DIVERSIFICATION THROUGH TRADE*

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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. *JEL* Codes: E32, F41, F44.

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

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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 article 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 article is to show analytically that when country-specific shocks are 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.

Second, the article questions the mechanical assumption that higher sectoral 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, as well as the covariance among sectoral shocks and between sectoral and country-wide shocks.

We make these points in the context of a quantitative, multisector, 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]

1. See, for example, Department of International Development (2011).

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.

3. Variations of this model have been used to address a number of questions in international economics. An incomplete list includes Hsieh and Ossa (2016) and

In each sector, production combines equipped labor with a variety of tradeable inputs. Producers source tradeable inputs from the lowest-cost supplier (where supply costs depend on the supplier's productivity and trade costs), after productivity shocks have been realized. This generates the potential for trade 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 sectoral shocks by reallocating resources to other sectors. An extension of the model allows for ex post sectoral reallocation of equipped labor in the presence of reallocation costs.

We use the model in conjunction with production and bilateral trade data for 24 sectors and a diverse group of 25 countries to quantitatively assess how changes in trading costs have affected income volatility between 1972 and 2007.[4] We find that the decline in trade costs since the 1970s has caused sizable reductions in income volatility in the vast majority of the countries in our sample. On average, volatility fell 36% compared to a counterfactual where trade barriers remain at their early 1970s level. The range of changes in volatility due to trade varies significantly across countries, with the largest reductions being on the order of 80%.

The general decline in volatility due to trade is the net result of the two different mechanisms discussed above: sectoral specialization and country-wide diversification. The country-wide diversification mechanism again contributed to lower volatility in most of the countries in our sample, consistent with our key idea that trade is a source of diversification of country-wide shocks. On the other hand, the sectoral-specialization mechanism increased volatility in only just above one-half of the countries in the sample.

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 labor markets; Burstein and Vogel (2017) and Parro (2013), who study the effect of international trade on the skill premium; Caliendo et al. (2018), who study the impact of regional productivity changes on the U.S. economy, and so on. None of these applications, however, focus on the impact of openness to trade on volatility. A partial exception is Burgess and Donaldson (2012), which we discuss below.

4. We stop the analysis in 2007 because our model abstracts from the factors underlying the financial crisis.

Consistent with our theoretical points above, then, the common wisdom that specialization leads to greater volatility fails to apply almost as often as it does. The crucial and most important point, however, is that the country-wide diversification effect is on average eight times larger than 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 trade's impact on volatility. We also find that the impact of trade on volatility is not driven by the emergence of China but 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 preference-based ideal price deflator. In the data counterpart, the cost of living index is the Consumer Price Index (CPI). Hence, we work with a welfare-relevant notion of income.[5]

Because our focus is the volatility of income, we abstract from trade in financial assets. Trade in financial assets has important potential implications for consumption volatility (because it allows for consumption risk sharing) but not for income volatility, which is driven by the production side of the economy. Having said that, for most countries in the world income and consumption fluctuations are very highly correlated, so consumption risk sharing via asset trade does not appear to be empirically significant anyway.[6]

5. Kehoe and Ruhl (2008) and Burstein and Cravino (2015) study the theoretical impact of foreign productivity shocks on various measures of domestic 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), whereas they have first-order effects on welfare-based measures.

6. For recent contributions showing that risk sharing seems quite limited empirically, especially outside of a small number of rich economies, see, for example, Ho and Ho (2015), Rangvida, Santa-Clara, and Schmeling (2016), Fuleky, Ventura, and Zhao (2017), and Hevia and Servén (2018). Fitzgerald (2012) points out that lowering trade costs for goods also reduces the costs of trade in assets, increasing consumption risk sharing and lowering consumption volatility. Along similar lines, Reyes-Heroles (2017) argues that lower trade costs leads to more intertemporal trade. Because we do not allow for asset trade, these effects of lower trade costs are not present in our model.

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 2006; Cavallo 2008; Parinduri 2011; Burgess and Donaldson 2012; Haddad et al. 2013), whereas 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 article 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 an open economy than in a closed economy, because 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 multicountry, multisector setting, instead, income volatility can—and often does—decrease with openness, as intratemporal trade in inputs allows countries with less favorable productivity shocks to source inputs from abroad, thus reducing income (and consumption) volatility.[7]

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 lowered the impact of productivity shocks on real income, implying

7. 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 Kose and Yi 2001; Arkolakis and Ramanarayanan 2009). Our main focus here is on the effect of trade on volatility—and the channels mediating this effect—but the quantitative approach we follow in our counterfactual exercises can potentially be extended to also identify the effect of trade on bilateral comovement—and indeed, other higher-order moments.

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.[8]

Although this article focuses on contrasting our new diversification-through-trade mechanism with the traditional sectoral specialization mechanism, it leaves to future work analysis of the role of "granular" shocks. As pointed out by di Giovanni and Levchenko (2012), if openness to trade increases concentration, the impact of granular shocks is exacerbated, potentially leading to an increase in volatility. See also di Giovanni, Levchenko and Mejean (2014) for a country-level application.

The remainder of the article 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 data sets used in the article.

II. A Model of Trade with Stochastic Shocks

The baseline model builds on a multisector variation of Eaton and Kortum (2002), Alvarez and Lucas (2007), and Caliendo and Parro (2015), augmented to allow for stochastic shocks, as well as frictions to the allocation of nonproduced (and nontraded) 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. In turn, each sectoral output is a bundle of sector-specific varieties. Each sectoral variety can be produced domestically or imported. Domestic

8. See also Donaldson (2018), 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 article, 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.

production of sectoral varieties uses nonproduced inputs, which we refer to 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 α's are allowed to change over time to capture possible changes in tastes. In Section IV.B we investigate the robustness of our results to a specification of preferences in which the elasticity of substitution among sectoral goods is not unitary.

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 labor; $z_n(\omega^j)$ is a time-invariant variety-specific productivity factor; and A_{nt}^{j} 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 equation (3) allows for a rich input-output structure, as the intensity with which each sector's output is used as an intermediate input by other sectors varies across all sector pairs.

Building on the literature, we assume that the productivities $z_n(\omega^j)$ follow a sector-specific, time-invariant Fréchet distribution $F_n^j(z) = \exp(-T_n^j z^{-\theta})$. A higher T_n^j shifts the distribution of productivities to the right, leading to probabilistically higher productivities. A higher θ decreases the dispersion of the productivity distribution and thus 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_{nt}^j over time are interpreted as standard TFP shocks and make the model stochastic at the aggregate level. We decompose them later 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 $0 < \kappa_{mnt}^j \leqslant 1$ goods arriving at m; we assume that $\kappa_{mnt}^j \geqslant \kappa_{mkt}^j \kappa_{knt}^j \quad \forall m, n, k, j, t$ and $\kappa_{nnt}^j = 1$. All costs incurred are net losses.[9] Under the assumption of perfect competition, goods are sourced from the lowest-cost producer after adjusting for transport costs. The sectoral outputs Q_{nt}^j are nontraded.

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

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

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. 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

9. In the calibration, the κ's will reflect all trading costs, including tariffs. Hence, 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.

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.[10]

The representative agent has a per period utility flow $\log(C_{nt})$.[11] Because there is no (endogenous) intertemporal trade and no capital in the economy, the only decision the representative agent has to take in each period is the allocation of equipped labor across sectors before observing the shock realizations. Because labor can be freely reallocated at the beginning of each period, this is a purely static decision.

Since equipped labor is the only nonproduced input, the per period budget constraint 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 IV.B we relax this assumption.

Using equation (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 the rational expectation over the possible realizations of period t shocks. In particular, the representative agent at the beginning of time t knows the previous values of the shock processes A_{nt-1}^{j}, as well as the distribution of A_{nt}^{j} conditional

10. 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 labor subject to an adjustment cost, which we calibrate to match sectoral reallocation flows in the data.

11. The log utility assumption gives rise to a particularly intuitive and tractable decision rule for the labor allocation.

on A^j_{nt-1} (which we specify in Section III.A) and is therefore able to compute the rational expectation in equation (5).

