A Global View of Productivity Growth in China*

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Abstract

How does a country's productivity growth affect worldwide real incomes through international trade? In this paper, we take this classic question to the data by measuring the spillover effects of China's productivity growth. Using a quantitative trade model, we first estimate China's productivity growth between 1995-2007 and then isolate what would have happened to real incomes around the world if only China's productivity had changed. We find that the spillover effects are small for all countries in our sample, ranging from a cumulative real income loss of at most -0.2 percent to a cumulative real income gain of at most 0.2 percent.

JEL classification: F1, F4, O4

Keywords: Spillovers; Productivity growth; China

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1 Introduction

One of the classic insights of international trade theory is that a country's productivity growth can affect other countries' real incomes through international trade. This is perhaps best known from traditional models of inter-industry trade which show that real incomes can change as a result of terms-of-trade effects (Hicks, 1953). But it is also implied by newer models of intra-industry trade which illustrate that there can further be profit-shifting (Venables, 1985) or firm delocation effects (Venables, 1987). Importantly, the sign of these spillover effects is theoretically ambiguous so that countries could benefit or suffer from a trading partner's productivity growth.

These classic analyses have gained new relevance in light of China's spectacular productivity growth. For example, they clarify under what conditions China's rise might harm its trading partners thereby addressing widely held concerns. As we will review in detail later on, China's trading partners would suffer from adverse terms-of-trade effects if China's productivity growth was biased towards industries in which China is a net importer. Moreover, they would suffer from detrimental profit shifting effects if productivity growth was biased towards industries in which firms are particularly profitable. Finally, they would suffer from harmful firm delocation effects if productivity growth was biased towards industries in which consumers are particularly sensitive to changes in domestic variety.

In this paper, we use a quantitative general equilibrium trade model to measure the spillover effects of China's productivity growth. Our model nests the three spillover effects identified by the theoretical literature and specifies a rich economic environment featuring multiple sectors, multiple factors, realistic input-output linkages, and so on. Our approach is to first estimate China's industry-level productivity growth and then use our model to calculate what would have happened to real incomes around the world if only China's productivity had changed. We need a model for this calculation because we want to isolate the spillover effects of China's productivity growth holding fixed all other shocks which simultaneously affect the world economy.

Our main finding is that the spillover effects of China's productivity growth are small. Focusing on the years 1995-2007 and the 14 largest economies in the world, we find that the cumulative real income effects range from a loss of at most -0.2 percent to a gain of at most 0.2 percent with the average effect being zero. There are two main reasons for this result. First, Chinese imports actually only account for a small share of total expenditure averaging a mere 1.3 percent in 2007. Second, China's productivity growth does not exhibit any strong biases of the sort described earlier so that the resulting terms-of-trade, firm delocation, and profit shifting effects do not have a clear sign.

Despite the considerable attention our subject received in the theoretical literature, there is relatively little related empirical work. Our paper is preceded mainly by Eaton and Kortum (2002) who illustrate their seminal framework by quantifying the spillover effects of hypothetical US and German productivity shocks on other OECD countries. Eaton and Kortum's framework features only terms-of-trade effects but no firm delocation or profit shifting effects and therefore ignores some of the channels through which productivity shocks transmit. Also, it predicts full specialization according to comparative advantage but allows only for aggregate productivity shocks so that productivity growth is always export-biased in effect.[1]

Having said this, additional work has emerged since the first draft of our paper. Probably most closely related is the work by Di Giovanni et al (2014) who also consider the welfare effects of China's productivity growth. While our analysis has an ex post nature isolating the spillover effects of actual productivity shocks, Di Giovanni et al (2014) take an ex ante approach simulating the spillover effects of hypothetical growth scenarios. Our exercise is also in a similar spirit as the analysis by Levchenko and Zhang (2016) who measure the evolution of sectoral productivities in the world economy over multiple decades. Their main point is that there has been productivity convergence in the sense that productivity grew faster in sectors that were less productive initially.

In terms of its question, our paper is also related to the work of Autor et al (2013) which

[1] Fieler (2011) provides a similar exercise in an Eaton and Kortum (2002) model with non-homothetic preferences.

investigates the local labor market consequences of Chinese import competition in the US. Their main finding is that local labor markets which are more exposed to Chinese import competition also have higher unemployment, lower labor market participation, and reduced wages. The same is true for the work of Bloom et al (forthcoming) which examines the impact of Chinese import competition on technical change in the EU. Their main punchline is that Chinese import competition lead to increased technical change within firms and reallocated employment between firms towards more technologically advanced firms.

The remainder of this paper is organized as follows: Section 2 presents an illustrative model designed to convey our methodology in the clearest possible way. Section 3 extends this illustrative model along a number of dimensions to develop a more realistic quantitative framework. Section 4 turns to the empirical application in which we use this more realistic framework for our calculations and presents the data, the parameter estimation, and the results.

2 Illustrative model

2.1 Setup

Our illustrative model is based on a simple multi-country and multi-sector version of Krugman (1980). Households supply a fixed amount L_j of labor and make their consumption choices according to the following nested Cobb-Douglas-CES preferences:

$$U_j = \prod_{s=1}^{S} \left(\sum_{i=1}^{N} \int_0^{M_{is}^e} x_{ijs} \left(\nu_{is} \right)^{\frac{\sigma_s - 1}{\sigma_s}} d\nu_{is} \right)^{\frac{\sigma_s}{\sigma_s - 1} \mu_{js}} \tag{1}$$

where N is the number of countries, S is the number of industries, M_{is}^e is the number of entrants in industry s of country i, x_{ijs} is the quantity of an industry s variety from country i consumed in country j, μ_{js} is the fraction of country j income spent on industry s varieties, and $\sigma_s > 1$ is the elasticity of substitution between industry s varieties.

Firms have monopoly power over a single variety and produce according to the following inverse production functions:

$$l_{is} = f_{is}^e + \sum_{j=1}^{N} \frac{\tau_{ijs} x_{ijs}}{\varphi_{is}} \tag{2}$$

where l_{is} is the labor requirement of an industry s firm from country i, φ_{is} is the productivity of an industry s firm from country i, τ_{ijs} is an iceberg trade barrier applying to industry s shipments from country i to country j, and f_{is}^e is a fixed cost of entry. Notice that firms are homogeneous within countries and industries but not across countries and industries which gives rise to Ricardian comparative advantage.

We consider two versions of our model, one with free entry and one without. In the version with free entry, $f_{is}^e > 0$ and M_{is}^e adjusts until profits are zero for all firms. In the version without free entry, $f_{is}^e = 0$ and M_{is}^e is taken as given so that profits are positive for all firms. As we will see, the spillover effects of productivity shocks differ across these two versions both qualitatively as well as quantitatively. They can be thought of as capturing long-run and short-run adjustments and we will therefore refer to them as "long-run version" and "short-run version" from now on.

2.2 Equilibrium for given productivities

Utility maximization yields the familiar demands $x_{ijs} = \frac{p_{ijs}^{-\sigma_s}}{P_{js}^{1-\sigma_s}} \mu_{js} E_j$, where p_{ijs} is the price of an industry s variety from country i in country j, $P_{js} = \left(\sum_{i=1}^{N} M_{is}^e p_{ijs}^{1-\sigma_s} \right)^{\frac{1}{1-\sigma_s}}$ is the ideal price index in industry s of country j, and E_j is the total expenditure in country j. Profit maximization implies that firms charge a constant markup over marginal costs giving rise to the standard pricing formula $p_{ijs} = \frac{\sigma_s}{\sigma_s - 1} \frac{w_i \tau_{ijs}}{\varphi_{is}}$, where w_i is the wage rate in country i. Using these formulas, it should be easy to verify that the equilibrium for given productivities can be characterized by the following four conditions in which π_{is} denote the profits of an industry s firm in country i:

$$E_i = w_i L_i + \sum_{s=1}^{S} M_{is}^e \pi_{is} \tag{3}$$

$$P_{js}=\left(\sum_{i=1}^{N}M_{is}^{e}\left(\frac{\sigma_s}{\sigma_s-1}\frac{w_i\tau_{ij}}{\varphi_{is}}\right)^{1-\sigma_s}\right)^{\frac{1}{1-\sigma_s}} \tag{4}$$

$$\pi_{is}+w_i f_{is}^{e}=\frac{1}{\sigma_s}\sum_{j=1}^{N}\left(\frac{\sigma_s}{\sigma_s-1}\frac{w_i\tau_{ijs}}{\varphi_{is}P_{js}}\right)^{1-\sigma_s}\mu_{js}E_j \tag{5}$$

$$w_iL_i=\sum_{s=1}^{S}M_{is}^{e}\left(\pi_{is}\left(\sigma_s-1\right)+w_i f_{is}^{e}\sigma_s\right) \tag{6}$$

The first condition captures that total income consists of labor income and profit income and the second is the formula for the ideal price index after substituting the pricing rule. The third condition follows from the fact that firm profits are given by a constant share of firm revenues minus fixed entry costs and the last imposes that labor income has to equal the sum of industry labor costs. To obtain the long-run version of the model, we set $\pi_{is}=0$ and treat M_{is}^{e} as endogenous. To obtain the short-run version, we instead set $f_{is}^{e}=0$ and treat π_{is} as endogenous. In both cases we get $2NS+2N$ equations in $2NS+2N$ unknowns with the unknowns being $\{E_i, w_i, M_{is}^{e}, P_{is}\}$ and $\{E_i, w_i, \pi_{is}, P_{is}\}$, respectively.

2.3 General equilibrium effects of productivity shocks

These conditions can be used to isolate the general equilibrium effects of productivity shocks by performing a quantitative comparative statics analysis. This can be done most easily by first rewriting them in changes following the "exact hat algebra" approach of Dekle et al (2007) allowing for changes in productivity as well as all endogenous variables. Letting a "hat" denote a proportional change, defining the trade shares $\alpha_{ijs}=\frac{X_{ijs}}{\sum_{m=1}^{N}X_{mjs}}$ and $\beta_{ijs}=\frac{X_{ijs}}{\sum_{n=1}^{N}X_{ins}}$, where $X_{ijs}=M_{is}^{e}p_{ijs}x_{ijs}$ is the value of industry s trade flowing from country i to country j, and introducing the shorthand $L_{is}=M_{is}^{e}l_{is}$, it should be easy to verify that the long-run and short-run versions of conditions (3) - (6) imply:

Case I: Long-run

$$\hat{E}_i=\hat{w}_i \tag{7}$$

$$\hat{P}_{js} = \left(\sum_{i=1}^{N} \alpha_{ijs} \hat{M}_{is}^{e} \left(\frac{\hat{w}_i}{\hat{\varphi}_{is}} \right)^{1-\sigma_s} \right)^{\frac{1}{1-\sigma_s}} \tag{8}$$

$$\hat{w}_i = \sum_{j=1}^{N} \beta_{ijs} \left(\frac{\hat{w}_i}{\hat{\varphi}_{is} \hat{P}_{js}} \right)^{1-\sigma_s} \hat{E}_j \tag{9}$$

$$1 = \sum_{s=1}^{S} \frac{w_i L_{is}}{w_i L_i} \hat{M}_{is}^{e} \tag{10}$$

Case II: Short-run

$$\hat{E}_i = \frac{w_i L_i}{E_i} \hat{w}_i + \sum_{s=1}^{S} \frac{M_{is}^{e} \pi_{is}}{E_i} \hat{\pi}_{is} \tag{11}$$

$$\hat{P}_{js} = \left(\sum_{i=1}^{N} \alpha_{ijs} \left(\frac{\hat{w}_i}{\hat{\varphi}_{is}} \right)^{1-\sigma_s} \right)^{\frac{1}{1-\sigma_s}} \tag{12}$$

$$\hat{\pi}_{is} = \sum_{j=1}^{N} \beta_{ijs} \left(\frac{\hat{w}_i}{\hat{\varphi}_{is} \hat{P}_{js}} \right)^{1-\sigma_s} \hat{E}_j \tag{13}$$

$$1 = \sum_{s=1}^{S} \frac{w_i L_{is}}{w_i L_i} \frac{\hat{\pi}_{is}}{\hat{w}_i} \tag{14}$$

The main advantage of this reformulation is that all coefficients of equations (7) - (14) can now be backed out from widely available trade data and an estimate of σ_s. In the long-run, all industry revenues accrue to industry workers so that $w_i L_{is} = \sum_{j=1}^{N} X_{ijs}$. In the short-run, they are instead split into industry labor costs and industry profits such that $w_i L_{is} = \frac{\sigma_s - 1}{\sigma_s} \sum_{j=1}^{N} X_{ijs}$ and $M_{is}^{e} \pi_{is} = \frac{1}{\sigma_s} \sum_{j=1}^{N} X_{ijs}$. In both cases, total expenditure is given by $E_i = \sum_{j=1}^{N} \sum_{s=1}^{S} X_{ijs}$ and total labor income can be calculated from $w_i L_i = \sum_{s=1}^{S} w_i L_{is}$. Notice that this procedure also ensures that equations (7) - (14) perfectly match industry-level trade flows before the productivity shock.

To provide a sense of the general equilibrium adjustments predicted by these equations, Panel A of Table 1 reports the effects of a hypothetical productivity shock in a simple example economy consisting of two countries (China and the US) and two industries (1 and 2). Productivity is assumed to grow by 10 percent in industry 1 of China and trade flows are taken to be fully symmetric as detailed in the note to Table 1. The results under Case I refer to the long-run and report adjustments in relative wages and entry, while the results under Case II turn to the short-run and show adjustments in relative wages and profits, where the profits are normalized by the corresponding wage effects.

