] Parro, F. (2013), "Capital-Skill Complementarity and the Skill Premium in a Quantitative Model of Trade," American Economic Journal: Macroeconomics, American Economic Association, vol. 5(2): 72-117, April.

[43] Rodrik, D., (1998), "Why Do More Open Economies Have Bigger Governments?," Journal of Political Economy, vol. 106(5): 997-1032, October.

[44] Simonovska, I. and M. E. Waugh (2014), "The Elasticity of Trade: Estimates & Evidence," Journal of International Economics, 92(1), 34-50.

[45] Stockman, A. (1988), "Sectoral and National Aggregate Disturbances to Industrial Output in Seven European Countries," Journal of Monetary Economics 21 (March): 387-409.

[46] Buch, C., J. Döpke and H. Strotmann (2009), "Does trade openness increase firm-level volatility?," World Economy.

[47] Wacziarg, R. and J. S. Wallack (2004), "Trade liberalization and intersectoral labor movements," Journal of International Economics 64 (2004) 411– 439.

Appendix

Derivation of GDP under free trade

In the one-sector economy, under free trade, prices are equalized across countries.

$$P_t = P_{nt} = (\xi B)^{1/\beta} \left\{ \sum_{m=1}^{N} T_m (A_{mt})^{\theta} (w_{mt})^{-\beta\theta} \right\}^{\frac{-1}{\beta\theta}}$$

Thus, from $d_{nmt} = (\xi B)^{-\theta} T_m (A_{mt})^{\theta} (w_{mt})^{-\beta\theta} (P_{mt})^{\beta\theta}$ we obtain:

$$d_{mnt} = T_n (A_{nt})^{\theta} (w_{nt})^{-\beta\theta} \left\{ \sum_{m=1}^{N} T_m (A_{mt})^{\theta} (w_{mt})^{-\beta\theta} \right\}^{-1}$$

and from $w_{nt} L_{nt} = \sum_{m=1}^{N} d_{mnt} w_{mt} L_{mt},$, we have:

$$w_{nt} = \left(\frac{T_n (A_{nt})^{\theta}}{L_{nt}} \right)^{\frac{1}{1+\beta\theta}} V_t$$

where $V_t \equiv \left[\sum_{m=1}^{N} \frac{w_{mt} L_{mt}}{\sum_{i=1}^{N} T_i (A_{it})^{\theta} (w_{it})^{-\beta\theta}} \right]^{\frac{1}{1+\beta\theta}}$ is common to all countries. Therefore, using the definition of Z_{nt}, and recalling our definition of real income, $Y_{nt} = \frac{w_{nt} L_{nt}}{P_{nt}}$, we have

$$\begin{aligned} Y_{nt} &= L_{nt} \left(\frac{T_n (A_{nt})^{\theta}}{L_{nt}} \right)^{\frac{1}{1+\beta\theta}} V_t (\xi B)^{1/\beta} \left\{ \sum_{i=1}^{N} T_i (A_{it})^{\theta} \left(\left(\frac{T_i (A_{it})^{\theta}}{L_{it}} \right)^{\frac{1}{1+\beta\theta}} V_t \right)^{-\beta\theta} \right\}^{\frac{1}{\beta\theta}} \\ &= (\xi B)^{1/\beta} \left(T_n A_{nt}^{\theta} L_{nt}^{\beta\theta} \right)^{\frac{1}{1+\beta\theta}} \left[\sum_{i=1}^{N} \left(T_i (A_{it})^{\theta} L_{it}^{\beta\theta} \right)^{\frac{1}{1+\beta\theta}} \right]^{\frac{1}{\beta\theta}} \\ &= (\xi B)^{1/\beta} Z_{nt}^{\frac{1}{1+\beta\theta}} \left(\sum_{m=1}^{N} Z_{mt}^{\frac{1}{1+\beta\theta}} \right)^{\frac{1}{\beta\theta}} \end{aligned}$$

Numerical Procedure for Model Equilibrium

We use nested iterations to compute the model equilibrium.

Inner Loop

For a given pair of sectoral resource allocation (L_{nt}^j) and sectoral wages (w_{nt}^j) solve the system below for sectoral prices indexes P_{nt}^j.

$$P_{nt} = \prod_{j=1}^{J} \alpha_t^{j\,-\alpha_t^j} P_{nt}^{j\ \alpha_t^j}$$

$$P_{nt}^j = \xi \Phi_{nt}^{j\ -\frac{1}{\theta}}$$

$$\Phi_{nt}^j = B^{j\,-\theta} \sum_{i=1}^{N} T_i^j A_{it}^{j\ \theta} \left(\frac{w_{it}^{j\ \beta^j} \prod_{k=1}^{J} P_{it}^{k\,\gamma^{kj}}}{\kappa_{nit}^j} \right)^{-\theta}$$

Simplify Φ_{nt}^j :

$$\begin{aligned}
\Phi_{nt}^j &= B^{j\,-\theta} \sum_{i=1}^{N} \underbrace{T_i^j A_{it}^{j\ \theta}}_{\frac{Z_{it}^j}{L_{it}{}^{\beta^j \theta}}} \left(\frac{w_{it}^{j\ \beta^j} \prod_{k=1}^{J} P_{it}^{k\,\gamma^{kj}}}{\kappa_{nit}^j} \right)^{-\theta} \\
&= B^{j\,-\theta} \sum_{i=1}^{N} Z_{it}^j L_{it}{}^{-\beta^j \theta} w_{it}^{j\ -\beta^j \theta} \kappa_{nit}^{j\ \theta} \prod_{k=1}^{J} P_{it}^{k\,-\theta\gamma^{kj}} \\
&= B^{j\,-\theta} \sum_{i=1}^{N} \underbrace{Z_{it}^j \Big((L_{it} w_{it}^j)^{-\beta^j} \kappa_{nit}^j \Big)^{\theta}}_{D_{nit}^j} \prod_{k=1}^{J} P_{it}^{k\,-\theta\gamma^{kj}} \\
&= B^{j\,-\theta} \sum_{i=1}^{N} D_{nit}^j \prod_{k=1}^{J} P_{it}^{k\,-\theta\gamma^{kj}}
\end{aligned}$$