Note that the model above implicitly assumes that producers can switch suppliers relatively easily in response to shocks. Since we later calibrate a period to one year, we are saying that firms can react to problems with one supplier by finding another source within 12 months of the shock. The trade literature suggests considerable churning on the extensive margin. For example, Bernard et al. (2009) document that changes in the set of products and countries that firms source from account for between one-third and one-half of annual import fluctuations. Furthermore, much of the diversification benefits can accrue at the intensive margin: firms build a diversified portfolio of suppliers, and then use the intensive margin vis-à-vis each supplier to absorb shocks—that is, increasing the volumes from suppliers experiencing a positive shock and reducing volumes from suppliers experiencing a negative shock. Cadot, Carrère, and Strauss-Kahn (2014) find evidence of increased diversification of suppliers among OECD firms. Paid consultants give open advice on diversification of suppliers as a way to protect firms from shocks.[12]

II.B. Model Solution

Conditional on the realization of the country-and-sector specific shocks A^j_{nt}, our model is very similar to other general equilibrium, multisector versions of the Eaton-Kortum model. The main difference is that equipped labor is preallocated across sectors. Hence, we do not offer a detailed derivation of the key equilibrium conditions that are unaffected by the ex ante allocation of resources, but merely state them in the following list.

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

12. For example, https://www.exostar.com/blog/can-supply-chain-diversification-reduce-risk/ and https://www.ideasforleaders.com/ideas/supply-chain-risk-diversification-vs-under-diversification.

$$P_{nt}^{j} = \xi \sum_{m=1}^{N} T_{m}^{j} \left(\frac{B^{j} \left(w_{mt}^{j}\right)^{\beta^{j}} \prod_{k=1}^{J} \left(P_{mt}^{k}\right)^{\gamma^{kj}}}{A_{mt}^{j} \kappa_{nmt}^{j}} \right), \tag{7}$$

$$P_{nt} = \prod_{j=1}^{J} \left(\frac{1}{\alpha_{n}^{j}} \right)^{\alpha^{j}} \left(P_{nt}^{j}\right)^{\alpha^{j}}, \tag{8}$$

$$R_{nt}^{j} = \sum_{m=1}^{N} d_{mnt}^{j} E_{mt}^{j}, \tag{9}$$

$$E_{nt}^{j} = \alpha_{t}^{j} P_{nt} C_{nt} + \sum_{k=1}^{J} \gamma^{jk} R_{nt}^{k}, \tag{10}$$

$$w_{nt}^{j} L_{nt}^{j} = \beta^{j} R_{nt}^{j}, \tag{11}$$

and the budget constraint equation (4). In the equations above, d_{nmt}^{j} is the fraction of country n's total spending on sector-j goods that is imported from country m; P_{nt}^{j} is the price of sectoral-good j in country n; R_{nt}^{j} is total revenues accruing to firms operating in sector j in country n; and E_{nt}^{j} is total expenditure by country n residents (consumers and firms) on sectoral good j. $B^{j} \equiv (\beta^{j})^{-\beta^{j}} \prod_{k=1}^{J} (\gamma^{kj})^{-\gamma^{kj}}$ and $\xi \equiv \Gamma(\frac{\theta+1-\eta}{\theta})$, 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_{m}^{j} and A_{mt}^{j}; low wages w_{mt}^{j} and sectoral prices P_{mt}^{k}; 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 the first-order conditions for the allocation of inputs to sectors, that is, the solution to equation (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 $\frac{1}{\sum_k w_{nt}^k L_{nt}^k}$ 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.[13]

The model can conceptually be solved backward 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}^{j}'s, the T_n^{j}'s, the A_{nt}^{j}'s, and of course the L_{nt}^{j}'s. For calibration purposes, it turns out to be both possible and convenient to express the dependence of these solutions on T_n^{j}, A_{nt}^{j}, and L_{nt}^{j} in terms of the augmented productivity factors

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

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 equation (12) to find the ex ante shares $\frac{L_{nt}^{j}}{L_{nt}}$. Our solution method computes the rational expectation in equation (12) by drawing from the estimated distribution of A_{nt}^{j}. In particular, we begin with a choice of candidate values for the L_{nt}^{j}'s, and draw a large number of realizations of the A_{nt}^{j}'s from their estimated distributions (conditional on the A_{nt-1}^{j}'s). For each realization, we compute the solution for the w_{nt}^{j}'s from the system (6)–(11), and then the term in brackets on the right side of equation (12). The rational expectation is then

13. Compared with the allocation in a deterministic 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 $\frac{1}{\sum_k w_{nt}^k L_{nt}^k}$ will be high, and hence the optimal allocation entails allocating more resources to these sectors.

the average of the terms in brackets across all the simulated realizations. If this is (close enough to being) equal to the starting guess for $\frac{L_{nt}^{j}}{L_{nt}}$, the algorithm stops. Otherwise, it moves to a new guess for $\frac{L_{nt}^{j}}{L_{nt}}$. More details are provided at the end of Section III.A and in the Appendix.

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 Section I, 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.[14]

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: 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.

1. Volatility under Autarky. Under complete autarky, it can be easily shown that value added in the one-sector economy is a

14. In contrast, if we were to deflate nominal GDP by using the CES price aggregates of the sector-level variety baskets, we would retrieve the Kehoe-Ruhl invariance of GDP to shocks to the terms of trade. It is doubtful, however, that GDP as constructed by statistical agencies maps well into this theoretical construct. They may measure the price of a representative variety within each sector, the average price of an aggregate variety basket, or a random sample of continuously used varieties. This choice might also depend on the source country, as import price indices are computed differently from producer price indices (Nakamura and Steinsson 2008, 2012). In contrast, the CPI is easier to map to our model, because consumers only consume J different final goods, not a continuum of varieties. Our welfare-relevant price index, which is the geometric average of final-good prices, is a very close approximation of the expenditure-weighted Törnqvist price index, the way the CPI is usually calculated.

function of augmented productivity:

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

where, recall, $Z_{nt} \equiv T_n(L_{nt} A_{nt}^{\frac{1}{\beta}})^{\beta\theta}$. 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 an 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 $Var(\hat{Z}_{nt})$:

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

2. Volatility under Costless International Trade. Under costless international trade ($\kappa_{nmt} = 1$) in the one-sector economy income per capita is:[15]

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

and hence income 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 $\hat{Y}_{nt} = \frac{1}{\beta\theta}[\frac{\gamma_n+\beta\theta}{1+\beta\theta}\hat{Z}_n + \frac{1}{1+\beta\theta}\sum_{m\neq n}^{N} \gamma_m \hat{Z}_m]$. Volatility under free trade is hence given by:

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

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

Compared with 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 $(\frac{\gamma_n+\beta\theta}{1+\beta\theta})^2 < 1$ since $\gamma_n < 1$. The smaller the country (as gauged by its share γ_n), the smaller the impact of domestic volatility of shocks, $\hat{Z}_n$, on its income, when compared with autarky. Openness to trade, however, exposes the economy to other countries' productivity shocks, which also contribute to the country's overall volatility.

Whether 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.[16] 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 oversimplified variance and covariance structure, these examples abstract from the traditional channel thought to link trade to increased volatility, namely, sectoral specialization. To evaluate the relative importance of country diversification and sectoral specialization, ground the analysis on a more realistic stochastic environment based on the data, and evaluate inframarginal changes in trade costs, the rest of the article focuses on the full multisector model with frictions to the reallocation of labor following the realization of shocks.

III. Quantification

Our goal is to quantitatively assess the effect of historical changes in trade barriers on income volatility for as large a

16. To see this, note that $2\beta\theta\gamma_n + \sum_{j=1}\gamma_j^2 < 2\beta\theta + 1$ because $\gamma_m \leqslant 1$ 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.

sample of countries and as fine a level of sectoral disaggregation as available data allow. It turns out that the necessary data are available for a sample of 24 core countries, and an aggregate of the remaining countries, 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.

To solve the model numerically, we need to estimate the values of the exogenous trading costs κ_{nmt}^{j} and the augmented productivity processes Z_{nt}^{j}. We also need to calibrate the parameters α_t^j, 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 trade costs κ_{nmt}^{j} and augmented productivities Z_{nt}^{j} from (versions of) the gravity equation (6) (e.g., Costinot, Donaldson, Komunjer 2012; Levchenko and Zhang 2014, 2016). Allen, Arkolakis, and Takahashi (forthcoming) 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_{nmt}^{j} independently from the Z_{nt}^{j}'s. We can then plug the estimated κ_{nmt}^{j}'s back into equation (6) to back out the Z_{nt}^{j}'s.[17]

17. 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 κ's explicitly as functions of these determinants. Then equation (6) can be estimated econometrically and the Z's recovered as (functions of) country-sector fixed effects. See, for example, Levchenko and Zhang (2014).