As can be seen, the relative wage of China is predicted to rise as a result of China's productivity growth. Moreover, industry 1 of China either experiences entry or an increase in profits while industry 2 of China either experiences exit or a decrease in profits with the mirror image occurring in the US. Intuitively, industry 1 of China expands as a result of the productivity shock which then bids up Chinese wages and forces industry 2 of China to contract. In the long-run, this expansion occurs at the extensive margin while in the short-run it occurs at the intensive margin which then brings about changes in industry profits as they are proportional to industry scale.[2]

2.4 Welfare effects of productivity shocks

Given these general equilibrium effects of productivity shocks, the implied welfare effects can be computed straightforwardly. Changes in welfare are given by changes in real income which are changes in nominal expenditure deflated by changes in the ideal aggregate price index: $\widehat{V}_j = \frac{\hat{E}_j}{\widehat{P}_j}$. Given the Cobb-Douglas structure of aggregate preferences, this can be rewritten in terms of changes in the ideal industry price indices as:

$$\hat{V}_j = \frac{\hat{E}_j}{\prod_{s=1}^{S} \left(\hat{P}_{js}\right)^{\mu_{js}}} \tag{15}$$

A decomposition of this expression confirms that our framework indeed captures terms-of-trade, firm delocation, and profit shifting effects. In particular, small welfare changes can be

[2] It is easy to verify that $M_{is}^e = \frac{L_{is}}{f_{is}^e \sigma_s}$ in the long-run and $\frac{\pi_{is}}{w_i} = \frac{L_{is}}{M_{is}^e(\sigma_s - 1)}$ in the short-run which should further clarify this point. The change in the pattern of specialization can also be understood in terms of two basic equilibrium constraints. First, labor market clearing requires that the expansion of one industry leads to the contraction of the other industry in the same country. Second, constant expenditure shares imply that the expansion of one industry leads to the contraction of the same industry in the other country.

written in terms of log-changes as $d\ln V_j = d\ln E_j - \sum_{s=1}^{S}\mu_{js} d\ln P_{js}$. Log-differentiating (3) and (5) then yields $d\ln E_i = d\ln w_i$ and $d\ln P_{js} = \sum_{i=1}^{N}\alpha_{ijs}\left(d\ln w_i - d\ln\varphi_{is} - \frac{1}{\sigma_s-1} d\ln M_{is}^e\right)$ in the long-run version of the model and $d\ln E_i = d\ln w_i + \sum_{s=1}^{S}\gamma_{is}\left(d\ln\pi_{is} - d\ln w_i\right)$ and $d\ln P_{js} = \sum_{i=1}^{N}\alpha_{ijs}\left(d\ln w_i - d\ln\varphi_{is}\right)$ in the short-run version of the model, where we have defined $\gamma_{is} = \frac{M_{is}^e \pi_{is}}{E_i}$. In combination, this then yields the following decomposition of the welfare effects of small productivity shocks:

Case I: Long-run

$$\begin{aligned}\frac{dV_j}{V_j} &= \underbrace{\sum_{i=1}^{N}\sum_{s=1}^{S}\mu_{js}\alpha_{ijs}\left(\left(\frac{dw_j}{w_j} - \frac{d\varphi_{js}}{\varphi_{js}}\right) - \left(\frac{dw_i}{w_i} - \frac{d\varphi_{is}}{\varphi_{is}}\right)\right)}_{\text{terms-of-trade effect}} \\ &\quad \underbrace{+\sum_{i=1}^{N}\sum_{s=1}^{S}\mu_{js}\alpha_{ijs}\frac{1}{\sigma_s - 1}\frac{dM_{is}^e}{M_{is}^e}}_{\text{firm delocation effect}} \\ &\quad +\sum_{s=1}^{S}\mu_{js}\frac{d\varphi_{js}}{\varphi_{js}}\end{aligned} \tag{16}$$

Case 2: Short-run

$$\begin{aligned}\frac{dV_j}{V_j} &= \underbrace{\sum_{i=1}^{N}\sum_{s=1}^{S}\mu_{js}\alpha_{ijs}\left(\left(\frac{dw_j}{w_j} - \frac{d\varphi_{js}}{\varphi_{js}}\right) - \left(\frac{dw_i}{w_i} - \frac{d\varphi_{is}}{\varphi_{is}}\right)\right)}_{\text{terms-of-trade effect}} \\ &\quad \underbrace{+\sum_{s=1}^{S}\gamma_{js}\left(\frac{d\pi_{js}}{\pi_{js}} - \frac{dw_j}{w_j}\right)}_{\text{profit shifting effect}} \\ &\quad +\sum_{s=1}^{S}\mu_{js}\frac{d\varphi_{js}}{\varphi_{js}}\end{aligned} \tag{17}$$

The terms-of-trade effect captures that country j's real income increases if the prices of its export goods increase relative to the prices of its import goods. The firm delocation effect captures that country j's real income increases if it gains firms in industries in which consumers have a high valuation of domestic variety at the expense of industries in which consumers have a low valuation of domestic variety. The profit shifting effect captures that country j's real income increases if it expands more profitable industries at the expense of less profitable industries. The last term shows what the welfare effects of country j's productivity growth would be in the benchmark case of autarky.

The key determinants of the signs of these spillover effects can be best explained using the simple numerical example introduced above. Panel A of Table 2 reports the effects of a hypothetical 10 percent productivity growth in industry 1 of China on US welfare for three different scenarios: China is a net exporter in industry 1, China is a net importer in industry 1, and there is no inter-industry trade. As one expects from the classic literature, the US experiences a terms-of-trade gain if China's productivity growth is biased towards China's export-oriented industry but a terms-of-trade loss if China's productivity growth is biased towards China's import-competing industry.

One subtle difference from the textbook analysis is that the terms-of-trade gain the US experiences if China's productivity growth is biased towards China's export-oriented industry exceeds the terms-of-trade loss it experiences if China's productivity growth is biased towards China's import-competing industry. This is also reflected in the fact that the US experiences a positive terms-of-trade effect even if there is no inter-industry trade. This difference is due to the existence of Krugman (1980) type intra-industry trade. In a sense, productivity growth always features an export-bias in a Krugman (1980) model since each country specializes in a unique set of varieties.

Panel A of Table 3 returns to the case of fully symmetric trade flows and illustrates the role played by cross-industry differences in σ_s. It again reports the effects of a 10 percent productivity growth in industry 1 of China on US welfare. As can be seen, the US experiences a positive firm delocation or profit shifting effect if China's productivity growth is biased towards the high σ_s industry and a negative firm delocation or profit shifting effect if it is biased towards the low σ_s industry. The intuition is that consumers have a higher valuation for domestic variety in the low σ_s industry and firms make higher profits in the low σ_s industry so that an expansion of this industry is good news.

For example, if China's productivity growth is biased towards the high σ_s industry, the high σ_s industry contracts and the low σ_s industry expands in the US. In the long-run, these adjustments occur at the extensive margin and benefit the US because there is a domestic variety gain in the more differentiated industry at the expense of a domestic variety loss in the less differentiated industry. In the short-run, these adjustments occur at the intensive margin and benefit the US because the higher markup industry expands at the expense of the lower markup industry thus increasing the total profits generated in the US.[3]

Overall, this discussion suggests that there are two key determinants of the sign of the global spillover effects of China's productivity growth: the correlation between China's productivity growth and China's export-orientation, and the correlation between China's productivity growth and the elasticity parameters σ_s which parameterize the differentiation of products and the profitability of firms. Of course, the magnitude of the spillover effects also depends critically on the pattern and volume of international trade as captured by the trade shares $\mu_{js}\alpha_{ijs}$ and γ_{js} in equations (16) and (17).

Notice that the firm delocation and profit shifting effects from decompositions (16) and (17) can also be seen in simple sufficient statistics of the Arkolakis et al (2012) kind. Substituting the formulas for p_{ijs} and x_{ijs} into the definition of X_{ijs}, it should be easy to verify that $\frac{\hat{w}_i}{\hat{P}_{is}} = \hat{\varphi}_{is} \left(\frac{\hat{\alpha}_{iis}}{\hat{M}^e_{is}} \right)^{-\frac{1}{\sigma_s - 1}}$, where $\alpha_{ijs} = \frac{X_{ijs}}{\sum_{m=1}^{N} X_{mjs}}$ just as above. Using the relationship $\hat{P}_i = \prod_{s=1}^{S} \left(\hat{P}_{is} \right)^{\mu_{is}}$, this immediately implies $\frac{\hat{w}_i}{\hat{P}_i} = \prod_{s=1}^{S} \left(\hat{\varphi}_{is} \left(\frac{\hat{\alpha}_{iis}}{\hat{M}^e_{is}} \right)^{-\frac{1}{\sigma_s - 1}} \right)^{\mu_{is}}$. Recalling that welfare is given by $V_i = \frac{E_i}{P_i}$ and $E_i = w_i L_i + \sum_{s=1}^{S} M^e_{is} \pi_{is}$ in general from (3), we can thus write $\hat{V}_i = \frac{1}{\hat{\vartheta}_i} \prod_{s=1}^{S} \left(\hat{\varphi}_{is} \left(\frac{\hat{\alpha}_{iis}}{\hat{M}^e_{is}} \right)^{-\frac{1}{\sigma_s - 1}} \right)^{\mu_{is}}$, where $\vartheta_i = \frac{w_i L_i}{E_i}$ is the share of labor income in total income.

In the long-run, $\hat{\vartheta}_i = 1$ so that this simplifies to $\hat{V}_i = \prod_{s=1}^{S} \left(\hat{\varphi}_{is} \left(\frac{\hat{\alpha}_{iis}}{\hat{M}^e_{is}} \right)^{-\frac{1}{\sigma_s - 1}} \right)^{\mu_{is}}$. Bearing

[3] One might wonder why US consumers benefit from domestic entry into the low σ_s industry even though it comes at the expense of foreign exit out of the low σ_s industry so that the total number of low σ_s varieties available to US consumers might go up or down. The reason is that our examples from Tables 1-3 all make the realistic assumption that US consumers spend more on US varieties than on imported varieties so that they care more about domestic variety effects.

in mind the constraint $1 = \sum_{s=1}^{S} \frac{L_{is}}{L_i} \hat{M}_{is}^e$ implied by condition (14), this shows that entry into low σ_s industries improves welfare other things equal thus again highlighting the firm delocation effect. In the short-run, instead $\hat{M}_{is}^e = 1$ so that welfare changes are given by $\hat{V}_i = \frac{1}{\hat{\vartheta}_i} \prod_{s=1}^{S} \left(\hat{\varphi}_{is} \left(\hat{\alpha}_{iis} \right)^{-\frac{1}{\sigma_s - 1}} \right)^{\mu_{is}}$. From this we can see that a reduction in the share of labor income in total income (and hence an increase in the share of profits in total income) improves welfare other things equal which illustrates again the profit shifting effect. Of course, just measuring $\hat{\alpha}_{iis}$, $\hat{M}_{is}^e$, and $\hat{\vartheta}_i$ in the data would not be informative of the spillover effects of China's productivity growth since these are endogenous objects which are also affected by all other contemporaneous shocks.[4]

2.5 Limitations of this illustrative model

While this model usefully illustrates the essence of our methodology, it seems too stylized to deliver plausible quantitative results. For this reason, we extend it along a number of dimensions with the goal of addressing the most obvious concerns. In particular, we add multiple factors, input-output linkages, aggregate trade imbalances, and heterogeneous firms which all play important roles in trading economies. The end result is essentially a Ricardo-Heckscher-Ohlin-Krugman-Melitz model with input-output linkages which combines all the main traditions in the field.

As we will see, this extended model still behaves similarly to the illustrative model which is largely due to our specification of firm heterogeneity. In particular, we model firm heterogeneity using the Arkolakis et al (2012) version of Melitz (2003) which implies that it behaves like a Krugman (1980) model in many ways. However, adding firm heterogeneity still proves useful when it comes to estimating China's productivity growth. In particular, China's productivity can also grow as a result of Melitz (2003) type selection effects and we want to make

[4] As should be clear from Arkolakis et al (2012), this sufficient statistic would take the form $\hat{V}_i = \prod_{s=1}^{S} \left(\hat{\varphi}_{is} \left(\hat{\alpha}_{iis} \right)^{\frac{1}{\varepsilon_s}} \right)^{\mu_{is}}$ in perfectly competitive gravity models such as Eaton and Kortum (2002), where $\varepsilon_s < 0$ denotes the trade elasticity. This again illustrates how such models do not capture the firm delocation or profit shifting effects identified in Venables (1985) and Venables (1987).

sure not to erroneously ascribe such effects to fundamental productivity growth.

3 Full model

3.1 Setup

Consumers again have Cobb-Douglas preferences across industries and CES preferences across varieties within industries. However, the number of entrants into industry s of country i, which we continue to denote by M_{is}^{e}, no longer conforms to the number of industry s firms from country i serving market j, which we now label M_{ijs}, because firms are heterogeneous and face fixed market access costs. Taking this into consideration and using a superscript "F" to denote final consumption, the utility function becomes:

$$U_j = \prod_{s=1}^{S} \left(\sum_{i=1}^{N} \int_0^{M_{ijs}} x_{ijs}^{F} \left(\nu_{is}\right)^{\frac{\sigma_s - 1}{\sigma_s}} d\nu_{is} \right)^{\frac{\sigma_s}{\sigma_s - 1}\mu_{js}^{F}} \tag{18}$$

Firms no longer just hire workers but produce using a Cobb-Douglas combination of labor, capital, and intermediate goods. In order to allow for cross-country and cross-industry variation in factor-intensities and the importance of intermediate inputs, we allow for cross-country and cross-industry variation in the respective Cobb-Douglas parameters and define the aggregate input specific to industry s of country i as:

$$I_{is} = \left(\frac{1}{\eta_i^s} \left(\frac{L_{is}}{\rho_i^{L,s}} \right)^{\rho_i^{L,s}} \left(\frac{K_{is}}{\rho_i^{K,s}} \right)^{\rho_i^{K,s}} \right)^{\eta_i^s} \left(\frac{C_i^{I,s}}{1 - \eta_i^s} \right)^{1 - \eta_i^s} \tag{19}$$

where L_{is} is the required amount of labor, K_{is} is the required amount of capital, $C_i^{I,s}$ is the required amount of intermediate consumption, η_i^s are the shares of value added in gross production and $\rho_i^{L,s}$ and $\rho_i^{K,s}$, $\rho_i^{L,s} + \rho_i^{K,s} = 1$, are the shares of labor and capital in value added. To be clear, we refer to these inputs as "aggregate" because they combine labor, capital, and intermediate goods and "country-industry-specific" because this is done with country-industry-specific weights. Labor and capital are freely mobile across sectors within countries as usual.

Intermediate consumption is defined analogously to final consumption using a Cobb-Douglas-CES aggregator. However, we now also allow the Cobb-Douglas shares to vary by downstream industry so that we can take the full input-output structure of the economy into account. Using a superscript "I" to denote intermediate consumption, a superscript "t" (or sometimes "s") to denote the downstream industry, and a subscript "s" (or sometimes "t") to denote the upstream industry, we now model:

$$C_j^{I,t} = \prod_{s=1}^{S} \left(\sum_{i=1}^{N} \int_0^{M_{ijs}} x_{ijs}^{I,t} \left(\nu_{is}\right)^{\frac{\sigma_s - 1}{\sigma_s}} d\nu_{is} \right)^{\frac{\sigma_s}{\sigma_s - 1} \mu_{js}^{I,t}} \tag{20}$$

Firm heterogeneity is captured by the following production process. Entrants into industry s of country i have to hire f_{is}^e units of I_{is} to draw their productivities φ from a Pareto distribution $G_{is}(\varphi) = 1 - \left(\frac{b_{is}}{\varphi}\right)^{\theta_s}$, where f_{is}^e is a fixed cost of entry, b_{is} is the Pareto location parameter, and θ_s is the Pareto shape parameter. Entrants into industry s of country i wishing to sell to country j further need to hire $\frac{x_{ijs}\tau_{ijs}}{\varphi}$ units of I_{is} and f_{ijs} units of I_{js} to deliver x_{ijs} units of output to country j, where f_{ijs} is a fixed cost of serving market j. Notice that the fixed market access costs are denoted in destination country inputs which simplifies the algebra.