Note that we can compute the coefficients of the equation (the D values) before starting the search for prices. Now we can write the system of equations as

$$
\begin{aligned}
{P_{nt}^{j}}^{-\theta} &= \xi^{-\theta}\Phi_{nt}^{j} \\
{P_{nt}^{j}}^{-\theta} &= \xi^{-\theta}{B^{j}}^{-\theta}\sum_{i=1}^{N} D_{nit}^{j}\prod_{k=1}^{J} {P_{it}^{k}}^{-\theta\gamma^{kj}}
\end{aligned}
$$

or

$$
\mathcal{P}_{nt}^{j} = \left(\xi B^{j}\right)^{-\theta}\sum_{i=1}^{N} D_{nit}^{j}\prod_{k=1}^{J} {\mathcal{P}_{it}^{k}}^{\gamma^{kj}} \tag{18}
$$

where $\mathcal{P}_{nt}^{j} \equiv {P_{nt}^{j}}^{-\theta}$. We iterate (18) until convergence.

Middle loop

For a given resource allocation, L_{nt}^{j}, this loop searches for sectoral wages w_{nt}^{j} that solve the system of equations below. For notational simplicity we solve the system in terms of sectoral revenue and then calculate corresponding wages from $w_{nt}^{j}L_{nt}^{j} = \beta^{j}R_{nt}^{j}$.

$$
\begin{aligned}
R_{nt}^{j} &= \sum_{m=1}^{N} E_{mt}^{j} d_{mnt}^{j}\left(w_{nt}^{j}\right) \\
E_{mt}^{j} &= \alpha_{t}^{j} P_{mt} C_{mt} + \sum_{k=1}^{J} \gamma^{jk} R_{mt}^{k} \\
P_{mt}C_{mt} &= \sum_{j=1}^{J} \beta^{j} R_{mt}^{j} - S_{mt},
\end{aligned}
$$

where S_{mt} is the exogenous trade surplus of country m in year t, with $\sum_m S_{mt} = 0$. In the baseline specification, we set $S_{mt} = 0$ for each country. (A subsequent appendix explains how the trade surplus enters into the numerical algorithm in the way it does).

Substituting in, we get a system of linear equations in R^j_{nt} for any given value of $d^j_{mnt}(w^j_{nt})$:

$$R^j_{nt} = \sum_{m=1}^{N} d^j_{mnt}(w^j_{nt}) \left[\alpha^j_t \sum_{k=1}^{J} \beta^k R^k_{mt} - \alpha^j_t S_{mt} + \sum_{k=1}^{J} \gamma^{jk} R^k_{mt} \right] \tag{19}$$

Note that d^j_{mnt} depends on w^j_{nt} through

$$d^j_{mnt} = \frac{B^{j^{-\theta}} T^j_n {A^j_{nt}}^{\theta} \left(\frac{{w^j_{nt}}^{\beta^j} \prod_{k=1}^{J} {P^k_{nt}}^{\gamma^{kj}}}{\kappa^j_{mnt}} \right)^{-\theta}}{B^{j^{-\theta}} \sum_{i=1}^{N} T^j_i {A^j_{it}}^{\theta} \left(\frac{{w^j_{it}}^{\beta^j} \prod_{k=1}^{J} {P^k_{it}}^{\gamma^{kj}}}{\kappa^j_{mit}} \right)^{-\theta}},$$

where prices were solved for in the inner loop. To facilitate computation we introduce D, the coefficients from the inner loop. We can rewrite the definition of d as

$$\begin{aligned} d^j_{mnt} &= \frac{\overbrace{T^j_n {A^j_{nt}}^{\theta}}^{\frac{Z^j_{nt}}{{L_{nt}}^{\beta^j\theta}}} \left(\frac{{P_{nt}}^{1-\beta^j} {w^j_{nt}}^{\beta^j}}{\kappa^j_{mnt}} \right)^{-\theta}}{\sum_{i=1}^{N} \underbrace{T^j_i {A^j_{it}}^{\theta}}_{\frac{Z^j_{it}}{{L_{it}}^{\beta^j\theta}}} \left(\frac{{P_{it}}^{1-\beta^j} {w^j_{it}}^{\beta^j}}{\kappa^j_{mit}} \right)^{-\theta}} \\
&= \frac{Z^j_{nt} {L_{nt}}^{-\beta^j\theta} {w^j_{nt}}^{-\beta^j\theta} {\kappa^j_{mnt}}^{\theta} {P_{nt}}^{\theta(\beta^j-1)}}{\sum_{i=1}^{N} Z^j_{it} {L_{it}}^{-\beta^j\theta} {w^j_{it}}^{-\beta^j\theta} {\kappa^j_{mit}}^{\theta} {P_{it}}^{\theta(\beta^j-1)}} \\
&= \frac{\overbrace{Z^j_{nt} {L_{nt}}^{-\beta^j\theta} {w^j_{nt}}^{-\beta^j\theta} {\kappa^j_{mnt}}^{\theta}}^{D^j_{mnt}} {P_{nt}}^{\theta(\beta^j-1)}}{\sum_{i=1}^{N} \underbrace{Z^j_{it} {L_{it}}^{-\beta^j\theta} {w^j_{it}}^{-\beta^j\theta} {\kappa^j_{mit}}^{\theta}}_{D^j_{mit}} {P_{it}}^{\theta(\beta^j-1)}} \\
&= \frac{D^j_{mnt} {P_{nt}}^{\theta(\beta^j-1)}}{\sum_{i=1}^{N} D^j_{mit} {P_{it}}^{\theta(\beta^j-1)}} \end{aligned}$$

Note that d does not depend on the resource allocation.

We guess a wage to compute d, then solve the linear equations (19) for revenue. Our new wage can be computed from the revenue, and we iterate until convergence.

Outer loop

The goal of this loop is to find the sectoral resource allocations L_{nt}^j that satisfy

$$\frac{L_{nt}^j}{L_{nt}} = E_{t-1}\left(\frac{w_{nt}^j L_{nt}^j}{w_{nt} L_{nt}}\right)$$

where w_{nt} is the average wage. This loop runs over iterations of L_{nt}^j until it converges up to a predefined threshold.

