Country Size, International Trade, and Aggregate Fluctuations in Granular Economies*

Julian di Giovanni
International Monetary Fund

Andrei A. Levchenko
University of Michigan
and NBER

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Abstract

This paper proposes a new mechanism by which country size and international trade affect macroeconomic volatility. We study a multi-country, multi-sector model with heterogeneous firms that are subject to idiosyncratic firm-specific shocks. When the distribution of firm sizes follows a power law with exponent sufficiently close to -1, the idiosyncratic shocks to large firms have an impact on aggregate volatility. We explore the quantitative properties of the model calibrated to data for the 50 largest economies in the world. Smaller countries have fewer firms, and thus higher volatility. The model performs well in matching this pattern both qualitatively and quantitatively: the rate at which macroeconomic volatility decreases in country size in the model is very close to what is found in the data. Opening to trade increases the importance of large firms to the economy, thus raising macroeconomic volatility. Our simulation exercise shows that the contribution of trade to aggregate fluctuations depends strongly on country size: in an economy such as the U.S., which accounts for one-third of world GDP, international trade increases volatility by about 3.5%. By contrast, trade increases aggregate volatility by some 15-20% in a small open economy, such as Denmark or Romania.

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1 Introduction

Macroeconomic volatility varies substantially across economies. Over the past 35 years, the standard deviation of per capita GDP growth has been 2.5 times higher in non-OECD countries compared to the OECD countries. Understanding the sources of these differences is important, as aggregate volatility itself has an impact on a wide variety of economic outcomes.[1]

This paper investigates the role of large firms in explaining cross-country differences in aggregate volatility. We show that the impact of large firms on aggregate volatility can help account for two robust empirical regularities: (i) smaller countries are more volatile; and (ii) more open countries are more volatile.[2] The key ingredient of our study is that the distribution of firm size is very fat-tailed – the typical economy is dominated by a few very large firms (Axtell, 2001). In a recent contribution, Gabaix (2010) demonstrates that under these conditions, idiosyncratic shocks to individual firms do not average out and can instead generate aggregate fluctuations (see also Delli Gatti et al., 2005). The economy is "granular," rather than smooth. Gabaix (2010) provides both statistical and anecdotal evidence that even in the largest and most diversified economy in the world – the United States – the biggest firms can appreciably affect macroeconomic fluctuations.

We develop a theoretical and quantitative framework to study the consequences of this phenomenon in a large cross-section of countries. The analysis is based on the canonical multi-country model with heterogeneous firms in the spirit of Melitz (2003) and Eaton et al. (2008). In order to study the impact of large firms on aggregate fluctuations, we must model both the equilibrium total number of firms as well as their size distribution. To capture the former, our framework endogenizes the equilibrium number of potential entrepreneurs through a free entry condition. We then show how the model can be calibrated to match the observed distribution of firm size. The quantitative framework has a number of realistic features, such as a non-traded sector and input-output linkages between traded and non-traded sectors, and is solved using data for the 50 largest economies in the world by total GDP.

Our main results can be summarized as follows. First, the model endogenously generates

[1]Numerous studies identify its effects on long-run growth (Ramey and Ramey, 1995), welfare (Pallage and Robe, 2003; Barlevy, 2004), as well as inequality and poverty (Gavin and Hausmann, 1998; Laursen and Mahajan, 2005).

[2]Canning et al. (1998) and Furceri and Karras (2007), among others, find that smaller countries are more volatile. A number of empirical studies show that trade openness is associated with higher volatility in a cross-section of countries (Easterly et al., 2001; Kose et al., 2003), as well as at the industry level (di Giovanni and Levchenko, 2009).

the negative relationship between country size and aggregate volatility. The reason is that smaller countries will have a smaller equilibrium number of firms (a result known since at least Krugman, 1980), and thus shocks to the largest firms will matter more for aggregate volatility. In effect, smaller economies are less diversified, when diversification is measured at the firm level. The model not only matches this relationship qualitatively, but also quantitatively: the rate at which volatility decreases in country size in the model is very similar to what is observed in the data. Both in the model and in the data, a typical country that accounts for 0.5% of world GDP (such as Poland or South Africa) has aggregate volatility that is 2 times higher than the largest economy in the world – the U.S..

Second, when it comes to the impact of international trade on volatility there are two effects, which we label "net entry" and "selection into exporting." When a country opens to trade, the equilibrium number of potential entrepreneurs increases. All else equal, this net entry effect drives down aggregate volatility after trade opening, since there are more firms of any given size. At the same time, only the largest and most productive firms export, while smaller firms shrink or disappear (Melitz, 2003). This selection into exporting effect implies that after opening the biggest firms become even larger relative to the size of the economy, thus contributing more to overall GDP fluctuations. Which effect dominates depends on parameter values.

In the first counterfactual exercise, we compute what aggregate volatility would be for each country in autarky, and compare it to the volatility under the current trade regime. It turns out that at the levels of trade openness observed today, international trade increases granular volatility relative to autarky in every country. The importance of trade for aggregate volatility varies greatly depending on country characteristics. In the largest economies like Japan or the U.S., aggregate volatility is only 1.5-3.5% higher than it would have been in complete autarky. In small, but remote economies such as South Africa or New Zealand, trade raises volatility by about 10% compared to autarky. Finally, in small, highly integrated economies such as Denmark or Romania, international trade raises aggregate volatility by some 15-20%.

The result that at the current levels of openness, trade contributes positively to aggregate volatility is in line with existing empirical evidence. However, we also find that the effect of further trade opening is in some cases non-monotonic: reductions in trade barriers can actually reduce granular volatility slightly in some countries. We compute the change in aggregate volatility that would occur if trade costs decreased below their current levels. Our simulations show that a 50% reduction in international trade costs will on average leave aggregate volatility unchanged in our set of countries, with the impact ranging from negative 2.7% to positive 8.4%. Thus, as trade costs fall below their current levels, the net entry effect practically cancels out the selection into exporting effect on average. In addition, the magnitude and sign of the impact depends strongly on country size: when trade costs fall below their current levels, volatility increases the most in the largest countries (the G-8), where the net entry effect is least pronounced. Correspondingly, volatility falls the most in the smaller countries (Israel, Venezuela), which tend to experience larger changes in net entry.

Anecdotal evidence on the importance of large firms for aggregate fluctuations abounds. Here, we describe two examples in which the roles of country size and international trade are especially evident. In New Zealand a single firm, Fonterra, is responsible for a full one-third of global dairy exports (it is the world's single largest exporter of dairy products). Such a large exporter from such a small country would clearly matter for the macroeconomy. Indeed, Fonterra's sales account for 20% of New Zealand's overall exports, and 7% of its GDP.[3] Two additional points about this firm are worth noting. First, 95% of Fonterra's output is exported. Thus, international trade clearly plays a prominent role in making Fonterra as large as it is. And second, the distribution of firm size in the dairy sector is indeed highly skewed. The second largest producer of dairy products in New Zealand is 1.3% the size of Fonterra.[4] This phenomenon is not confined to commodity exporting countries. In Korea, a larger manufacturing-based economy, the 10 biggest business groups account for 54% of GDP and 51% of total exports. Even among the top 10, the distribution of firm size and total exports is extremely skewed. The largest one, Samsung, is responsible for 23% of exports and 14% of GDP (see Figure 1).[5]

The theoretical link between country size, trade openness, and volatility we explore in this paper has not previously been proposed. Head (1995) and Crucini (1997) examine the relationship between country size and volatility in a 2-country international real business cycle (IRBC) model. In those papers, the smaller country has higher volatility because the

[3]It is important to note that GDP represents value added, and thus Fonterra's total sales are less than 7% of the total sales of all firms in New Zealand. However, because exports are recorded as total sales, Fonterra's export sales are directly comparable to New Zealand's total exports. The same caveat applies to the example that follows.

[4]These figures are obtained from http://www.maf.govt.nz/mafnet/rural-nz/profitability-and-economics/contribution-of-land-based-industries-nz-economic-growth/contribution07.htm and http://tvnz.co.nz/view/page/423466/146647.

[5]It turns out that the size distribution of firms is quite skewed even within business groups. For instance, breaking Samsung down into its constituent firms reveals that the sales of Samsung Electronics alone accounted for 7% of GDP and 15.5% of Korea's exports in 2006. We would like to thank Wonhyuk Lim of KDI for providing us with data on Korean firm and business group sales and exports.

world interest rate is less sensitive to shocks occurring in that country. Thus, following a positive shock it can expand investment without much of an impact on interest rates.[6] Our explanation for the size-volatility relationship is qualitatively different, and relies instead on the notion that smaller countries have fewer firms. When it comes to the relationship between trade openness and volatility, existing explanations have focused on the propagation of global demand or supply shocks (Newbery and Stiglitz, 1984; Kraay and Ventura, 2007). We show that trade can increase volatility even if the nature of shocks affecting the firms is unchanged upon opening. Finally, the mechanism in our model bears an affinity to the traditional arguments that smaller countries, and more open countries, will have a less diversified sectoral production structure, and thus exhibit higher volatility (see Katzenstein, 1985; OECD, 2006; Blattman et al., 2007, among many others). Our analysis shows that this argument applies to individual firms as well as sectors, and makes this point quantitatively precise by calibrating the model to the observed firm size distribution.

Our work is also related to the empirical literature that studies macroeconomic volatility using disaggregated data. Koren and Tenreyro (2007) explore the importance of sector-specific shocks in explaining the relationship between a country's level of development and its aggregate volatility, while di Giovanni and Levchenko (2009, 2010b) use sector-level data to study the openness-volatility relationship. Canals et al. (2007) analyze sector-level export data and demonstrate that exports are highly undiversified, both across sectors and across destinations. Furthermore, they show that this feature of export baskets can explain why aggregate macroeconomic variables cannot account for much of the movements in the current account.[7]

The rest of the paper is organized as follows. Section 2 presents the theoretical framework. Section 3 simulates the model economy and presents the main quantitative and empirical results. Section 4 presents robustness checks and results based on model perturbations. Section 5 concludes.

[6] Appendix A implements the canonical IRBC model of Backus et al. (1995), and examines the relationship between country size and volatility, and between trade openness and volatility, in that model. It turns out that while the calibrated IRBC model can produce higher volatility in smaller countries, the relationship between country size and volatility in that model is two orders of magnitude flatter than what is observed in the data. The relationship between trade openness and volatility in the IRBC model is ambiguous, its sign depending crucially on the elasticity of substitution between domestic and foreign goods.

[7] Our work is complementary to the research agenda that studies the impact of firm dynamics on macroeconomic outcomes in 2-country IRBC models. Ghironi and Melitz (2005) use the heterogeneous firms model to help account for the persistence of deviations from purchasing power parity, while Alessandria and Choi (2007) and Ruhl (2008) evaluate the quantitative importance of firm entry and exit for aggregate trade dynamics. An important difference between these papers and our work is that these contributions examine consequences of aggregate shocks, while in our paper all the shocks are at the firm level. In addition, our work features multiple countries, and explains cross-sectional differences in volatility between countries.

2 Theoretical Framework

Consider a model in the spirit of Melitz (2003), but with a discrete number of goods as in Krugman (1980). The world is comprised of $\mathcal{C}$ countries, indexed by $i, j = 1, \ldots, \mathcal{C}$. In each country there are two broad sectors, the tradeable T and the non-tradeable N. In country i, consumers maximize

$$\max_{\{y_i^N(k), y_i^T(k)\}} \left(\sum_{k=1}^{J_i^N} y_i^N(k)^{\frac{\varepsilon_N - 1}{\varepsilon_N}} \right)^{\frac{\alpha \varepsilon_N}{\varepsilon_N - 1}} \left(\sum_{k=1}^{J_i^T} y_i^T(k)^{\frac{\varepsilon_T - 1}{\varepsilon_T}} \right)^{\frac{(1-\alpha)\varepsilon_T}{\varepsilon_T - 1}}$$

$$s.t.$$

$$\sum_{k=1}^{J_i^N} p_i^N(k)\, y_i^N(k) + \sum_{k=1}^{J_i^T} p_i^T(k)\, y_i(k) = Y_i,$$

where $y_i^s(k)$ is consumption of good k belonging to sector $s = N, T$ in country i, $p_i^s(k)$ is the price of this good, Y_i is total final consumption expenditure in the economy, and J_i^s is the number of varieties available in sector s in country i, coming from all countries. Since consumer preferences are Cobb-Douglas in CES aggregates of N and T, it is well known that consumption expenditure on sector N is equal to αY_i, and on the T sector, $(1 - \alpha) Y_i$.

The CES composites of both N and T are used both as consumption and as intermediate inputs in production. Let X_i^s denote the total spending – final and intermediate – on sector $s = N, T$ in country i. Given this total expenditure, it is well known that demand for an individual variety k is equal to

$$x_i^s(k) = \frac{X_i^s}{(P_i^s)^{1-\varepsilon_s}} p_i^s(k)^{-\varepsilon_s} \tag{1}$$

in country i, where P_i^s is the ideal price index of sector s in this economy,

$$P_i^s = \left[\sum_{k=1}^{J_i^s} p_i^s(k)^{1-\varepsilon_s} \right]^{\frac{1}{1-\varepsilon_s}}. \tag{2}$$

There is one factor of production, labor, with country endowments given by L_j, $j = 1, \ldots, \mathcal{C}$, and wages denoted by w_j. Production in both sectors uses both labor and CES composites of N and T as intermediate inputs. In particular, a firm with marginal cost a must use a input bundles to produce one unit of output. An input bundle in country j and sector s has a cost $c_j^s = w_j^{\beta_s} \left[\left(P_j^N\right)^{\eta_s} \left(P_j^T\right)^{1-\eta_s} \right]^{1-\beta_s}$. That is, production in sector $s = N, T$ requires labor, inputs of N, and inputs of T. The share of labor in value added, β_s, and the share of non-tradeable inputs in total input usage, η_s, both vary by sector.

As in Krugman (1980) and Melitz (2003), each country has a potentially infinite number of entrepreneurs with zero outside option. In order to become an entrepreneur, an agent must pay an "exploration" cost f_e. Upon paying this cost, the entrepreneur k discovers her productivity, indexed by a marginal cost $a(k)$, and develops an ability to produce a unique variety of N or T valued by consumers and other firms. Thus, each potential firm has some market power: it faces the downward-sloping demand for its variety given by (1).

There are both fixed and variable costs of production and trade. The timing in this economy is depicted in Figure 2. At the beginning of the period, each potential entrant $k = 1, \ldots, \bar{I}_j^s$ in each $s = N, T$ and $j = 1, \ldots, \mathcal{C}$ pays the exploration cost f_e and learns its type, which is the marginal cost $a(k)$. On the basis of this cost, each entrepreneur in country j decides whether or not to pay the fixed cost of production f_{jj}^s, and which, if any, export markets to serve. In the N sector, we assume that trade costs are infinite, and thus a firm in country j may only serve its own market. In sector T, to start exporting from country j to country i, a firm must pay a fixed cost f_{ij}, and an iceberg per-unit cost of $\tau_{ij} > 1$.[8] We normalize the iceberg cost of domestic sales to one: $\tau_{jj} = 1$. Having paid the fixed costs of entering these markets, the firm learns the realization of transitory shock $z(k)$.We assume that $z(k)$ are i.i.d. across firms. Once all of the uncertainty has been realized, each firm produces with a marginal cost $a(k)z(k)$, markets clear, and consumption takes place.

Note that the assumptions we put on the timing of events, namely that the decision to enter markets takes place before $z(k)$ is realized, implies that the realization of the firm-specific transitory shock does not affect the equilibrium number of firms in each market. This simplification lets us analyze the equilibrium production allocation as an approximation around a case in which the variance of z is zero. That is, we abstract from the extensive margin of exports, and entry and exit of firms in response to transitory shocks.[9] This simplification delivers substantial analytical convenience, while it is unlikely to affect the results. This is because the focus of the paper is on the role of the largest firms in generating aggregate volatility, and the largest firms are inframarginal: their entry decision will not be affected by the realization of the transitory shock. Note also that this timing assumption implies that our analytical approach is akin to the common one of analyzing the response to shocks in deviations from a non-stochastic steady state.

Firm k from country j selling to country i thus faces a demand curve given by (1), and

[8] That is, the firm in country j must ship $\tau_{ij} > 1$ units to country i in order for one unit of the good to arrive there.