3.2 Equilibrium for given productivities

Given the Cobb-Douglas structure of the aggregate input, labor costs account for a fraction $\eta_i^s \rho_i^{L,s}$ of total input costs, $w_i L_{is} = \eta_i^s \rho_i^{L,s} c_{is} I_{is}$, capital costs account for a fraction $\eta_i^s \rho_i^{K,s}$ of total input costs, $r_i K_{is} = \eta_i^s \rho_i^{K,s} c_{is} I_{is}$, and intermediate goods expenditures account for a fraction $1 - \eta_i^s$ of total input costs, $E_i^{I,s} = (1 - \eta_i^s) c_{is} I_{is}$, where c_{is} is the unit cost of the aggregate input I_{is}, w_i is the wage rate, and r_i is the interest rate. This implies that intermediate goods expenditures and capital costs can be expressed in terms of labor costs as follows:

$$E_i^{I,s} = \frac{1-\eta_i^s}{\rho_i^{L,s}\eta_i^s} w_i L_{is} \tag{21}$$

$$r_i K_{is} = \frac{\rho_i^{K,s}}{\rho_i^{L,s}} w_i L_{is} \tag{22}$$

All labor income, capital income, and profit income is distributed to households who are further assumed to make an international transfer Ω_i which can be positive or negative, satisfies $\sum_{i=1}^N \Omega_i = 0$, and is introduced to accommodate aggregate trade imbalances. As a result, households in country i spend $E_{is}^F = \mu_{is}^F \left(\sum_{t=1}^S (w_i L_{it} + r_i K_{it} + M_{it}^e \bar{\pi}_{it}) - \Omega_i\right)$ on industry s varieties, where $\bar{\pi}_{is}$ are the expected profits of an entrant into industry s of country i. It is useful to define $E_{is} = E_{is}^F + \sum_{t=1}^S \mu_{is}^{I,t} E_i^{I,t}$ which captures the total expenditure on industry s varieties in country i in the sense that $E_{is} = \sum_{m=1}^N X_{mis}$, where X_{ijs} is again the value of industry s trade flowing from country i to country j. Together with equations (21) and (22), this implies

$$E_{is} = \mu_{is}^F \left(\sum_{t=1}^S \left(\frac{w_i L_{it}}{\rho_i^{L,t}} + M_{it}^e \bar{\pi}_{it}\right) - \Omega_i\right) + \sum_{t=1}^S \mu_{is}^{I,t} \frac{1-\eta_i^t}{\eta_i^t} \frac{w_i L_{it}}{\rho_i^{L,t}} \tag{23}$$

Profit maximization again requires that industry s firms from country i which serve market j charges $p_{ijs} = \frac{\sigma_s}{\sigma_s - 1} \frac{\tau_{ijs} c_{is}}{\varphi}$ in market j. However, the fixed market access costs now imply that only sufficiently productive firms choose to serve market j. Given that the associated revenues are $r_{ijs} = \left(\frac{\sigma_s}{\sigma_s - 1} \frac{\tau_{ijs} c_{is}}{\varphi P_{js}}\right)^{1-\sigma_s} E_{js}$, the associated variable profits are $\pi_{ijs}^v = \frac{1}{\sigma_s} \left(\frac{\sigma_s}{\sigma_s - 1} \frac{\tau_{ijs} c_{is}}{\varphi P_{js}}\right)^{1-\sigma_s} E_{js}$ which only exceed the fixed market access costs $c_{js} f_{ijs}$ if $\varphi_{ijs}^* = \frac{\sigma_s}{\sigma_s - 1} \frac{\tau_{ijs} c_{is}}{P_{js}} \left(\frac{\sigma_s c_{js} f_{ijs}}{E_{js}}\right)^{\frac{1}{\sigma_s - 1}}$. As should be clear, profit maximization also implies that the unit costs of the aggregate input can be written as a Cobb-Douglas aggregate of wages, capital, and industry price indices so that:

$$c_{is} = \left((w_i)^{\rho_i^{L,s}} (r_i)^{\rho_i^{K,s}}\right)^{\eta_i^s} \prod_{t=1}^S (P_{it})^{(1-\eta_i^s)\mu_{it}^{I,s}} \tag{24}$$

The ideal price indices are now given by $P_{js} = \left(\sum_{i=1}^{N} M_{ijs} p_{ijs} \left(\tilde{\varphi}_{ijs}\right)^{1-\sigma_s}\right)^{\frac{1}{1-\sigma_s}}$, where $\tilde{\varphi}_{ijs} = \left(\int_{\varphi^*_{ijs}}^{\infty} \varphi^{\sigma_s-1} dG_{is}\left(\varphi | \varphi > \varphi^*_{ijs}\right)\right)^{\frac{1}{\sigma_s-1}}$ is an average productivity measure familiar from the heterogeneous literature which reduces to $\widetilde{\varphi}_{ijs} = \left(\frac{\theta_s}{\theta_s-\sigma_s+1}\right)^{\frac{1}{\sigma_s-1}} \varphi^*_{ijs}$ after imposing the Pareto assumption. The Pareto assumption also implies that the probability of drawing a productivity above the cutoff is given by $prob\left(\varphi > \varphi^*_{ijs}\right) = \left(\frac{b_{is}}{\varphi^*_{ijs}}\right)^{\theta_s}$ so that the relationship between the eventual number of firms and the initial number of entrants is simply $M_{ijs} = \left(\frac{b_{is}}{\varphi^*_{ijs}}\right)^{\theta_s} M^e_{is}$. This relationship can be used together with the pricing formula, the definition of $\tilde{\varphi}_{ijs}$, and the definition of φ^*_{ijs} to rewrite P_{js} as:

$$P_{js} = \left(\sum_{i=1}^{N} \frac{\theta_s}{\theta_s - \sigma_s + 1} M^e_{is} \left(\frac{\sigma_s}{\sigma_s - 1} \frac{\tau_{ijs} c_{is}}{b_{is}}\right)^{-\theta_s} \left(\frac{\sigma_s c_{js} f_{ijs}}{E_{js}}\right)^{\frac{\sigma_s-\theta_s-1}{\sigma_s-1}}\right)^{-\frac{1}{\theta_s}} \tag{25}$$

Given our assumptions on fixed and variable costs, the expected profits of an entrant into industry s of country i are $\bar{\pi}_{is} = \sum_{j=1}^{N} prob\left(\varphi > \varphi^*_{ijs}\right)\left(E\left(\pi^v_{ijs} | \varphi > \varphi^*_{ijs}\right) - f_{ijs}\right) - c_{is} f^e_{is}$. We have already seen that $prob\left(\varphi > \varphi^*_{ijs}\right) = \left(\frac{b_{is}}{\varphi^*_{ijs}}\right)^{\theta_s}$ from the Pareto assumption. Moreover, it should be easy to verify that our earlier formula $\pi^v_{ijs} = \frac{1}{\sigma_s}\left(\frac{\sigma_s}{\sigma_s-1} \frac{\tau_{ijs} c_{is}}{\varphi P_{js}}\right)^{1-\sigma_s} E_{js}$ implies $E\left(\pi^v_{ijs} | \varphi > \varphi^*_{ijs}\right) = \frac{1}{\sigma_s}\left(\frac{\sigma_s}{\sigma_s-1} \frac{\tau_{ijs} c_{is}}{\widetilde{\varphi}_{ijs} P_{js}}\right)^{1-\sigma_s} E_{js}$. These results can be used together with the price index formula (25) to write:

$$\bar{\pi}_{is} = \sum_{j=1}^{N} \frac{\sigma_s - 1}{\sigma_s \theta_s} \frac{\left(f_{ijs}\right)^{\frac{\sigma_s-\theta_s-1}{\sigma_s-1}} \left(\frac{\tau_{ijs} c_{is}}{b_{is}}\right)^{-\theta_s}}{\sum_{m=1}^{N} M^e_{ms} \left(f_{mjs}\right)^{\frac{\sigma_s-\theta_s-1}{\sigma_s-1}} \left(\frac{\tau_{mjs} c_{ms}}{b_{ms}}\right)^{-\theta_s}} E_{js} - c_{is} f^e_{is} \tag{26}$$

Input market clearing requires $c_{is} I_{is} = M^e_{is} c_{is} f^e_{is} + M^e_{is} c_{is} E\left(i^v_{is}\right) + \sum_{m=1}^{N} M_{mis} c_{is} f_{mis}$, where $E\left(i^v_{is}\right)$ denotes the expected demand for inputs used directly in production so that the three terms capture entry costs, production costs, and market access costs. Proceeding analogously to the derivation of equation (26), it should be easy to verify that $c_{is} E\left(i^v_{is}\right) = \theta_s\left(\bar{\pi}_{is} + c_{is} f^e_{is}\right)$. Moreover, $E\left(r_{ijs} | \varphi > \varphi^*_{ijs}\right) = \left(\frac{\sigma_s}{\sigma_s-1} \frac{\tau_{ijs} c_{is}}{\widetilde{\varphi}_{ijs} P_{js}}\right)^{1-\sigma_s} E_{js}$ which can be combined with the formulas for $\widetilde{\varphi}_{ijs}$ and φ^*_{ijs} to yield $E\left(r_{ijs} | \varphi > \varphi^*_{ijs}\right) = \frac{\theta_s \sigma_s}{\theta_s-\sigma_s+1} c_{js} f_{ijs}$ so that

$\sum_{m=1}^{N} M_{mis} c_{is} f_{mis} = \frac{\theta_s - \sigma_s + 1}{\theta_s \sigma_s} E_{is}$. Substituting these terms into the input market clearing condition, solving for M_{is}^{e}, invoking again that $w_i L_{is} = \rho_i^{L,s} \eta_i^s c_{is} I_{is}$, and adding basic labor market and capital market clearing, yields:

$$M_{is}^{e} = \frac{\frac{w_i L_{is}}{\rho_i^{L,s} \eta_i^s} - \frac{\theta_s - \sigma_s + 1}{\theta_s \sigma_s} E_{is}}{\theta_s \bar{\pi}_{is} + c_{is} \left(\theta_s + 1\right) f_{is}^{e}} \tag{27}$$

$$L_i = \sum_{s=1}^{S} L_{is} \tag{28}$$

$$K_i = \sum_{s=1}^{S} K_{is} \tag{29}$$

Analogously to the illustrative model, we can now again distinguish between the long-run and the short-run by setting $\bar{\pi}_{is} = 0$ and treating M_{is}^{e} as endogenous or by setting $f_{is}^{e} = 0$ and treating $\bar{\pi}_{is}$ as endogenous. In both cases, equations (22) - (29) represent a system of $6NS+2N$ equations in $6NS+2N$ unknowns with the unknowns being $\{E_{is}, c_{is}, P_{is}, L_{is}, K_{is}, M_{is}^{e}, w_i, r_i\}$ and $\{E_{is}, c_{is}, P_{is}, L_{is}, K_{is}, \bar{\pi}_{is}, w_i, r_i\}$, respectively.

3.3 General equilibrium effects of productivity shocks

The general equilibrium effects of productivity shocks can again be calculated using the "exact hat algebra" approach. After calculating the trade shares $\alpha_{ijs} = \frac{X_{ijs}}{\sum_{m=1}^{N} X_{mjs}}$ and $\beta_{ijs} = \frac{X_{ijs}}{\sum_{n=1}^{N} X_{ins}}$, we now recover labor incomes, capital incomes, and intermediate good expenditures using the relationships $w_i L_{is} = \eta_i^s \rho_i^{L,s} c_{is} I_{is}$ and $w_i L_i = \sum_{s=1}^{S} w_i L_{is}$, $r_i K_{is} = \eta_i^s \rho_i^{K,s} c_{is} I_{is}$ and $r_i K_i = \sum_{s=1}^{S} r_i K_{is}$, and $E_i^{I,s} = (1 - \eta_i^s) c_{is} I_{is}$, where $c_{is} I_{is} = \sum_{n=1}^{N} X_{ins} - \frac{\theta_s - \sigma_s + 1}{\theta_s \sigma_s} NX_{is}$ in the long-run in which case also $M_{is}^{e} c_{is} f_{is}^{e} = \sum_{n=1}^{N} \frac{\sigma_s - 1}{\sigma_s \theta_s} X_{ins}$ and $c_{is} I_{is} = \sum_{n=1}^{N} X_{ins} - M_{is}^{e} \bar{\pi}_{is} - \frac{\theta_s - \sigma_s + 1}{\theta_s \sigma_s} NX_{is}$ in the short-run in which case also $M_{is}^{e} \bar{\pi}_{is} = \sum_{n=1}^{N} \frac{\sigma_s - 1}{\sigma_s \theta_s} X_{ins}$. These expressions for $c_{is} I_{is}$, $M_{is}^{e} c_{is} f_{is}^{e}$, and $M_{is}^{e} \bar{\pi}_{is}$ can be backed out from equations (26) and (27) after defining industry net exports $NX_{is} = \sum_{n=1}^{N} X_{ins} - \sum_{m=1}^{N} X_{mis}$ and recognizing that $X_{ijs} = M_{is}^{e} \frac{(f_{ijs})^{\frac{\sigma_s - \theta_s - 1}{\sigma_s - 1}} \left(\frac{\tau_{ijs} c_{is}}{b_{is}}\right)^{-\theta_s}}{\sum_{m=1}^{N} M_{ms}^{e} (f_{mjs})^{\frac{\sigma_s - \theta_s - 1}{\sigma_s - 1}} \left(\frac{\tau_{mjs} c_{ms}}{b_{ms}}\right)^{-\theta_s}} E_{js}$ which follows straightforwardly from $X_{ijs} =$

$M_{ijs}\left(\frac{\sigma_s}{\sigma_s-1}\frac{c_{is}\tau_{ijs}}{\tilde{\varphi}_{ijs}P_{js}}\right)^{1-\sigma_s}E_{js}$ together with $M_{ijs}=\left(\frac{b_{is}}{\varphi^*_{ijs}}\right)^{\theta_s}M^e_{is}$, the price index equation (25), and the definitions of $\tilde{\varphi}_{ijs}$ and φ^*_{ijs}.