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

$$\frac{d_{nmt}^{j} d_{mnt}^{j}}{d_{mmt}^{j} d_{nnt}^{j}} = \left(\kappa_{nmt}^{j}\right)^{2\theta}. \tag{14}$$

Recall that d_{nmt}^{j} 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 $\{\kappa_{nmt}^{j}\}$.

Figure I shows the histograms of bilateral κ's in manufacturing and agriculture in the first and last year of our sample (recall that services are treated as a nontradeable sector). In 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 not only that the trade barriers reflect both transport costs and tariff and nontariff trade barriers but also that many manufacturing and especially agricultural goods are not fully tradeable (e.g. perishable products). They may also pick up a home-bias effect that is not explicitly modeled in Eaton and Kortum.

2. Productivity in Tradeable Sectors. Using again equation (6), together with equation (7) and our definition of augmented productivity equation (13), some algebra yields

$$Z_{nt}^{j} = \underbrace{B^{j\theta} \xi^{\theta} d_{mnt}^{j} \left(\frac{w_{nt}^{j}}{w_{nt}} w_{nt} L_{nt}\right)^{\theta\beta^{j}} \left(\kappa_{mnt}^{j}\right)^{-\theta} \prod_{k=1}^{J} (P_{nt}^{k})^{\theta\gamma^{kj}}}_{\equiv \exp(\zeta_{mnt}^{j})} \left(P_{mt}^{j}\right)^{-\theta}. \tag{15}$$

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

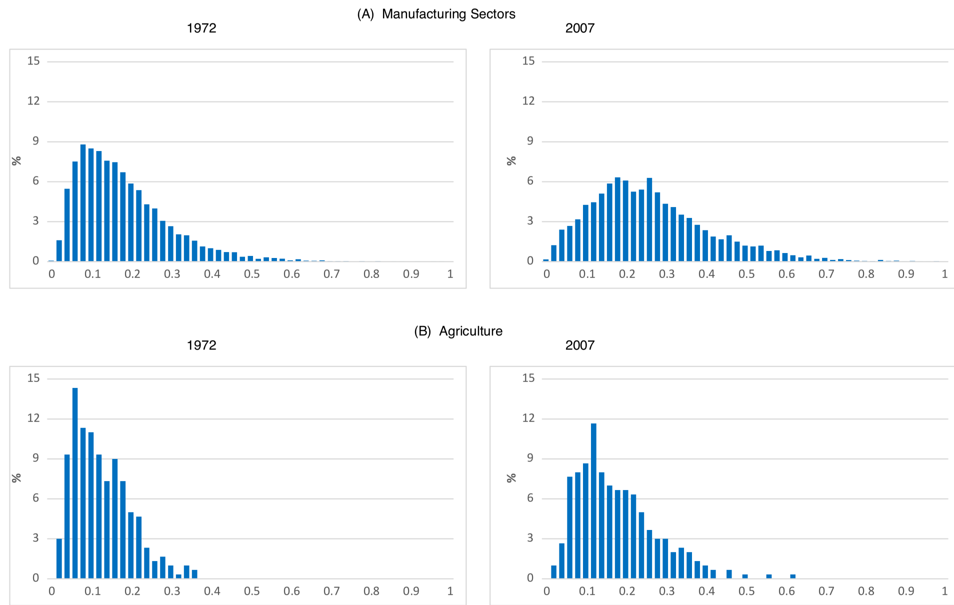

FIGURE I

Histogram of Bilateral Trading Costs: 1972 and 2007.

Distribution of (inverse) trade costs implied by equation (14), using data on trade flows, at different dates and in different (broad) sectors. Figures on the horizontal axis represent the fractions of shipped values that arrive at their destination.

if country n exports a lot to country m, or d^j_{mnt} is large; aggregate value added $w_{nt}L_{nt}$ is large, or if the sector has a high $\frac{w^j_{nt}}{w_{nt}}$ wage premium.

For all countries, we can directly observe several of the terms collected in the object we have called $\exp(\zeta^j_{mnt})$. In particular, data are available for sectoral import shares d^j_{mnt} (as already used in the previous subsection), nominal value added $w_{nt}L_{nt}$, and aggregate prices P_{nt}. We do not directly observe the sectoral wage premium $\frac{w^j_{nt}}{w_{nt}}$, especially since w is interpreted as the rental rate of equipped labor. To recover a series for the sectoral wage premium we begin by rewriting the first-order condition for the allocation of labor across sectors, equation (12), as

$$\frac{w^j_{nt}}{w_{nt}} = \frac{\left(\frac{w^j_{nt}L^j_{nt}}{w_{nt}L_{nt}}\right)}{E_{t-1}\left(\frac{w^j_{nt}L^j_{nt}}{w_{nt}L_{nt}}\right)}.$$

This says that a sector's wage exceeds the average wage if its share in aggregate value added, $\frac{w^j_{nt}L^j_{nt}}{w_{nt}L_{nt}}$, exceeds its expected share in aggregate value added. We directly observe each sector's share in aggregate value added—or the numerator. To compute expectations of the value-added share in the denominator, we use the (nonlinear) time trend of $\frac{w^j_{nt}L^j_{nt}}{w_{nt}L_{nt}}$. We can check the validity of this procedure by comparing the trend of $\frac{w^j_{nt}L^j_{nt}}{w_{nt}L_{nt}}$ with the rational expectation of $\frac{w^j_{nt}L^j_{nt}}{w_{nt}L_{nt}}$ in model-generated data. The correlation is 0.99 across all countries, sectors, and time periods, and 0.94 after taking out country-sector means.[18]

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

18. 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.

we can use equation (15) more efficiently to estimate productivity processes.

Taking logs and rearranging equation (15) yields.

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

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

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

Rearranging this and averaging over n, we get

$$\theta \log\left(P^j_{mt}\right) = \frac{1}{N}\sum_{n=1}^{N}\left(\zeta^j_{mnt} - \zeta^j_{m'nt}\right) + \theta \log\left(P^j_{m't}\right).$$

Recalling that the ζ's 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 United States. We choose units of account for each sector so that U.S. nominal sectoral prices are equal to 1 in 1972.

Having thus obtained sectoral price series P^j_{mt} for all countries and sectors, we can return to equation (15) and recover Z^j_{nt} from

$$\log(Z^j_{nt}) = \frac{1}{N}\sum_{m=1}^{N}\left[\zeta^j_{mnt} - \theta \log\left(P^j_{mt}\right)\right].$$

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.

3. Productivity in Nontradeables. The procedure in the previous subsection uses data on trade flows and is only applicable to the recovery of augmented productivities in the tradeable 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, that is, 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, $\frac{P_{nt}}{P_{US,t}}$. $P_{US,\,t}$ is simply the U.S. general price index. With the price series for services at hand, we can construct augmented productivity in services, Z^s_{nt}, using equation (15) again, for the case $n = m$ (implying, therefore, $d^s_{mnt} = \kappa^s_{mnt} = 1$).

4. Shock Processes. We assume that the recovered time series $\{\log Z^j_{nt}\}$ are generated by a deterministc (trend) component and a stochastic component. We identify the deterministic component of each $\log Z^j_{nt}$ with its band-pass filter. The stochastic component, which is the log deviation from this trend, is further decomposed into sector- and country-specific components, as in the factor model described in Koren and Tenreyro (2007). In particular, and without loss of generality, we decompose the cyclical component, denoted $\hat{Z}^j_{nt} =$, as:

$$\hat{Z}^j_{nt} = \lambda^j_t + \mu_{nt} + \epsilon^j_{nt}, \tag{16}$$

where μ_{nt} is the country-specific factor, affecting all sectors within the country; λ^j_t is the global sectoral factor, affecting sector j in all countries; and the residual ϵ^j_{nt} is the idiosyncratic component, specific to the country and sector.[19] In the counterfactual

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

$$\lambda^j_t = N^{-1} \sum_{n=1}^{N} \hat{Z}^j_{nt}$$

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

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

where $\bar{\alpha}^j$ is the time average of sectoral expenditure shares α^j_t, and we impose the restriction $\sum_n \mu_n = 0$, implying that the country-specific effect is expressed exercises, we can mute the sector- or country-specific factors by setting the corresponding components equal to 0, to identify the separate effects of the two trade channels affecting volatility. Once we have recovered the historical series $\left\{\lambda_t^j, \mu_{nt}, \epsilon_{nt}^j\right\}$ we assume that they are generated by AR(1) processes, and for each of them we estimate the autoregressive coefficient and the variance.