To approximate the expectation we use a band pass filtered trend that allows for breaks in growth rates.

1. We start from the initial value $(L_{nt}^j)^0 = \alpha^j L_{nt}$.

2. In iteration i for the actual $(L_{nt}^j)^i$ we get sectoral and aggregate wages, $(w_{nt}^j)^i$ and $(w_{nt})^i$, from the middle loop.

3. We calculate the implied total value added and the sectoral value added shares as $\left(\frac{w_{nt}^j L_{nt}^j}{w_{nt} L_{nt}}\right)^i = \frac{(w_{nt}^j)^i (L_{nt}^j)^i}{(w_{nt})^i L_{nt}}$.

4. Decompose all $N \cdot J$ value added share series to trend and cycle components using a band pass filter with the same specification as in the shock decomposition:

$$\left(\frac{w_{nt}^j L_{nt}^j}{w_{nt} L_{nt}}\right)^i = \left(trend_{nt}^j\right)^i + \left(cycle_{nt}^j\right)^i.$$

5. Replace the expectation with the adjusted trend value.

$$\left(E_{t-1}\left(\frac{w_{nt}^j L_{nt}^j}{w_{nt} L_{nt}}\right)\right)^i = \left(\widehat{\frac{w_{nt}^j L_{nt}^j}{w_{nt} L_{nt}}}\right)^i$$

6. Update the resource allocations

$$(L_{nt}^j)^{i+1} = L_{nt}\left(E_{t-1}\left(\frac{w_{nt}^j L_{nt}^j}{w_{nt} L_{nt}}\right)\right)^i$$

Data Sources

We first describe the sample of countries and then the various sources of data.

Sample of Countries

Our sample consists of 24 core countries, for which we were able to collect all the information needed to carry out the quantitative analysis with no need—or very limited need—of estimation. Other countries, for which data are nearly complete and estimation of some sectors' output or value added was needed, are grouped as "Rest of the World" (ROW); the sectoral trade data are available for virtually all countries. Some countries were aggregated (for example Belgium and Luxembourg, and, before making to ROW, Former USSR, Former Yugoslavia.). In particular, the minimum condition to keep a country (or an aggregation of countries) in the sample is the availability of complete series of sectoral value added and the presence of trade data.

The core sample of countries include the United States, Mexico, Canada, Australia, China, Japan, South Korea, India, Colombia, the United Kingdom, a composite of France and its overseas departments, Germany, Italy, Spain, Portugal, a composite of Belgium and Luxembourg, the Netherlands, Finland, Sweden, Norway, Denmark, Greece, Austria and Ireland. While some important countries appear only in our ROW group (most notably Brazil, Russia, Turkey, Indonesia, Malaysia and oil exporters), the selection of core countries is meaningful both in terms of geographic location (covering all continents) and in terms of their share in global trade and GDP. The time period we study covers years from 1972 to 2007. 1970–1971 are slightly problematic for trade data, as there are many missing observations; hence the decision to start in 1972. The end period is chosen in order to avoid confounding the trade effects we are after with the financial crisis, which had other underlying causes. We focus on annual data.

Sectoral Gross Output

The data are disaggregated into 24 sectors: agriculture (including mining and quarrying), 22 manufacturing sectors, and services, all available in US dollars for the core countries and the Rest of the world (ROW). The 22 manufacturing sectors correspond to the industries numbered 15 to 37 in the ISIC Rev. 3 classification (36 and 37 are bundled together).

The final dataset is obtained by combining different sources and some estimation. Data on agriculture, aggregate manufacturing, and services for core countries come mostly from the EU KLEMS database. There is no available series for services output in China and India, so they are obtained as residuals. Additional data come from the UN National Accounts.

Data on manufacturing subsectors come from UNIDO and EU KLEMS. For some subsectors, EU KLEMS data are available only at a higher level of aggregation (i.e. sector 15&16 instead of the two separately); in those cases, we use the country specific average shares from

UNIDO for the years in which they are available to impute values for each subsectors.

For the countries in the ROW, the output dataset is completed through estimation, using sectoral value added, aggregate output, GDP and population (the latter two from the Penn World Table 7.1) in a Poisson regressions.

Finally, for the few countries for which we have sectoral value added data (described below) but no PWT data, we estimate sectoral output by calculating for each year and sector the average value added/output ratio,

$$\bar{\beta}_t^j = \frac{1}{N} \sum_{i=1}^{N} \frac{VA_{i,t}^j}{Output_{i,t}^j}$$

and then use it in

$$\widehat{Output}_{i,t}^j = \frac{VA_{i,t}^j}{\bar{\beta}_t^j}$$

Data collection notes on the core countries are as follows:

- USA: missing years 1970-76 generated using a growth rate of each sector from EU KLEMS (March 2008 edition).
- Canada: 1970-04 EU KLEMS (March 2008 edition), for 2005-06 sectoral growth rates from the Canadian Statistical Office's National Economic Accounts (table Provincial gross output at basic prices by industries).
- China: data are from the Statistical yearbooks of China. Output in agriculture is defined as gross output value of farming, forestry, animal husbandry and fishery and is available for all years. Mining and manufacturing is reported as a single unit labelled output in industry, which apart from the extraction of natural resources and manu-

facture of industrial products includes sectors not covered by other countries: water and gas production, electricity generation and supply and repair of industrial products (no adjustment was made). The primary concern was the methodological change initiated around 1998, when China stopped reporting *total* industrial output and limited the coverage to industrial output of firms with annual sales above 5m yuan (USD 625 000). The sectoral coverage remained the same in both series. There were 5 years of overlapping data of both series over which the share of the 5m+ firms on total output decreased from 66 to 57 percent. The chosen approach to align both series was to take the levels of output from the pre-1999 series (output of all firms) and apply the growth rate of output of 5m+ firms in the post-1999 period. This procedure probably exaggerates the level of output in the last seven years and leads to an enormous increase in the output/GDP in industry ratio (from 3.5 in 1999 to 6.0 in 2006). Our conjecture is that the ratio would be less steep if the denominator was value added in industry (unavailable on a comparable basis) because the GDP figure includes net taxes, which might take large negative values. Output in industry of all firms reflects the 1995 adjustment with the latest economic census.