[9] The adjustment in the extensive margin in response to aggregate transitory shocks has been studied by Ghironi and Melitz (2005), Alessandria and Choi (2007), and Ruhl (2008).

has a marginal cost $\tau_{ij}c_j^s a(k)z(k)$ of serving this market in sector s. As is well known, the profit maximizing price is a constant markup over marginal cost, $p_i^s(k) = \frac{\varepsilon_s}{\varepsilon_s-1}\tau_{ij}c_j^s a(k)z(k)$, the quantity supplied is equal to $\frac{X_i^s}{(P_i^s)^{1-\varepsilon_s}}\left(\frac{\varepsilon_s}{\varepsilon_s-1}\tau_{ij}c_j^s a(k)z(k)\right)^{-\varepsilon_s}$, and the total ex-post variable profits are:

$$\pi_{ij}^{V,s}(a(k)z(k)) = \frac{X_i^s}{\varepsilon_s (P_i^s)^{1-\varepsilon_s}}\left(\frac{\varepsilon_s}{\varepsilon_s-1}\tau_{ij}c_j^s a(k)z(k)\right)^{1-\varepsilon_s}, \tag{3}$$

where once again we assume throughout that the only firms that can sell in sector N in country i are those based in that country. Note that these are variable profits of a firm in country j from selling its good to country i only, and are valid for destination-source pair i, j, including domestic sales: $i = j$.

The production structure of the economy is pinned down by (i) the number of entrepreneurs who pay the exploration cost to find out their type in each country and each sector, $\bar{I}_i^s$, and (ii) the number of firms from each country that actually enter each market and produce. In particular, there is a cutoff marginal cost a_{ij}^s, above which firms in country j do not serve market i. Assuming that the firm maximizes expected profits, the cutoff a_{ij}^s is given by the following condition:

$$\mathrm{E}\left[\pi_{ij}^{V,s}(a(k)z(k)) - c_j^s f_{ij}^s \mid a(k) = a_{ij}^s\right] = 0.$$

To go forward with the analysis, we make the following two assumptions:

Assumption 1 *The marginal firm is small enough that it ignores the impact of its own realization of $z(k)$ on the total expenditure X_i^s and the price level P_i^s in all potential destination markets $i = 1, \ldots, \mathcal{C}$ and sectors $s = N, T$.*

Assumption 2 *The marginal firm treats X_i^s and P_i^s as fixed (non-stochastic).*

The first assumption is not controversial, and has been made in the literature since Dixit and Stiglitz (1977) and Krugman (1980). The second assumption allows us to take X_i^s and P_i^s outside of the expectation operator. It amounts to assuming that the entrepreneur ignores the volatility of aggregate output and the price level when deciding to enter a market.[10] Under these two assumptions, plugging in variable profits from (3) and taking

[10]It is important to emphasize that these are assumptions placed on the behavior of the marginal entrepreneur. They allow us to compute the cutoffs for production and exporting a_{ij}^s as if the model was non-stochastic. This delivers substantial analytical and computational simplicity without affecting any of the main conclusions, since in our model the economy is dominated by very large firms, and thus the marginal ones are not important for the aggregate outcomes. On the other hand, one may question our assumption

the expectation over z, the zero profit cutoff condition for serving sector s in market i from country j reduces to:

$$a_{ij}^s = \frac{\varepsilon_s - 1}{\varepsilon_s} \frac{P_i^s}{\tau_{ij} c_j^s} \left(\frac{X_i^s}{\varepsilon_s c_j^s f_{ij}^s} \right)^{\frac{1}{\varepsilon_s - 1}} \left[\mathrm{E}_z \left(z^{1-\varepsilon_s} \right) \right]^{\frac{1}{\varepsilon_s - 1}} = \frac{\varepsilon_s - 1}{\varepsilon_s} \frac{P_i^s}{\tau_{ij} c_j^s} \left(\frac{X_i^s}{\varepsilon_s c_j^s f_{ij}^s} \right)^{\frac{1}{\varepsilon_s - 1}}, \tag{4}$$

where the second equality comes from normalizing the transitory shocks z such that $\mathrm{E}_z \left(z^{1-\varepsilon_s} \right) = 1$.

The equilibrium number of potential entrepreneurs $\bar{I}_j^s$ is then pinned down by the familiar free entry condition in each sector and each country. Entrepreneurs will enter until the expected profit equals the cost of finding out one's type:

$$E \left[\sum_{i=1}^{\mathcal{C}} \left(\pi_{ij}^{V,s}(a(k)z(k)) - c_j^s f_{ij}^s \right) \right] = c_j^s f_e, \tag{5}$$

for each country j and sector s, where once again in sector N, profits can only be positive for $i = j$.

Closing the model involves finding expressions for a_{ij}^s, P_i^s, and w_i for all $s = N, T$, $i, j = 1, \ldots, \mathcal{C}$. As an approximation, we solve for the equilibrium production allocation and the price levels ignoring firm-specific transitory shocks. Taking the expectations over $a(k)$ and $z(k)$, and using the fact that $\mathrm{E}_z \left(z^{1-\varepsilon_s} \right) = 1$, the price levels become:

$$P_i^N = \left[\left(\frac{\varepsilon_N}{\varepsilon_N - 1} \right)^{1-\varepsilon_N} I_i^N \left(c_i^N \right)^{1-\varepsilon_N} \mathrm{E}_a \left(a^{1-\varepsilon_N} \mid a < a_{ii}^N \right) \right]^{\frac{1}{1-\varepsilon_N}} \tag{6}$$

and

$$P_i^T = \left[\left(\frac{\varepsilon_T}{\varepsilon_T - 1} \right)^{1-\varepsilon_T} \sum_{j=1}^{\mathcal{C}} I_{ij}^T \left(\tau_{ij} c_j^T \right)^{1-\varepsilon_T} \mathrm{E}_a \left(a^{1-\varepsilon_T} \mid a < a_{ij}^T \right) \right]^{\frac{1}{1-\varepsilon_T}}, \tag{7}$$

where I_i^N is the number of varieties actually produced in the N sector in country i, and I_{ij}^T is the number of varieties exported from country j to country i. In order to solve the model, we must make a distributional assumption on productivity:

about the behavior of the largest firms, namely that markups are a constant multiple of marginal cost. If the largest firms in the economy are so large that their pricing decisions can affect the price level, their profit-maximizing prices will depart from the simple Dixit-Stiglitz constant markup benchmark. Note that qualitatively, this critique applies to all implementations of the Dixit-Stiglitz framework, and their extensions to heterogeneous firms. It is ultimately a quantitative question how much this force matters (Yang and Heijdra, 1993; Dixit and Stiglitz, 1993). While the full solution of our model under flexible markups would be impractical, and to our knowledge has not yet been implemented in this type of large-scale setting, we can perform a simple simulation that assesses the quantitative importance of allowing for variable markups in this setting. Appendix B describes the exercise in detail, and shows that quantitatively, the deviations of flexible-markup prices from the constant-markup benchmark are very small even for the largest firms in small countries.

Assumption 3 *Firm productivity in sector s, $1/a$, follows a Pareto(b_s, θ_s) distribution:* $\Pr(1/a < y) = 1 - \left(\frac{b_s}{y}\right)^{\theta_s}$, *where b_s is the minimum value labor productivity can take, and θ_s regulates dispersion.*

It is then straightforward to show that the marginal cost, a, has a distribution function $G_s(a) = (b_s a)^{\theta_s}$ in sector s. Furthermore, following Helpman et al. (2004), we define $V_s(y) = \int_0^y a^{1-\varepsilon_s} dG_s(a) = \frac{b_s^{\theta_s}\theta_s}{\theta_s-(\varepsilon_s-1)} y^{\theta_s-(\varepsilon_s-1)}$. The expression $V_s(a_{ij}^s)$ is useful for writing the price levels and expected profits in the economy. This implies that $\mathrm{E}_a\left(a^{1-\varepsilon_s} \mid a < a_{ij}^s\right) = \frac{V_s(a_{ij}^s)}{G_s(a_{ij}^s)}$.

The number of actual entrants into market i from country j in the T sector is $I_{ij}^T = \bar{I}_j^T G_T(a_{ij}^T)$, while the number of actual entrants in the N sector in country i is $I_i^N = \bar{I}_i^N G_N(a_{ii}^N)$. After plugging in the expressions for a_{ij}^s in (4), the price levels become:

$$P_i^N = \frac{1}{b_N}\left[\frac{\theta_N}{\theta_N-(\varepsilon_N-1)}\right]^{-\frac{1}{\theta_N}} \frac{\varepsilon_N}{\varepsilon_N-1}\left(\frac{X_i^N}{\varepsilon_N}\right)^{-\frac{\theta_N-(\varepsilon_N-1)}{\theta_N(\varepsilon_N-1)}} \left(\bar{I}_i^N\left(\frac{1}{c_i^N}\right)^{\theta_N}\left(\frac{1}{c_i^N f_{ii}^N}\right)^{\frac{\theta_N-(\varepsilon_N-1)}{\varepsilon_N-1}}\right)^{-\frac{1}{\theta_N}} \tag{8}$$

and

$$P_i^T = \frac{1}{b_T}\left[\frac{\theta_T}{\theta_T-(\varepsilon_T-1)}\right]^{-\frac{1}{\theta_T}} \frac{\varepsilon_T}{\varepsilon_T-1}\left(\frac{X_i^T}{\varepsilon_T}\right)^{-\frac{\theta_T-(\varepsilon_T-1)}{\theta_T(\varepsilon_T-1)}} \left(\sum_{j=1}^{\mathcal{C}}\bar{I}_j^T\left(\frac{1}{\tau_{ij}c_j^T}\right)^{\theta_T}\left(\frac{1}{c_j^T f_{ij}^T}\right)^{\frac{\theta_T-(\varepsilon_T-1)}{\varepsilon_T-1}}\right)^{-\frac{1}{\theta_T}}. \tag{9}$$

Having expressed P_i^s, and a_{ij}^s in terms of X_i^s and c_i^s, for all $i, j = 1, \ldots, \mathcal{C}$, it remains to close the model by solving for the X_i^s's and w_i's (once we know w_i's, c_i^s's will follow, since they are functions of w_i's and P_i^s's). To do this, we impose balanced trade for each country and the market clearing conditions in each sector and country. Free entry implies that the total profits are zero, and thus final expenditure in country i simply equals labor income: $Y_i = w_i L_i$. Total expenditure X_i^N and X_i^T equals final spending plus expenditure on sector s as intermediate inputs in both sectors:

$$\begin{aligned} X_i^N &= \alpha w_i L_i + (1-\beta_N)\,\eta_N X_i^N + (1-\beta_T)\,\eta_T X_i^T \\ X_i^T &= (1-\alpha) w_i L_i + (1-\beta_N)(1-\eta_N)\, X_i^N + (1-\beta_T)(1-\eta_T)\, X_i^T. \end{aligned}$$

Note that even though the T sector has both imports and exports, the assumption that only T-sector goods can be traded amounts to imposing balanced trade within the T sector, and thus the second condition must be satisfied in equilibrium as written. These two conditions imply that total spending in each sector is a constant multiple of labor income $w_i L_i$.

The total sales from country i to country j can be written as:

$$X_{ji}^T = \frac{X_j^T}{\left(P_j^T\right)^{1-\varepsilon_T}} \left(\frac{\varepsilon_T}{\varepsilon_T - 1}\tau_{ji} c_i^T\right)^{1-\varepsilon_T} \bar{I}_i^T \frac{b_T^{\theta_T}\theta_T}{\theta_T - (\varepsilon_T - 1)} \left(a_{ji}^T\right)^{\theta_T - (\varepsilon_T - 1)}.$$

Using expressions for a_{ji}^T in (4), and P_j^T in (9), the total exports from i to j become:

$$X_{ji}^T = \frac{\bar{I}_i^T X_j^T \left(\frac{1}{\tau_{ji} c_i^T}\right)^{\theta_T} \left(\frac{1}{c_i^T f_{ji}^T}\right)^{\frac{\theta_T - (\varepsilon_T - 1)}{\varepsilon_T - 1}}}{\sum_{l=1}^{\mathcal{C}} \bar{I}_l^T \left(\frac{1}{\tau_{jl} c_l^T}\right)^{\theta_T} \left(\frac{1}{c_l^T f_{jl}^T}\right)^{\frac{\theta_T - (\varepsilon_T - 1)}{\varepsilon_T - 1}}}.$$

Using the trade balance conditions, $X_i^T = \sum_{j=1}^{\mathcal{C}} X_{ji}^T$ for each $i = 1, \ldots, \mathcal{C}$, as well as the property that total spending X_i^T is a constant multiple of $w_i L_i$ leads to the following system of equations in w_i:

$$w_i L_i = \sum_{j=1}^{\mathcal{C}} \frac{\bar{I}_i^T \left(\frac{1}{\tau_{ji} w_i^{\beta_T}\left[\left(P_i^N\right)^{\eta_T}\left(P_i^T\right)^{1-\eta_T}\right]^{1-\beta_T}}\right)^{\theta_T} \left(\frac{1}{w_i^{\beta_T}\left[\left(P_i^N\right)^{\eta_T}\left(P_i^T\right)^{1-\eta_T}\right]^{1-\beta_T} f_{ji}^T}\right)^{\frac{\theta_T - (\varepsilon_T - 1)}{\varepsilon_T - 1}}}{\sum_{l=1}^{\mathcal{C}} \bar{I}_l^T \left(\frac{1}{\tau_{jl} w_l^{\beta_T}\left[\left(P_l^N\right)^{\eta_T}\left(P_l^T\right)^{1-\eta_T}\right]^{1-\beta_T}}\right)^{\theta_T} \left(\frac{1}{w_l^{\beta_T}\left[\left(P_l^N\right)^{\eta_T}\left(P_l^T\right)^{1-\eta_T}\right]^{1-\beta_T} f_{jl}^T}\right)^{\frac{\theta_T - (\varepsilon_T - 1)}{\varepsilon_T - 1}}} w_j L_j, \tag{10}$$

$i = 1, \ldots, \mathcal{C}$. There are $\mathcal{C} - 1$ independent equations in this system, with wage in one of the countries as the numéraire.

A monopolistically competitive equilibrium is a set of prices $\left\{w_i, P_i^N, P_i^T\right\}_{i=1}^{\mathcal{C}}$, and factor allocations such that (i) consumers maximize utility; (ii) firms maximize profits, and (iii) all goods and factor markets clear. The equilibrium is obtained as a solution to $(\mathcal{C} - 1) + 2 \times \mathcal{C} + 2 \times \mathcal{C}$ equations in w_i, P_i^N, P_i^T, $\bar{I}_i^N$ and $\bar{I}_i^T$ that satisfies equations (5), (8), (9), and (10) for each $i = 1, \ldots, \mathcal{C}$. We will solve these equations numerically in order to carry out the main quantitative exercise in this paper.

Given the equilibrium solution, we can solve for firm sales in each economy, and thus aggregate volatility arising from idiosyncratic shocks. Note that there are no aggregate shocks in the model, only the firm-specific idiosyncratic shocks. Total sales in the economy is defined by:

$$X = \sum_{k=1}^{I} x(a(k), z(k)), \tag{11}$$

where I is the total number of operating firms, $x(a(k), z(k))$ is the sales of firm k, and we omit country and sector subscripts. Appendix C shows that the variance of the growth rate of aggregate sales, or more precisely of the deviation from the expected aggregate sales, is equal to:

$$\mathrm{Var}_z\left(\frac{\Delta X}{\mathrm{E}_z\left(X\right)}\right) = \sigma^2 h, \tag{12}$$

where h is the Herfindahl index of production shares of firms in this economy, $h = \sum_{k=1}^{I} h(k)^2$, and σ^2 is the variance of the growth rate of sales of an individual firm. This is a familiar expression for the variance of a sum of random variables, and is the same as the one used by Gabaix (2010). Equation (12) forms the basis of the quantitative exercise below. We will simulate the world economy with a large number of firms in each country, and calculate how the Herfindahl indices relate to country size and international trade. This will reveal the role of country size, and the contribution of international trade to aggregate (granular) volatility of individual countries as a function of their characteristics.