When solving the model, particularly equation (12), we assume that the representative agent fully knows the deterministic component of each $\log Z_{nt}^j$ process, as well as the autoregressive coefficients and variances of λ_t^j, μ_{nt}, and ϵ_{nt}^j. Furthermore, at the beginning of each period t, the agent has observed all the realizations of λ_{t-1}^j, μ_{nt-1}, and ϵ_{nt-1}^j. With this information, conditional on a candidate value of $\frac{L_{nt}^j}{L_{nt}}$, he or she can form the rational expectation on the right side of equation (12).

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^j's 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. 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; Simonovska and Waugh 2014; Donaldson 2018). We use $\theta = 4$ as the baseline case, and report the results 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.

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% of value added in many economies. This is in contrast to Koren and Tenreyro (2007), who use an unweighted average. Their application focuses on manufacturing sectors, which do not differ as much in size.

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 analyze the baseline model's results and then perform a series of sensitivity checks and extensions.

IV.A. Baseline Results

Figure II 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 volatility in the model and data series is 0.96 (0.88 without China) for the standard deviation and 0.99 (0.89 without China) for the variance. The analysis that follows focuses 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 I 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_{nmt}^{j}'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 all countries except for China

20. The absolute numbers of the volatilities generated by the scenarios discussed in this section are reported in Appendix Table A.I.

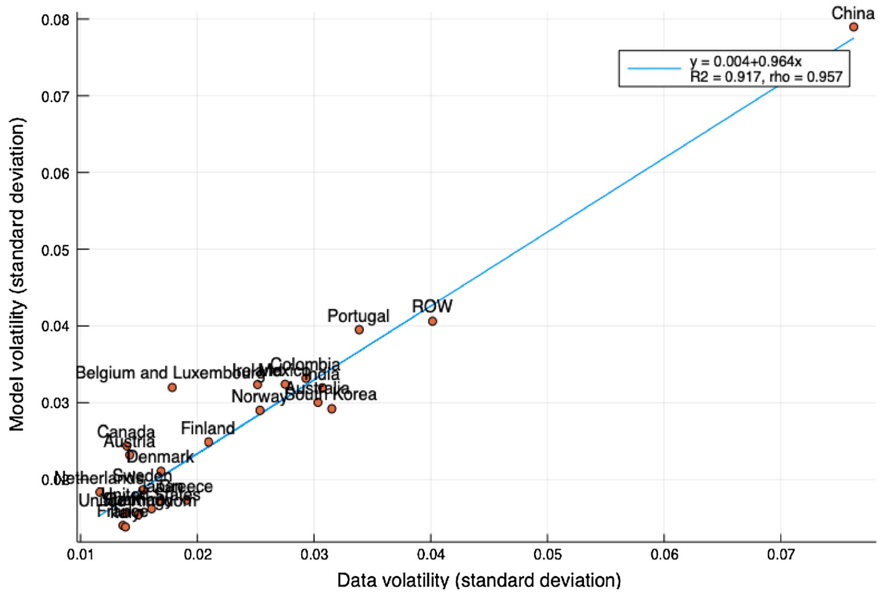

FIGURE II

Income Volatility in the Model and in the Data (1972–2007).

Standard deviation of log deviations of real income from trend in the baseline model against standard deviation of log deviations of real income from trend in the data.

TABLE I
BASELINE RESULTS

	Volatility change due to changes in trade costs (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)
Australia	−2.2%	−0.6%	−1.6%
Austria	−43.3%	−117.6%	74.3%
Belgium and Luxembourg	−66.1%	−106.7%	40.6%
Canada	−72.9%	−100.3%	27.4%
China	1.4%	0.5%	0.9%
Colombia	−43.7%	−65.1%	21.5%
Denmark	−78.0%	−40.1%	−37.8%
Finland	−37.9%	−66.6%	28.7%
France	−25.5%	26.5%	−52.0%
Germany	−53.3%	−49.0%	−4.4%
Greece	−21.9%	8.9%	−30.8%
India	−16.2%	−6.1%	−10.1%
Ireland	−59.0%	−69.0%	10.0%
Italy	−27.7%	21.8%	−49.5%
Japan	−3.1%	8.0%	−11.1%
Mexico	−56.8%	−92.9%	36.1%
Netherlands	−72.9%	−133.2%	60.3%
Norway	−33.1%	−90.0%	56.9%
Portugal	−6.2%	−60.3%	54.2%
ROW	1.1%	−1.5%	2.6%
South Korea	−1.3%	−9.8%	8.5%
Spain	−80.5%	−43.8%	−36.7%
Sweden	−41.6%	−27.0%	−14.5%
United Kingdom	−60.6%	−29.6%	−31.0%
United States	−1.7%	8.2%	−9.8%
Average	−36.1%	−41.4%	5.3%

Notes. Differences in variance of log deviations of real income from trend between model run with declining trade costs and model run with trading costs held at 1972 level (as percentages of model run with trading costs held at 1972 level). Column (1): all shocks included; Column (2): sectoral shocks excluded; Column (3): difference between Columns (2) and (1).

and the rest of the world, there would have been more volatility under constant trade costs than there actually was. For almost all countries, therefore, the common wisdom that predicts greater volatility following trade integration does not seem to apply.

The biggest declines in volatility caused by trade occurred in Belgium-Luxembourg, Canada, Denmark, Germany, Ireland, Mexico, the Netherlands, Spain, and the United Kingdom, all of which saw volatility reductions due to trade in excess of 50% (meaning their volatility has been 50% lower than it would have been had trading costs stayed at their 1972 levels). In the two countries-regions where trade has created additional volatility, the excess volatility is negligible. The (unweighted) average country in our sample experienced a 36% 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.

As discussed at several points, openness affects volatility through two channels: a diversification effect and a specialization effect. While neither effect has an unambiguous effect, 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.

To quantify the effect of the diversification effect, we compare two counterfactual scenarios. As before, the two scenarios differ in the path of trading costs, with one 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). 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 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 1972's trading cost levels and is reported in column (2). Once again, overwhelmingly volatility at 1972 trade barriers is larger than volatility in the baseline case, confirming that the diversification channel strongly operates in the direction of lower volatility, as expected. It is interesting that there are a few 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 41% 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 increase in volatility due to trade integration when only sectoral shocks (global or country specific) are present. The change is positive for 13 out of 25 countries. This is remarkable because according to the standard view the specialization channel should increase volatility in the vast majority of cases. Evidently, many countries 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 an increase in volatility of just 5%.

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 about eight times as large, in absolute value, as the average change due to the specialization mechanism. The specialization effect, on which the policy debate seems centered, is not as important as the diversification effect. We have hinted at the likely reason for this in Section I: country-specific shocks are simply much more important quantitatively than sector-specific ones.

In Table II, we briefly present a dynamic view of how the overall changes seen in Table I came about. As in Table I, the table presents comparisons of volatility under different scenarios, but volatility is computed by decade.[21] Not surprisingly, the impact of trade (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 rest of the period, the gap between actual volatility and volatility at 1972 trade costs opens steadily, as the world economy becomes more and more integrated.

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

TABLE II
RESULTS BY DECADE

	Volatility change due to changes in trade costs (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)
1970s	−3.5%	−15.8%	12.3%
1980s	−12.3%	−35.9%	23.6%
1990s	−34.0%	−66.2%	32.2%
2000s	−67.0%	−64.6%	−2.4%

Notes. Differences in variance of log deviations of real income from trend between model run with declining trade costs and model run with trading costs held at 1972 level (as percentages of model run with trading costs held at 1972 level). Column (1): all shocks included; Column (2): sectoral shocks excluded; Column (3): difference between Columns (2) and (1). Variances computed over decades and averaged across countries. Decadal volatility computed as the variance of log GDP growth rates over the decade.

This overall monotonic decline in volatility, however, masks some more nuanced dynamics of the diversification and specialization effects. In particular, the diversification effect peters out in the period 2000–2007. This petering out in the last seven years of the sample may reflect some noisiness due to the relatively 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 heterogeneous not only across countries but also over time. For example, the decline in the diversification effect could be due to country-wide shocks becoming more correlated in the 2000s.