There is no available estimate for output in services, so we use the predicted values from a Poisson regression on the other core countries, with sectoral value added (see below for details on the source), output in agriculture, output in manufacturing, GDP and population (the latter two from the Penn World Table 7.1) and year dummies as regressors.

- India: data are from the Statistical Office of India, National Accounts Statistics. Years

1999-06 are reported on the SNA93 basis. Earlier years were obtained using the growth rates of sectoral output as defined in their 'Back Series' database. The main issue with India was the large share of 'unregistered' manufacturing that is reported in the SNA93 series but missing in the pre-1999 data. The 'unregistered' manufacturing covers firms employing less than 10 workers and is also referred to as the informal or unorganized sector. We reconstructed the total manufacturing output using the assumption that the share of registered manufacturing output in total manufacturing output mirrors the share of value added of the registered manufacturing sector in total value added in manufacturing (available from the 'Back Series' database).

As for China, output in services was estimated through a Poisson regression method.

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

- Japan: data for 1973-06 are from EU KLEMS (November 2009 Edition), for 1970-72 the source is the OECD STAN database (growth rate).

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

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

The exchange rates used for the conversion of output data come from the IMF.

Sectoral Value Added

The data on sectoral value added is obtained by combining data from the World Bank, UN National Accounts, EU KLEMS and UNIDO. For the World Bank and UN cases, the format of the data does not allow to have exactly the same sectoral classification as the output data: namely, mining here is not included in agriculture.

The World Bank and UN data are cleaned (we noted a contradiction in the UN data for Ethiopia and Former Ethiopia, which we correct to include in ROW final sample).

Data on manufacturing subsectors come from UNIDO and EU KLEMS. For some subsectors, EU KLEMS data are available only at a higher level of aggregation (i.e. sector 15&16 instead of the two separately); in those cases, we use the country specific average shares from UNIDO for the years in which they are available to impute values for each subsectors; if no such data are available in UNIDO, we use the average shares for the whole sample. We use the UNIDO data as baseline and complete it with EU KLEMS when necessary (in these cases the growth rates of the EU KLEMS series are used to impute values; this is done because sometimes the magnitudes are quite different in the two datasets). If an observation is missing in both datasets, we impute it using the country specific average sectoral shares for the years in which data are available.

Trade flows

We use bilateral imports and exports at the sectoral level from 1972 to 2007 from the UN COMTRADE database. This dataset contains the value of all the transactions with international partners reported by each country. Since every transaction is potentially recorded twice (once reported by the exporter and once by the importer) we use the values reported by the importer when possible and integrate with the corresponding values reported by the exporter if only those are available. Re-exports and re-imports are not included in the exports and imports figures.

We use the SITC1 classification for all the sample. This is made in order to ensure a consistent definition of the sectors throughout the whole time period. In order to construct the agricultural sector we aggregate the subsectors in the SITC1 classification corresponding to the BEC11 group. For the manufacturing sectors, we use the correspondence tables available on the UN website to identify the SITC1 groups corresponding to the ISIC 3 groups used for output and value added.

Prices

In order to back out the augmented productivity processes Z_{nt}^{j} we require aggregate price indices for all countries. For the resulting Z_{nt}^{j} to be comparable across countries, these price indices must be in a common currency. Hence, we use the price of GDP variable from the Penn World Tables (PWT) which is expressed in a common unit (so-called "international dollars").[24] In particular, we use version 7.1 of PWT for all countries, except for Former USSR, Former Czechoslovakia and Former Yugoslavia, for which we use the PWT 5.6. For the ROW, we compute a weighted average of the relative prices of GDP for all the countries for which the PWT data are available (most of the ROW countries), where the weights are

[24] Strictly speaking a better match between the price of GDP in the model and in the data would have been the price of consumption, but as is well known these variables take almost identical values in the PWTs. It is important to note that we use the PWT for P_{nt} only in the procedure to back out the Z_{nt}^{j}s. As discussed later, when we compute real agregate income in the data to generate aggregate volatility figures to compare to the model output, we do not need to worry about having the prices in the same currency, and we are therefore able to use national CPIs, which map exactly into the theoretical counterpart.

each country's share of total output. Similarly, for Belgium-Luxembourg, we compute the weighed average of the two.

For the augmented productivity processes we also require sectoral price deflators from the USA. These are taken from EU KLEMS.

Real Income

We need a time series for real income to generate volatility figures to compare to the volatility implied by our model. We use nominal value added (the aggregate for all sectors) in local currency units, deflated by the countries' CPI. The data are provided by the World Bank's World Development Indicators, in turn sourced by the International Monetary Fund (IMF). For Germany we use the CPI index provided by the OECD, as the IMF index is not consistent over time. For the United Kingdom we use the Retail Price Index, as the CPI index is not available.

Trade Imbalances

In the presence of trade imbalances, equation (4) becomes

$$P_{nt}C_{nt} = \sum\nolimits_{j=1}^{J} w_{nt}^{j} L_{nt}^{j} - S_{nt},$$

where S_{nt} is the exogenously given current account surplus. As a consequence, the first order condition for labor allocations becomes

$$\frac{L_{nt}^j}{L_{nt}} = \frac{E_{t-1}\left(\frac{w_{nt}^j L_{nt}^j}{\sum_{j=1}^J w_{nt}^j L_{nt}^j - S_{nt}}\right)}{E_{t-1}\left(\frac{\sum_{j=1}^J w_{nt}^j L_{nt}^j}{\sum_{j=1}^J w_{nt}^j L_{nt}^j - S_{nt}}\right)}.$$

It can easily be shown that (12) is the first order approximation of the expression above around $S_{nt} = 0$. Hence, there is no compelling quantitative reason to change this part of the model when allowing for trade imbalances.