2.1 Power Law in Firm Size and Aggregate Volatility in the Model and the Data

This economy is granular, that is, idiosyncratic shocks to firms result in aggregate fluctuations if the distribution of firm size follows a power law with an exponent sufficiently close to 1 in absolute value. As above, let $x(a(k), z(k))$ denote the sales of an individual firm k. Firm sales x in the economy must conform to:

$$\Pr(x > q) = \delta q^{-\zeta}, \tag{13}$$

where ζ is close to 1. Gabaix (2010, Proposition 2) shows that when the distribution of firm size follows a power law with exponent $-\zeta$, the economy is populated by $\mathcal{N}$ firms, and each firm has a standard deviation of sales growth equal to σ, the volatility of GDP is proportional to $\sigma/\mathcal{N}^{1-1/\zeta}$ for $1 < \zeta < 2$, and to $\sigma/\log\mathcal{N}$ when $\zeta = 1$. This result means that when $\zeta < 2$ and thus the distribution of firm size has infinite variance, the conventional Law of Large Numbers does not apply, and aggregate volatility decays in the number of firms $\mathcal{N}$ only very slowly. In other words, under finite variance in the firm size distribution, aggregate volatility decays at rate $\sqrt{\mathcal{N}}$ in the number of firms. But under Zipf's Law – defined as $\zeta \approx 1$ – it decays only at rate $\log\mathcal{N}$.

In this paper, we take this statistical result for granted. This section relates it to our theoretical framework by first demonstrating how the parameters of the model can be calibrated to the observed distribution of firm size. Then, we discuss the two key comparative statics: the role of country size and the role of trade openness in aggregate granular volatility. In order to proceed, we first consider a simplified version of the model laid out above.

In particular, we assume that there is no non-tradeable sector, N: $\alpha = \eta_N = \eta_T = 0$ (and thus drop sector subscripts on the parameters: $\beta_T = \beta$, $\theta_T = \theta$ and $\varepsilon_T = \varepsilon$). After deriving a number of analytical results under this simplifying assumption, the next section presents the results of the full quantitative model that features the N sector.

It turns out that the baseline Melitz-Pareto model delivers a power law in firm size. We demonstrate the power law in an autarkic economy, and then discuss how the distribution of firm size is affected by international trade. In our model, the expected sales of a firm as a function of its marginal cost are: $x(a) = Da^{1-\varepsilon}$, where the constant D reflects the size of domestic demand, and we drop the sector and country subscripts. Under the assumption that $1/a \sim$Pareto(b, θ), the power law follows:

$$\Pr(x > q) = \Pr(Da^{1-\varepsilon} > q) = \Pr\left(a^{1-\varepsilon} > \frac{q}{D}\right) =$$
$$\Pr\left(\left(\frac{1}{a}\right)^{\varepsilon-1} > \frac{q}{D}\right) = \Pr\left(\frac{1}{a} > \left(\frac{q}{D}\right)^{\frac{1}{\varepsilon-1}}\right) = \left(\frac{b^{\varepsilon-1}D}{q}\right)^{\frac{\theta}{\varepsilon-1}} = \left(b^{\varepsilon-1}D\right)^{\frac{\theta}{\varepsilon-1}} q^{-\frac{\theta}{\varepsilon-1}},$$

satisfying (13) for $\delta = \left(b^{\varepsilon-1}D\right)^{\frac{\theta}{\varepsilon-1}}$ and $\zeta = \frac{\theta}{\varepsilon-1}$. This relationship is depicted in Figure 3. In addition, the calculation shows that $x \sim$Pareto$\left(b^{\varepsilon-1}D, \frac{\theta}{\varepsilon-1}\right)$. Thus, our economy will be granular if $\frac{\theta}{\varepsilon-1}$ is close enough to 1, which appears to be the case in practice (see, among others, Axtell, 2001; di Giovanni and Levchenko, 2010a; di Giovanni et al., 2010).

2.2 Country Size and Aggregate Volatility

Gabaix (2010) shows that though aggregate volatility decays in the number of firms much more slowly than under the conventional LLN, countries with a greater number of firms $\mathcal{N}$ will nonetheless have lower aggregate volatility. This forms the basis of the relationship between country size and aggregate volatility. As has been understood since Krugman (1980), larger countries – those with higher L in our model – will feature a larger number of firms in equilibrium. Thus, they can be expected to have lower granular volatility. This can be demonstrated most transparently in the autarky equilibrium of a one-sector model. Using equations (4), (5) and (9), assuming a one-sector economy ($\alpha = \eta_N = \eta_T = 0$), and setting the number of countries $\mathcal{C} = 1$, the equilibrium number of entrants $\bar{I}_{aut}$ is proportional to:

$$\bar{I}_{aut} \sim L^{\overline{1-\frac{1-\beta}{\beta}\frac{1}{\varepsilon-1}}^{1}}. \tag{14}$$

This is the well-known result that the number of firms increases in country size, measured by L. It is immediate that without input-output linkages ($\beta = 1$), the relationship is simply linear.[11] The presence of input-output linkages actually tends to raise this elasticity above 1: as long as $\beta\varepsilon > 1$, the number of firms responds more than proportionately to the increases in market size. This restriction is likely to be comfortably satisfied in the data, as available estimates put β in the range of 0.5, while ε is typically assumed to be around 6. We discuss the details of how these parameters are calibrated in the quantitative exercise below.[12] Result (14) thus forms the basis for the first main result of the paper: smaller countries will have fewer firms, and thus higher granular volatility.

2.3 International Trade and Aggregate Volatility

How does international trade affect the distribution of firm size and therefore aggregate volatility? As first demonstrated by Melitz (2003), there are two effects, which for our purposes we label the "net entry" effect and the "selection into exporting" effect. When a country opens to trade, the possibility of getting a sufficiently high productivity draw and becoming an exporter induces more potential entrepreneurs to enter and draw their productivity: $\bar{I}$ rises. To demonstrate this effect in the simplest possible way, we assume that countries are symmetric: $L_i = L$, $f_{ii} = f \; \forall i$, and $\tau_{ij} = \tau$, $f_{ij} = f^X \; \forall i, j$. Under trade, the number of entrants is equal to:

$$\bar{I}_{trade} = \left[1 + (\mathcal{C} - 1)\,\tau^{-\theta}\left(\frac{f}{f^X}\right)^{\frac{\theta-(\varepsilon-1)}{\varepsilon-1}}\right]^{\frac{1-\beta}{\beta\theta}\frac{1}{1-\frac{1-\beta}{\beta}\frac{1}{\varepsilon-1}}} \bar{I}_{aut}. \tag{15}$$

The number of entrants under trade is linear in the autarky value, $\bar{I}_{aut}$, and thus the country size effect still operates in the trade equilibrium: larger countries have more firms. Since the additional term in the square brackets is larger than 1, and increasing in the number of countries $\mathcal{C}$, opening to trade tends to increase the number of entrants relative to autarky. Because aggregate granular volatility decreases in the number of firms, this "net entry" effect will tend to decrease volatility when a country opens to trade, as long as $\beta\varepsilon > 1$.

The other effect that operates when the country opens to trade is that only the largest firms enter the export markets. As a result, the distribution of firm size becomes more unequal under trade: compared to autarky, the least productive firms exit, and only the most productive firms export abroad. Due to competition from foreign varieties, domestic

[11] In that case, the solution for the equilibrium number of entrants has the particularly simple form: $\bar{I}_{aut} = \frac{L}{\varepsilon f_e}\frac{\varepsilon-1}{\theta}$.

[12] One may wonder whether the larger number of number of entrants $\bar{I}$ actually translates into a larger number of operating firms, since not all firms decide to produce. The number of operating firms is given by $\bar{I}_{aut}G(a_A)$, where a_A is the marginal cost of the least productive operating firm. The solution to a_A does not depend on L in this model, and thus the number of actual operating firms is linear in $\bar{I}_{aut}$.

sales and profits decrease. Thus, as a country opens to trade, sales of most firms shrink, while the largest firms grow larger as a result of exporting.[13] Figure 3 depicts this effect. In the two-country case, there is a single productivity cutoff, above which firms export abroad. Compared to autarky, there is a higher probability of finding larger firms above this cutoff. In the $\mathcal{C}$-country case, with multiple export markets there will be cutoffs for each market, with progressively more productive firms exporting to more and more markets and growing larger and larger relative to domestic GDP. Thus, if the distribution of firm sales follows a power law and the economy is granular, international trade has the potential to increase the size of the largest firms, in effect creating a "hyper-granular" economy, with clear implications for the relationship between trade openness and aggregate volatility. We label this the "selection into exporting" effect. All else equal, this effect implies that after trade opening, granular volatility increases.

While qualitatively both of these results are straightforward applications of the baseline model of trade with heterogeneous firms, the key question is how important these mechanisms are quantitatively. In addition, they affect aggregate volatility in the opposite ways. Thus, how reductions in trade costs affect volatility is ultimately a quantitative question. This is what we turn to in the next section.

2.4 Discussion

Before describing the simulation results, it is important to discuss a number of issues regarding the calibration and implementation of the model. First, while above we argue that in a one-sector Melitz-Pareto economy, "steady-state" firm size follows a power law with exponent $\theta/(\varepsilon - 1)$, our quantitative model features two sectors, as well as idiosyncratic shocks to firm sales. We start by showing that the aggregate model economy with these

[13] Firm-level studies of dynamic adjustment to trade liberalization appear to find empirical support for these predictions. Pavcnik (2002) provides evidence that trade liberalization led to a shift in resources from the least to the most productive firms in Chile. Bernard et al. (2003) show that a fall in trade costs leads to both exit by the least productive firms and entry by firms into export markets. In addition, existing exporters ship more abroad. A recent contribution by Holmes and Stevens (2010) shows that in the U.S., in some sectors the large firms are the ones suffering the most from foreign competition, because smaller firms are highly specialized boutique operations that are less affected by imports than the large factories producing standardized products with close foreign substitutes. The point made by Holmes and Stevens (2010) is a very important one, but it can be thought of as one about industrial classification: large factories and boutique ones produce different types of goods, which face very different market structures – competitive environments, trade costs, and so on. This comes through most clearly in the modeling approach adopted in that paper, in which it classifies the small boutique producers as nontradeable. Thus, the Holmes and Stevens (2010) finding can be easily reconciled with our model by assuming that the standardized producers are part of the T sector, while the boutique producers are part of the N sector. Indeed, this is very close to the assumption that Holmes and Stevens (2010) actually adopt in their model.

additional features will still feature Zipf's Law in firm size.

Deriving an aggregate power law in an economy with two sectors involves computing the (counter-)cdf of the following mixture of distributions. Let Q be a random variable that follows a power law with exponent ζ_1 with probability p, and with exponent ζ_2 with probability $1-p$. It is straightforward to show that the counter-cdf of Q is equal to: $\Pr(Q > q) = pD_1 q^{-\zeta_1} + (1-p)D_2 q^{-\zeta_2}$. Importantly, when $\zeta_1 = \zeta_2 = \zeta$, Q is itself is a power law with exponent ζ. This means that a two-sector economy in which both sectors follow a power law with the same exponent will, on aggregate, also exhibit a power law with that exponent. Our quantitative exercise will adopt the assumption that both the N and T sectors follow Zipf's Law. Though we are not aware of any comprehensive set of estimates of power law exponents in both traded and non-traded sectors, di Giovanni et al. (2010) estimate power law exponents for a wide range of both traded and non-traded sectors using a census of French firms, and find that power law exponents do not differ systematically between traded and non-traded sectors.

Another concern is that even if "steady-state" firm size in the aggregate economy follows Zipf's Law, when firms are hit by idiosyncratic shocks z, the resulting distribution would be something else. It turns out, however, that power laws are preserved under multiplication by a random variable with finite variance. That is, if firm sales are driven by a random productivity that generates Zipf's Law (a in our notation), and a finite variance shock (z), the resulting distribution of sales is still Zipf (Gabaix, 2009, pp. 258-259). Thus, even though we enrich the model with these additional features, the resulting aggregate distribution of firm size that the model produces still follows Zipf's Law.

Another point regarding the calibration of power law parameters is that strictly speaking, when not all firms export selection into exporting implies that the power law exponent estimated on total sales – domestic plus exporting – is lower than $\theta/(\varepsilon-1)$. Di Giovanni et al. (2010) explore this bias in detail using the census of French firms, and suggest several corrections to the estimating procedure that can be used to estimate $\theta/(\varepsilon-1)$ in an internally consistent way. Their analysis shows that the bias introduced by selection into exporting is not large. Corrected estimates obtained by di Giovanni et al. (2010) show that $\theta/(\varepsilon-1)$ is about 1.05, roughly the same as the value used in the quantitative exercise below.

Finally, we discuss the empirical validity of the assumption embedded in equation (12), namely that the volatility of the proportional change in firm sales, σ, is invariant to the firm size x. If the volatility of sales decreases sufficiently fast in firm size, larger firms will be so much less volatile that they will not impact aggregate volatility. In fact, an economy in which larger firms are just agglomerations of smaller units each subject to i.i.d. shocks is not granular: shocks to firms cannot generate aggregate fluctuations. Several papers estimate the relationship between firm size and firm volatility of the type $\sigma = Ax^{-\xi}$ using Compustat data (see, e.g., Sutton, 2002). The benchmark case in which larger firms are simply collections of independent smaller firms would imply a value of $\xi = 1/2$, and the absence of granular fluctuations. Instead, the typical estimate of this parameter is about 1/6, implying that larger firms are not substantially less volatile than smaller ones. Gabaix (2010) argues that these estimates may not be reliable, since they are obtained using only data on the largest listed firms. In addition, it is not clear whether estimates based on the U.S. accurately reflect the experience of other countries. Hence, our baseline analysis sets $\xi = 0$, and a value of σ based on the largest 100 listed firms in the U.S.. In other words, we assume that all firms in the economy have a volatility as low as the largest firms in the economy. However, in the robustness Section 4, we repeat the analysis under the assumption that $\xi = 1/6$, and show that it makes our results stronger.[14]

Another possible determinant of firm volatility that would be relevant to our analysis is exporting. The baseline model assumes that the volatility of a firm's sales growth does not change when it becomes an exporter. If exporters became systematically more or less volatile than non-exporters, the quantitative results could be affected. We are not aware of any estimates in the literature on whether exporters differ systematically in their sales volatility from non-exporters. We thus used the Compustat Quarterly database of listed U.S. firms together with information on whether a firm is an exporter from the Compustat Segments database. Table A1 estimates the relationship between firm-level volatility – based on either the growth rate of sales or a measure of "granular residual" following Gabaix (2010) – and its export status and size. Controlling for size, export status is always insignificant, and even the magnitude of the coefficient is exceedingly small, implying that volatility of exporters is between 96 and 99% of the volatility of non-exporters. Furthermore, the estimated elasticity of volatility with respect to firm size is similar to what is reported in the literature, and used in the sensitivity check.

[14] A related point concerns multi-product firms: if large firms sell multiple imperfectly correlated products, then the volatility of the total sales for multiproduct firms will be lower than the volatility of single product firms. Evidence suggests, however, that even in multiproduct firms the bulk of sales and exports is accounted for by a single product line. Sutton (2002) provides evidence that in large corporations, the constituent business units themselves follow a power law, with just a few very large business units and many much smaller ones. Along similar lines, Adalet (2009) shows that in the census of New Zealand firms, only about 6.5% to 9.5% of sales variation is explained by the extensive margin (more products per firm), with the rest explained by the intensive margin (greater sales per product).

3 Quantitative Evidence

Though the analytical results obtained with symmetric countries in a one-sector model are informative, we would like to exploit the rich heterogeneity among the countries in the world. In order to do this, we numerically implement the general multi-country model laid out in Section 2. We use information on country size and trade barriers to solve the model, and then simulate the random draws of firm productivity to compute the Herfindahl indices of firm sales in each country. This will allow us to examine the relationship between granular volatility and various country characteristics in the model, as well as to evaluate the contribution of international trade to aggregate volatility in each country.

In order to fully solve the model numerically, we must find the wages and price indices for each country, w_i, P_i^N, P_i^T, that satisfy equations (8), (9), and (10), jointly with the values of $\bar{I}_i^N$ and $\bar{I}_i^T$ that satisfy equations (5). The system is non-reducible, such that all of the prices and numbers of entrants must be solved simultaneously. To solve this system, we must calibrate all the values of the parameters, as well as country sizes and fixed and variable trade costs.