We then proceed to calculating $\Omega_i=\sum_{s=1}^{S}\frac{(\theta_s+1)(\sigma_s-1)}{\sigma_s\theta_s}NX_{is}$ which are the international transfers required to accommodate the observed aggregate trade imbalances. This follows from summing equation (23) across all s and solving for Ω_i, substituting for $\frac{w_iL_{is}}{\rho_i^{L,s}\eta_i^s}$ obtained by rearranging equation (27), and then substituting for $M^e_{is}\left(\bar{\pi}_{is}+c_{is}f^e_{is}\right)$ obtained after rearranging equation (26) recognizing again that $X_{ijs}=M^e_{is}\frac{(f_{ijs})^{\frac{\sigma_s-\theta_s-1}{\sigma_s-1}}\left(\frac{\tau_{ijs}c_{is}}{b_{is}}\right)^{-\theta_s}}{\sum_{m=1}^{N}M^e_{ms}(f_{mjs})^{\frac{\sigma_s-\theta_s-1}{\sigma_s-1}}\left(\frac{\tau_{mjs}c_{ms}}{b_{ms}}\right)^{-\theta_s}}E_{js}$. International transfers differ from aggregate net exports because the fixed market access costs are denominated in source country inputs which already implies that the income of country i is generally different from the total expenditure on goods from country i. Combining this with the earlier results, it is then easy to calculate total final expenditures in the long-run, $E_i^F=\sum_{s=1}^{S}\left(w_iL_{is}+r_iK_{is}\right)-\Omega_i$, and in the short-run, $E_i^F=\sum_{s=1}^{S}\left(w_iL_{is}+r_iK_{is}+M^e_{is}\bar{\pi}_{is}\right)-\Omega_i$. Moreover, we can then recover the consumer expenditure shares from $\mu^F_{is}=\frac{E^F_{is}}{E^F_i}$, where $E^F_{is}=E_{is}-\sum_{t=1}^{S}\mu^{I,t}_{is}E^{I,t}_i$, and $E_{is}=\sum_{m=1}^{N}X_{mis}$. This then allows us to write equations (22) - (29) in changes as:

Case I: Long-run

$$\hat{K}_{is}=\frac{\hat{w}_i\hat{L}_{is}}{\hat{r}_i} \tag{30}$$

$$\hat{E}_{is}=\mu^F_{is}\left(\sum_{t=1}^{S}\frac{w_iL_{it}}{E_{is}}\frac{\hat{w}_i\hat{L}_{it}}{\rho_i^{L,t}}-\frac{\Omega_i}{E_{is}}\right)+\sum_{t=1}^{S}\mu^{I,t}_{is}\frac{1-\eta_i^t}{\eta_i^t}\frac{w_iL_{it}}{E_{is}}\frac{\hat{w}_i\hat{L}_{it}}{\rho_i^{L,t}} \tag{31}$$

$$\hat{c}_{is}=\left((\hat{w}_i)^{\rho_i^{L,s}}(\hat{r}_i)^{\rho_i^{K,s}}\right)^{\eta_i^s}\prod_{t=1}^{S}\left(\hat{P}_{it}\right)^{(1-\eta_i^s)\mu^{I,s}_{it}} \tag{32}$$

$$\hat{P}_{js}=\left(\sum_{i=1}^{N}\alpha_{ijs}\hat{M}^e_{is}\left(\frac{\hat{c}_{is}}{\hat{b}_{is}}\right)^{-\theta_s}\left(\frac{\hat{c}_{js}}{\hat{E}_{js}}\right)^{\frac{\sigma_s-\theta_s-1}{\sigma_s-1}}\right)^{-\frac{1}{\theta_s}} \tag{33}$$

$$\hat{c}_{is} = \sum_{j=1}^{N} \frac{\beta_{ijs} \left(\frac{\hat{c}_{is}}{\hat{b}_{is}}\right)^{-\theta_s}}{\sum_{m=1}^{N} \alpha_{mjs} \hat{M}^e_{ms} \left(\frac{\hat{c}_{ms}}{\hat{b}_{ms}}\right)^{-\theta_s}} \hat{E}_{js} \tag{34}$$

$$\hat{M}^e_{is} = \frac{\frac{w_i L_{is}}{\rho_i^{L,s} \eta_i^s} \hat{w}_i \hat{L}_{is} - \frac{\theta_s - \sigma_s + 1}{\theta_s \sigma_s} E_{is} \hat{E}_{is}}{(\theta_s + 1) M^e_{is} c_{is} f^e_{is} \hat{c}_{is}} \tag{35}$$

$$1 = \sum_{s=1}^{S} \frac{w_i L_{is}}{w_i L_i} \hat{L}_{is} \tag{36}$$

$$1 = \sum_{s=1}^{S} \frac{r_i K_{is}}{r_i K_i} \hat{K}_{is} \tag{37}$$

Case II: Short-run

$$\hat{K}_{is} = \frac{\hat{w}_i \hat{L}_{is}}{\hat{r}_i} \tag{38}$$

$$\hat{E}_{is} = \mu^F_{is} \left(\sum_{t=1}^{S} \left(\frac{w_i L_{it}}{E_{is}} \frac{\hat{w}_i \hat{L}_{it}}{\rho_i^{L,t}} + \frac{M^e_{it} \bar{\pi}_{it}}{E_{is}} \widehat{\bar{\pi}}_{it} \right) - \frac{\Omega_i}{E_{is}} \right) + \sum_{t=1}^{S} \mu^{I,t}_{is} \frac{1 - \eta_i^t}{\eta_i^t} \frac{w_i L_{it}}{E_{is}} \frac{\hat{w}_i \hat{L}_{it}}{\rho_i^{L,t}} \tag{39}$$

$$\hat{c}_{is} = \left((\hat{w}_i)^{\rho_i^{L,s}} (\hat{r}_i)^{\rho_i^{K,s}} \right)^{\eta_i^s} \prod_{t=1}^{S} \left(\hat{P}_{it} \right)^{\left(1-\eta_i^s\right) \mu^{I,s}_{it}} \tag{40}$$

$$\hat{P}_{js} = \left(\sum_{i=1}^{N} \alpha_{ijs} \hat{M}^e_{is} \left(\frac{\hat{c}_{is}}{\hat{b}_{is}} \right)^{-\theta_s} \left(\frac{\hat{c}_{js}}{\hat{E}_{js}} \right)^{\frac{\sigma_s - \theta_s - 1}{\sigma_s - 1}} \right)^{-\frac{1}{\theta_s}} \tag{41}$$

$$\widehat{\bar{\pi}}_{is} = \sum_{j=1}^{N} \beta_{ijs} \frac{\left(\frac{\hat{c}_{is}}{\hat{b}_{is}}\right)^{-\theta_s}}{\sum_{m=1}^{N} \alpha_{mjs} \left(\frac{\hat{c}_{ms}}{\hat{b}_{ms}}\right)^{-\theta_s}} \hat{E}_{js} \tag{42}$$

$$1 = \frac{w_i L_{is} \frac{\hat{w}_i \hat{L}_{is}}{\rho_i^{L,s} \eta_i^s} - \frac{\theta_s - \sigma_s + 1}{\theta_s \sigma_s} E_{is} \hat{E}_{is}}{\theta_s M^e_{is} \bar{\pi}_{is} \widehat{\bar{\pi}}_{is}} \tag{43}$$

$$1 = \sum_{s=1}^{S} \frac{w_i L_{is}}{w_i L_i} \hat{L}_{is} \tag{44}$$

$$1 = \sum_{s=1}^{S} \frac{r_i K_{is}}{r_i K_i} \hat{K}_{is} \tag{45}$$

Given estimates of σ_s, θ_s, η_i^s, $\rho_i^{L,s}$, $\rho_i^{K,s}$, $\mu_{is}^{I,t}$, and the full matrix of bilateral trade flows, these equations can be used to calculate the general equilibrium effects of productivity shocks which are now captured by changes in the Pareto location parameters b_{is}. This procedure again ensures that these general equilibrium effects are calculated from a reference point which perfectly matches industry-level trade. Essentially, it imposes a restriction on the set of unknown parameters $\{b_{is}, \tau_{ijs}, f_{ijs}, f_{is}^e, L_i, K_i\}$ such that the predicted X_{ijs} perfectly match the observed X_{ijs} for given values of σ_s, θ_s, η_i^s, $\rho_i^{L,s}$, $\rho_i^{K,s}$, $\mu_{is}^{I,t}$.

In order to corroborate our earlier assertion that the behavior of the model does not change much as a result of adding firm heterogeneity, Panel B of Table 1 again reports the effects of a hypothetical productivity shock in a simple example economy which is set up just as before. However, we now use our full model to calculate the counterfactuals setting $\rho_i^{L,s} = 1$, $\rho_i^{K,s} = 0$, and $\eta_i^s = 1$ to focus on the role played by firm heterogeneity. As can be seen, the effects are identical assuming that we set the value of θ_s in the full model equal to the value for $\sigma_s - 1$ in the illustrative model, just as one would expect from the Arkolakis et al (2012) literature.[5]

3.4 Welfare effects of productivity shocks

Given these general equilibrium adjustments, it is again straightforward to calculate welfare changes as real income changes. However, nominal income is now equal to final goods expenditure so that it is necessary to first back $\hat{E}_i^F$ out. This can be done using the relationship $E_i^F = \sum_{s=1}^{S} \frac{w_i L_{is}}{\rho_i^{L,s}} - \Omega_i$ in the long-run and the relationship $E_i^F = \sum_{s=1}^{S} \left(\frac{w_i L_{is}}{\rho_i^{L,s}} + M_{is}^e \bar{\pi}_{is} \right) - \Omega_i$ in the short-run which follows immediately from the definition of E_i^F and equation (22).

[5] While the exact isomorphism between a Krugman (1980) model and a Melitz (2003) model with Pareto distributed productivities breaks down when there are multiple sectors, Costinot and Rodriguez-Clare (2014) have already shown that both models then still produce similar results. Our results are exactly identical in Panel A and B of Table 1 only because we assume balanced trade in each industry.

In particular, we can calculate $\hat{E}_i^F = \sum_{s=1}^S \frac{w_i L_{is}}{\rho_i^{L,s} E_i^F} \hat{w}_i \hat{L}_{is} - \frac{\Omega_i}{E_i^F}$ in the long-run and $\hat{E}_i^F = \sum_{s=1}^S \left(\frac{w_i L_{is}}{\rho_i^{L,s} E_i^F} \hat{w}_i \hat{L}_{is} + \frac{M_{is}^e \bar{\pi}_{is}}{E_i^F} \widehat{\bar{\pi}}_{is} \right) - \frac{\Omega_i}{E_i^F}$ in the short-run and then compute:

$$\hat{V}_j = \frac{\hat{E}_j^F}{\prod_{s=1}^S \left(\hat{P}_{js} \right)^{\mu_{js}^F}} \tag{46}$$

Decomposing this expression for the special case $\rho_i^{L,s} = 1$, $\rho_i^{K,s} = 0$, $\eta_i^s = 1$, and $\Omega_i = 0$, illustrates further that firm heterogeneity alone does not affect the behavior of the model in major ways. In particular, small welfare changes can then be written in terms of log-changes as $d \ln V_j = d \ln E_j^F - \sum_{s=1}^S \mu_{js}^F d \ln P_{js}$. Log-differentiating the definition of E_i^F and equation (25) then yields $d \ln E_i^F = d \ln w_i$ and $d \ln P_{js} = \sum_{i=1}^N \alpha_{ijs} \left(d \ln c_{is} - d \ln b_{is} - \frac{1}{\theta_s} d \ln M_{is}^e \right)$ in the long-run version of the model and $d \ln E_i^F = d \ln w_i + \sum_{s=1}^S \delta_{is} \left(d \ln \bar{\pi}_{is} - d \ln w_i \right)$ and $d \ln P_{js} = \sum_{i=1}^N \alpha_{ijs} \left(d \ln c_{is} - d \ln b_{is} \right)$ in the short-run version of the model, where $\delta_{is} = \frac{\frac{\sigma_s - 1}{\sigma_s \theta_s} \sum_{j=1}^N X_{ijs}}{\sum_{s=1}^S \sum_{n=1}^N X_{ins}}$ which is very similar to γ_{is} in the illustrative model. Together, this implies:

Case I: Long-run

$$\begin{aligned} \frac{dV_j}{V_j} &= \underbrace{\sum_{i=1}^N \sum_{s=1}^S \mu_{js} \alpha_{ijs} \left(\left(\frac{dw_j}{w_j} - \frac{db_{js}}{b_{js}} \right) - \left(\frac{dw_i}{w_i} - \frac{db_{is}}{b_{is}} \right) \right)}_{\text{terms-of-trade effect}} \\ &\quad + \underbrace{\sum_{i=1}^N \sum_{s=1}^S \mu_{js} \alpha_{ijs} \frac{1}{\theta_s} \frac{dM_{is}^e}{M_{is}^e}}_{\text{firm delocation effect}} \\ &\quad + \sum_{s=1}^S \mu_{js} \frac{db_{js}}{b_{js}} \end{aligned} \tag{47}$$

Case 2: Short-run

$$
\begin{aligned}
\frac{dV_j}{V_j} &= \underbrace{\sum_{i=1}^{N}\sum_{s=1}^{S}\mu_{js}\alpha_{ijs}\left(\left(\frac{dw_j}{w_j}-\frac{db_{js}}{b_{js}}\right)-\left(\frac{dw_i}{w_i}-\frac{db_{is}}{b_{is}}\right)\right)}_{\text{terms-of-trade effect}} \\
&\quad \underbrace{+\sum_{s=1}^{S}\delta_{js}\left(\frac{d\bar{\pi}_{js}}{\bar{\pi}_{js}}-\frac{dw_j}{w_j}\right)}_{\text{profit shifting effect}} \\
&\quad +\sum_{s=1}^{S}\mu_{js}\frac{db_{js}}{b_{js}}
\end{aligned} \tag{48}
$$

As can be seen, decompositions (47) and (48) which are based on a special case of the full model are very similar to decompositions (16) and (17) which are based on the illustrative model. The reason is that the additional selection effects brought about by firm heterogeneity exactly cancel in this specification as we discuss in detail in the working paper version of this paper (Hsieh and Ossa (2015)). For example, Chinese productivity growth allows a larger fraction of Chinese entrants to export but allows a smaller fraction of US entrants to survive which has offsetting effects on the US price index.

Panels B of Table 2 and Table 3 verify that this similarity also holds quantitatively by repeating the exercises from Panels A of Table 2 and Table 3 now using the full model assuming again that $\rho_i^{L,s}=1$, $\rho_i^{K,s}=0$, and $\eta_i^s=1$ to focus on the role played by firm heterogeneity. These tables again set the value of θ_s in the full model equal to the value for σ_s-1 in the illustrative model to make sure that the trade elasticities align. As we will see in our empirical application, relaxing the restrictions $\rho_i^{L,s}=1$, $\rho_i^{K,s}=0$, and $\eta_i^s=1$ does not change the results too much in practice so that we only discuss the simplified case here.

It is instructive to consider again the sufficient statistics of the Arkolakis et al (2012) type for the same special case. Using $X_{ijs}=M_{is}^e\frac{(f_{ijs})^{\frac{\sigma_s-\theta_s-1}{\sigma_s-1}}\left(\frac{\tau_{ijs}c_{is}}{b_{is}}\right)^{-\theta_s}}{\sum_{m=1}^{N}M_{ms}^e(f_{mjs})^{\frac{\sigma_s-\theta_s-1}{\sigma_s-1}}\left(\frac{\tau_{mjs}c_{ms}}{b_{ms}}\right)^{-\theta_s}}E_{js}$ together with equations (23) and (25), it can be shown that $\frac{\hat{w}_i}{\hat{P}_{is}}=\hat{b}_{is}\left(\frac{\hat{\alpha}_{iis}}{\hat{M}_{is}^e}\right)^{-\frac{1}{\theta_s}}\left(\hat{\vartheta}_i\right)^{\frac{\sigma_s-\theta_s-1}{\theta_s(\sigma_s-1)}}$, where again $\alpha_{ijs} = \frac{X_{ijs}}{\sum_m X_{mjs}}$ and $\vartheta_i = \frac{w_i L_i}{E_i^F}$. Taking into account that $\hat{V}_i = \frac{\hat{E}_i^F}{\prod_{s=1}^S (\hat{P}_{is})^{\mu_{is}^F}}$ and $E_i^F = w_i L_i + \sum_{s=1}^S M_{is}^e \bar{\pi}_{is}$ in general given our restrictions $\rho_i^{L,s} = 1$, $\rho_i^{K,s} = 0$, $\eta_i^s = 1$, and $\Omega_i = 0$, this can be rewritten as $\hat{V}_i = \frac{1}{\hat{\vartheta}_i} \prod_{s=1}^S \left(\hat{b}_{is} \left(\frac{\hat{\alpha}_{iis}}{\hat{M}_{is}^e} \right)^{-\frac{1}{\theta_s}} \left(\hat{\vartheta}_i \right)^{\frac{\sigma_s - \theta_s - 1}{\theta_s(\sigma_s - 1)}} \right)^{\mu_{is}^F}$.