On the other hand, equation (10) becomes

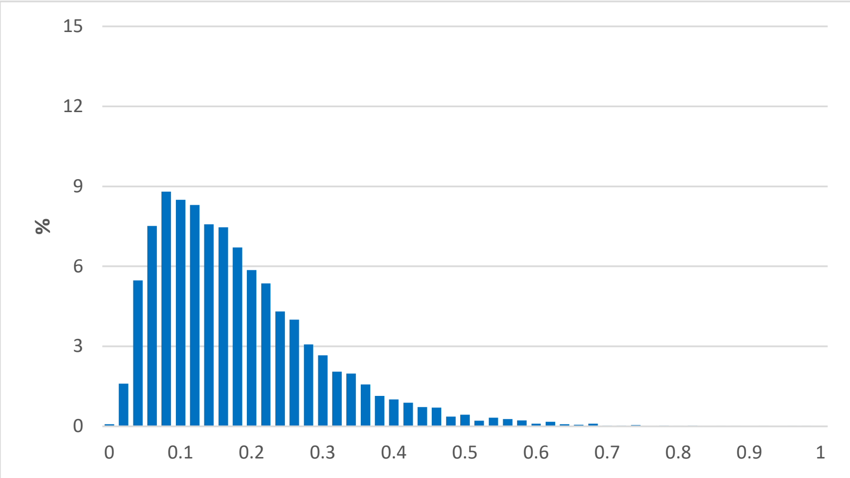
$$E_{mt}^j = \alpha_t^j \left(P_{mt}C_{mt} - S_{mt}\right) + \sum\nolimits_{k=1}^J \gamma^{jk} R_{mt}^k.$$

Since S_{mt} enters this linearly, the model must be solved again with this equation instead of the original (10).

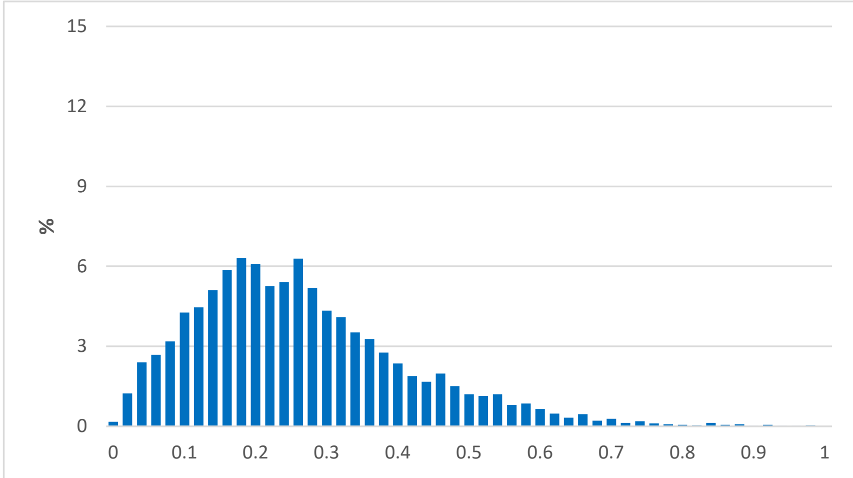
Figure 1: Histogram of bilateral trading costs: 2002 and 2007