We simulate the economy under the following parameter values (see Table 1 for a summary). The elasticity of substitution is $\varepsilon_s = 6$. Anderson and van Wincoop (2004) report available estimates of this elasticity to be in the range of 3 to 10, and we pick a value close to the middle of the range. The key parameter is θ_s, as it governs the slope of the power law. As described above, in this model firm sales follow a power law with the exponent equal to $\frac{\theta_s}{\varepsilon_s - 1}$. In the data, firm sales follow a power law with the exponent close to 1. Axtell (2001) reports the value of 1.06, which we use to find θ_s given our preferred value of ε_s: $\theta_s = 1.06 \times (\varepsilon_s - 1) = 5.3$. We set both the elasticity of substitution and the Pareto exponent to be the same in the N and the T sectors. As discussed above, the reduced form exponent in the empirical distribution of firm size, which corresponds to $\theta_s/(\varepsilon_s - 1)$ in sector s is similar between the traded and non-traded sectors. It still could be the case that while $\theta_T/(\varepsilon_T - 1) \approx \theta_N/(\varepsilon_N - 1)$, the actual values of θ_s and ε_s differ. Since we do not have reliable information about how these two individual parameters differ across sectors, we adopt the most agnostic and neutral assumption that both θ_s and ε_s are the same in the two sectors.

We set the value of α – the share of non-tradeables in consumption – to be 0.65. This is the mean value of services value added in total value added in the database compiled by the Groningen Growth and Development Center and extended to additional countries by

Yi and Zhang (2010). It is the value also adopted by Alvarez and Lucas (2007). The values of β_N and β_T – share of labor/value added in total output – are calibrated using the 1997 U.S. Benchmark Input-Output Table. We take the Detailed Make and Use tables, featuring more than 400 distinct sectors, and aggregate them into a 2-sector Direct Requirements Table. This table gives the amount of each input required to produce a unit of final output. Thus, β_s is equal to the share of total output that is not used pay for intermediate inputs, i.e., the payments to factors of production. According to the U.S. Input-Output Matrix, $\beta_N = 0.65$ and $\beta_T = 0.35$. Thus, the traded sector is considerably more input-intensive than the non-traded sector. The shares of non-traded and traded inputs in both sectors are also calibrated based on the U.S. I-O Table. According to the data, $\eta_N = 0.77$, while $\eta_T = 0.35$. Thus, more than 75% of the inputs used in the N sector come from the N sector itself, while 65% of T-sector inputs come from the T sector. Nonetheless, these values still leave substantial room for cross-sectoral input-output linkages.

Next, we must calibrate the values of τ_{ij} for each pair of countries. To do that, we use the gravity estimates from the empirical model of Helpman et al. (2008). Combining geographical characteristics such as bilateral distance, common border, common language, whether the two countries are in a currency union and others, with the coefficient estimates reported by Helpman et al. (2008) yields, up to a multiplicative constant, the values of τ_{ij} for each country pair. We vary the multiplicative constant so as to match the mean and median imports/GDP ratios observed in the data in our sample of countries. The advantage of the Helpman et al. (2008) estimates is that they are obtained in an empirical model that accounts explicitly for both fixed and variable costs of exporting, and thus correspond most closely to the theoretical structure in our paper. Note that in this formulation, $\tau_{ij} = \tau_{ji}$ for all i and j.[15]

Next, we must take a stand on the values of f_{ii}^s and f_{ij}^s. To do this, we follow di Giovanni and Levchenko (2010a) and use the information on entry costs from the Doing Business Indicators database (The World Bank, 2007a). This database collects information on the administrative costs of setting up a firm – the time it takes, the number of procedures, and the monetary cost – in a large sample of countries in the world. In this application, the particular variable we use is the amount of time required to set up a business. We favor this indicator compared to others that measure entry costs either in dollars or in units of per capita income, because in our model f_{ii}^s is a quantity of inputs rather than value. We must

[15] An earlier version of the paper also computed τ_{ij} using the estimates of Eaton and Kortum (2002) as a robustness check. The results were very similar.

normalize the f^s_{ii} for one country. Thus, we proceed by setting $f^s_{US,US}$ to a level just high enough to ensure an interior solution for production cutoffs.[16] This value of $f^s_{US,US}$ is a rather low one, implying that in the U.S. 95% of potential entrepreneurs produce. Then, for every other country f^s_{ii} is set relative to the U.S.. To be precise, if according to the Doing Business Indicators database, in country i it takes 10 times longer to register a business than in the U.S., then $f^s_{ii} = 10 \times f^s_{US,US}$. Since we do not have data on fixed costs of operating a business that vary by sector, we set f^s_{ii} to be equal in the N and T sectors.

To measure the fixed costs of international trade, we use the Trading Across Borders module of the Doing Business Indicators. This module provides the costs of exporting a 20-foot dry-cargo container out of each country, as well as the costs of importing the same kind of container into each country. Parallel to our approach to setting the domestic cost f^s_{ii}, the indicators we choose are the amount of time required to carry out these transactions. This ensures that f^T_{ii} and f^T_{ij} are measured in the same units. We take the bilateral fixed cost f^T_{ij} to be the sum of the cost of exporting from country j and the cost of importing into country i. The foreign trade costs f^T_{ij} are on average about 40% of the domestic entry costs f^T_{ii}. This is sensible, as it presumably is more difficult to set up production than to set up a capacity to export.[17]

Finally, we set the value of the "exploration cost" f_e such that the equilibrium number of operating firms in the U.S. is equal to 7 million. According to the 2002 U.S. Economic Census, there were 6,773,632 establishments with a payroll in the United States. There are an additional 17,646,062 business entities that are not employers, but they account for less than 3.5% of total shipments. Thus, while the U.S. may have many more legal entities than what we assume here, 7 million is a number sufficiently high as to let us consider consequences of granularity. Since we do not have information on the total number of firms in other countries, we choose to set f_e to be the same in all countries. In the absence of data, this is the most agnostic approach we could take. In addition, since f_e represents the cost of finding out one's abilities, we do not expect it to be affected by policies and thus differ across countries. The resulting value of f_e is 15 times higher than $f^s_{US,US}$, and 2.4 times higher than the average f^s_{ii} in the rest of the sample. The finding that the ex-ante fixed

[16] That is, we set $f^s_{US,US}$ to a level just high enough that $a^s_{ji} < 1/b_s$ for all $i, j = 1, ..., \mathcal{C}$ in all the baseline and counterfactual exercises, with $1/b_s$ being the upper limit of the distribution of a.

[17] An earlier version of the paper was more agnostic about the nature of domestic fixed costs f^T_{ii}, and assumed instead that they are equal (and low) in every country. The results were very similar. In addition, we carried out the analysis setting the bilateral fixed cost to be the sum of domestic costs of starting a business in the source and destination countries: $f^T_{ij} = f^T_{ii} + f^T_{jj}$. This approach may be preferred if fixed costs of exporting involved more than just shipping, and required, for instance, the exporting firm to create a subsidiary for the distribution in the destination country. The results were virtually identical.

cost of finding out one's type is much higher than the ex-post fixed cost of production is a common one in the quantitative models of this type (see, e.g., Ghironi and Melitz, 2005).

Using these parameter values, summarized in Table 1, we can solve the full model for a given vector of L_i. For finding the values of L_i, we follow the approach of Alvarez and Lucas (2007). First, we would like to think of L_i not as population per se, but as "equipped labor," to take explicit account of TFP and capital endowment differences between countries. To obtain the values of L_i that are internally consistent in the model, we start with an initial guess for L_i for all $i = 1, \ldots, \mathcal{C}$, and use it to solve the full model. Given the solution for wages, we update our guess for L_i for each country in order to match the GDP ratio between each country i and the U.S.. Using the resulting values of L_i, we solve the model again to obtain the new set of wages, and iterate to convergence (for more on this approach, see Alvarez and Lucas, 2007). Thus, our procedure generates vectors w_i and L_i in such a way as to match exactly the relative total GDPs of the countries in the sample. In practice, the results are close to simply equating L_i to the relative GDPs. In this procedure, we must normalize the population of one of the countries. We thus set L_{US} to its actual value of 291 million as of 2003, and compute L_i of every other country relative to this U.S. value. An important consequence of this approach is that countries with higher TFP and capital abundance will tend to have a greater number of potential productivity draws $\bar{I}_i^s$, all else equal, since our procedure will effectively give them a higher L_i. This is akin to the assumption adopted by Alvarez and Lucas (2007) and Chaney (2008), that the number of productivity draws is a constant multiple of equipped labor L_i. The difference in our approach is that though we take labor-cum-productivity to be a measure of market size, we solve for $\bar{I}_i^N$ and $\bar{I}_i^T$ endogenously within the model.

We carry out the analysis on the sample of the largest 49 countries by total GDP, plus the 50th that represents the rest of the world. These 49 countries together cover 97% of world GDP. We exclude the entrepôt economies of Hong Kong and Singapore, both of which have total trade well in excess of their GDP due to significant re-exporting activity. Thus, our model is not intended to fit these countries. (We do place them into the rest-of-the-world category.) The country sample, sorted by total GDP, is reported in Table 2.

3.1 Model Fit: Trade Volumes, Export Participation, and the Size of Large Firms

Before describing the quantitative results, we assess the model fit along three dimensions: overall and bilateral trade volumes; the relationship between country size and the size of the largest firms in each country; and the share of exporting firms in the economy.

Figure 4 reports the scatterplot of bilateral trade ratios, $\pi_{ij} = X_{ij}/w_i L_i$. Note that since in the data we only have bilateral trade as a share of GDP, not of total sales, we compute the same object in the model. This captures both the distinction between trade, which is recorded as total value, and GDP, which is recorded as value added; as well as the fact that there is a large non-traded sector in both the model and in the data. On the horizontal axis is the natural logarithm of π_{ij} that comes from the model, while on the vertical axis is the corresponding value of that bilateral trade flow in the data.[18] Hollow dots represent exports from one country to another, π_{ij}, $i \neq j$. Solid dots, at the top of the scatterplot, represent sales of domestic firms as a share of domestic absorption, π_{ii}. For convenience, we add a 45-degree line. It is clear that the trade volumes implied by the model match the actual data well. Most observations are quite close to the 45-degree line. It is especially important that we get the variation in the overall trade openness $(1 - \pi_{ii})$ right, since that will drive the contribution of trade to the granular volatility in each country. Figure 5 plots the actual values of $(1 - \pi_{ii})$ against those implied by the model, along with a 45-degree line. We can see that though the relationship is not perfect, it is quite close.

Table 3 compares the means and medians of π_{ii} and π_{ij}'s for the model and the data, and reports the correlations between the two. The correlation between domestic shares π_{ii} calculated from the model and those in the data for this sample of countries is around 0.48. The correlation between export shares, π_{ij}, is actually higher at 0.78.[19] Since we use estimated gravity coefficients together with the actual data on bilateral country characteristics to compute trade costs, it is not surprising that our model fits bilateral trade data quite well given the success of the empirical gravity relationship. Nonetheless, since the gravity estimates we use come from outside of our calibration procedure, it is important to check that our model delivers outcomes similar to observed trade volumes.

The model also makes predictions about the features of the firm size distributions across countries that are important for the central mechanism of the paper. To compare the model predictions regarding the firm size distribution to the data, we use ORBIS, a large multi-country database published by Bureau van Dijk that contains information on more than 50 million companies worldwide. The data come from a variety of sources, including, but

[18]Note that the scatterplot is in log-log scale, so that the axes report the trade shares in levels.

[19]We also experimented with increasing the number of countries in the simulation to 60. The model fit the data well, but there are more zeros in bilateral trade data in the 60-country sample compared to the 50-country one. (With 50 countries, among the 2500 possible unidirectional bilateral trade flows, only 18 are zeros.) Since our model does not generate zero bilateral trade outcomes, we stick with the largest 49 countries in our analysis.

not limited to, registered filings and annual reports. Coverage varies by world region: there are data on some 17 million companies in the U.S. and Canada, 22 million companies in the 46 European countries, 6.2 million companies from Central and South America, 5.3 million from Asia, but only 260,000 from Africa and 45,000 from the Middle East. Importantly, the database includes both publicly traded and privately held firms. Though we use the largest available non-proprietary firm-level database in this analysis, coverage is quite uneven across countries and years, implying that measures of concentration may not be reliable or comparable across countries. Nonetheless, as we describe below, the model is quite consistent with the firm-level patterns found in the data. While in principle data are available going back to mid-1990s for some countries, coverage improves dramatically for more recent years. For this reason, we focus our analysis on 2006, the year with the most observations available. The main variable used in the analysis is total sales.

We first assess whether the firm-level indices of concentration in the data behave in the way predicted by the model. To that end, we calculate the Herfindahl indices of firm sales in each country, and regress those on the share of the country in world GDP (the main indicator of country size used throughout the paper), as well as per-capita income to control for the level of development. Panel A of Table 4 reports the results – note that all variables are in natural logarithms. The first column uses all 134 countries for which it is possible to calculate the Herfindahl index in ORBIS data. The second column restricts the sample to those countries for which there are at least 100 firms; the third column, at least 1,000 firms. The last column reports the same relationship in the calibrated multi-country model (see Section 3.2 for details on calculations of model indices). In the data, the relationship between concentration and country size is highly statistically significant, even controlling for the level of development. At the same time, comparing the slope coefficients in the data to those implied by the model, we can see that the relationship between the concentration and country size is, if anything, more pronounced in the data than in the model.

The Herfindahl index is the variable most relevant to the quantitative results in the paper. However, because ideally it requires information on the entire firm size distribution, the Herfindahl index may also suffer the most from the incomplete coverage problems in the ORBIS database. Because of this, we also check the model fit using two other indicators of firm size: the combined sales of the largest 10 firms in the country, and the size of the single largest firm. Because these indicators focus on the very largest firms that are measured more reliably in the data, the problems of coverage are less severe.

Panel B of Table 4 compares the relationship between the combined size of the 10 largest firms to country size in the data to the model. There is a significant positive relationship between the absolute size of the largest 10 firms and country size: not surprisingly, larger countries have bigger firms. Thus, qualitatively, the data agree with the model. The magnitudes of the coefficients in the data and the model are remarkably similar as well. Panel C reports the analogous results for the size of the single largest firm in each country. The conclusions are virtually the same as in Panel B. We conclude that overall, the predictions of the model regarding these aspects of the firm size distribution across countries match fairly well the patterns observed in the data.

Finally, we use the model solution to calculate the percentage of firms that export in the total economy, as well as the tradeable sector. In particular, the total number of exporters in country i equals $\bar{I}_i^T \times \left(b_T \max_{j \neq i} \left\{a_{ji}^T\right\}\right)^{\theta_T}$. The total number of firms operating in the tradeable sector equals $\bar{I}_i^T \times \left(b_T \max_j \left\{a_{ji}^T\right\}\right)^{\theta_T}$, and in the non-tradeable sector $\bar{I}_i^N \times \left(b_N a_i^N\right)^{\theta_N}$. We would like to compare the export participation shares in the model to what is found in the data. Unfortunately, there is no systematic empirical evidence on these shares across countries (and time). However, we have examined publicly available data and existing literature and found these shares for 8 countries: U.S., Germany, France, Argentina, Colombia, Ireland, Chile, and New Zealand. Table 5 compares the export participation shares produced by the model to those found in the data in this subset of countries. The first two columns report the values in the model, with the shares of exporters relative to all the firms in the economy in column 1 and in the tradeable sector only in column 2. Data sources differ across countries, in particular the shares of exporting firms are sometimes reported only relative to all firms in the economy (which we record in column 3), and sometimes relative to all the firms in the tradeable sector (which we record in column 4). Thus, data in column 3 should be compared to model outcomes in column 1, while data in column 4 should be compared to model outcomes in column 2.

It is clear from this table that the model produces quite reasonable results. Larger countries tend to have fewer exporters relative to the overall number of firms (compare U.S. to Colombia); countries closer to large markets tend to have higher shares of exporters compared to faraway countries (compare Ireland to New Zealand). In most cases the model implied value is close to the data. We should note that by making *ad hoc* adjustments to trade costs in individual countries, we can match each and every one of these numbers exactly. We do not adopt this approach because this information is not available systematically for every country in our sample, and because the available data themselves are noisy. Instead, our approach takes trade costs as implied by a basic gravity model, and the variation in fixed costs as implied by the Doing Business Indicators, an approach that is rather straightforward and does not involve any manual second-guessing. And yet, our model matches the rough values and orders of magnitude more or less right for a number of different countries.