IV.B. Sensitivity Analysis

In this section we evaluate the robustness of our baseline results to four alternative implementation choices: (i) allowing for unbalanced trade; (ii) alternative calibration values; (iii) allowing for costly labor reallocation across sectors; and (iv) allowing for elasticities of substitution in consumption other than 1.

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 because 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

TABLE III
ROBUSTNESS TO TRADE IMBALANCES

	Volatility change due to changes in trade costs (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)
Australia	−3.7%	−1.7%	−1.9%
Austria	−44.0%	−119.5%	75.5%
Belgium and Luxembourg	−65.5%	−113.1%	47.7%
Canada	−74.1%	−100.7%	26.6%
China	1.7%	1.6%	0.1%
Colombia	−44.4%	−66.8%	22.4%
Denmark	−76.0%	−41.9%	−34.1%
Finland	−36.6%	−65.1%	28.5%
France	−25.1%	25.5%	−50.6%
Germany	−52.8%	−49.5%	−3.3%
Greece	−24.8%	2.4%	−27.1%
India	−15.6%	−7.3%	−8.4%
Ireland	−55.2%	−67.6%	12.4%
Italy	−26.7%	21.2%	−48.0%
Japan	−0.4%	7.4%	−7.8%
Mexico	−55.5%	−93.3%	37.8%
Netherlands	−73.7%	−131.3%	57.6%
Norway	−33.7%	−89.5%	55.8%
Portugal	−6.8%	−60.7%	54.0%
ROW	0.7%	−1.3%	2.1%
South Korea	−0.3%	−7.8%	7.5%
Spain	−80.1%	−43.7%	−36.4%
Sweden	−41.1%	−27.9%	−13.2%
United Kingdom	−59.3%	−29.9%	−29.4%
United States	−2.2%	6.8%	−9.0%
Average	−35.8%	−42.2%	6.4%

Notes. Differences in variance of log deviations of real income from trend between model run with declining trade costs and model run with trading costs held at 1972 level (as percentages of model run with trading costs held at 1972 level). Column (1): all shocks included; Column (2): sectoral shocks excluded; Column (3): difference between Columns (2) and (1). Model modified to allow for exogenous trade imbalances.

of the Eaton and Kortum model, we treat the trade surplus as an exogenous process, which we take from the data. The required modifications to the baseline model are described in the Appendix. As shown in Table III, the quantitative results with trade imbalances are extremely similar to those in the baseline.

2. Scope for Comparative Advantage θ. Table IV 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

TABLE IV
ROBUSTNESS TO CHOICE OF PARAMETERS

	$\theta = 2$			$\theta = 8$		
	Volatility change due to changes in trade costs (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)	Volatility change due to changes in trade costs (4)	Volatility change due to diversification (5)	Volatility change due to specialization (6)
Australia	−19.5%	−7.6%	−11.9%	0.7%	0.6%	0.0%
Austria	−66.3%	−144.2%	77.9%	−31.3%	−71.2%	39.9%
Belgium and Luxembourg	−78.3%	−129.0%	50.7%	−53.9%	−73.6%	19.7%
Canada	−79.6%	−111.7%	32.0%	−56.0%	−71.6%	15.6%
China	1.2%	1.1%	0.1%	0.7%	−0.2%	0.8%
Colombia	−69.7%	−104.7%	35.0%	−18.7%	−25.4%	6.7%
Denmark	−87.7%	−54.5%	−33.1%	−56.4%	−27.2%	−29.3%
Finland	−60.1%	−120.0%	59.9%	−22.3%	−30.9%	8.6%
France	−44.1%	60.7%	−104.8%	−13.9%	10.8%	−24.7%
Germany	−73.7%	−84.8%	11.1%	−28.8%	−18.8%	−9.9%
Greece	−57.2%	−16.5%	−40.7%	−6.3%	15.9%	−22.2%
India	−37.6%	−18.4%	−19.2%	−5.3%	−0.5%	−4.8%
Ireland	−70.5%	−102.2%	31.7%	−45.5%	−29.3%	−16.3%
Italy	−49.3%	43.8%	−93.1%	−15.6%	9.3%	−24.9%
Japan	−10.6%	10.8%	−21.5%	1.2%	4.8%	−3.7%

TABLE IV

CONTINUED

	$\theta = 2$			$\theta = 8$		
	Volatility change due to changes in trade costs (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)	Volatility change due to changes in trade costs (4)	Volatility change due to diversification (5)	Volatility change due to specialization (6)
Mexico	−74.2%	−144.5%	70.4%	−33.2%	−43.9%	10.7%
Netherlands	−85.2%	−151.1%	65.9%	−53.5%	−89.3%	35.8%
Norway	−61.0%	−137.3%	76.3%	−11.8%	−36.0%	24.1%
Portugal	−43.8%	−116.7%	72.9%	5.0%	−18.3%	23.3%
ROW	1.0%	−1.0%	2.0%	0.2%	−1.7%	1.9%
South Korea	−22.1%	−55.2%	33.2%	3.5%	4.4%	−0.9%
Spain	−91.0%	−59.3%	−31.7%	−59.6%	−22.2%	−37.4%
Sweden	−56.7%	−64.2%	7.6%	−27.4%	−9.0%	−18.4%
United Kingdom	−78.8%	−48.7%	−30.2%	−35.6%	−10.9%	−24.7%
United States	−1.2%	17.8%	−19.0%	0.4%	3.9%	−3.5%
Average	−52.6%	−61.5%	8.9%	−22.5%	−21.2%	−1.3%

Notes. Differences in variance of log deviations of real income from trend between model run with declining trade costs and model run with trading costs held at 1972 level (as percentages of model run with trading costs held at 1972 level). Columns (1) and (4): all shocks included; Columns (2) and (5): sectoral shocks excluded; Columns (3) and (6): difference between two immediately preceding columns. Baseline model with alternative choices of the parameter which regulates the distribution of comparative advantage.

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 has pretty heterogeneous effects on volatility across countries; and (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, that is, when the scope for comparative advantage increases.[22]

3. Adjustment Costs and Ex Post Sectoral Reallocation. The baseline model assumes that the sectoral allocation of equipped labor 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 labor 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

$$U_n = \sum_{t=0}^{\infty} \delta^t \left\{ \log(C_{nt}) - \frac{\varrho}{2} \sum_{j=1}^{J} \left[\psi^j_{nt_+} - \psi^j_{nt_-} \right]^2 \right\}, \tag{17}$$

where $\psi^j_{nt_-} = \frac{L^j_{nt_-}}{L_{nt}}$ and $\psi^j_{nt_+} = \frac{L^j_{nt_+}}{L_{nt}}$, and $L^j_{nt\_}$ ($L^j_{nt_+}$) is the equipped labor assigned to sector j before (after) observing the realization of the shocks. A higher value of ϱ implies higher adjustment costs.

The ex post sectoral input allocation solves:

$$L^k_{nt_+} = \arg\max \left[\log\left(\frac{\sum_{j=1}^{J} w^j_{nt} L^j_{nt_+}}{P_{nt}} \right) - \frac{\varrho}{2} \sum_{j=1}^{J} \left[\psi^j_{nt_+} - \psi^j_{nt_-} \right]^2 \right],$$

$$s.t.: \sum_{j=1}^{J} \psi^j_{nt_+} = \sum_{j=1}^{J} \psi^j_{nt_-} = 1,$$

22. This exercise underscores the importance of the parameter θ, and adds to the message of Arkolakis, Costinot, and Rodríguez-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.

and the first-order conditions lead to:

$$\psi^k_{nt_+} = \psi^k_{nt_-} + \frac{1}{\varrho}\left[\frac{w^k_{nt} - \frac{1}{J}\sum_{j=1}^{J} w^j_{nt}}{\left(\frac{\sum_{j=1}^{J} w^j_{nt} L^j_{nt_+}}{L_{nt}}\right)}\right]. \tag{18}$$

The ex post input shares $\psi^k_{nt_+}$ equal the ex ante optimal shares $\psi^k_{nt_-}$ plus a fraction of the percentage differential between the sectoral input cost w^k_{nt} and the average equipped labor cost in the economy $\frac{1}{J}\sum_{j=1}^{J} w^j_{nt}$. (Note that the denominator is the average input cost in the economy.) The adjustment cost parameter ϱ determines the semielasticity of sectoral adjustment to the cost differential.