A. Manufacturing Sectors

1972

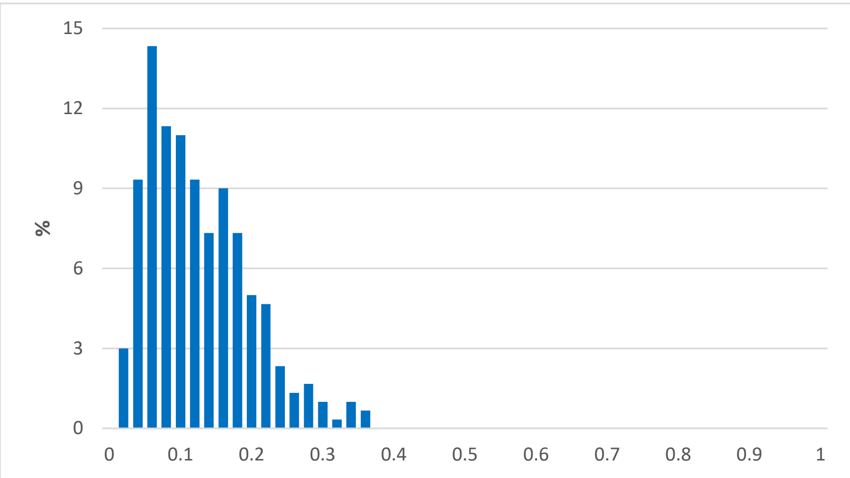


2007



B. Agriculture

1972



2007

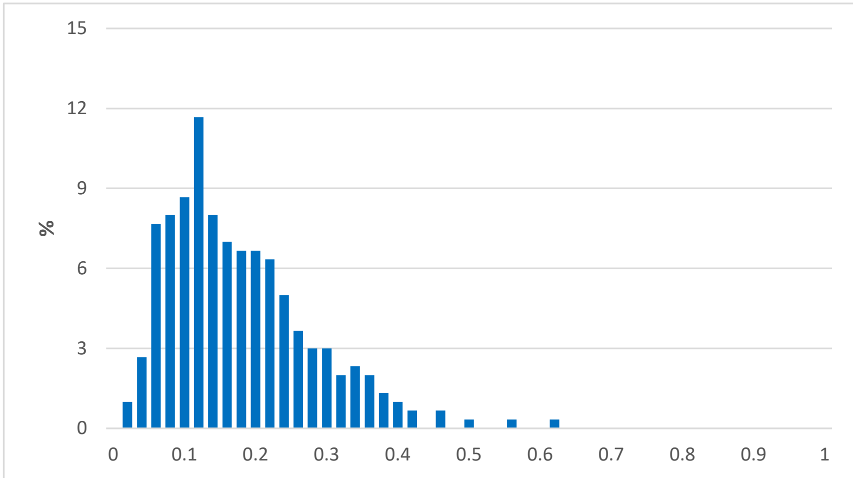


Figure 2: Income volatility in the model and in the data

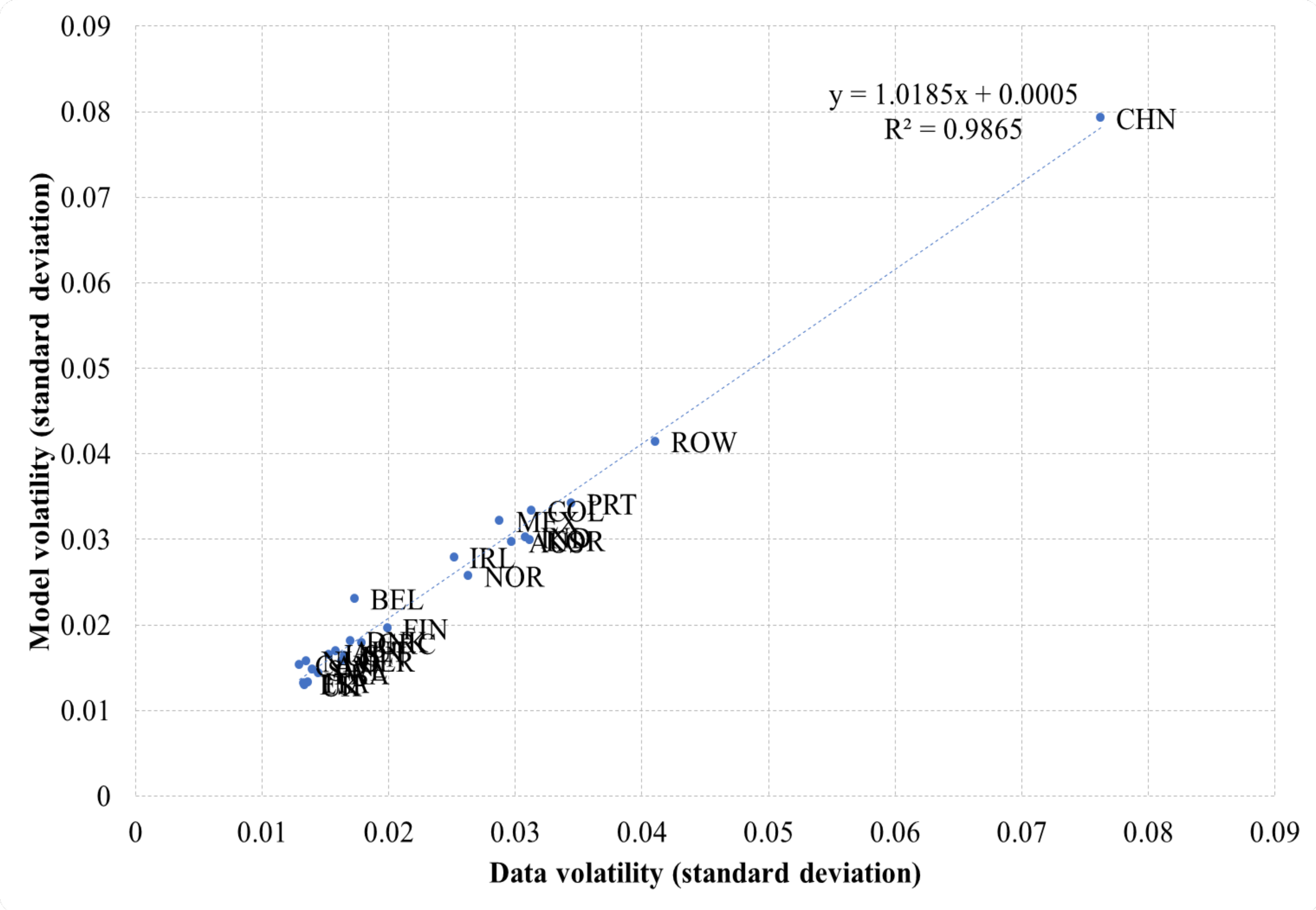


Table 1: Baseline Results

	Volatility change due to changes in trade barriers (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)
Australia	4.4%	-3.7%	8.1%
Austria	-64.3%	-22.6%	-41.7%
Belgium and Luxembourg	-59.1%	-107.4%	48.3%
Canada	-55.9%	-102.4%	46.6%
China	2.3%	1.4%	0.9%
Colombia	-6.2%	-10.9%	4.7%
Denmark	-57.0%	-54.4%	-2.6%
Finland	-37.8%	-87.6%	49.8%
France	-5.8%	4.9%	-10.6%
Germany	-6.1%	-8.5%	2.4%
Greece	7.8%	3.3%	4.5%
India	1.9%	-2.9%	4.9%
Ireland	-67.9%	-45.6%	-22.3%
Italy	-2.4%	3.7%	-6.1%
Japan	-0.2%	-0.2%	0.0%
Mexico	-49.8%	-77.6%	27.9%
Netherlands	-50.4%	-131.4%	81.0%
Norway	-39.2%	-90.3%	51.1%
Portugal	-12.2%	-34.0%	21.9%
ROW	1.0%	-2.4%	3.4%
South Korea	-0.5%	-6.2%	5.8%
Spain	-16.4%	-6.5%	-9.9%
Sweden	-34.6%	-25.5%	-9.0%
United Kingdom	-11.3%	-7.1%	-4.2%
United States	0.6%	0.9%	-0.3%
Average	-22.4%	-32.5%	10.2%

Column 1: Variance of real income deviations from trade in baseline model less variance of the same when trade costs are held at 1972 levels, as percent of volatility when trade costs are held at 1972 levels

Column 2: Same as Column 1 but both models are run without sectoral shocks

Column 3: Difference between Column 1 and Column 2

Table 2: Results by decade

	Volatility change due to changes in trade barriers (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)
1972-1980	-4.2%	-11.0%	6.8%
1980-1990	-13.4%	-18.9%	5.5%
1990-2000	-26.2%	-39.1%	12.9%
2000-2007	-24.0%	-43.8%	19.8%

Columns 1-3: Same model runs as in Table 1, but income volatilities computed over decades and averaged across countries. We measure decadal volatility as the variance of log GDP growth rates over the decade.