3.2 Quantitative Results

Having solved the model given the data on country GDPs and trade costs, we now simulate it using random productivity draws for each firm in each economy. Namely, in each country i, in each sector s we draw $\bar{I}_i^s$ productivities from a Pareto(b_s,θ_s) distribution. For each firm, we use the cutoffs a_{ji}^s for serving each market j (including its own market $j = i$) given by equation (4) to determine whether the firm operates, and which, if any, foreign markets it serves.

Given the simulations, we next calculate the total sales of each firm as the sum of its sales in each market, and compute the Herfindahl index of firm sales in country i. Since the distribution of firm productivities gives rise to a highly skewed distribution of firm sales, there is variation in the Herfindahl index from simulation to simulation, even though we draw as many as 7 million operating firms in a given country – note that this number is the total for the N and T sectors, where we take independent draws for each sector. We thus repeat the exercise 1001 times, and take the median values of the Herfindahl index in each country. In parallel, we also compute the Herfindahl index of firm sales in autarky for each country, given all the parameters. This counterfactual exercise allows us to gauge the contribution of international trade to aggregate volatility. Given these values of the Herfindahl index h, we can then construct each country's granular volatility under trade and in autarky using the formula for total variance (12) and a realistic value of σ. Following Gabaix (2010), we set $\sigma = 0.1$; though since in this paper we will not exploit any variation in σ across countries, none of the results will be driven by this choice.

How well does the model predict the actual GDP volatility found in the data? Table 6 presents regressions of actual volatility of GDP growth over the period 1970-2006 against the one predicted by the model (σ_T) – note that all variables are in natural logarithms. Column (1) includes no controls. We can see that the fit is not perfect ($R^2 = 0.353$), but the relationship is clearly positive and significant. The second column includes GDP per capita. The fit of the model improves, and though the coefficient on the model volatility is somewhat smaller, it remains significant at the 1% level. The next two columns include measures of export structure volatility and sectoral specialization, since our earlier work (di Giovanni and Levchenko, 2009, 2010b) shows that opening to trade can impact aggregate volatility through changes in these variables. Column (3) adds the *risk content of exports*, which captures the overall riskiness of a country's export structure.[20] The model volatility remains significant, and the R^2 of the regression is now 0.477. Finally, the fourth column adds a measure of production specialization for the manufacturing sector (Herfindahl of production shares).[21] The number of observations drops to 35 due to limited data availability, but the model volatility still remains significant.

As would be expected, the level of granular volatility is lower than what is observed in the data. Column 1 of Table 7 reports the ratio of the granular volatility implied by the model to the actual GDP volatility found in the data. It ranges between 0.14 and 0.72, with a value of 0.377 for the United States, almost identical to what Gabaix (2010) finds using a very different methodology. Note that the variation in aggregate volatility in the model across countries is generated by differences in country size as well as variation in bilateral trade costs.

How much of the elasticity of the aggregate volatility with respect to country size can the model account for? We now plot the predicted volatility as a function of country size in the data and the model. Figure 6 reports the results. Note that since the level of aggregate volatility in the model does not match up with the level in the data, this graph is only informative about the comparison of slopes, not intercepts. In the data the elasticity of GDP volatility with respect to country size is -0.139 (σ_{GDP}) in this sample of countries. Table A2 reports the results of estimating the volatility-size relationship in the data for various country samples and with and without controls. The baseline coefficient we use in Figure 6 comes from the 50-country sample and controlling for income per capita. Our calibrated model produces an elasticity of -0.135 (σ_{T}), which is extremely close to the one in the data though slightly below it in absolute terms. We can also calculate what this relationship would look like in the absence of trade. Figure 6 reports the volatility-size relationship in autarky. Without trade this relationship is somewhat flatter: the elasticity of volatility with respect to country size in autarky is -0.115 (σ_{A}), lower than the -0.139 in the data.

[20] This measure is taken from di Giovanni and Levchenko (2010b). A country's export structure can be volatile due to a lack of diversification and/or exporting in sectors that are more volatile.

[21] This measure is calculated using the UNIDO database of sectoral production, and is taken from di Giovanni and Levchenko (2009).

3.2.1 Counterfactuals: The Impact of Trade Openness on Volatility

We now assess the contribution of international trade to the aggregate granular volatility in our sample of countries. Our model yields not only the predicted granular volatility in the simulated trade equilibrium, but also the granular volatility of autarky. Column 2 of Table 7 reports the ratio of the two in each country in the sample. In the table, countries are ranked by overall size in descending order. We can see that international trade contributes very little to overall GDP volatility in the U.S.. The country is so large and trade volumes are so low (relative to total output) that its volatility under trade is only 1.035 times higher than it would be in complete absence of trade. By contrast, smaller countries experience substantially higher volatility as a result of trade openness. For instance, in a country like Romania, the volatility under trade is some 22 percent higher than it would be in autarky.

Having computed what granular volatility would be in the absence of trade, we next carry out the opposite counterfactual experiment: a reduction in trade costs. It would not be very informative to consider totally free trade ($\tau_{ij} = 1 \ \forall i, j$), since it is unrealistic to model a case in which distance between countries does not affect trade costs, for instance. In this section, we simulate a halving of ad valorem trade costs. When the model was calibrated to the data, the median domestic sales as a share of GDP was equal to 0.79, which matches the actual data reasonably well. When trade costs decrease by 50%, this share drops to 0.64, representing a 15 percentage point increase in world trade relative to GDP. Given that 65% of consumption is assumed to be non-tradeable, this is a significant increase in the volume of trade.

Column 3 of Table 7 reports, for each country, the ratio of granular volatility under these lower trade costs compared to the baseline. Strikingly, a further reduction in trade costs leads to practically no change in granular volatility on average. For the median country, granular volatility is 0.1% higher under these trade costs relative to today's trade costs. Evidently, the impact of trade openness on volatility is non-monotonic. How can we explain this result? Changes in trade costs will lead to an expansion in the number of potential entrants ($\bar{I}_i^s$), which will lower granular volatility. This is the net entry effect. However, the distribution of firm size will also become more fat-tailed, as only the most productive firms expand their sales abroad and become larger. This selection into exporting effect will tend to raise granular volatility, at least for sufficiently high values of τ_{ij}. In the average country, when trade costs are lowered from their current values, the net entry effect dominates the selection into exporting effect, and the volatility decreases slightly.

This explains why smaller countries tend to experience a decrease in volatility in this counterfactual, while larger countries an increase. In the U.S. and Japan, volatility actually goes up slightly, while it falls the most in the small open economies such as Israel and Venezuela. This is because a reduction in trade costs generates a much larger net entry response in smaller countries. Indeed, the percentage change in volatility across countries in this counterfactual exercise has a correlation of 0.62 with the concomitant percentage change in the total number of entrants $\bar{I}_i^N + \bar{I}_i^T$. Table A3 presents the distribution of changes in aggregate volatility relative to the current level of trade costs for various magnitudes of trade cost reductions, from 10% to 75%. All in all, volatility rises slightly as trade costs are decreased, but the impact always ranges from positive to negative.

4 Robustness Checks and Model Perturbations

4.1 Volatility Varying with Firm Size

An assumption that simplifies the analysis above is that the volatility of the proportional change in sales, σ, does not change in firm size x. As discussed at the end of Section 2, if firm-level volatility decreases sharply enough in size, shocks to large firms will not generate aggregate volatility. In practice, however, the negative relationship between firm size and volatility of its sales is not very strong. Stanley et al. (1996) and Sutton (2002) estimate the relationship of the type $\sigma = Ax^{-\xi}$, and find a value of $\xi = 1/6$. That is, firm-level volatility does decrease with size, but this elasticity is quite low. To check robustness of our results, we allow the firm-specific volatility to decrease in firm size at the rate estimated by these authors. In that case, aggregate (granular) variance is given by

$$\mathrm{Var}_z\left(\frac{\Delta X}{\mathrm{E}_z\left(X\right)}\right) = \sum_{k=1}^{I}\left(Ax(k)^{-\xi}h(k)\right)^2,$$

where, once again, $x(k)$ are sales of firm k, while $h(k)$ is the share of firm k's sales in total output in the economy.

The rest of the simulation remains unchanged. Since we are not matching the level of aggregate volatility, just the role of country size and trade, we do not need to posit a value of the constant A. However, it would be easy to calibrate to match the volatility of the top 100 firms in the U.S. as reported by Gabaix (2010), for example. Note that compared to the baseline simulation, modeling a decreasing relationship between country size and volatility is a double-edged sword: while larger firms may be less volatile as a result, smaller firms are actually more volatile. This implies that the impact of either country size or international trade will not necessarily be more muted when we make this modification to the basic model.

Table 8 reports the results of this robustness check. For ease of comparison, in row 1 of this table, we report the two key results from the baseline analysis. The first key result is that the model generates higher volatility in smaller countries, with the elasticity of volatility with respect to country size of -0.135. (As we report above, in the data this elasticity is very close, -0.139.) The second column reports the second key result of the paper, which is the contribution of trade openness to aggregate volatility. That is, in column 2 we report the mean ratio of aggregate volatility under the current level of trade openness relative to complete autarky.

In row 2 of Table 8 we report these two main results of the paper under the alternative assumption that firm volatility decreases with firm size. In turns out that in this case, smaller countries are even more volatile relative to large ones (the size-volatility elasticity doubles to -0.286), and the contribution of trade is also larger, with trade leading to an average 29% increase in volatility, compared to 9.7% in the baseline. Somewhat surprisingly, therefore, allowing volatility to decrease in firm size implies a larger contribution of trade to aggregate volatility, not a smaller one. In fact, this is the case in every country in the sample save the U.S..

4.2 Robustness to Parameter Changes

We assess the sensitivity of the results in two additional ways. The first is an alternative assumption on the curvature of the firm size distribution. Eaton et al. (2008) estimate a range of values for $\theta/(\varepsilon-1)$ of between 1.5 and 2.5. Though Gabaix (2010) shows that the shocks to large firms can still generate granular volatility when the power law exponent is less than 2, it is still important to check whether the main results of our paper survive under alternative values of $\theta/(\varepsilon-1)$. Row 3 of Table 8 presents the two main results of the paper under the assumption that the slope of the power law in firm size is 1.5 instead of 1.06. Though in each case the numbers are slightly smaller in absolute value, the main qualitative and quantitative results remain unchanged: smaller countries still have lower volatility, with elasticity of -0.123, and trade contributes slightly more to granular volatility, with the average increase of 11.6%.

Second, we re-calibrate the model under two alternative values of ε, 4 and 8. In these exercises, we continue to assume that the economy is characterized by Zipf's Law, so that $\theta/(\varepsilon-1)$ is still equal to our baseline value of 1.06. Thus, as we change ε, we change θ

along with it. The results are presented in the last two rows of Table 8. The size-volatility relationship is robust to these alternative assumptions. The elasticity of volatility with respect to country size is similar to the baseline, though slightly lower when $\varepsilon = 4$. The contribution of trade is quite similar as well, with 9.9% and 11.1% for $\varepsilon = 4$ and $\varepsilon = 8$, respectively.

5 Conclusion

Recent literature in both macroeconomics and international trade has focused attention on the role of firms. Recent research argues that large firms matter for the macroeconomy. Gabaix (2010) demonstrates that if the distribution of firm size follows a power law with an exponent close to negative 1 – which appears to be the case in the data – shocks to the largest firms can lead to aggregate fluctuations, which are dubbed "granular."

This paper argues that the preponderance of large firms and their role in aggregate volatility can help explain two empirical regularities found in cross-country data: (i) smaller countries are more volatile, and (ii) more open countries are more volatile. We calibrate and simulate a multi-country model of firm-level production and trade that can generate granular fluctuations. The model matches quite well a number of features of the data, such as observed bilateral and overall trade volumes, export participation ratios, and the size of the largest firms in different countries. We show that the model reproduces the elasticity of GDP volatility with respect to country size found in the data. The counterfactual exercises reveal that the contribution of international trade to aggregate volatility varies a great deal depending on country characteristics. While it is minimal in large, relatively closed economies like the U.S. or Japan, trade increases volatility by up to 15-20% in small open economies such as Denmark or Romania. However, we also find that the impact of trade on volatility is sometimes non-monotonic: our model implies that reductions in trade costs relative to their present levels may actually reduce aggregate volatility slightly in some countries.

Recent research incorporates heterogeneous firms into fully dynamic general equilibrium macroeconomics models, focusing on the impact of persistent aggregate shocks and firm entry and exit (Ghironi and Melitz, 2005; Alessandria and Choi, 2007; Ruhl, 2008). The importance of firm-specific idiosyncratic shocks for macroeconomic volatility via the granular channel emphasized in this paper should be viewed as complementary to this work. Future research incorporating these different mechanisms, as well as bringing disaggregated data to the models, will help provide an even more complete picture of the macroeconomic impact of trade integration.

Appendix A Impact of Country Size and Openness in a Canonical IRBC Model

This Appendix evaluates whether the standard International Real Business Cycle (IRBC) model produces the relationship between country size and volatility observed in the data, and whether it features a positive relationship between openness and growth. To answer these questions, we implement the standard IRBC model and vary relative country size and openness, focusing on the response of aggregate volatility to those two variables. The modeling approach and calibration details follow as closely as possible the classic treatment of Backus et al. (1995, henceforth BKK).

A.1 Country Size

Let there be two economies, Home and Foreign, with Foreign variables denoted by an asterisk. The time horizon is infinite and indexed by t. In the Home country, each agent's utility depends on consumption and leisure:

$$U = \sum_{t=0}^{\infty} \gamma^t \frac{[c_t^{\mu}(1-n_t)^{1-\mu}]^{1-\eta} - 1}{1-\eta},$$

where c_t is an individual's consumption, and n_t is the share of the time endowment dedicated to working in period t. In order to model countries of differing sizes, we follow the approach of Head (1995) and Crucini (1997) and assume that Home is populated by $\mathcal{T}$ identical agents, and Foreign is populated by $\mathcal{T}^*$. Adding up utilities of all agents in Home, we obtain how total welfare in period t depends on the aggregate consumption C_t and total labor supply N_t:

$$\begin{aligned} U(C_t, N_t) = \mathcal{T} u(c_t, n_t) &= \mathcal{T} \left(\frac{[c_t^{\mu}(1-n_t)^{1-\mu}]^{1-\eta} - 1}{1-\eta} \right) \\ &= \mathcal{T} \left\{ \frac{\left[\left(\frac{C_t}{\mathcal{T}}\right)^{\mu} \left(\frac{\mathcal{T}-N_t}{\mathcal{T}}\right)^{1-\mu} \right]^{1-\eta} - 1}{1-\eta} \right\} \\ &= \frac{\mathcal{T}^{\eta}[C_t^{\mu}(\mathcal{T}-N_t)^{1-\mu}]^{1-\eta} - \mathcal{T}}{1-\eta}, \end{aligned}$$

with the analogous aggregation in Foreign.

Production uses both labor and capital. Total output in Home is given by the Cobb-Douglas production function: $Y_t = Z_t K_{t-1}^{\rho} N_t^{1-\rho}$, where Z_t is aggregate productivity, and

K_{t-1} is the capital stock available for production at the beginning of period t. Capital accumulation is subject to standard quadratic adjustment costs: investment of I_t in period t has the adjustment cost equal to $\frac{\phi}{2}\frac{(I_t-\delta K_{t-1})^2}{K_{t-1}}$, where δ is the depreciation rate. That is, it is costless to invest to cover depreciation exactly, but deviations from that incur an additional cost.