In the long-run, $\hat{\vartheta}_i = 1$ so that $\hat{V}_i = \prod_{s=1}^S \left(\hat{b}_{is} \left(\frac{\hat{\alpha}_{iis}}{\hat{M}_{is}^e} \right)^{-\frac{1}{\theta_s}} \right)^{\mu_{is}^F}$ which is exactly analogous to the respective formula in the illustrative model. In the short-run, $\hat{M}_{is}^e = 1$ so that $\hat{V}_i = \frac{1}{\hat{\vartheta}_i} \prod_{s=1}^S \left(\hat{b}_{is} \left(\hat{\alpha}_{iis} \right)^{-\frac{1}{\theta_s}} \left(\hat{\vartheta}_i \right)^{\frac{\sigma_s - \theta_s - 1}{\theta_s(\sigma_s - 1)}} \right)^{\mu_{is}^F}$ which differs only from the respective formula in the illustrative model because of the term $\prod_{s=1}^S \left(\hat{\vartheta}_i \right)^{\frac{\mu_{is}^F(\sigma_s - \theta_s - 1)}{\theta_s(\sigma_s - 1)}}$. As should be clear from the derivation of this expression, this term appears because the productivity cutoff φ_{iis}^* also changes if there are changes in $\hat{\vartheta}_i$ as a result of our particular assumptions about the nature of fixed exporting costs. Therefore, it does not reflect a deep feature of heterogeneous firm models either but arises from a mere technicality.

4 Empirical application

We now apply our framework to isolate the spillover effects of China's productivity growth between 1995 and 2007. We focus on the world's 14 largest economies and a residual Rest of the World. In our baseline specification, we include 14 traded goods sectors which comprise agriculture, mining, and manufacturing as well as 1 nontraded sector which aggregates over all other remaining industries of the economy. The goods made by these residual industries are actually not all entirely nontraded so that our nontraded goods sector is really a traded goods sector with little trade.

We need the complete matrix of industry-level trade flows X_{ijs} including domestic sales, industry-level estimates of the elasticity parameters σ_s and θ_s, and industry-level estimates of China's productivity growths $\widehat{b}_{is}$. We further need information on the shares of value added in gross production η_i^s, the coefficients from the input-output tables $\mu_{is}^{I,t}$, and the shares of labor and capital in value added ρ_{is}^L and ρ_{is}^K. Our main data sources are China's Annual Survey of Industrial Production and the World Input-Output Database but we also use information from the China Statistical Yearbook.[6]

4.1 Aggregation procedure for X_{ijs}

Our data on international and internal trade flows comes from the world input-output tables included in the World Input-Output Database. The data originally has 35 industries which we aggregate to 15 industries by combining "Agriculture, Hunting, Forestry, and Fishing" and "Mining and Quarrying" into "Other Tradables", "Textiles and Textile Products" and "Leather, Leather and Footwear" into "Textiles and Leather", and everything from "Electricity, Gas, and Water Supply" until "Private Households with Employed Persons" into "Nontraded Goods".

4.2 Estimation procedure for σ_s and θ_s

We estimate the demand elasticities σ_s using the theoretical prediction that industry factor payments are proportional to industry value added with the factor of proportionality being equal to $\frac{\sigma_s-1}{\sigma_s}$: $w_i L_{is} + r_i K_{is} = \frac{\sigma_s-1}{\sigma_s}\eta_i^s \sum_{j=1}^N X_{ijs}$.[7] Calculating factor payments involves the rental rate of capital which we obtain by assuming that the sum of factor payments across all industries amounts to $\frac{2}{3}$ of the sum of value added across all industries: $r_i = \frac{\frac{2}{3}\sum_{s=1}^S \eta_i^s \sum_{j=1}^N X_{ijs} - \sum_{s=1}^S w_i L_{is}}{\sum_{s=1}^S K_{is}}$. We make this assumption since it implies a plausible aggregate profit share of $\frac{1}{3}$.

We estimate the trade elasticities θ_s using the estimates of σ_s and the theoretical prediction that firm sales follow a Pareto distribution with shape parameter $\frac{\theta_s}{\sigma_s-1}$ within industries. We follow Eaton et al (2011) in restricting attention to exporters only and back out the shape

[6] The Annual Survey of Industrial Production is a census of all state-owned plants and all large private plants collected by China's National Bureau of Statistics. Additional details on this dataset can be found, for example, in Hsieh and Klenow (2009). The World Input-Output Database is documented in Timmer et al (forthcoming.)

[7] Strictly speaking, the model predicts that *variable* industry factor payments are proportional to industry value added given the assumption that fixed costs are also incurred in terms of labor, capital, and intermediate goods. We do not take this assumption literally when taking the model to the data and treat all reported factor payments as variable factor payments.

parameter of the firm sales distribution from a regression of the logarithm of the firm sales rank on the logarithm of firm sales. For our estimation of σ_s and θ_s, we use data on wage payments, capital stocks, and firm sales from the Chinese Annual Survey of Industrial Production.

4.3 Estimation procedure for $\hat{b}_{is}$

Our estimation of China's productivity growth proceeds in two steps. In the first step, we estimate the productivity growth of the representative Chinese firm in each industry $\widehat{\widetilde{\varphi}}_{iis}$. In the second step, we calculate the fundamental Chinese productivity growth $\widehat{b}_{is}$ in each industry from $\widehat{\widetilde{\varphi}}_{iis}$ by correcting for Melitz (2003) selection effects. Recall that an increase in the Pareto location parameter b_{is} shifts the entire distribution of possible productivity draws to the right. It differs from $\widetilde{\varphi}_{iis}$ because not all Chinese entrants find it optimal to serve the Chinese market given the fixed costs f_{iis}.

Our model suggests to estimate $\widehat{\widetilde{\varphi}}_{iis}$ as the growth rate of real industry output per input, where the input is the Cobb-Douglas combination of labor, capital, and intermediate goods from equation (19). To see this, recall that the input use of a given firm is $\sum_j \frac{\tau_{ijs} x_{ijs}(\varphi)}{\varphi}$ which can be manipulated after substituting the pricing formula to yield $\widehat{\widetilde{\varphi}}_{iis} = \frac{1}{\widehat{p_{iis}(\widetilde{\varphi}_{iis})}} \frac{\widehat{S}_{is}}{\hat{I}_{is}}$, where S_{is} are the total sales in industry s of country i and I_{is} is the total input use in industry s of country i.[8] The representative price $p_{iis}(\widetilde{\varphi}_{iis})$ is an output share weighted average of the prices charged by domestic producers in the industry which follows from rewriting it as $p_{iis}(\widetilde{\varphi}_{iis}) = \int_{\varphi^*_{iis}}^{\infty} p_{iis}(\varphi) \frac{x_{iis}(\varphi)}{x_{iis}(\widetilde{\varphi}_{iis})} g_{si}(\varphi | \varphi > \varphi^*_{iis}) d\varphi$.

One practical problem is that calculating $\hat{I}_{is}$ requires information on $\hat{C}_i^{I,s}$ since $\hat{I}_{is} = \left(\left(\hat{L}_{is}\right)^{\rho_i^{L,s}} \left(\hat{K}_{is}\right)^{\rho_i^{K,s}} \right)^{\eta_i^s} \left(\hat{C}_i^{I,s}\right)^{1-\eta_i^s}$ from equation (19). Recall that $C_i^{I,s}$ is the Cobb-Douglas-CES aggregate (20) which is not directly observable. One solution would be to deflate intermediate good expenditures $P_i^{I,s} C_i^{I,s}$ with some proxy for the intermediate good price index $P_i^{I,s}$ but our datasets do not include any such price deflators. We therefore rewrite

[8] Strictly speaking, I_{is} is the total input use in industry s of country i *net of fixed costs* because we have assumed fixed costs to be incurred in terms of the same input. As explained in footnote 7, we do not take this assumption literally when taking the model to the data.

the above estimation formula as $\widehat{\widetilde{\varphi}}_{iis} = \left(\frac{\widehat{S}_{is}/\widehat{p_{iis}(\widetilde{\varphi}_{iis})}}{\left(\hat{L}_{is}\right)^{\rho_i^{L,s}} \left(\hat{K}_{is}\right)^{\rho_i^{K,s}}} \right)^{\eta_i^s} \left(\frac{\widehat{S}_{is}/\widehat{p_{iis}(\widetilde{\varphi}_{iis})}}{\hat{C}_i^{I,s}} \right)^{1-\eta_i^s}$, make the reasonable assumption that the growth rate of real industry output $\widehat{S}_{is}/\widehat{p_{iis}\left(\widetilde{\varphi}_{iis}\right)}$ is approximately equal to the growth rate of real industry intermediate consumption $\hat{C}_i^{I,s}$, and work with $\widehat{\widetilde{\varphi}}_{iis} = \left(\frac{\widehat{S}_{is}/\widehat{p_{iis}(\widetilde{\varphi}_{iis})}}{\left(\hat{L}_{is}\right)^{\rho_i^{L,s}} \left(\hat{K}_{is}\right)^{\rho_i^{K,s}}} \right)^{\eta_i^s}$. We proxy for the representative price $p_{iis}\left(\widetilde{\varphi}_{iis}\right)$ using producer price deflators which we obtain from the China Statistical Yearbook.[9]

Effectively, we therefore calculate $\widehat{\widetilde{\varphi}}_{iis}$ as the growth rate of real output per composite factor of production scaled by the share of value added in gross production η_i^s. The intuition underlying the scaling is that $\frac{\widehat{S}_{is}/\widehat{p_{iis}(\widetilde{\varphi}_{iis})}}{\left(\hat{L}_{is}\right)^{\rho_i^{L,s}} \left(\hat{K}_{is}\right)^{\rho_i^{K,s}}}$ alone overestimates the productivity growth rate $\widehat{\widetilde{\varphi}}_{iis}$ because $\widehat{S}_{is}$ also grows due to the improved supply of intermediate goods. Given our restriction $\widehat{S}_{is}/\widehat{p_{iis}\left(\widetilde{\varphi}_{iis}\right)} = \hat{C}_i^{I,s}$ and our decision to proxy for $\widehat{p_{iis}\left(\widetilde{\varphi}_{iis}\right)}$ using producer price deflators, we expect some measurement error in our estimates of $\widehat{\widetilde{\varphi}}_{iis}$ which we attempt to mitigate by averaging them across years.

We use the structure of the model to back out the fundamental productivity growth rates $\hat{b}_{is}$ from the measured productivity growth rates $\widehat{\widetilde{\varphi}}_{iis}$. In particular, we use the relationship $\hat{b}_{is} = \left(\frac{\hat{M}_{iis}}{\hat{M}_{is}^e} \right)^{\frac{1}{\theta_s}} \widehat{\widetilde{\varphi}}_{iis}$ which captures that fundamental productivity growth can be inferred from measured productivity growth after correcting for selection effects and follows straightforwardly from $M_{ijs} = \left(\frac{b_{is}}{\varphi_{ijs}^*} \right)^{\theta_s} M_{is}^e$ as well as the formula for $\tilde{\varphi}_{ijs}$. The correction is necessary because, for example, an increase in M_{iis} leads to a decrease in measured productivity other things equal since the new firms are less productive than the incumbent firms due to selection effects.

Our implementation of the formula $\hat{b}_{is} = \left(\frac{\hat{M}_{iis}}{\hat{M}_{is}^e} \right)^{\frac{1}{\theta_s}} \widehat{\widetilde{\varphi}}_{iis}$ depends on whether we use the long-run or the short-run version of the model. In the short-run version of the model, $\hat{M}_{is}^e = 1$ by assumption so that we can simply calculate $\left(\hat{b}_{is}\right)_{SR} = \left(\hat{M}_{iis}\right)^{\frac{1}{\theta_s}} \widehat{\widetilde{\varphi}}_{iis}$ using the changes in the number of active Chinese plants documented in the Annual Survey of Industrial Pro-

[9]Notice that the growth rate of total sales is the same as the growth rate of value added in our model since we assume that value added makes up a constant share of gross production. We work with the growth rate of value added in our calculations.

duction. In the long-run version of the model, we have to take a more indirect approach in order to infer $\hat{M}^e_{is}$ which is unobservable. We do so by combining $M_{ijs} = \frac{\theta_s-\sigma_s+1}{\theta_s\sigma_s}\frac{X_{ijs}}{c_{js}f_{ijs}}$, which follows from $X_{ijs} = M_{ijs}\left(\frac{\sigma_s}{\sigma_s-1}\frac{c_{is}\tau_{ijs}}{\widetilde{\varphi}_{ijs}P_{js}}\right)^{1-\sigma_s} E_{js}$, the definition of $\widetilde{\varphi}_{ijs}$, and the definition of φ^*_{ijs}, with $M^e_{is} = \frac{\sigma_s-1}{\sigma_s\theta_s}\frac{\sum_{n=1}^N X_{ins}}{c_{is}f^e_{is}}$, which follows from realizing that equation (26) can be rewritten as $0 = \frac{\sigma_s-1}{\sigma_s\theta_s}\sum_{n=1}^N X_{ins} - M^e_{is}c_{is}f^e_{is}$ in the long-run, to get $\frac{M_{iis}}{M^e_{is}} = \frac{\theta_s-\sigma_s+1}{\sigma_s-1}\frac{f^e_{is}}{f_{iis}}\beta_{iis}$, where $\beta_{iis} = \frac{X_{iis}}{\sum_{n=1}^N X_{ins}}$ is the inverse measure of trade openness introduced earlier. Assuming $\hat{f}^e_{is} = \hat{f}_{iis}$, we can then calculate $\left(\hat{b}_{is}\right)_{LR} = \left(\hat{\beta}_{iis}\right)^{\frac{1}{\theta_s}}\widehat{\widetilde{\varphi}}_{iis}$.

4.4 Estimation procedure for η^s_i, $\mu^{I,t}_{is}$, $\rho^{L,s}_i$, and $\rho^{K,s}_i$

We obtain our estimates of the shares of value added in gross production, η^s_i, and the coefficients of the input-output tables, $\mu^{I,t}_{is}$, from the world input-output tables included in the World Input-Output Database. In particular, we calculate $\eta^s_i = 1 - \frac{\sum_{m=1}^N\sum_{n=1}^N\sum_{t=1}^S X^{I,s}_{mnt}}{\sum_{m=1}^N\sum_{n=1}^N X_{mns}}$ and $\mu^{I,t}_{is} = \frac{\sum_{m=1}^N\sum_{n=1}^N\sum_{p=1}^S X^{I,p}_{mns}}{\sum_{m=1}^N\sum_{n=1}^N\sum_{q=1}^S\sum_{p=1}^S X^{I,p}_{mnq}}$, where $X^{I,s}_{mit}$ is the value of intermediate goods from industry t in country m purchased by industry s in country i and X_{ins} is again just the total value of industry s trade flowing from country i to country n.