Using equation (18) in equation (17) we can solve for the ex ante allocation. The first-order condition for $\psi^j_{nt_-}$ is formally identical to equation (12), namely, the ex ante labor shares should equal expected wage bill shares. Note, however, that the stochastic process for w^j_{nt} is different with labor adjustment, so the solution to the ex ante labor allocation problem will be different than in our baseline case.

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 brackets in equation (18). We then regress yearly changes in labor shares on yearly changes in the wage differentials to obtain estimates of $\frac{1}{\varrho}$. The estimated regression coefficient is 0.001 (p-value .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 V. 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.

4. Nonunitary Elasticity of Substitution. In our baseline model, preferences over sectoral goods aggregate in Cobb-Douglas fashion. In this robustness check we replace equation (1) by a CES

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

TABLE V
ROBUSTNESS TO (COSTLY) LABOR ADJUSTMENT

	Volatility change due to changes in trade costs (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)
Australia	−2.7%	−0.6%	−2.1%
Austria	−42.4%	−118.3%	76.0%
Belgium and Luxembourg	−66.1%	−107.4%	41.2%
Canada	−73.2%	−100.0%	26.8%
China	1.4%	0.5%	0.9%
Colombia	−44.0%	−60.8%	16.8%
Denmark	−78.1%	−40.9%	−37.2%
Finland	−38.0%	−66.6%	28.5%
France	−25.2%	28.0%	−53.1%
Germany	−53.8%	−49.1%	−4.6%
Greece	−20.4%	8.4%	−28.9%
India	−16.0%	−6.1%	−9.9%
Ireland	−58.8%	−69.9%	11.1%
Italy	−27.2%	23.8%	−51.0%
Japan	−2.4%	8.0%	−10.4%
Mexico	−57.6%	−91.7%	34.1%
Netherlands	−73.4%	−134.7%	61.4%
Norway	−32.8%	−89.2%	56.4%
Portugal	−8.6%	−58.3%	49.7%
ROW	1.1%	−1.4%	2.5%
South Korea	−1.4%	−10.4%	9.0%
Spain	−80.3%	−44.2%	−36.1%
Sweden	−41.8%	−27.5%	−14.3%
United Kingdom	−60.9%	−29.3%	−31.6%
United States	−0.9%	8.7%	−9.6%
Average	−36.1%	−41.2%	5.0%

Notes. Differences in variance of log deviations of real income from trend between model run with declining trade costs and model run with trading costs held at 1972 level (as percentages of model run with trading costs held at 1972 level). Column (1): all shocks included; Column (2): sectoral shocks excluded; Column (3): difference between Columns (2) and (1). Model with finite cost of reallocating labor across sectors.

formulation,

$$C_{nt} = \left[\sum_{j=1}^{J} \left(\nu_t^j\right)^{\frac{1}{\sigma}} \left(C_{nt}^j\right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \quad (19)$$

where $\sigma > 0$ is the elasticity of substitution across sectors and ν_t^j is a demand shifter. We normalize $\sum_{j=1}^{J} \nu_t^j = 1$. As in the Cobb-Douglas case, we let demand shifters vary over time.

This requires calibrating the J demand parameters ν_t^j for each year, as well as the elasticity of substitution σ. Our strategy is to calibrate the demand parameters by matching the share of each final-good sector in global expenditure for each year. We then look at how our results vary with different values of the elasticity of substitution.

The results for $\sigma = 0.5$ and $\sigma = 1.5$ are presented in Table VI. The overall effect of trade on volatility is quite similar across different specifications of preferences. Our diversification effect from trade robustly contributes to lower volatility across choices of the elasticity of substitution, though comparison with Table I suggests that it is strongest for intermediate values of σ. The strength and direction of the sectoral effect turns out to be quite sensitive to the elasticity of substitution, with low values of σ associated with a significant increase in the fraction of countries experiencing less volatility due to trade.

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 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 on other countries' volatility through trade?

1. Input-Output Linkages. Our model features input-output linkages because 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 these linkages to provide diversification benefits to sectors, because 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 create excessive exposure to particularly volatile suppliers, potentially leading to greater volatility relative to a benchmark where each sector only uses nonproduced 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 associated with input-output linkages.

TABLE VI
ROBUSTNESS TO NONUNITARY ELASTICITY OF SUBSTITUTION

	$\sigma = 0.5$			$\sigma = 1.5$		
	Volatility change due to changes in trade costs (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)	Volatility change due to changes in trade costs (4)	Volatility change due to diversification (5)	Volatility change due to specialization (6)
Australia	−4.4%	0.2%	−4.6%	−2.3%	−0.6%	−1.7%
Austria	−51.3%	−59.4%	8.1%	−37.7%	−102.9%	65.2%
Belgium and Luxembourg	−72.2%	−48.5%	−23.7%	−62.9%	−67.8%	4.9%
Canada	−74.5%	−52.3%	−22.2%	−67.8%	−76.9%	9.1%
China	2.6%	−4.9%	7.5%	0.4%	−0.1%	0.5%
Colombia	−37.1%	−130.9%	93.8%	−35.0%	−32.8%	−2.2%
Denmark	−80.2%	−13.5%	−66.7%	−82.2%	−41.9%	−40.3%
Finland	−38.6%	−28.6%	−9.9%	−38.7%	−48.7%	10.0%
France	−21.9%	37.8%	−59.7%	−21.7%	20.3%	−42.0%
Germany	−43.7%	−8.7%	−35.0%	−61.9%	−85.2%	23.3%
Greece	−30.2%	31.4%	−61.5%	−9.9%	14.1%	−23.9%
India	−32.8%	−29.3%	−3.5%	−6.9%	−2.0%	−4.9%
Ireland	−58.2%	−29.8%	−28.5%	−59.4%	−44.9%	−14.5%
Italy	−26.9%	37.6%	−64.6%	−22.9%	19.4%	−42.3%
Japan	−3.6%	4.7%	−8.3%	−5.3%	1.2%	−6.5%

TABLE VI
CONTINUED

	$\sigma = 0.5$			$\sigma = 1.5$		
	Volatility change due to changes in trade costs (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)	Volatility change due to changes in trade costs (4)	Volatility change due to diversification (5)	Volatility change due to specialization (6)
Mexico	−69.0%	−29.3%	−39.7%	−44.5%	−46.6%	2.1%
Netherlands	−74.2%	−47.5%	−26.7%	−72.2%	−93.6%	21.5%
Norway	−30.5%	−65.2%	34.8%	−40.2%	−58.2%	18.0%
Portugal	−14.1%	−14.4%	0.3%	1.3%	−59.0%	60.2%
ROW	3.5%	−7.7%	11.2%	−1.2%	−2.2%	1.0%
South Korea	3.1%	−25.1%	28.2%	0.4%	4.8%	−4.4%
Spain	−81.4%	−28.6%	−52.8%	−77.1%	−52.5%	−24.6%
Sweden	−46.5%	13.2%	−59.6%	−32.6%	2.2%	−34.8%
United Kingdom	−59.8%	5.3%	−65.1%	−60.1%	−39.7%	−20.3%
United States	0.1%	7.5%	−7.4%	−0.6%	1.1%	−1.7%
Average	−37.7%	−19.4%	−18.2%	−33.6%	−31.7%	−1.9%

Notes. Differences in variance of log deviations of real income from trend between model run with declining trade costs and model run with trading costs held at 1972 level (as percentages of model run with trading costs held at 1972 level). Columns (1) and (4): all shocks included; Columns (2) and (5): sectoral shocks excluded; Columns (3) and (6): difference between two immediately preceding columns. Baseline model with alternative choices of the elasticity of substitution among sectors in final good production.