Finally, (log) productivity follows a bivariate AR(1) process:

$$\begin{bmatrix} \log Z_t \\ \log Z_t^* \end{bmatrix} = \begin{bmatrix} (1-\psi)\log \bar{Z} \\ (1-\psi)\log \bar{Z}^* \end{bmatrix} + \begin{bmatrix} \psi_{11} & \psi_{12} \\ \psi_{21} & \psi_{22} \end{bmatrix} \times \begin{bmatrix} \log Z_{t-1} \\ \log Z_{t-1}^* \end{bmatrix} + \begin{bmatrix} \epsilon_t \\ \epsilon_t^* \end{bmatrix}.$$

Following BKK, Head (1995), and Crucini (1997), we assume that there is a single good, produced in both countries, that is used for both consumption and investment. Markets are complete, and thus equilibrium is found by solving a global planning problem that maximizes the net present value of world welfare subject to the global resource constraint:

$$C_t + C_t^* + K_t - (1-\delta)K_{t-1} + \frac{\phi}{2}\frac{(K_t - K_{t-1})^2}{K_{t-1}} + K_t^* - (1-\delta)K_{t-1}^* + \frac{\phi}{2}\frac{(K_t^* - K_{t-1}^*)^2}{K_{t-1}^*}$$
$$\leq Z_t K_{t-1}^{\rho} N_t^{1-\rho} + Z_t^* K_{t-1}^{*\rho} N_t^{*1-\rho},$$

that is, global output $Z_t K_{t-1}^{\rho} N_t^{1-\rho} + Z_t^* K_{t-1}^{*\rho} N_t^{*1-\rho}$ is used for consumption in the two countries, plus investment inclusive of adjustment costs.

With the exception of the differing country sizes, the model is standard, and is solved using conventional techniques of a first-order approximation around a deterministic steady state. In choosing parameter values, we follow BKK: the discount rate is set to $\gamma = 0.99$; risk aversion/intertemporal elasticity of substitution $\eta = 2$; the weight of consumption in utility $\mu = 0.5$, depreciation rate $\delta = 0.025$, capital share $\rho = 0.36$, the persistence of the technology shock $\psi_{11} = \psi_{22} = 0.906$, the spillover terms $\psi_{12} = \psi_{21} = 0.088$ and the adjustment cost of investment parameter $\phi = 8.5$. With identical country sizes, the model is exactly the same as in BKK, and we do not discuss its properties here.

We simulate the model for a range of relative country sizes intended to mimic the size of countries relative to the rest of the world found in our data: from two countries accounting for 0.5 of the world GDP at one extreme to one country accounting for 2.5% of world GDP and the other for 97.5% of world GDP (in our data, the smallest countries are about 2% of world GDP). For each pair of relative country sizes, we draw random shocks ϵ_t and ϵ_t^* for 80,100 periods, and calculate the volatility of GDP growth for the last 80,000 periods (discarding the first 100 "burn-in" periods). Using these model-generated volatilities, we run the same regression as we do with the actual data, regressing log standard deviation of GDP growth on log share of the country in the world GDP. Consistent with previous findings (Head, 1995; Crucini, 1997), we do find that smaller countries are more volatile, but the elasticity of volatility with respect to country size is -0.004, two orders of magnitude lower than the volatility found in the data (-0.139), or the granular model in this paper (-0.135). We conclude that the standard IRBC model is not as successful as our model at generating the size-volatility relationship observed in the data.

A.2 Trade Openness

Because the one-good model above has steady state imports/GDP equal to zero, in order to evaluate the relationship between observed openness (trade/GDP) and volatility in the standard IRBC model, we augment it to feature Armington aggregation between domestic and foreign goods. That is, Home consumption and investment inclusive of adjustment costs comes from CES aggregation of domestic and foreign intermediate inputs:

$$C_t + K_t - (1-\delta)K_{t-1} + \frac{\phi}{2}\frac{(K_t - K_{t-1})^2}{K_{t-1}} = \left[\omega^{\frac{1}{\nu}}\left(y_t^h\right)^{\frac{\nu-1}{\nu}} + (1-\omega)^{\frac{1}{\nu}}\left(y_t^f\right)^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}}, \quad \text{(A.1)}$$

where y_t^h is the output of the Home intermediate good that is used in Home production, and y_t^f is the amount of the Foreign intermediate used in Home production. In this standard formulation, consumption and investment are perfect substitutes, and Home and Foreign goods are aggregated in a CES production function. Domestic output is then divided between domestic intermediate inputs y_t^d and exports y_t^h:

$$Y_t = y_t^d + y_t^f = Z_t K_{t-1}^{\rho} N_t^{1-\rho}.$$

The rest of the model and calibration details remain unchanged. The key parameter is the Armintgon elasticity of substitution between domestic and foreign goods ν. We perform our simulation for two standard values of this elasticity, the "classic" BKK value of 1.5, and the alternative value suggested by BKK, and used in the subsequent literature of 0.9, implying that domestic and foreign goods are complements. Once again, we do not discuss the details of the model's performance, as it is highly standard. Instead, we simulate the model for a range of values of trade openness. Following BKK, we use the parameter ω – home bias in preferences – to vary trade openness. As it happens, the steady state ratio of imports to GDP corresponds exactly to ω. Thus, we solve the model for a range of values of ω between 0.01 to 0.5, the latter being the case of no home bias. Similarly to the previous exercise, we then simulate the model for 80,100 periods, recording the volatility of the growth rate of output for each level of trade openness. It turns out that the sign of the openness-volatility relationship depends crucially on the Armington elasticity ν. For $\nu = 1.5$, output volatility actually decreases in openness, with the elasticity of standard deviation of output growth with respect to imports/GDP of -0.029. However, under $\nu = 0.9$, volatility increases in openness, with an elasticity of similar order of magnitude but reverse sign, 0.085. Thus, it appears that there is no "natural" openness-volatility relationship in the standard IRBC framework; instead, the direction of the relationship depends a great deal on key parameter values.

Appendix B Endogenous Markups

The model in the main text is solved under the assumption that each firm treats the sectoral price level as given setting its prices and maximizing profits. This assumption is adopted in the overwhelming majority of the trade under monopolistic competition literature that followed Krugman (1980) and Melitz (2003), and leads to the well-known property of constant markup over marginal cost. However, because our paper emphasizes the role of extremely large firms in the economy, it is important to assess whether, and to what extent, price setting by the large firms departs from the constant-markup benchmark. Unfortunately, fully taking this phenomenon into account would be impractical. To incorporate this feature into the solution of the model would lead us to lose all of the analytical results that help solve the model, such as the expressions for the price levels and sales. This is because each firm's profit-maximizing price is a function of all the other firms' prices, so that just to pin down a single firm's price, quantity, total sales, and profits, we would have to solve a fixed point problem involving all the firms selling to that market. In the trade equilibrium, to do this while at the same time solving for wages and imposing a free-entry condition that pins down the equilibrium number of firms would not be feasible.

However, in some simpler cases we can check whether this phenomenon is quantitatively important. In this Appendix, we solve for the individual firms' prices and the aggregate price level in the autarky equilibrium for any particular draw of productivities. We start by finding the profit-maximizing price for each firm taking the prices of all the other firms as given. We then take all the firms' prices, and use those as the next starting point for finding each firm's profit maximizing price. Iterating to convergence, we obtain the full set of equilibrium prices for each firm, as well as the overall price levels in this economy. We then compare those to the individual firm prices and sectoral price levels that we would get if we instead assumed the constant markup equal to $\varepsilon/(\varepsilon - 1)$.

Solving the firm's profit maximization problem, firm k's optimal price $p(k)$ is given implicitly by the following expression:

$$p(k) = \underbrace{\frac{\varepsilon}{\varepsilon - 1} ca(k)}_{\text{“constant-markup price”}} \times \underbrace{\frac{1}{1 - \frac{p(k)^{1-\varepsilon}}{\sum_{l=1}^{J} p(l)^{1-\varepsilon}} \left(1 - \frac{ca(k)}{p(k)}\right)}}_{\text{general equilibrium contribution}}, \tag{B.1}$$

where c is the cost of the input bundle, $a(k)$ is the firm's marginal cost and there are J firms in this market in total. The first term is the simple "constant-markup" price that is used in the large majority of the literature. The second term is the adjustment due to the firm's impact on the overall price level.

This equation does not have an analytical solution in $p(k)$, making it necessary to resort to numerical simulations. We thus take each country's autarky equilibrium number of firms, draw productivity for each firm, and solve for a fixed point in prices when each firm sets its price according to equation (B.1). Note that while this does not represent the full solution to the autarky model, it does allow us to evaluate how much flexible-markup prices differ from the constant-markup prices *for the constant-markup equilibrium number of firms.*

It turns out that in our sample of 50 countries, the maximum proportional difference between the flexible-markup price and the simplistic constant-markup price is 0.0225 (not percentage points of markup!). This is the maximum over all the firms in all the countries and all the sectors $s = N, T$. Thus, it appears that even for the very largest firms in the smallest countries, the constant-markup case is a very good approximation of their pricing behavior.

When it comes to the aggregate price levels, this phenomenon is even less important. Among the 50 countries and the 2 sectors (N and T) in our model, the maximum proportional difference in the price level is 0.4% (0.004). Thus, the general equilibrium effect whereby a large firm will take into account the impact of its own price on the aggregate price level appears to be quite minor quantitatively.

What is the intuition for this result? Though the flexible-markup price (B.1) does not have an analytical solution, it can be approximated as follows. The term $p(k)^{1-\varepsilon} / \sum_{l=1}^{J} p(l)^{1-\varepsilon}$ roughly corresponds to the share of the firm in total sales in the market. The term $ca(k)/p(k)$ is the inverse of the markup over the marginal cost, which we will approximate by $(\varepsilon - 1)/\varepsilon$. The price then becomes, approximately:

$$p(k) \approx \underbrace{\frac{\varepsilon}{\varepsilon - 1} ca(k)}_{\text{“constant-markup price”}} \times \underbrace{\frac{\varepsilon}{\varepsilon - share(k)}}_{\text{general equilibrium contribution}},$$

where $share(k)$ is the share of firm k in total sales in the market. That second term is thus the proportional deviation of the actual profit-maximizing price from the simplistic constant-markup price. How large does the firm have to be before this adjustment starts to appreciably affect the price? Under the baseline value of $\varepsilon = 6$, when $share(k)$ is 5%, the $\varepsilon/(\varepsilon - share(k))$ adjustment amounts to 1.0084; when $share(k)$ is 10%, that adjustment is 1.0169, and when $share(k)$ is 50%, the adjustment is 1.0909. Thus, even for firms that capture 50% of the total sales in a market, we are no more than 10% off if we simply assume the constant-markup price. As described above, given the number of firms that we actually draw for each country, we are never more than 0.0225 off for any given firm in the world.

This derivation can be used to make an additional point. While we perform this simulation for the autarky case, under trade these price deviations will become strictly smaller. This is because after trade opening, the market share of each firm *in any given market* will be strictly lower than in autarky, due to the appearance of foreign varieties (this result is well known in the heterogeneous firms literature). This in turn implies that the markup adjustment term $\varepsilon/(\varepsilon - share(k))$ will shrink further under trade.

Appendix C Aggregate Volatility Derivation

Firm k in country i with marginal cost $a(k)$ and realization of transitory shock $z(k)$ has sales of

$$\begin{aligned} x^s(a(k), z(k)) &= \sum_{j=1}^{\mathcal{C}} \mathbf{1}[k,j] \frac{X_j^s}{\left(P_j^s\right)^{1-\varepsilon_s}} \left(\frac{\varepsilon_s}{\varepsilon_s - 1} \tau_{ji} c_i^s a(k) z(k)\right)^{1-\varepsilon_s} \\ &= \left[\sum_{j=1}^{\mathcal{C}} \mathbf{1}[k,j] \frac{X_j^s}{\left(P_j^s\right)^{1-\varepsilon_s}} \left(\frac{\varepsilon_s}{\varepsilon_s - 1} \tau_{ji} c_i^s a(k)\right)^{1-\varepsilon_s}\right] \tilde{z}, \end{aligned} \quad \text{(C.1)}$$

where $\mathbf{1}[k,j]$ is the indicator function for whether firm k serves market j, and $\tilde{z} \equiv z^{1-\varepsilon_s}$. We already assumed that $\mathrm{E}_z(\tilde{z}) = 1$, and now we further suppose that $\mathrm{Var}_z(\tilde{z}) = \sigma^2$. Expected sales for the firm with productivity $a(k)$ are:

$$\mathrm{E}_z[x^s(a(k), z(k))] = \sum_{j=1}^{\mathcal{C}} \mathbf{1}[k,j] \frac{X_j^s}{\left(P_j^s\right)^{1-\varepsilon_s}} \left(\frac{\varepsilon_s}{\varepsilon_s - 1} \tau_{ji} c_i^s a(k)\right)^{1-\varepsilon_s}. \quad \text{(C.2)}$$

Given the expression for the actual sales of the firm with a transitory shock $z(k)$ in (C.1), and the expected sales of the firm with productivity $a(k)$ in (C.2), the actual sales as an approximation around $\mathrm{E}_z[x^s(a(k), z(k))]$ are:

$$x^s(a(k), z(k)) \approx \mathrm{E}_z[x^s(a(k), z(k))] + \left.\frac{dx}{d\tilde{z}}\right|_{\tilde{z}=1} \Delta\tilde{z}.$$

Therefore, the proportional change in $x^s(a(k), z(k))$, or the growth rate, is given by:

$$\frac{\Delta x^s(a(k), z(k))}{\mathrm{E}_z\left(x^s(a(k), z(k))\right)} = \tilde{z} - 1,$$

and the variance of this growth rate is:

$$\mathrm{Var}_z\left(\frac{\Delta x^s(a(k), z(k))}{\mathrm{E}_z\left(x^s(a(k), z(k))\right)}\right) = \sigma^2,$$

which we assume for simplicity is the same in the two sectors $s = N, T$. Dropping the sector superscripts, the total sales in the economy are given by (11), thus the change in the total sales relative to the non-stochastic steady state (the growth rate) is:

$$\frac{\Delta X}{\mathrm{E}_z X} = \frac{\sum_{k=1}^{I} \Delta x(a(k), z(k))}{\mathrm{E}_z X} = \sum_{k=1}^{I} \frac{\Delta x(a(k), z(k))}{\mathrm{E}_z\left[x(a(k), z(k))\right]} \frac{\mathrm{E}_z\left[x(a(k), z(k))\right]}{\mathrm{E}_z X}.$$

This means that the aggregate volatility is

$$\begin{aligned}
\mathrm{Var}_z\left(\frac{\Delta X}{\mathrm{E}_z X}\right) &= \mathrm{Var}_z\left(\sum_{k=1}^{I} \frac{\Delta x(a(k), z(k))}{\mathrm{E}_z\left[x(a(k), z(k))\right]} \frac{\mathrm{E}_z\left[x(a(k), z(k))\right]}{\mathrm{E}_z X}\right) \\
&= \sum_{k=1}^{I} \mathrm{Var}_z\left(\frac{\Delta x(a(k), z(k))}{\mathrm{E}_z\left[x(a(k), z(k))\right]}\right)\left(\frac{\mathrm{E}_z\left[x(a(k), z(k))\right]}{\mathrm{E}_z X}\right)^2 \\
&= \sigma^2 \sum_{k=1}^{I}\left(\frac{\mathrm{E}_z\left[x(a(k), z(k))\right]}{\mathrm{E}_z X}\right)^2 \\
&= \sigma^2 \sum_{k=1}^{I} h(k)^2,
\end{aligned}$$

where $h(k)$ is the share of the firm k's expected sales in total expected sales in the economy. As expected, the volatility of total output in the economy is equal to the volatility of an individual firm's output times the Herfindahl index of production shares.

Appendix D Data Description and Sources

Data on total GDP come from the World Bank's World Development Indicators database (The World Bank, 2007b). In order to compute the share of each country in world GDP, we compute shares of each country in world GDP expressed in nominal U.S. dollars in each year over the period 1970-2006, and take the average share over this period. To compute the GDP volatility, we compute the yearly growth rates of GDP expressed in constant local currency units, and take the standard deviation of that growth rate over 1970-2006. We also use the real PPP-adjusted per capita GDP figures from The World Bank (2007b) to control for the overall level of development in Section 3.

To obtain values τ_{ij} following the estimates of Helpman et al. (2008), we use data on bilateral distance, common border, whether the country is an island or landlocked, common language, and colonial ties from Centre d'Etudes Prospectives et Informations Internationales (CEPII). Data on legal origins come from La Porta et al. (1998). Finally, information on currency unions and free-trade areas come from Rose (2004), and supplemented by internet searches whenever needed.