Notice that these estimates average over countries and downstream industries, $\eta^s_i = \eta^s$ and $\mu^{I,t}_{is} = \mu^I_s$ for all i and t. As is explained in detail in Costinot and Rodriguez-Clare (2014), we cannot use the more disaggregated estimates $\eta^s_i = 1 - \frac{\sum_{m=1}^N\sum_{t=1}^S T^{I,s}_{mit}}{\sum_{n=1}^N T_{ins}}$ and $\mu^{I,t}_{is} = \frac{\sum_{m=1}^N T^{I,t}_{mis}}{\sum_{m=1}^N\sum_{s=1}^S T^{I,t}_{mis}}$ in our calculations because entry would then lead to a process of cumulative causation in some countries and industries in the long-run version of our model. Intuitively, if the share of value added in gross production is too low and the expenditure share on intermediates is too high in some industries, entry induces further entry because the increased variety reduces input costs too much.[10]

[10] When faced with the same problem, Balisteri et al (2011) only average over downstream industries. Unfortunately, this is not sufficient in our case so that we average over countries as well. Strictly speaking, our model even suggests to calculate $\eta^s_i = 1 - \frac{\sum_{m=1}^N\sum_{t=1}^S X^{I,s}_{mit}}{\sum_{n=1}^N X_{ins} - \frac{\theta_s-\sigma_s+1}{\theta_s\sigma_s}NX_{is}}$, where NX_{is} is the value of net exports in industry s of country i. The adjustment $\frac{\theta_s-\sigma_s+1}{\theta_s\sigma_s}NX_{is}$ is necessary because of our assumption that the fixed costs of exporting are incurred in destination country labor, capital, and intermediates. We do not take this assumption literally when taking the model to the data.

We calculate the shares of labor and capital in value added from the Socio Economic Accounts available from the World Input Output Database. These accounts include information on labor compensation, capital compensation, and value added so that we can construct the shares $\rho_i^{L,s}$ and $\rho_i^{K,s}$ straightforwardly.

4.5 Isolating the effects of China's productivity growth

Our goal is to isolate the spillover effects of China's productivity growth. To this end, we plug the measured productivity growth rates $\hat{b}_{is}$ into our model and simulate what would have happened to the world economy if only China's productivity had changed. We do this on a year-to-year basis considering all time periods from 1995-1996 until 2006-2007 and aggregate over the entire time span 1995-2007 in the end. For each time period, we use the trade data from the base year, that is 1995 trade data for the time period 1995-1996 and so on.[11] Of course, world trade flows change for many reasons other than China's productivity growth so that the factual end-of-period trade flows are generally different from the counterfactual end-of-period trade flows our productivity growth counterfactuals predict.

When calculating our counterfactuals using the long-run version of the model, we relax the implicit assumption that the free entry condition always binds in all countries and industries which results in the prediction of negative entry if zero profits are not compatible with positive production. Specifically, we do not immediately compute the counterfactuals with the actual vector of productivity growths but instead take slowly increasing fractions of it, starting at zero and progressing in five percentage point steps. Whenever the number of entrants is predicted to be less than 1 percent of its original value in a particular country and industry, $\hat{M}_{is}^e < 0.01$, we replace the free entry condition for that country and industry with the condition that there is no entry in that country and industry, $\hat{M}_{is}^e = 0$, thereby imposing a corner solution. This happens very rarely in practice.

[11] More precisely, we allow X_{ijs}, η_i^s, and $\mu_{is}^{I,t}$ to vary over time but use the same values for σ_s, θ_s, $\hat{b}_{is}$, $\rho_i^{L,s}$, and $\rho_i^{K,s}$ throughout.

4.6 Results

Table 4 reports the share of imports from all countries in total expenditure, both excluding as well as including nontraded goods. Table 5 summarizes the share of imports from China in total expenditure, again excluding as well as including nontraded goods. As can be seen, the share of Chinese imports in total expenditure is small in absolute terms even though the share of Chinese imports in total imports is rising over time. This suggests that the spillover effects of China's productivity growth will be small since they transmit through import shares as the decompositions (47) and (48) make clear.

Our estimates of σ_s and θ_s are listed in Table 6. Our estimates of σ_s range from 3.1 to 16.1 and average 6.1 and our estimates of θ_s range from 3.0 to 39.9 and average 8.5. These averages are broadly within the range of existing estimates found in the literature.[12] Notice that our estimates of σ_s and θ_s are such that θ_s is larger than $\sigma_s - 1$ throughout. This is consistent with our earlier theoretical assumption that $\theta_s > \sigma_s - 1$ and implies that the sales distribution deviates somewhat from Zipf's law. It ensures that the expected profits of entrants are always finite in all industries.

Our estimates of China's annual productivity growth rates are also listed in Table 6. We obtain these numbers by first calculating the annual productivity growth rates over the time period 1995-2007 and then taking geometric averages. $\left(\frac{\Delta\tilde{\varphi}}{\tilde{\varphi}}\right)_{raw}$ is the growth rate of real value added per composite factor of production before adjusting for intermediate goods: $\left(\frac{\Delta\tilde{\varphi}_{is}}{\tilde{\varphi}_{is}}\right)_{raw} = \frac{\widehat{S}_{is}/\widehat{p_{iis}(\tilde{\varphi}_{iis})}}{(\hat{L}_{is})^{\rho_i^{L,s}}(\hat{K}_{is})^{\rho_i^{K,s}}} - 1$. $\left(\frac{\Delta\tilde{\varphi}}{\tilde{\varphi}}\right)_{adj}$ adjusts this by the share of value added in gross production in order to take into account the effect of intermediate goods: $\left(\frac{\Delta\tilde{\varphi}_{is}}{\tilde{\varphi}_{is}}\right)_{adj} = \left(\frac{\widehat{S}_{is}/\widehat{p_{iis}(\tilde{\varphi}_{iis})}}{(\hat{L}_{is})^{\rho_i^{L,s}}(\hat{K}_{is})^{\rho_i^{K,s}}}\right)^{\eta_i^s} - 1$. $\left(\frac{\Delta b}{b}\right)_{lr}$ and $\left(\frac{\Delta b}{b}\right)_{sr}$ adjust this further to account for selection effects using the long-run and short-run version of the model: $\left(\frac{\Delta b}{b}\right)_{lr} = \left(\hat{\beta}_{is}\right)^{\frac{1}{\theta_s}}\left(\frac{\widehat{S}_{is}/\widehat{p_{iis}(\tilde{\varphi}_{iis})}}{(\hat{L}_{is})^{\rho_i^{L,s}}(\hat{K}_{is})^{\rho_i^{K,s}}}\right)^{\eta_i^s} - 1$ and $\left(\frac{\Delta b}{b}\right)_{sr} = \left(\hat{M}_{is}\right)^{\frac{1}{\theta_s}}\left(\frac{\widehat{S}_{is}/\widehat{p_{iis}(\tilde{\varphi}_{iis})}}{(\hat{L}_{is})^{\rho_i^{L,s}}(\hat{K}_{is})^{\rho_i^{K,s}}}\right)^{\eta_i^s} - 1$. As one would expect, our estimates of China's productivity growth fall substantially once we incorpo-

[12] Eaton and Kortum (2002), for example, estimate the trade elasticity to be 3.6 in one specification and 8.3 in another specification.

rate intermediate goods. This simply reflects the fact that productivity shocks then propagate through input-output linkages so that smaller changes in $\tilde{\varphi}_{is}$ are needed to generate the same change in real value added per composite factor of production.

Figure 1 shows a kernel density plot of the productivity growth rates $\left(\frac{\Delta\tilde{\varphi}}{\tilde{\varphi}}\right)_{adj}$, $\left(\frac{\Delta b}{b}\right)_{lr}$, and $\left(\frac{\Delta b}{b}\right)_{sr}$ from Table 6. Recall that $\left(\frac{\Delta b}{b}\right)_{lr}$ and $\left(\frac{\Delta b}{b}\right)_{sr}$ only differ from $\left(\frac{\Delta\tilde{\varphi}}{\tilde{\varphi}}\right)_{adj}$ by controlling for Melitz (2003) selection effects using the long-run or short-run version of the model. As can be seen from this figure and Table 6, these estimates are quite similar across specifications with the adjustments using the short-run model making somewhat more of a difference. This similarity reflects the fact that the trade exposure of Chinese industries and the number of firms in Chinese industries has not changed too much during our sample period so that the adjustment terms $\left(\hat{\beta}_{is}\right)^{\frac{1}{\theta_s}}$ and $\left(\hat{M}_{is}\right)^{\frac{1}{\theta_s}}$ tend to be relatively small.

Table 7 summarizes the welfare effects of China's productivity growth between 1995-2007 calculated using our methodology. In particular, we take the productivity estimates from Table 6 and calculate their welfare implications using formula (46) after solving for their general equilibrium effects using conditions (30) - (37) or (38) - (45). We calibrate all equations using our parameter estimates for $\left\{\sigma_s, \theta_s, \eta_i^s, \rho_i^{L,s}, \rho_i^{K,s}, \mu_{is}^{I,t}\right\}$ and the full matrix of bilateral trade flows for the respective base year. We use the geometric average of our annual productivity growth estimates to attenuate measurement error but update our trade data each year to take into account China's rising trade openness.

The entries in Table 7 capture what would have happened to welfare around the world if only China's productivity had changed. The top panel shows the results computed using the long-run version of the model while the bottom panel turns to the results computed using the short-run version of the model. The first column gives the predicted welfare effects on China, the second and third columns the predicted welfare effects on the "World" and the "Rest of the World" defined as the output share weighted averages of the predicted welfare effects on all countries and all countries other than China, and the last column the ratios of the entries in columns three and two. The last row computes the cumulative effects by taking geometric averages of the annual effects in the previous rows.

Using the long-run version of the model, China's welfare is predicted to increase by a cumulative 253.7 percent, "World" welfare is predicted to increase by a cumulative 7.9 percent, and "Rest of the World" welfare is predicted to decrease by a cumulative -0.029 percent. Using the short-run version of the model, China's welfare is predicted to increase by a cumulative 218.4 percent, "World" welfare is predicted to increase by a cumulative 7.2 percent, and "Rest of the World" welfare is predicted to increase by a cumulative 0.016 percent. This implies that only a small fraction of the overall welfare gains brought about by China's productivity growth is predicted to spill over to other countries (-0.4 percent according to the long-run version of the model and 0.2 percent according to the short-run version of the model).

One reason for this is that Chinese imports only account for a small share of total expenditure, as we saw from Tables 4 and 5. This is a simple but often overlooked point since all international trade shocks have to filter through import shares eventually. Another reason is that China's productivity growth does not exhibit any strong correlation with respect to China's export orientation or trade elasticity, as we will see below. Recall from our earlier discussion that these correlations are important because they determine the signs of the terms-of-trade, firm delocation, and profit shifting effects.

The entries under "Full model" in Table 8 elaborate on the averages presented in Table 7 by showing the welfare effects of China's productivity growth by country. They show that the predicted spillover effects are not only close to zero on average but also small for each country individually, ranging from -0.23 percent until 0.23 percent using the long-run model and ranging from -0.02 percent to 0.08 percent using the short-run model. These are again cumulative welfare effects calculated over the entire time period 1995-2007.

The entries under "Special case" in Table 8 show the results calculated using a simplified version of the model without multiple factors, nontraded, and intermediate goods. Notice that the average predictions of the full model and the special case are very similar which is because nontraded goods tend to dampen while intermediate goods tend to magnify spillover effects.

However, there is more variation in the country-by-country predictions as is also visualized in Figure 2.

We consider this special case to get a rough sense of the terms-of-trade, firm delocation, and profit shifting effects. Recall that we can decompose the welfare effects of productivity shocks into their terms-of-trade, firm delocation, and profit shifting components following formulas (47) and (48) in the absence of multiple factor and intermediate goods. The result of this decomposition is shown in Table 9 where we have scaled all entries to sum to the numbers in Table 8. Recall that formulas (47) and (48) only provide a linear approximation so that the decomposition is not exact given China's large productivity shocks.

As can be seen, the terms-of-trade, firm delocation, and profit shifting effects appear to be just as small as the overall welfare effects. The reason for this can be seen in Figures 3 and 4 which plot the estimated productivity growth rates against China's export-orientation and the trade elasticity revealing only weak correlations in the long-run version of the model and essentially no correlations in the short-run version of the model. The strongest among them is the positive correlation in the top panel of Figure 3 but even this is too weak to generate more than minimally negative terms-of-trade effects.

It is interesting to contrast these findings with the broader literature on the characteristics of Chinese exports and their impact on other countries' firms and labor markets such as Khandewal (2010), Autor et al (2013), or Bloom et al (forthcoming). This literature finds that China's exports expanded primarily in its comparative advantage industries which make unskilled-labor intensive, low-quality goods. Our results suggest that this is likely due to lowering trade barriers as China's productivity growth does not appear to be biased towards its comparative advantage industries. If anything, the correlation goes in the other direction suggesting that China might instead be catching up with the frontier.

Figure 5 plots the average entry rates predicted by the long-run and short-run versions of the model against China's productivity growth. Recall that both versions make extreme assumptions regarding entry, either allowing for completely free entry or for no entry at all.

These extreme assumptions are also reflected in extreme entry predictions, which range from -19 percent until 21 percent in the long-run version of the model and are always 0 percent in the short-run version of the model. Actual entry rates averaged between -1 percent and 6 percent according to our micro data so that one might think reality lies somewhere in between these two extremes. In any case, both versions deliver the same overall message which is that the spillover effects of China's productivity shocks are small.

5 Conclusion

How does a country's productivity growth affect worldwide real incomes through international trade? In this paper, we took this classic question to the data by measuring the spillover effects of China's productivity growth. Using a rich quantitative general equilibrium trade model, we first estimated China's industry-level productivity growth during the time period 1995-2007 and then isolated what would have happened to real incomes around the world if only China's productivity had changed. We found that the spillover effects were small for all countries, ranging from a cumulative real income loss of at most -0.2 percent to a cumulative real income gain of at most 0.2 percent.

There are advantages and disadvantages to our choice of using a model to quantify the spillover effects of China's productivity growth. The main advantage is that it allows us to hold constant all other shocks that might have contemporaneously hit the world economy thereby cleanly isolating the effects of productivity growth. The main disadvantage is that we have to maintain the assumption that our model is an accurate description of reality which would not have been necessary in a more reduced-form approach. On balance, our findings therefore have to be interpreted with some caution and are probably best thought of as providing a sense of the orders of magnitude.

In any case, our analysis is only a first pass at this question. Of the many possible extensions, a particularly interesting one would be to let aggregate manufacturing employment respond endogenously to productivity growth. On the one hand, this would dampen relative wage growth in China thereby generating terms-of-trade gains for the rest of the world. On the other hand, this would relocate aggregate manufacturing employment to China thereby inflicting firm delocation and profit shifting losses on the rest of the world. These counteracting effects may well been quantitatively important in the case of China given the extent of rural-urban migration observed during the sample period.