TABLE VII
ROLE OF INPUT-OUTPUT LINKAGES

	Volatility change due to changes in trade costs (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)
Australia	1.7%	−0.3%	2.0%
Austria	−3.8%	−9.2%	5.4%
Belgium and Luxembourg	−10.6%	−34.2%	23.6%
Canada	−8.0%	−9.6%	1.6%
China	0.8%	0.2%	0.6%
Colombia	−5.1%	−5.2%	0.1%
Denmark	−12.0%	−10.5%	−1.5%
Finland	−3.1%	−10.7%	7.6%
France	0.6%	0.1%	0.6%
Germany	−0.4%	−1.0%	0.7%
Greece	3.9%	−0.3%	4.2%
India	0.8%	0.0%	0.8%
Ireland	−13.7%	−13.2%	−0.5%
Italy	0.3%	−0.3%	0.7%
Japan	1.2%	0.1%	1.2%
Mexico	−21.1%	−36.9%	15.8%
Netherlands	−4.8%	−12.7%	7.9%
Norway	−7.0%	−9.1%	2.1%
Portugal	2.5%	−9.4%	11.9%
ROW	0.2%	−0.3%	0.5%
South Korea	−2.3%	−1.8%	−0.5%
Spain	−6.1%	−3.2%	−2.9%
Sweden	0.4%	−4.4%	4.8%
United Kingdom	−1.8%	−2.6%	0.8%
United States	0.4%	0.1%	0.2%
Average	−3.5%	−7.0%	3.5%

Notes. Differences in variance of log deviations of real income from trend between model run with declining trade costs and model run with trading costs held at 1972 level (as percentages of model run with trading costs held at 1972 level). Column (1): all shocks included; Column (2): sectoral shocks excluded; Column (3): difference between Columns (2) and (1). Baseline model with no input-output linkages.

To see if input-output linkages do amplify the impact of trade on income volatility in our model, we compare our baseline results to those of an alternative model without intermediates, that is, where we set $\gamma^{kj} = 0$ for all j and k (and consequently $\beta^j = 1$). We recalibrate the productivity shocks to fit value-added and trade data, as before. The results from this no-input-output model are presented in Table VII, and should as usual be compared to those of Table I. Although 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 3.5% (as usual, entirely because of the diversification effect). Hence, allowing firms to source inputs from other sectors is crucial to capture the full effects of trade on volatility.

2. The Role of China. Our model can be used to generate more counterfactuals that shed light on the sources of changes in income volatility over the past 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, that is, 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; Caliendo, Dvorkin, and Parro 2019), and its influence on innovation (Bloom, Draca, 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, we imagine a counterfactual world where China does not exist. That is, we perform our usual set of simulations but 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 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 VIII. 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 because China was obviously quite closed in 1972, so holding its trade costs constant limits its impact on other countries in a similar way as not having China at all.

TABLE VIII
THE ROLE OF CHINA

	$\kappa_{China,t} = 0.0001$ for all t			$\kappa_{China,t} = \kappa_{China,1972}$ for all t		
	Volatility change due to changes in trade costs (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)	Volatility change due to changes in trade costs (4)	Volatility change due to diversification (5)	Volatility change due to specialization (6)
Australia	−2.2%	−0.4%	−1.7%	−2.0%	−0.1%	−1.9%
Austria	−41.6%	−115.1%	73.4%	−43.9%	−112.2%	68.3%
Belgium and Luxembourg	−65.5%	−104.8%	39.3%	−65.4%	−105.3%	39.9%
Canada	−71.7%	−97.9%	26.2%	−71.6%	−97.9%	26.3%
China	0.0%	0.0%	0.0%	0.2%	−0.4%	0.6%
Colombia	−43.6%	−63.4%	19.8%	−42.8%	−63.4%	20.6%
Denmark	−77.1%	−42.8%	−34.3%	−77.9%	−41.7%	−36.1%
Finland	−38.8%	−65.9%	27.1%	−38.8%	−65.8%	27.0%
France	−24.8%	25.0%	−49.8%	−24.8%	24.1%	−48.9%
Germany	−52.1%	−48.1%	−4.0%	−52.1%	−48.8%	−3.3%
Greece	−23.0%	9.3%	−32.3%	−21.4%	10.1%	−31.6%
India	−16.2%	−6.5%	−9.7%	−16.3%	−5.9%	−10.5%
Ireland	−57.2%	−71.8%	14.5%	−60.7%	−64.4%	3.7%
Italy	−27.6%	21.7%	−49.2%	−27.4%	21.3%	−48.7%
Japan	−2.0%	7.9%	−9.9%	−2.6%	8.1%	−10.7%

TABLE VIII

CONTINUED

	$\kappa_{China,t} = 0.0001$ for all t			$\kappa_{China,t} = \kappa_{China,1972}$ for all t		
	Volatility change due to changes in trade costs (1)	Volatility change due to diversification (2)	Volatility change due to specialization (3)	Volatility change due to changes in trade costs (4)	Volatility change due to diversification (5)	Volatility change due to specialization (6)
Mexico	−56.2%	−92.6%	36.4%	−55.9%	−93.2%	37.3%
Netherlands	−71.8%	−130.4%	58.7%	−71.7%	−130.3%	58.5%
Norway	−34.5%	−85.5%	51.0%	−34.7%	−85.9%	51.2%
Portugal	−8.3%	−57.6%	49.3%	−10.9%	−55.6%	44.7%
ROW	0.8%	−1.4%	2.3%	1.2%	−1.2%	2.4%
South Korea	−1.4%	−8.8%	7.4%	−1.6%	−7.6%	6.0%
Spain	−79.5%	−43.4%	−36.1%	−79.4%	−43.4%	−36.1%
Sweden	−39.2%	−24.8%	−14.4%	−40.2%	−25.6%	−14.6%
United Kingdom	−58.5%	−29.6%	−28.9%	−58.5%	−29.7%	−28.8%
United States	−1.3%	7.4%	−8.7%	−2.0%	6.2%	−8.2%
Average (w/out China)	−37.2%	−42.5%	5.3%	−37.6%	−42.0%	4.4%

Notes. Differences in variance of log deviations of real income from trend between model run with declining trade costs and model run with trading costs held at 1972 level (as percentages of model run with trading costs held at 1972 level). Columns (1) and (4): all shocks included; Columns (2) and (5): sectoral shocks excluded; Columns (3) and (6): difference between two immediately preceding columns. In Columns (1)–(3) both models are run with China‘s trade costs held at prohibitive level (no China experiment); In Columns (4)–(6) both models are run with China‘s trade costs held at 1972 level (no Chinese integration experiment).

The most interesting comparison, however, is not between the two scenarios in Table VIII, but between the scenarios in Table VIII and our baseline Table I. The main thing to notice is that the figures in Table I are generally quite close to those in Table VIII. This means that the decline in volatility when all countries experience trade cost declines is similar to the decline in volatility when all countries except 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 income 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 lead to lower volatility in practice. The analysis indicates that diversification of country-specific shocks has generally led to lower volatility between 1972 and 2007 and has been quantitatively much more important than the specialization mechanism. The sizable heterogeneity in the effects of trade on volatility can contribute to understanding the heterogeneity of results documented by the existing empirical literature.

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Supplementary Material

Data and code replicating tables and figures in this article can be found in Caselli et al. (2019), in the Harvard Dataverse, doi:10.7910/DVN/FE0UYM.

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Appendix

A.1. Derivation of National Income Under Free Trade

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

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

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 $V_t \equiv [\sum_{m=1}^{N} \frac{w_{mt} L_{mt}}{\sum_{i=1}^{N} T_i (A_{it})^{\theta} (w_{it})^{-\beta\theta}}]^{\frac{1}{1+\beta\theta}}$ 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

$$Y_{nt} = L_{nt} \left(\frac{T_n (A_{nt})^{\theta}}{L_{nt}} \right)^{\frac{1}{1+\beta\theta}} V_t (\xi B)^{\frac{1}{\beta}} \left\{ \sum_{i=1}^{N} T_i (A_{it})^{\theta} \left(\left(\frac{T_i (A_{it})^{\theta}}{L_{it}} \right)^{\frac{1}{1+\beta\theta}} V_t \right)^{-\beta\theta} \right\}^{\frac{1}{\beta\theta}}$$

$$= (\xi B)^{\frac{1}{\beta}} \left(T_n A_{nt}^{\theta} L_{nt}^{\beta\theta} \right)^{\frac{1}{1+\beta\theta}} \left[\sum_{i=1}^{N} \left(T_i (A_{it})^{\theta} L_{it}^{\beta\theta} \right)^{\frac{1}{1+\beta\theta}} \right]^{\frac{1}{\beta\theta}}$$

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

A.2. Numerical Procedure for Model Equilibrium

We use nested iterations to compute the model equilibrium. In the inner loop, we search for equilibrium prices, taking labor allocations as given. The outer loop searches for the optimal labor allocation.