The bilateral and overall trade volumes as a share of GDP used for comparison to the model come from the Direction of Trade Statistics (International Monetary Fund, 2007).

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Table 1. Parameter Values for Symmetric and Non-Symmetric Country Simulations

Parameter	Baseline	Source
ε [a]	6	Anderson and van Wincoop (2004)
θ [b]	5.3	Axtell (2001): $\frac{\theta}{\varepsilon-1} = 1.06$
α	0.65	Yi and Zhang (2010)
$\{\beta_N, \beta_T\}$	$\{0.65, 0.35\}$	1997 U.S. Benchmark Input-Output Table
$\{\eta_N, \eta_T\}$	$\{0.77, 0.35\}$	
τ_{ij} [c,d]	2.30	Helpman et al. (2008)
f_{ii} [c]	14.24	The World Bank (2007a); normalizing $f_{US,US}$
f_{ij} [c]	7.20	so that nearly all firms the U.S. produce
f_e	34.0	To match 7,000,0000 firms in the U.S. (U.S. Economic Census)
σ [e]	0.1	Standard deviation of sales growth of the top 100 firms in COMPUSTAT

Notes:
[a] Robustness checks include $\varepsilon = 4$ and $\varepsilon = 8$.
[b] Robustness checks include $\frac{\theta}{\varepsilon-1} = 1.5$ and $\varepsilon = 6$, so that $\theta = 6.5$.
[c] Average in our sample of 50 countries.
[d] $\tau_{ij} = \tau_{ji}$. Trade costs are adjusted by a constant ratio to match the median-level of openness across the 50-country sample.
[e] Robustness checks include σ varying with firm sales: $\sigma = Ax^{-\xi}$, where $\xi = 1/6$.

Table 2. Top 49 Countries and the Rest of the World in Terms of 2006 GDP

Country	GDP/ World GDP	Country	GDP/ World GDP
United States	0.300	Indonesia	0.006
Japan	0.124	South Africa	0.006
Germany	0.076	Norway	0.006
France	0.054	Poland	0.005
United Kingdom	0.044	Finland	0.005
Italy	0.041	Greece	0.004
China	0.028	Venezuela, RB	0.004
Canada	0.026	Thailand	0.004
Brazil	0.021	Portugal	0.003
Spain	0.020	Colombia	0.003
India	0.017	Nigeria	0.003
Australia	0.016	Algeria	0.003
Russian Federation	0.015	Israel	0.003
Mexico	0.015	Philippines	0.003
Netherlands	0.015	Malaysia	0.002
Korea, Rep.	0.011	Ireland	0.002
Sweden	0.010	Egypt, Arab Rep.	0.002
Switzerland	0.010	Pakistan	0.002
Belgium	0.009	Chile	0.002
Argentina	0.008	New Zealand	0.002
Saudi Arabia	0.007	Czech Republic	0.002
Austria	0.007	United Arab Emirates	0.002
Iran, Islamic Rep.	0.007	Hungary	0.002
Turkey	0.007	Romania	0.002
Denmark	0.006	Rest of the World	0.027

Notes: Ranking of top 49 countries and the rest of the world in terms of 2006 U.S.$ GDP. We include Hong Kong, POC, and Singapore in Rest of the World. Source: The World Bank (2007b).

Table 3. Bilateral Trade Shares: Data and Model Predictions for the 50-Country Sample

	Model	Data
Domestic sales as a share of domestic absorption (π_{ii})		
mean	0.7900	0.7520
median	0.7717	0.7921
corr(model,data)	0.4783	
Export sales as a share of domestic absorption (π_{ij})		
mean	0.0043	0.0047
median	0.0021	0.0047
corr(model,data)	0.7799	

Notes: This table reports the means and medians of domestic output (top panel), and bilateral trade (bottom panel), both as a share of domestic absorption, in the model and in the data. Source: International Monetary Fund (2007).

Table 4. Cross-Country Evidence on the Relationship between Firm Sales' Distributions and Country Size

	(A) Dep. Variable: Log(Herfindahl)			
	(1)	(2)	(3)	(4)
		Data		*Model*
	All	obs(S)≥100	obs(S)≥1000	All
Log(Size)	-0.305**	-0.284**	-0.114**	-0.135**
	(0.017)	(0.038)	(0.037)	(0.010)
Log(GDP per capita)	0.000	0.009	-0.015	...
	(0.012)	(0.031)	(0.032)	...
Constant	-3.855**	-3.932**	-3.045**	-2.775**
	(0.190)	(0.428)	(0.422)	(0.052)
Observations	139	81	52	49
R^2	0.609	0.377	0.161	0.784
	(B) Dep. Variable: Log(Sales of 10 Largest Firms)			
	(1)	(2)	(3)	(4)
		Data		*Model*
	All	obs(S)≥100	obs(S)≥1000	All
Log(Size)	1.006**	0.933**	0.888**	0.903**
	(0.059)	(0.047)	(0.049)	(0.028)
Log(GDP per capita)	0.054*	0.054	0.075*	...
	(0.026)	(0.039)	(0.033)	...
Constant	22.638**	22.540**	22.177**	18.865**
	(0.440)	(0.450)	(0.451)	(0.139)
Observations	139	81	52	49
R^2	0.753	0.770	0.800	0.958
	(C) Dep. Variable: Log(Sales of Largest Firm)			
	(1)	(2)	(3)	(4)
		Data		*Model*
	All	obs(S)≥100	obs(S)≥1000	All
Log(Size)	0.906**	0.838**	0.865**	0.908**
	(0.065)	(0.062)	(0.063)	(0.028)
Log(GDP per capita)	0.055+	0.064	0.057	...
	(0.030)	(0.053)	(0.043)	...
Constant	20.623**	20.469**	20.710**	17.820**
	(0.501)	(0.628)	(0.586)	(0.141)
Observations	139	81	52	49
R^2	0.665	0.642	0.726	0.957

Notes: The dependent variables are based on 2006 firm sales data from ORBIS, where we have dropped energy, commodity, and public service firms. Column labeled 'All' uses all available countries; columns 'obs(S)≥100'/'obs(S)≥1000' constrain the sample to countries with at least 100/1000 firm-sales observations. 'Size' is a country's share of world GDP; 'GDP per capita' is PPP-adjusted per capita income. Column 'Model' reports the corresponding relationship in the calibrated model used in the paper. Robust standard errors in parentheses; + significant at 10%; * significant at 5%; ** significant at 1%.

Table 5. Export Participation: Data and Model Predictions for Whole Economy and Tradeable Sector

	(1)	(2)	(3)	(4)
	Model		Data	
Country	Total	Tradable	Total	Tradable
United States	0.010	0.018	0.040	0.150
Germany	0.111	0.238	0.100	...
France	0.029	0.065	0.040	0.090
Argentina	0.112	0.352	...	0.422
Colombia	0.148	0.548	...	0.363
Ireland	0.332	1.000	...	0.740
Chile	0.095	0.335	0.105	...
New Zealand	0.062	0.189	0.051	0.135

Notes: This table compares, for selected countries, the share of exporters among all firms in the model (column 1) and the share of exporters among the tradeable sector firms in the model (column 2) with available estimates of corresponding shares in existing literature. Since for some countries, data are reported relative to all the firms in the economy, while for other countries it is reported relative to all the firms in the traded sector, column 3 (data) should be compared to column 1 (model), and column 4 (data) should be compared to Column 2 (model). For the United States, data are imputed based on publicly available U.S. Economic Census data on the numbers of firms by sector, together with the summary statistics for the numbers of exporters reported in Bernard et al. (2007). Data for France is based on authors' calculations using the French Census data in di Giovanni et al. (2010). Data for Germany are from Arndt et al. (2009) (Table A2). Data for Argentina come from Bustos (2010), Table D.1. For New Zealand, data come from Fabling and Sanderson (2008), Table 4. Data on Ireland come from Fitzgerald and Haller (2010), Table 1. Data for Chile come from private communication with Miguel Fuentes at the Central Bank of Chile. Data for Colombia come from private communication with Jorge Tovar at the Universidad de los Andes.

Table 6. GDP and Granular Volatility: Data and Model Predictions

	(1)	(2)	(3)	(4)
Dep. Var: Log(GDP Volatility)				
Log(σ_T)	1.578**	1.365**	1.099**	0.765**
	(0.244)	(0.321)	(0.287)	(0.274)
Log(GDP per capita)		-0.093	-0.098	-0.146*
		(0.073)	(0.065)	(0.060)
Log(Risk Content of Exports)			0.100+	-0.064
			(0.053)	(0.052)
Log(Herfindahl of Production)				-0.134
				(0.217)
Constant	3.490**	3.417**	2.994**	0.282
	(1.092)	(1.145)	(1.079)	(1.045)
Observations	49	49	47	35
R^2	0.353	0.378	0.477	0.450

The dependent variable is the standard deviation of per capita GDP growth over the period 1970-2006. σ_T is the granular aggregate volatility implied by the simulated model. GDP-per-capita is the PPP-adjusted per capita GDP. Risk Content of Exports is the measure of the volatility of a country's export pattern taken from di Giovanni and Levchenko (2010b). Herfindahl of Production is the Herfindahl index of production shares, taken from di Giovanni and Levchenko (2009). Notes: Robust standard errors in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%.

Table 7. Counterfactual Exercises: International Trade and Granular Volatility

Country	(1) Trade/ Actual	(2) Trade/ Autarky	(3) Further Opening	Country	(1) Trade/ Actual	(2) Trade/ Autarky	(3) Further Opening
United States	0.377	1.035	1.057	Indonesia	0.376	1.060	1.001
Japan	0.405	1.014	1.039	South Africa	0.535	1.109	1.016
Germany	0.582	1.080	1.011	Norway	0.716	1.137	0.999
France	0.559	1.098	1.051	Poland	0.377	1.114	0.997
United Kingdom	0.476	1.076	1.050	Finland	0.437	1.109	1.005
Italy	0.463	1.098	1.044	Greece	0.414	1.116	0.999
China	0.280	1.024	1.049	Venezuela, RB	0.285	1.070	0.973
Canada	0.446	1.077	1.018	Thailand	0.337	1.099	1.018
Brazil	0.311	1.045	1.020	Portugal	0.379	1.068	0.997
Spain	0.550	1.061	0.988	Colombia	0.646	1.118	1.020
India	0.371	1.064	1.041	Nigeria	0.274	1.172	0.995
Australia	0.513	1.051	1.084	Algeria	0.271	1.156	1.001
Russian Federation	0.144	1.099	1.036	Israel	0.513	1.131	0.978
Mexico	0.329	1.052	1.025	Philippines	0.439	1.107	0.984
Netherlands	0.693	1.104	1.041	Malaysia	0.371	1.095	1.005
Korea, Rep.	0.296	1.059	1.035	Ireland	0.457	1.087	1.007
Sweden	0.634	1.099	1.021	Egypt, Arab Rep.	0.513	1.192	1.012
Switzerland	0.548	1.107	1.001	Pakistan	0.630	1.165	1.009
Belgium	0.713	1.072	1.003	Chile	0.262	1.119	1.025
Argentina	0.219	1.091	1.007	New Zealand	0.531	1.114	1.047
Saudi Arabia	0.168	1.069	0.988	Czech Republic	0.330	1.095	1.010
Austria	0.716	1.066	1.033	United Arab Emirates	0.178	1.089	0.994
Iran, Islamic Rep.	0.189	1.097	1.008	Hungary	0.399	1.114	1.009
Turkey	0.254	1.157	1.055	Romania	0.242	1.218	0.997
Denmark	0.612	1.156	1.011				

Notes: 'Trade/Actual' reports the ratio of granular volatility implied by the model under trade to the actual volatility of GDP growth. In calculating the granular volatility, this column assumes that the firm-level volatility is equal to $\sigma = 0.1$. 'Trade/Autarky' reports the ratio of granular volatility under trade to the granular volatility under autarky for each country. 'Further Trade Opening' reports the ratio of granular volatility under a 50% reduction in iceberg trade costs τ_{ij} to the granular volatility as implied by the model under current trade costs.

Table 8. Sensitivity Checks: The Impact of Trade on Granular Volatility

	(1) β_{Size}	(2) Trade/Autarky
Baseline	-0.135	1.097
Vol. Decr. in Firm Size	-0.286	1.291
$\zeta = 1.5$	-0.123	1.116
$\varepsilon = 4$	-0.119	1.099
$\varepsilon = 8$	-0.138	1.111

Notes: This table reports (1) the coefficient of regressing the log of granular volatility on the log of country size (β_{Size}) in the trade equilibrium, and (2) the contribution of international trade to aggregate volatility (ratio of volatility under trade to the volatility in autarky) under alternative assumptions. Row (1) reports the results of a simulation in which the firm-specific volatility decreases in firm size. Row (2) reports the results of applying a power law coefficient of 1.5 rather than the baseline of 1.06. Rows (3) and (4) report the results when using an elasticity of substitution of 4 or 8, respectively.

Table A1. U.S. Evidence on Relationship between Firm-Level Volatility and Exporter Status and Size

	(A) Sample period: 1980-2007			
	Growth		*Granular*	
	(1)	(2)	(1)	(2)
	All	Restricted	All	Restricted
Exporter	-0.022	-0.014	-0.024	-0.017
	(0.021)	(0.022)	(0.021)	(0.023)
Log(Sales)	-0.129**	-0.135**	-0.128**	-0.133**
	(0.005)	(0.005)	(0.005)	(0.004)
Observations	15,901	14,597	15,859	14,558
Number of SIC	440	415	427	403
R^2	0.181	0.183	0.198	0.201
	(B) Sample period: 1980-1989			
	Growth		*Granular*	
	(1)	(2)	(1)	(2)
	All	Restricted	All	Restricted
Exporter	-0.020	-0.013	-0.010	-0.013
	(0.021)	(0.023)	(0.020)	(0.023)
Log(Sales)	-0.128**	-0.133**	-0.126**	-0.133**
	(0.005)	(0.006)	(0.004)	(0.006)
Observations	8,529	7,693	8,509	7,693
Number of SIC	435	410	422	410
R^2	0.171	0.170	0.181	0.170
	(C) Sample period: 1990-2007			
	Growth		*Granular*	
	(1)	(2)	(1)	(2)
	All	Restricted	All	Restricted
Exporter	-0.025	-0.021	-0.041	-0.036
	(0.029)	(0.031)	(0.029)	(0.031)
Log(Sales)	-0.136**	-0.140**	-0.134**	-0.140**
	(0.008)	(0.008)	(0.008)	(0.007)
Number of SIC	409	386	398	375
Observations	6,881	6,467	6,857	6,443
R^2	0.149	0.151	0.165	0.174

Notes: This table presents the results from regressing a measure of firm-level sales volatility on measures of its export status ('Exporter') and size ('Sales'). Columns (1) and (2) ('Growth') take the natural logarithm of the standard deviation of firm real sales as the dependent variable. Columns of (3) and (4) ('Granular') uses a granular volatility measure, calculated as the standard deviation of the estimated residuals, $\hat{\varepsilon}_{ist}$, from the following firm-level panel regression: $\Delta \log(\text{Sales}_{ist}) = \alpha_i + \alpha_{st} + \varepsilon_{ist}$, where i is a firm, s is a sector, and t is a quarter, so that α_i is a firm-level effect, and α_{st} is a sector×time effect. Standard deviations are calculated over the given sample period, while export status and measures of firm size are averaged over the period. Regressions include sector-level fixed effects at the 4-digit SIC. 'All' includes all firms, while 'Restricted' excludes firms in the commodity, energy, and public sectors. Data are taken from the Compustat Quarterly database of listed U.S. firms together with information on whether a firm is an exporter from the Compustat Segments database. Robust standard errors in parentheses; + significant at 10%; * significant at 5%; ** significant at 1%.