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6 Tables

TABLE 1: Hypothetical Effect of Chinese Productivity Growth on Relative Wages, Entry, and Profits

A: Results obtained using the illustrative model				
Case I: Long-run				
$\hat{w}_{CH}/\hat{w}_{US}$	$\hat{M}^e_{CH,1}$	$\hat{M}^e_{CH,2}$	$\hat{M}^e_{US,1}$	$\hat{M}^e_{US,2}$
4.3%	21.5%	-21.5%	-22.4%	22.4%
Case II: Short-run				
$\hat{w}_{CH}/\hat{w}_{US}$	$\hat{\pi}_{CH,1}/\hat{w}_{CH}$	$\hat{\pi}_{CH,2}/\hat{w}_{CH}$	$\hat{\pi}_{US,1}/\hat{w}_{US}$	$\hat{\pi}_{US,2}/\hat{w}_{US}$
4.3%	7.5%	-7.5%	-7.8%	7.8%
B: Results obtained using a special case of the full model				
Case I: Long-run				
$\hat{w}_{CH}/\hat{w}_{US}$	$\hat{M}^e_{CH,1}$	$\hat{M}^e_{CH,2}$	$\hat{M}^e_{US,1}$	$\hat{M}^e_{US,2}$
4.3%	21.5%	-21.5%	-22.4%	22.4%
Case II: Short-run				
$\hat{w}_{CH}/\hat{w}_{US}$	$\hat{\pi}_{CH,1}/\hat{w}_{CH}$	$\hat{\pi}_{CH,2}/\hat{w}_{CH}$	$\hat{\pi}_{US,1}/\hat{w}_{US}$	$\hat{\pi}_{US,2}/\hat{w}_{US}$
4.3%	7.5%	-7.5%	-7.8%	7.8%

Notes: Entries are predicted growth rates in Chinese wage relative to US wage (column 1), Chinese number of entrants in industry 1 and 2 (columns 2 and 3, case I) or normalized Chinese profits in industry 1 and 2 (columns 2 and 3, case II), and US number of entrants in industry 1 and 2 (columns 4 and 5, case I) or normalized US profits in industry 1 and 2 (columns 4 and 5, case II) from 10% productivity growth in China in industry 1. Simulation assumes that nominal incomes are the same in both countries, industry expenditure shares are 50% in both countries and industries, and import expenditure shares are 20% in both countries and industries. Panel A uses the simple model and assumes sigma1=sigma2=6. Panel B uses the full model and assumes theta1=theta2=5, rhol1=rhol2=0.99, rhok1=rhok2=0.01, and eta1=eta2=1 (the values of sigma and the intermediate expenditure shares make no difference to the results in this special case).

TABLE 2: Hypothetical Effect of Chinese Productivity Growth on US Welfare

A: Results obtained using the illustrative model

Case I: Long-run

	Terms-of-trade	+	Firm delocation	≈	Total
$NX_{CH,1} > 0$	0.6%		0.0%		0.8%
$NX_{CH,1} = 0$	0.1%		0.0%		0.4%
$NX_{CH,1} < 0$	-0.4%		0.0%		-0.2%

Case II: Short-run

	Terms-of-trade	+	Profit shifting	≈	Total
$NX_{CH,1} > 0$	0.6%		0.0%		0.7%
$NX_{CH,1} = 0$	0.1%		0.0%		0.2%
$NX_{CH,1} < 0$	-0.4%		0.0%		-0.3%

B: Results obtained using a special case of the full model

Case I: Long-run

	Terms-of-trade	+	Firm delocation	≈	Total
$NX_{CH,1} > 0$	0.6%		0.0%		0.8%
$NX_{CH,1} = 0$	0.1%		0.0%		0.4%
$NX_{CH,1} < 0$	-0.4%		0.0%		-0.2%

Case II: Short-run

	Terms-of-trade	+	Profit shifting	≈	Total
$NX_{CH,1} > 0$	0.6%		0.0%		0.7%
$NX_{CH,1} = 0$	0.1%		0.0%		0.2%
$NX_{CH,1} < 0$	-0.4%		0.0%		-0.3%

Notes: Entries are predicted growth rates in US real income due to the terms-of-trade effect (column 1) and the firm delocation effect (column 2, case I) or profit shifting effect (column 2, case II) from 10% productivity growth in China in industry 1 following equations (16) and (17). Column 3 calculates net welfare gain following equation (15). Simulation assumes that nominal incomes are the same in both countries and industry expenditure shares are 50% in both countries and industries. In the first row, China is assumed to have an import expenditure share of 10% in industry 1 and an import expenditure share of 30% in industry 2 with the US being the mirror image so that China is a net exporter in industry 1. In the second row, import expenditure shares are assumed to be 20% in both countries and industries so that there is only intra-industry trade. In the third row, China is assumed to have an import expenditure share of 30% in industry 1 and an import expenditure share of 10% in industry 2 with the US being the mirror image so that China is a net importer in industry 1. Panel A uses the simple model and assumes sigma1=sigma2=6. Panel B uses the full model and assumes theta1=theta2=5, rhol1=rhol2=0.99, rhok1=rhok2=0.01, and eta1=eta2=1 (the values of sigma and the intermediate expenditure shares make no difference to the results in this special case).

TABLE 3: Hypothetical Effect of Chinese Productivity Growth on US Welfare

A: Results obtained using the illustrative model

Case I: Long-run

	Terms-of-trade	+	Firm delocation	≈	Total
$\sigma_1 > \sigma_2$	-0.2%		1.2%		1.2%
$\sigma_1 = \sigma_2$	0.1%		0.0%		0.4%
$\sigma_1 < \sigma_2$	0.5%		-1.0%		-0.4%

Case II: Short-run

	Terms-of-trade	+	Profit shifting	≈	Total
$\sigma_1 > \sigma_2$	-0.2%		0.5%		0.4%
$\sigma_1 = \sigma_2$	0.1%		0.0%		0.2%
$\sigma_1 < \sigma_2$	0.5%		-0.5%		0.1%

B: Results obtained using a special case of the full model

Case I: Long-run

	Terms-of-trade	+	Firm delocation	≈	Total
$\theta_1 > \theta_2$	-0.2%		1.0%		1.0%
$\theta_1 = \theta_2$	0.1%		0.0%		0.4%
$\theta_1 < \theta_2$	0.4%		-0.9%		-0.2%

Case II: Short-run

	Terms-of-trade	+	Profit shifting	≈	Total
$\theta_1 > \theta_2$	-0.2%		0.4%		0.4%
$\theta_1 = \theta_2$	0.1%		0.0%		0.2%
$\theta_1 < \theta_2$	0.4%		-0.4%		0.0%

Notes: Entries are predicted growth rates in US real income due to the terms-of-trade effect (column 1) and the firm delocation effect (column 2, case I) or profit shifting effect (column 2, case II) from 10% productivity growth in China in industry 1 following equations (16) and (17). Column 3 calculates net welfare gain following equation (15). Simulation assumes that nominal incomes are the same in both countries, industry expenditure shares are 50% in both countries and import expenditure shares are 20% in both countries and industries. Panel A uses the simple model and assumes sigma1=8 and sigma2=4 in the first row, sigma1=6 and sigma2=6 in the second row, and sigma1=4 and sigma2=8 in the third row. Panel B uses the full model and assumes theta1=7 and theta2=3 in the first row, theta1=5 and theta2=5 in the second row, and theta1=3 and theta2=7 in the third row, as well as rhol1=rhol2=0.99, rhok1=rhok2=0.01, eta1=eta2=1, and sigma1=sigma2=3 throughout (the values of sigma and the intermediate expenditure shares make no difference to the results in this special case).

TABLE 4: Share of Imports in Total Expenditure

	w/o non-traded			w/ non-traded		
	1995	2001	2007	1995	2001	2007
Brazil	10.3%	15.5%	13.0%	4.9%	7.4%	6.4%
Canada	44.3%	49.1%	45.9%	18.2%	19.9%	17.2%
Germany	28.6%	38.7%	46.1%	11.2%	15.8%	19.4%
Spain	24.5%	33.3%	38.8%	10.5%	14.5%	15.0%
France	29.6%	35.2%	40.5%	10.1%	12.7%	13.2%
United Kingdom	34.2%	41.7%	47.2%	13.1%	13.2%	13.6%
India	8.1%	12.5%	19.0%	5.7%	7.0%	11.1%
Italy	23.3%	27.7%	31.9%	10.5%	11.8%	13.3%
Japan	9.1%	12.6%	18.5%	3.7%	4.8%	7.6%
South Korea	21.8%	25.0%	26.6%	12.7%	14.5%	16.0%
Mexico	25.4%	31.2%	34.7%	12.9%	14.6%	16.0%
Russia	20.9%	22.8%	23.7%	10.7%	11.5%	11.0%
United States	17.6%	21.5%	26.1%	6.1%	6.5%	8.1%
Rest of the World	21.4%	23.4%	26.8%	12.3%	13.4%	14.8%
Median	22.6%	26.3%	29.4%	10.6%	12.9%	13.5%

Notes: Entries are imports/total expenditure, either excluding or including non-traded goods.

TABLE 5: Share of Chinese Imports in Total Expenditure

	w/o non-traded			w/ non-traded		
	1995	2001	2007	1995	2001	2007
Brazil	0.2%	0.4%	1.4%	0.1%	0.2%	0.6%
Canada	1.2%	1.6%	4.2%	0.5%	0.7%	1.5%
Germany	0.7%	1.1%	3.2%	0.2%	0.4%	1.2%
Spain	0.3%	0.6%	2.0%	0.1%	0.3%	0.9%
France	0.5%	0.8%	2.2%	0.1%	0.3%	0.7%
United Kingdom	0.8%	1.5%	3.2%	0.3%	0.5%	0.8%
India	0.3%	0.7%	2.8%	0.2%	0.4%	1.5%
Italy	0.4%	0.6%	1.6%	0.2%	0.3%	0.6%
Japan	0.8%	1.6%	3.4%	0.3%	0.6%	1.3%
South Korea	1.1%	2.4%	4.6%	0.7%	1.5%	2.8%
Mexico	0.2%	0.7%	3.4%	0.1%	0.3%	1.5%
Russia	0.5%	1.0%	2.8%	0.3%	0.5%	1.3%
United States	1.0%	1.4%	3.9%	0.3%	0.4%	1.1%
Rest of the World	0.8%	1.4%	4.0%	0.4%	0.8%	1.9%
Median	0.6%	1.1%	3.2%	0.3%	0.4%	1.3%

Notes: Entries are imports from China/total expenditure, either excluding or including non-traded goods.

TABLE 6: Estimated Elasticities and Productivity Growth

	σ	θ	$\left(\frac{\triangle\tilde{\varphi}}{\tilde{\varphi}}\right)_{raw}$	$\left(\frac{\triangle\tilde{\varphi}}{\tilde{\varphi}}\right)_{adj}$	$\left(\frac{\triangle b}{b}\right)_{lr}$	$\left(\frac{\triangle b}{b}\right)_{sr}$
Other tradables	6.1	8.5	11.2%	3.5%	3.5%	3.7%
Food, beverages, and tobacco	3.3	6.1	12.3%	3.5%	3.5%	3.3%
Textiles and leather	6.1	9.5	6.7%	2.1%	2.2%	2.6%
Wood and products of wood and cork	4.6	7.1	10.7%	3.5%	3.6%	4.3%
Pulp, paper, printing and publishing	16.1	39.9	9.3%	3.5%	3.5%	3.6%
Coke, refined petroleum, and nuclear fuel	6.5	8.5	7.5%	2.1%	2.1%	2.7%
Chemicals and chemical products	11.4	37.4	13.8%	4.5%	4.5%	4.6%
Rubber and plastics	6.3	11.5	9.6%	3.2%	3.2%	3.7%
Other non-metallic minerals	3.5	6.7	12.0%	4.7%	4.7%	4.7%
Basic metals and fabricated metals	3.1	4.9	12.4%	4.0%	4.0%	5.0%
Other machinery	8.0	22.3	12.5%	4.3%	4.3%	4.5%
Electrical and optical equipment	3.5	5.6	13.1%	4.2%	4.0%	5.3%
Transport equipment	7.4	18.9	11.2%	3.1%	3.0%	3.2%
Other manufacturing and recycling	3.1	3.0	7.3%	2.7%	0.5%	3.7%
Non-tradables	6.1	8.5	11.2%	3.5%	3.5%	3.7%
Median	6.1	8.5	11.2%	3.5%	3.5%	3.7%

Notes: Entries are industry descriptions, estimated σ_s, estimated θ_s, and the geometric averages of the estimated annual growth rates of measured productivity before adjusting for intermediate goods, measured productivity after adjusting for intermediate goods, and fundamental productivity after adjusting for intermediate goods derived from the long-run and short-run versions of the model. Since we only have data on Chinese manufacturing firms, we cannot estimate these parameters for "Other tradables" and "Non-tradables" and simply use the average values for those.

TABLE 7: Welfare Gains from China's Productivity Growth

Case I: Results obtained using the long-run version of the model				
	China	World	Rest of World	Share Rest of World
95-96	10.7%	0.4%	-0.001%	-0.3%
96-97	10.7%	0.4%	-0.001%	-0.1%
97-98	11.0%	0.5%	-0.001%	-0.2%
98-99	10.8%	0.5%	-0.001%	-0.2%
99-00	10.6%	0.5%	-0.001%	-0.2%
00-01	10.8%	0.6%	-0.002%	-0.4%
01-02	10.8%	0.6%	-0.003%	-0.6%
02-03	10.7%	0.7%	-0.003%	-0.5%
03-04	11.1%	0.7%	-0.003%	-0.4%
04-05	11.2%	0.8%	-0.002%	-0.2%
05-06	12.0%	0.9%	-0.004%	-0.4%
06-07	12.9%	1.1%	-0.007%	-0.7%
95-07	253.7%	7.9%	-0.029%	-0.4%
Case II: Results obtained using the short-run version of the model				
	China	World	Rest of World	Share Rest of World
95-96	9.8%	0.3%	0.001%	0.2%
96-97	9.8%	0.4%	0.001%	0.2%
97-98	10.0%	0.4%	0.000%	0.0%
98-99	9.9%	0.5%	0.000%	0.0%
99-00	9.7%	0.5%	0.000%	0.1%
00-01	9.9%	0.5%	0.000%	0.0%
01-02	9.9%	0.6%	0.000%	0.0%
02-03	9.9%	0.6%	0.000%	0.0%
03-04	10.1%	0.7%	0.002%	0.3%
04-05	10.2%	0.7%	0.003%	0.5%
05-06	10.8%	0.8%	0.004%	0.5%
06-07	11.5%	1.0%	0.005%	0.5%
95-07	218.4%	7.2%	0.016%	0.2%

Notes: Entries are predicted welfare changes from productivity growth in China computed using the long-run version of the model (Case I) and the short-run version of the model (Case II). World welfare gain is average welfare gain in the world weighted by each country's output share. Rest of World refers to countries other than China. 95-07 welfare gain (last row for each case) is cumulative welfare gain from 1995 to 2007.