1. Inner Loop. Introduce an auxiliary variable for the factory-gate price of intermediate goods,

$$\phi_{nt}^{j} = \xi B^{j} (T_n^{j})^{-\frac{1}{\theta}} (A_{nt}^{j})^{-1} w_{nt}^{j\beta^{j}} \prod_{k=1}^{J} P_{nt}^{k\gamma^{kj}}. \tag{20}$$

The prices of the final goods and wage rates can be directly expressed as a function of intermediate prices and parameters,

$$P_{mt}^{j}(\phi) = \left[\sum_{n=1}^{N} \left(\frac{\phi_{nt}^{j}}{\kappa_{mnt}^{j}} \right)^{-\theta} \right]^{-\frac{1}{\theta}}, \tag{21}$$

$$w_{nt}^{j}(\phi) = (\xi B^{j})^{-\frac{1}{\beta^{J}}} (\phi_{nt}^{j})^{\frac{1}{\beta^{J}}} (T_n^{j})^{\frac{1}{\beta^{J}\theta}} (A_{nt}^{j})^{\frac{1}{\beta^{J}}} \prod_{k=1}^{J} P_{nt}^{k}(\phi)^{-\frac{\gamma^{kj}}{\beta^{J}}}. \tag{22}$$

Sectoral revenues are a constant multiple of sectoral wage bills, so, given labor allocations, we can also express them as a function of only intermediate prices and parameters,

$$R_{nt}^{j}(\phi) = \frac{w_{nt}^{j}(\phi)L_{nt}^{j}}{\beta^{j}}. \tag{23}$$

Taking the market-clearing conditions in equations (9) and (10), we can write intermediate prices as a function of sectoral revenues,

$$\phi_{nt}^{j} = R_{nt}^{j}(\phi)^{-\frac{1}{\theta}} \left\{ \sum_{m=1}^{N} \left[\kappa_{mnt}^{j} P_{mt}^{j}(\phi)\right]^{\theta} \sum_{k=1}^{J} \left(\alpha_{t}^{j}\beta^{k} + \gamma^{jk}\right) R_{mt}^{k}(\phi) \right\}^{\frac{1}{\theta}}. \tag{24}$$

We start from a guess for sectoral revenues (computed analytically for the free-trade equilibrium) and then use equation (24) to obtain a guess for intermediate prices. We recompute sectoral revenues under these intermediate prices and iterate until convergence. Given a solution for intermediate prices, we have a closed-form solution for wage rates and other prices.

2. *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. When searching for the equilibrium value of L_{nt}^{j} the state of the economy is made up of the deterministic component of the augmented-productivity processes, $\bar{Z}_{nt}^{j}$, as well as the previous-period values of the log-deviation processes representing country, sector, and idiosyncratic shocks, λ_{t-1}^{j}, μ_{nt-1}, and ϵ_{nt-1}^{j}. This state is known to us and to the decision maker in the model, as are the autoregressive parameters driving the shock processes and their variances. Hence, we can draw values from the distribution of λ_{t}^{j}, μ_{nt}, and ϵ_{nt}^{j} and combine them with $\bar{Z}_{nt}^{j}$ to create corresponding draws for Z_{nt}^{j}. For each iteration over possible candidates for the L_{nt}^{j}'s, we draw 100 random realizations of the Z_{nt}^{j}'s, and for each of them we compute w_{nt}^{j} and w_{nt}, and hence $\frac{w_{nt}^{j}L_{nt}^{j}}{w_{nt}L_{nt}}$ from the inner loop. Then the expectation of these wage shares is simply the average across all the draws of Z^j_{nt}. The iteration ends when the left-hand side and right-hand side are close enough.

A.3. Data Sources

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

1. 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 (e.g., Belgium and Luxembourg, and, before making it into 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. Although 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 in terms of geographic location (covering all inhabited continents) and in terms of their share in global trade and GDP. The time period we study covers years from 1972 to 2007. The period 1970–1971 is slightly problematic for trade data, as there are many missing observations; hence the decision to start in 1972. The end period is chosen to avoid confounding the trade effects we are after with the financial crisis, which had other underlying causes. We focus on annual data.

2. Sectoral Gross Output. The data are disaggregated into 24 sectors: agriculture (including mining and quarrying), 22 manufacturing sectors, and services, for all of which we are able to construct gross output in U.S. dollars for the core countries and the ROW. The 22 manufacturing sectors correspond to the industries numbered 15 to 37 in the ISIC Rev. 3 classification (UN National Accounts 2012) (36 and 37 are bundled together).

The final data set 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 (2019) and EU KLEMS (2008). 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 subsector.

For the countries in the ROW, the output data set is completed through estimation, using sectoral value added, aggregate output, GDP and population (the latter two from the Penn World Table 7.1; Heston, Summers, and Aten 2012) in 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.

- United States: missing years 1970–1976 generated using a growth rate of each sector from EU KLEMS (March 2008 edition).
- Canada: 1970–2004 EU KLEMS (March 2008 edition), for 2005–2006 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 labeled output in industry, which apart from the extraction of natural resources and manufacture of industrial products includes sectors not covered by other countries: water and gas production, electricity generation and supply, and repair of industrial products (no adjustment was made). The primary concern was the methodological change initiated around 1998, when China stopped reporting total industrial output and limited the coverage to industrial output of firms with annual sales above 5m yuan ($625,000). The sectoral coverage remained the same in both series. There were five years of overlapping data of both series over which the share of the 5m+ firms on total output decreased from 66% to 57%. 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 1999–2006 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 fewer 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).

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

- Mexico: data are from the System of National Accounts published by INEGI and from the UN National Accounts Database. 2003–2006 Sistema de cuentas nacionales, INEGI (NAICS), 1980–2003 growth rate from the UN National Accounts Data, 1978–1979 growth rate from Sistema de cuentas nacionales, INEGI, 1970–1978 growth rate from System of National Accounts (1981), Volume I issued by the SPP.
- Japan: data for 1973–2006 are from EU KLEMS (November 2009 edition), for 1970–1972 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's estimate for both parts of Germany.

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

3. 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 us to use exactly the same sectoral classification as the output data: namely, mining 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 data sets). If an observation is missing in both data sets, we impute it using the country-specific average sectoral shares for the years in which data are available.

4. Trade Flows. We use bilateral imports and exports at the sectoral level from 1972 to 2007 from the UN COMTRADE database (UN Comtrade 2015). This data set contains the value of all the transactions with international partners reported by each country. Because every transaction is potentially recorded twice (reported once by the exporter and once by the importer) we use the values reported by the importer when possible and integrate with the corresponding values from 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 to ensure a consistent definition of the sectors throughout the whole time period. 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.

5. Prices. 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

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 elsewhere, when we compute real aggregate income in the data to generate

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

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

6. 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 (2015), 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.

A.4. Trade Imbalances

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

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

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

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

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.

It can easily be shown that equation (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

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

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

A.5. Baseline Model Output

TABLE A.5

INCOME VOLATILITY IN BASELINE MODEL

	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	0.000902	0.001048	0.000923	0.001054
Austria	0.000538	0.000694	0.000948	0.001810
Belgium and Luxembourg	0.001023	0.001121	0.003014	0.004336
Canada	0.000594	0.001071	0.002193	0.003270
China	0.006240	0.007010	0.006155	0.006982
Colombia	0.001101	0.002506	0.001954	0.003779
Denmark	0.000443	0.000481	0.002009	0.001287
Finland	0.000619	0.001000	0.000996	0.001664
France	0.000196	0.000259	0.000263	0.000190
Germany	0.000243	0.000431	0.000521	0.000686
Greece	0.000299	0.000442	0.000383	0.000408
India	0.001020	0.000864	0.001217	0.000938
Ireland	0.001048	0.002053	0.002555	0.003817
Italy	0.000190	0.000184	0.000263	0.000127
Japan	0.000296	0.000223	0.000305	0.000199
Mexico	0.001050	0.005229	0.002430	0.007485
Netherlands	0.000336	0.000662	0.001241	0.002316
Norway	0.000841	0.002095	0.001256	0.003226
Portugal	0.001562	0.001715	0.001664	0.002720
ROW	0.001650	0.002390	0.001631	0.002414
South Korea	0.000853	0.000793	0.000864	0.000877
Spain	0.000242	0.000253	0.001238	0.000795
Sweden	0.000346	0.000531	0.000592	0.000691
United Kingdom	0.000236	0.000183	0.000600	0.000361
United States	0.000262	0.000360	0.000266	0.000338

Notes. 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 (4): In baseline model without sectoral shocks and with trade costs held at 1972.