Table 3: Robustness to Trade Imbalances

	Volatility change due to changes in trade barriers (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)
Australia	4.5%	-4.2%	8.7%
Austria	-64.0%	-21.9%	-42.1%
Belgium and Luxembourg	-60.0%	-106.8%	46.9%
Canada	-62.0%	-94.3%	32.4%
China	2.0%	2.0%	-0.1%
Colombia	-6.8%	-13.2%	6.4%
Denmark	-54.7%	-54.7%	0.0%
Finland	-37.1%	-85.6%	48.4%
France	-5.5%	4.8%	-10.3%
Germany	-6.8%	-7.7%	0.9%
Greece	8.1%	0.8%	7.3%
India	2.0%	-3.1%	5.1%
Ireland	-65.4%	-46.8%	-18.6%
Italy	-1.9%	3.8%	-5.8%
Japan	0.7%	-0.3%	1.0%
Mexico	-48.3%	-77.3%	29.1%
Netherlands	-50.3%	-132.0%	81.6%
Norway	-42.3%	-83.5%	41.2%
Portugal	-9.8%	-32.0%	22.2%
ROW	0.9%	-2.3%	3.2%
South Korea	1.5%	-5.2%	6.7%
Spain	-14.8%	-5.8%	-9.1%
Sweden	-34.4%	-25.8%	-8.5%
United Kingdom	-10.1%	-6.5%	-3.6%
United States	0.5%	0.8%	-0.2%
Average	-22.2%	-31.9%	9.7%

Columns 1-3: Same as Table 1 but the model features unbalanced trade

Table 4: Robustness to choice of parameters

	θ = 2			θ = 8		
	Volatility change due to changes in trade barriers (1.a)	Volatility change due to diversification (2.a)	Volatility change due to specialization (3.a)	Volatility change due to changes in trade barriers (1.b)	Volatility change due to diversification (2.b)	Volatility change due to specialization (3.b)
Australia	8.8%	-6.2%	15.0%	2.1%	-2.1%	4.2%
Austria	-76.9%	-47.9%	-29.0%	-49.2%	-7.9%	-41.3%
Belgium and Luxembourg	-72.4%	-143.3%	70.9%	-38.1%	-62.2%	24.2%
Canada	-72.9%	-129.0%	56.1%	-27.7%	-56.4%	28.7%
China	3.4%	2.7%	0.8%	1.4%	0.7%	0.7%
Colombia	-10.4%	-24.5%	14.1%	-4.3%	-5.0%	0.8%
Denmark	-77.1%	-85.3%	8.2%	-27.1%	-28.0%	0.9%
Finland	-62.2%	-168.9%	106.6%	-19.3%	-35.0%	15.7%
France	-10.1%	18.8%	-28.9%	-3.3%	1.1%	-4.4%
Germany	-15.5%	-21.7%	6.3%	-2.7%	-3.3%	0.6%
Greece	5.3%	-7.6%	12.9%	3.9%	3.5%	0.4%
India	-3.5%	-12.1%	8.5%	2.5%	-0.4%	3.0%
Ireland	-79.1%	-85.0%	6.0%	-46.2%	-9.5%	-36.7%
Italy	-6.6%	16.3%	-23.0%	-1.2%	0.6%	-1.8%
Japan	-2.9%	1.9%	-4.7%	0.8%	-0.3%	1.2%
Mexico	-68.1%	-129.2%	61.1%	-29.9%	-37.5%	7.6%
Netherlands	-73.6%	-186.6%	112.9%	-22.6%	-61.3%	38.7%
Norway	-65.1%	-149.6%	84.6%	-14.8%	-35.6%	20.7%
Portugal	-30.7%	-105.7%	75.0%	-4.4%	-9.4%	4.9%
ROW	2.4%	-3.6%	6.0%	0.3%	-1.6%	1.9%
South Korea	-6.9%	-31.0%	24.2%	0.3%	-0.5%	0.8%
Spain	-33.9%	-5.9%	-28.0%	-7.6%	-4.3%	-3.3%
Sweden	-53.3%	-58.5%	5.2%	-19.7%	-8.7%	-11.0%
United Kingdom	-27.6%	-6.7%	-20.9%	-4.2%	-4.7%	0.5%
United States	1.6%	2.3%	-0.8%	0.2%	0.3%	-0.1%
Average	-33.1%	-54.7%	21.6%	-12.4%	-14.7%	2.3%

Columns 1.a - 3.b: same as Table 1 but using different values of θ

Table 5: Robustness to (costly) labor adjustment

	Volatility change due to changes in trade barriers (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)
Australia	4.4%	-3.7%	8.1%
Austria	-64.4%	-22.8%	-41.6%
Belgium and Luxembourg	-59.0%	-108.4%	49.6%
Canada	-55.8%	-102.5%	46.7%
China	2.3%	1.4%	0.9%
Colombia	-6.0%	-10.9%	5.0%
Denmark	-57.0%	-54.4%	-2.6%
Finland	-37.8%	-87.8%	50.1%
France	-5.7%	4.9%	-10.6%
Germany	-6.1%	-8.4%	2.4%
Greece	7.8%	3.3%	4.6%
India	1.8%	-2.9%	4.7%
Ireland	-67.9%	-45.7%	-22.2%
Italy	-2.4%	3.7%	-6.1%
Japan	-0.2%	-0.2%	0.0%
Mexico	-49.8%	-76.0%	26.3%
Netherlands	-50.5%	-132.3%	81.8%
Norway	-39.2%	-90.9%	51.8%
Portugal	-12.2%	-34.9%	22.8%
ROW	1.0%	-2.3%	3.4%
South Korea	-0.4%	-6.3%	5.8%
Spain	-16.4%	-6.4%	-9.9%
Sweden	-34.2%	-25.5%	-8.5%
United Kingdom	-11.2%	-7.1%	-4.0%
United States	0.6%	0.9%	-0.3%
Average	-22.3%	-32.6%	10.3%

Columns 1-3: Same as Table 1 but the model allows for ex-post costly adjustment of sectoral allocations of labor