TABLE 8: Welfare Effects in Full Model and Special Case

	Case I: Long-run		Case II: Short-run	
	Full model	Special case	Full model	Special case
Brazil	-0.05%	-0.01%	0.02%	0.06%
Canada	-0.23%	0.08%	0.05%	0.06%
Germany	-0.02%	-0.05%	-0.02%	0.01%
Spain	-0.11%	-0.03%	-0.02%	0.02%
France	-0.01%	-0.02%	0.00%	0.03%
United Kingdom	-0.07%	-0.06%	0.00%	0.01%
India	0.14%	0.11%	0.06%	0.07%
Italy	0.00%	0.00%	-0.01%	0.05%
Japan	0.08%	0.08%	-0.01%	-0.01%
South Korea	0.23%	0.29%	0.02%	0.17%
Mexico	0.07%	0.02%	0.08%	0.06%
Russia	-0.12%	-0.03%	0.06%	-0.02%
United States	0.00%	0.03%	0.03%	0.02%
Rest of the World	-0.14%	0.17%	0.03%	0.12%
Median	-0.02%	0.01%	0.02%	0.04%

Notes: Entries are cumulative effects from 1995 to 2007 from China's productivity growth. Case I reports the results obtained using the long-run version of the model and Case II reports the results obtained using the short-run version of the model. The results under "Special case" are computed using the special case of the full model without multiple factors, nontraded goods, and intermediate goods (which involves setting rhol1=rhol2=0.99, rhok1=rhok2=0.01, and eta1=eta2=1 as well as dropping non-tradables).

TABLE 9: Decomposition of Welfare Gains in Special Case

	Case I: Long-run		Case II: Short-run	
	Terms-of-trade	Firm delocation	Terms-of-trade	Profit shifting
Brazil	0.02%	-0.03%	0.04%	0.02%
Canada	-0.06%	0.14%	0.04%	0.02%
Germany	-0.01%	-0.04%	0.04%	-0.02%
Spain	0.00%	-0.03%	0.01%	0.00%
France	0.02%	-0.04%	0.03%	0.00%
United Kingdom	-0.01%	-0.05%	0.01%	-0.01%
India	0.15%	-0.04%	0.03%	0.04%
Italy	0.00%	0.00%	0.02%	0.04%
Japan	-0.03%	0.11%	-0.01%	0.00%
South Korea	0.05%	0.25%	0.10%	0.08%
Mexico	0.02%	0.00%	0.09%	-0.03%
Russia	-0.06%	0.04%	-0.06%	0.04%
United States	-0.04%	0.08%	0.04%	-0.02%
Rest of the World	-0.02%	0.18%	0.08%	0.04%
Median	-0.01%	0.00%	0.03%	0.01%

Notes: Entries are cumulative effects from 1995 to 2007 from China's productivity growth. The individual effects are calculated using formula (46) and are all scaled so that they add up to the corresponding entries in Table 8.

7 Figures

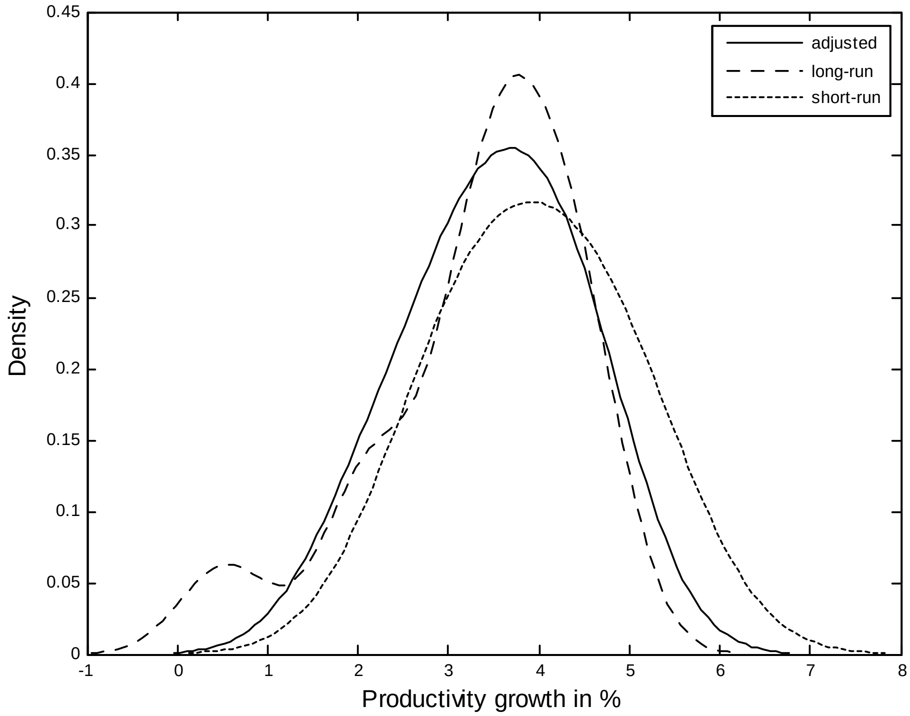

Figure 1: Distribution of productivity growth across manufacturing industries in China

Notes: These are kernel density plots of the geometric averages of the estimated productivity growth rates from 1995 to 2007 across manufacturing industries in China. The plotted growth rates are either adjusted only for intermediate goods or also for Melitz (2003) selection effects using the long-run or short-run version of the model.

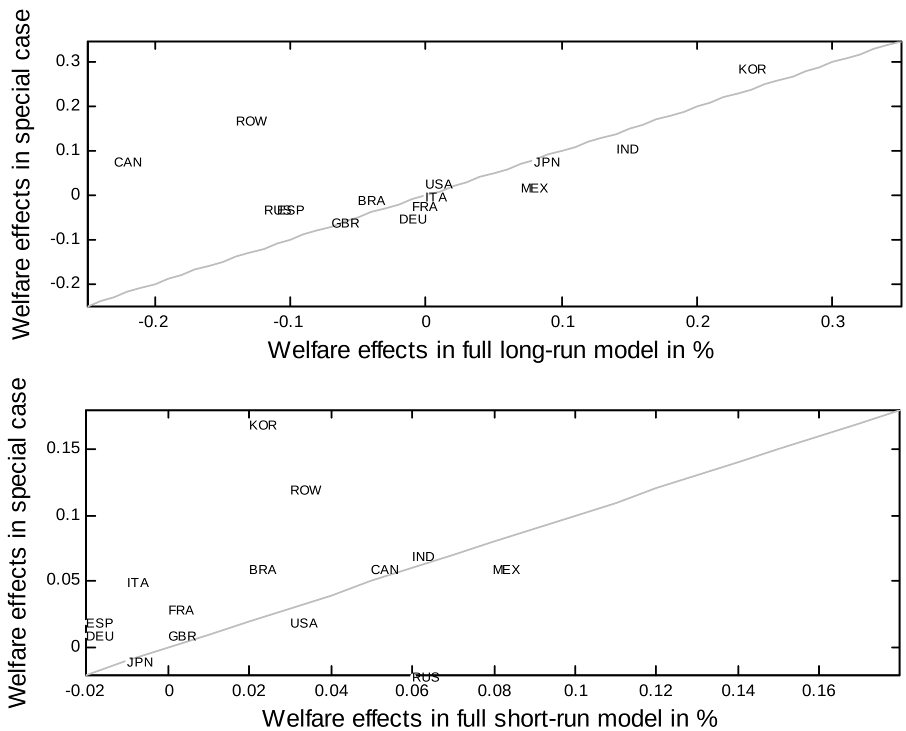

Figure 2: Welfare effect in full model versus special case

Notes: This figure plots the entries from Table 8. The lines indicate the location of equal welfare changes.

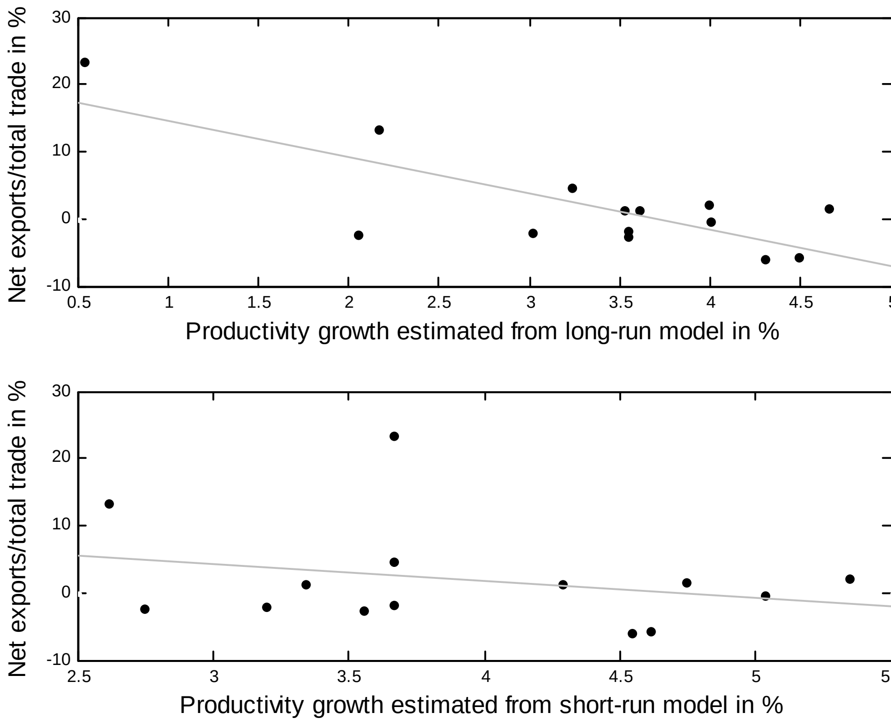

Figure 3: Industry productivity growth and industry net exports in China

Notes: This figure plots the relationship between industry productivity growth and normalized industry net exports in China. The productivity growth estimates are adjusted for intermediate goods and Melitz (2003) selection effects with the top panel using the long-run and the bottom panel using the short-run version of the model. Industry net exports are computed as the simple average of industry net exports from 1995-2007. Total trade is computed as the simple average of the sum of exports and imports from 1995-2007. The lines are linear regression lines.

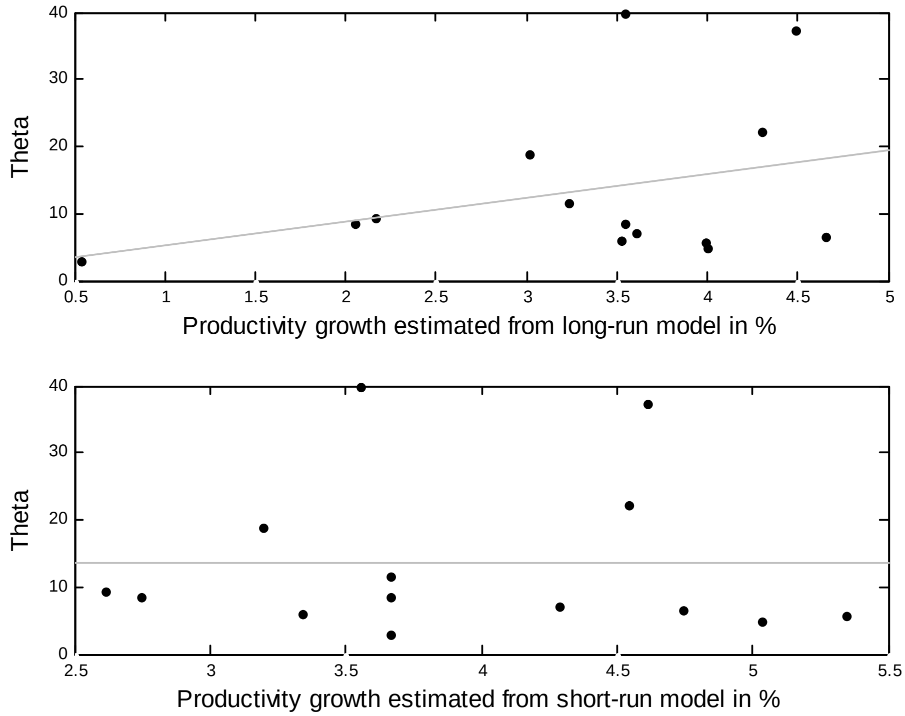

Figure 4: Industry productivity growth and industry trade elasticities in China

Notes: This figure plots the relationship between industry productivity growth and industry trade elasticities in China. The productivity growth estimates are adjusted for intermediate goods and Melitz (2003) selection effects with the top panel using the long-run and the bottom panel using the short-run version of the model. The lines are linear regression lines.

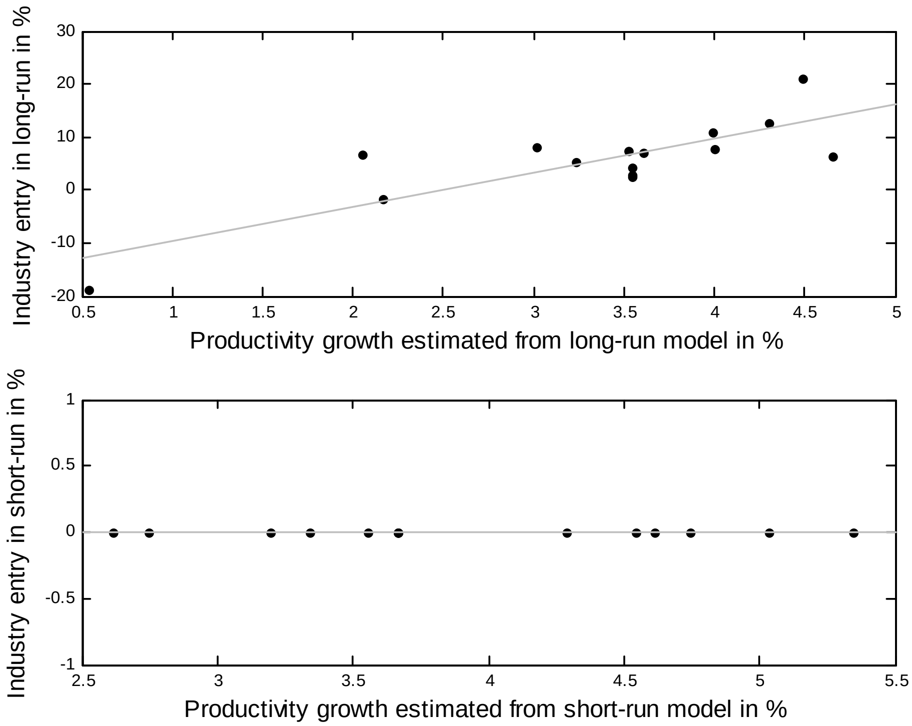

Figure 5: Industry entry and industry productivity growth in China

Notes: This figure plots the relationship between industry productivity growth and industry entry in China . The top panel shows results computed using the long-run version of the model while the bottom panel turns to results computed using the short-run version of the model. Productivity growth is computed as in Figure 1. Industry entry is computed as the simple average of the predicted annual changes in the number of industry entrants from 1995-2007. The lines are linear regression lines.