Table A2. GDP Volatility and Country Size Regressions

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var: Log(GDP Volatility)						
Log(Size)	-0.177**	-0.139**	-0.090+	-0.209**	-0.180**	-0.142**
	(0.038)	(0.044)	(0.045)	(0.035)	(0.027)	(0.023)
Log(GDP per capita)		-0.157*	-0.261**	-0.049	-0.019	0.018
		(0.069)	(0.070)	(0.057)	(0.045)	(0.037)
Constant	-4.352**	-2.696**	-1.533+	-4.010**	-4.154**	-4.291**
	(0.190)	(0.763)	(0.773)	(0.601)	(0.473)	(0.410)
Observations	49	49	30	75	100	143
R^2	0.192	0.273	0.337	0.328	0.296	0.225

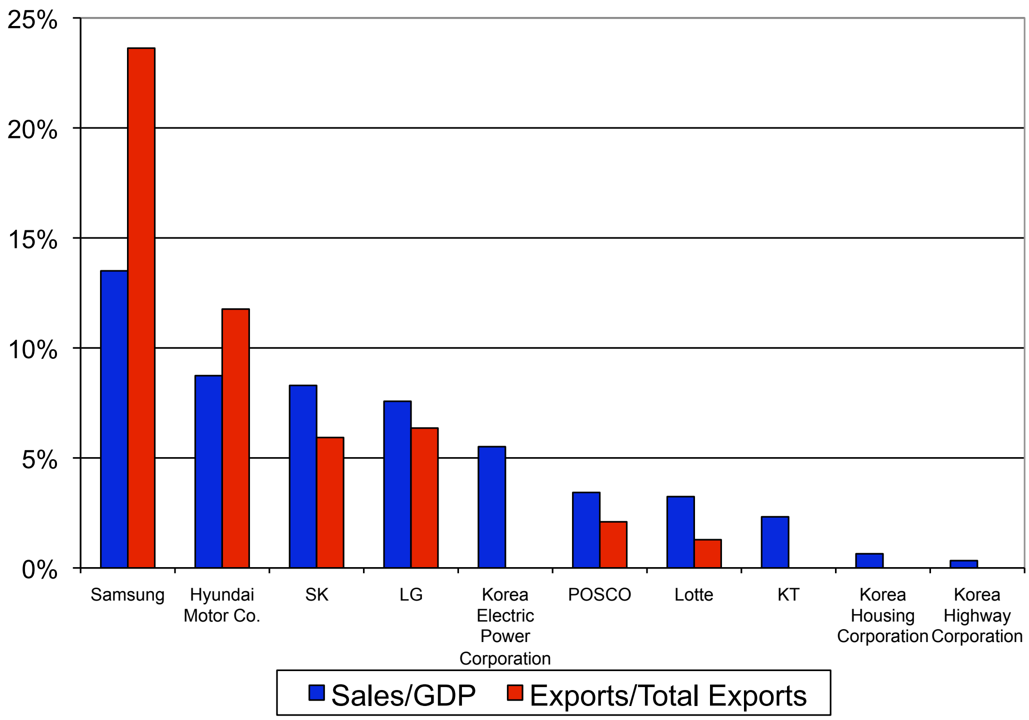
Notes: The dependent variable is the log of the standard deviation of per capita GDP growth over the period 1970-2006. Size is a country's GDP as a share of world GDP; GDP per capita is PPP-adjusted per capita income. All right-hand side variables are averages over 1970-2006. Robust standard errors in parentheses; + significant at 10%; * significant at 5%; ** significant at 1%.

Table A3. Counterfactual Exercises: Comparison of Reductions in Trade Costs and Granular Volatility

	(1)	(2)	(3)	(4)
	Percentage Reduction in Trade Costs			
	10%	25%	50%	75%
Percentile				
5	0.998	0.994	0.984	1.003
10	0.998	0.998	0.991	1.006
25	1.001	1.003	1.001	1.017
50	1.004	1.011	1.011	1.034
75	1.011	1.022	1.036	1.075
95	1.019	1.036	1.055	1.129
min	0.995	0.988	0.973	0.990
max	1.030	1.050	1.084	1.167

Notes: This table reports percentiles and minimum and maximums of the ratio of granular volatility under a four reductions in iceberg trade costs τ_{ij} to the granular volatility as implied by the model under current trade costs.

Figure 1. Korean Business Groups' Sales As a Share of GDP and Total Exports



Notes: This figure reports the sales of the top 10 Korean business groups, as a share of Korean GDP (blue/dark bars) and total Korean exports (red/light bars). Source: Korean Development Institute.

Figure 2. The Timing of the Economy

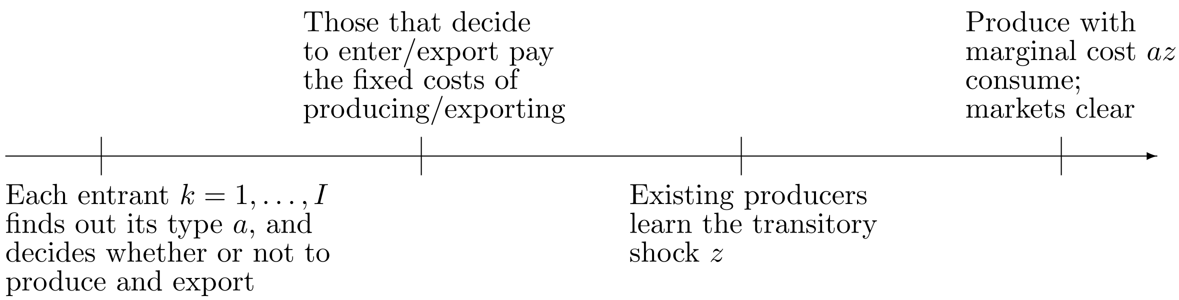
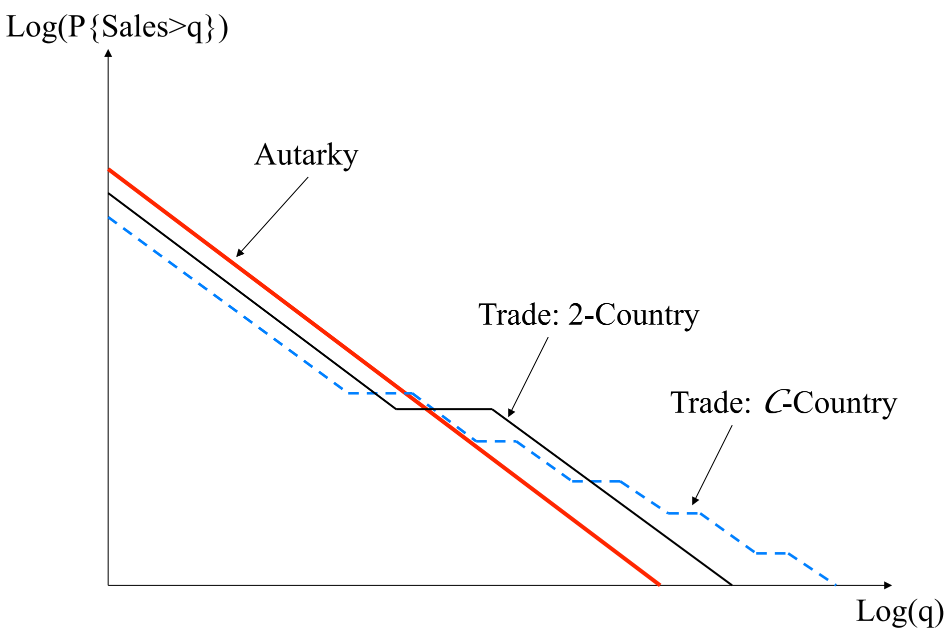
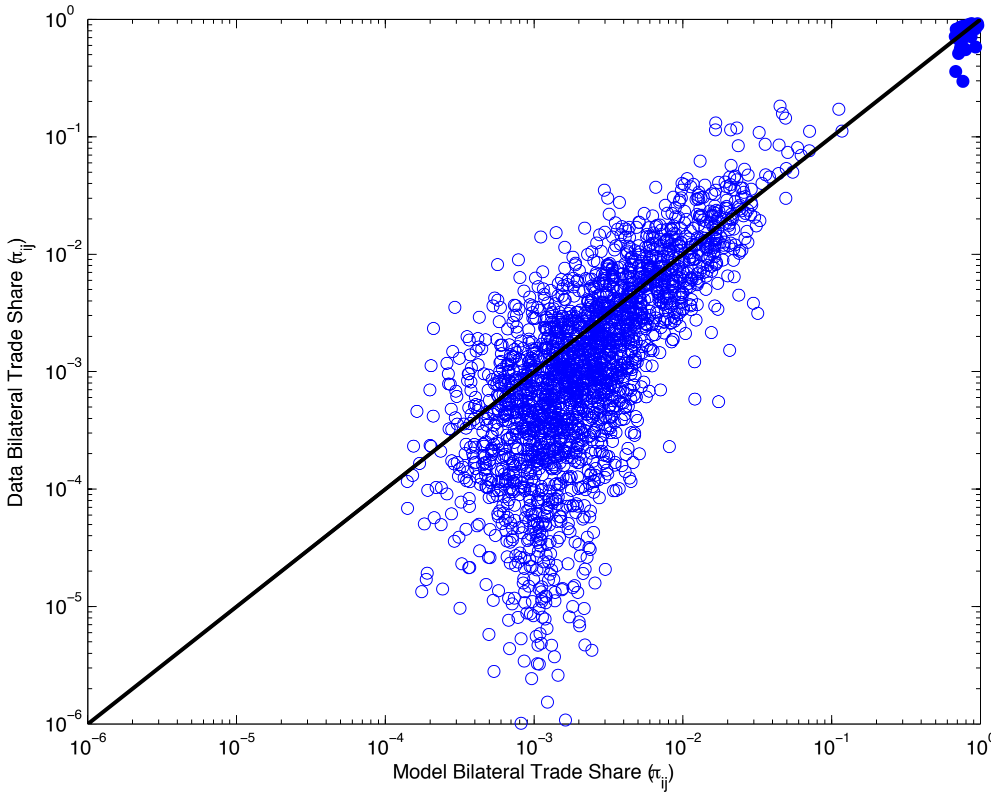


Figure 3. The Analytical Power Law in the Melitz-Pareto Model



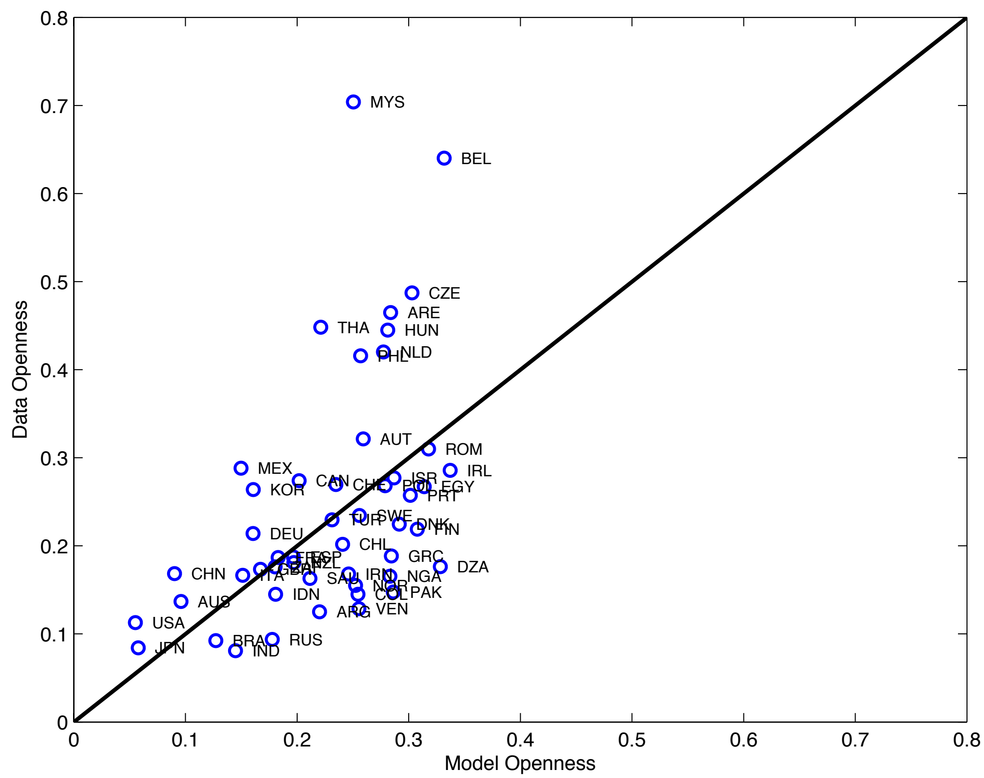
Notes: This figure depicts the distribution of firm size, measured by sales, and how it changes as it moves from Autarky to a 2-Country Trade equilibrium, and finally to a $\mathcal{C}$-Country Trade equilibrium. In the two-country case, there is a single productivity cutoff, above which firms export abroad. Compared to autarky, there is a higher probability of finding larger firms above this cutoff. In the $\mathcal{C}$-country case, with multiple export markets there will be cutoffs for each market, with progressively more productive firms exporting to more and more markets and growing larger and larger relative to domestic GDP.

Figure 4. Bilateral Trade Shares: Data and Model Predictions



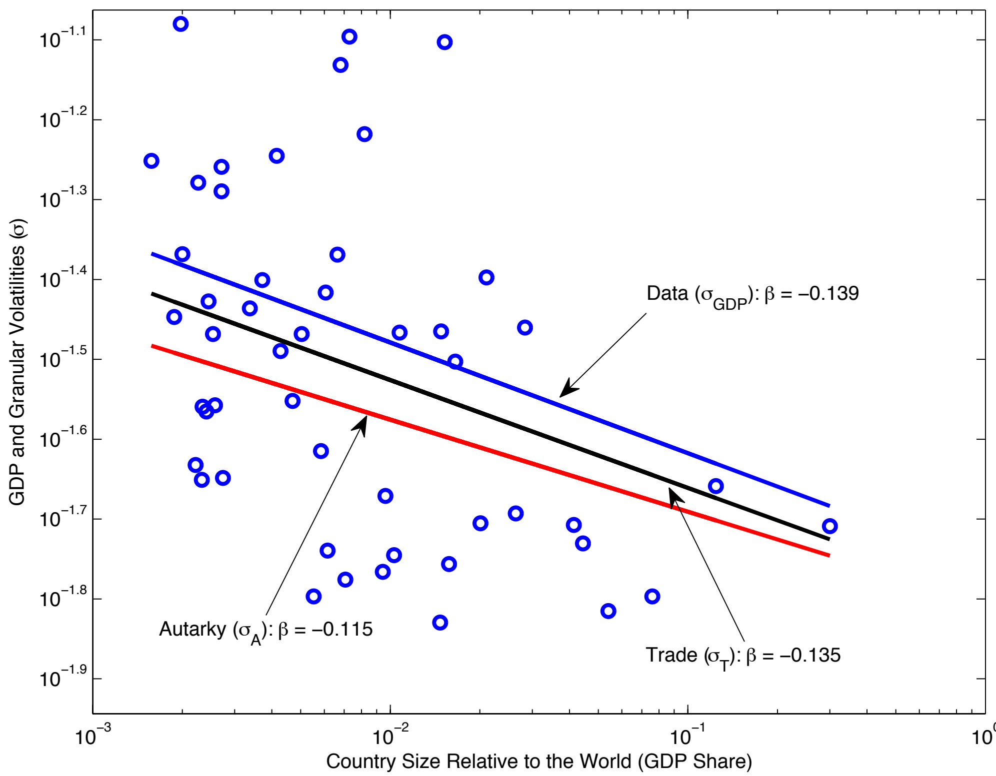
Notes: This figure reports the scatterplot of domestic output (π_{ii}) and bilateral trade (π_{ij}), both as a share of country i GDP. The figure plots the log of these ratios in log-log scale, so that the axes report the trade shares in levels. The values implied by the model are on the horizontal axis. Actual values are on the vertical axis. Solid dots represent observations of π_{ii}, while hollow dots represent bilateral trade observations (π_{ij}). The line through the data is the 45-degree line.

Figure 5. Trade Openness: Data and Model Predictions



Notes: This figure reports total imports as a share of GDP. The values implied by the model are on the horizontal axis. Actual values are on the vertical axis. The line through the data is the 45-degree line.

Figure 6. Volatility and Country Size: Data and Model Predictions



Notes: This figure plots the relationship between country size and aggregate volatility implied by the data (conditioning for per-capita GDP), the model under trade, and the model in autarky. The dots represent actual observations of volatility. Note that the data points and regression line are shifted by a constant for ease of visual comparability with the model regressions lines. Source: The World Bank (2007b).