Table 6: Role of Input-Output Linkages

	Volatility change due to changes in trade barriers (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)
Australia	1.4%	-0.3%	1.8%
Austria	-34.3%	-14.4%	-20.0%
Belgium and Luxembourg	-27.9%	-53.8%	25.9%
Canada	-6.6%	-14.9%	8.3%
China	0.9%	0.5%	0.5%
Colombia	-4.9%	-4.0%	-0.8%
Denmark	-17.2%	-18.4%	1.2%
Finland	-14.7%	-19.4%	4.7%
France	-2.3%	-0.3%	-2.0%
Germany	-1.3%	-1.3%	-0.1%
Greece	2.7%	1.4%	1.4%
India	1.9%	-0.4%	2.3%
Ireland	-25.5%	-24.2%	-1.3%
Italy	-1.5%	-1.4%	-0.1%
Japan	1.2%	-0.7%	1.9%
Mexico	-26.4%	-30.2%	3.8%
Netherlands	-20.4%	-37.9%	17.5%
Norway	-9.5%	-13.6%	4.1%
Portugal	-2.8%	-5.1%	2.3%
ROW	0.4%	-0.3%	0.7%
South Korea	0.5%	0.1%	0.4%
Spain	-5.9%	-3.1%	-2.8%
Sweden	-13.9%	-11.0%	-3.0%
United Kingdom	-2.4%	-6.5%	4.0%
United States	0.3%	0.2%	0.1%
Average	-8.3%	-8.5%	0.1%

Columns 1-3: Same as Table 1 but the model features $\gamma_{kj}=0$ for all j and k

Table 7: The Role of China

	China excluded from world trade			κ_China,t = κ_China,1972 for t > 1972		
	Volatility change due to changes in trade barriers (1.a)	Volatility change due to diversification (2.a)	Volatility change due to specialization (3.a)	Volatility change due to changes in trade barriers (1.b)	Volatility change due to diversification (2.b)	Volatility change due to specialization (3.b)
Australia	4.4%	-3.6%	8.0%	4.3%	-3.6%	7.9%
Austria	-63.4%	-23.0%	-40.4%	-63.3%	-21.5%	-41.7%
Belgium and Luxembourg	-58.4%	-106.0%	47.6%	-58.4%	-106.0%	47.6%
Canada	-55.4%	-100.7%	45.3%	-55.3%	-100.8%	45.4%
China				0.0%	-0.6%	0.6%
Colombia	-6.2%	-10.5%	4.3%	-6.2%	-10.5%	4.3%
Denmark	-55.0%	-56.3%	1.3%	-58.9%	-53.1%	-5.7%
Finland	-37.8%	-86.3%	48.5%	-37.7%	-86.2%	48.5%
France	-5.7%	4.7%	-10.3%	-5.6%	4.7%	-10.3%
Germany	-5.9%	-8.5%	2.6%	-5.9%	-8.4%	2.5%
Greece	8.2%	3.7%	4.5%	8.1%	3.7%	4.4%
India	1.7%	-3.1%	4.9%	1.7%	-3.2%	4.8%
Ireland	-66.5%	-47.1%	-19.4%	-67.2%	-45.7%	-21.5%
Italy	-2.4%	3.6%	-6.0%	-2.3%	3.7%	-6.0%
Japan	0.2%	0.0%	0.2%	0.2%	0.0%	0.2%
Mexico	-49.1%	-76.5%	27.4%	-49.2%	-76.4%	27.2%
Netherlands	-49.9%	-128.8%	78.9%	-50.0%	-128.7%	78.8%
Norway	-38.6%	-88.1%	49.4%	-38.8%	-87.1%	48.3%
Portugal	-11.6%	-31.5%	19.9%	-12.2%	-31.1%	19.0%
ROW	0.9%	-2.2%	3.2%	1.0%	-2.2%	3.2%
South Korea	-0.7%	-5.9%	5.2%	-0.6%	-6.0%	5.4%
Spain	-16.1%	-6.5%	-9.6%	-16.1%	-6.6%	-9.5%
Sweden	-33.8%	-24.7%	-9.2%	-33.8%	-24.7%	-9.2%
United Kingdom	-11.0%	-6.9%	-4.0%	-10.9%	-6.9%	-4.0%
United States	0.7%	0.9%	-0.2%	0.7%	0.9%	-0.2%
Average	-23.0%	-33.5%	10.5%	-22.3%	-31.9%	9.6%

Columns 1.a-3.a: same as Table 1 but the model is simulated without China

Columns 1.b-3.b: same as Table 1 but China's trading costs are kept at 1972 levels in both baseline and counterfactual

Appendix Table 1: Income volatility in baseline model and other scenarios

	Benchmark volatility (1)	Benchmark volatility without sectoral shocks (2)	Benchmark volatility at 1972 trade costs (3)	Benchmark volatility without sectoral shocks and at 1972 trade costs (4)
Australia	0.000885	0.000951	0.000847	0.000982
Austria	0.000289	0.000484	0.000809	0.000667
Belgium and Luxembourg	0.000533	0.000521	0.001304	0.001922
Canada	0.000235	0.000560	0.000533	0.001105
China	0.006282	0.007727	0.006139	0.007641
Colombia	0.001116	0.001375	0.001189	0.001504
Denmark	0.000328	0.000285	0.000763	0.000700
Finland	0.000384	0.000834	0.000618	0.001375
France	0.000206	0.000294	0.000219	0.000284
Germany	0.000251	0.000218	0.000267	0.000241
Greece	0.000320	0.000356	0.000297	0.000346
India	0.000916	0.000926	0.000899	0.000953
Ireland	0.000780	0.001868	0.002430	0.002976
Italy	0.000178	0.000163	0.000182	0.000157
Japan	0.000269	0.000299	0.000270	0.000299
Mexico	0.001034	0.003352	0.002058	0.004949
Netherlands	0.000250	0.000528	0.000504	0.001190
Norway	0.000663	0.001807	0.001092	0.002793
Portugal	0.001170	0.001816	0.001332	0.002270
ROW	0.001720	0.002495	0.001703	0.002536
South Korea	0.000895	0.000757	0.000899	0.000813
Spain	0.000173	0.000254	0.000207	0.000267
Sweden	0.000218	0.000179	0.000334	0.000264
United Kingdom	0.000168	0.000214	0.000189	0.000227
United States	0.000275	0.000267	0.000273	0.000265

Column 1: Variance of Real Income deviations from trend between 1972 and 2007 in baseline model

Column 2: In baseline model without sectoral shocks

Column 3: In baseline model with trade costs held at 1972 levels

Column 3: In baseline model without sectoral shocks and with trade costs held at 1972