Structural Adjustments and International Trade: Theory and Evidence from China

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Abstract

This paper studies how changes in factor endowment, technology, and trade costs jointly determine the structural adjustments, which are defined as changes in distributions of production and exports. We document the structural adjustments in Chinese manufacturing firms from 1999 to 2007 and find that production became more capital-intensive while exports did not. We structurally estimate a Ricardian and Heckscher-Ohlin model with heterogeneous firms to explain this seemingly puzzling pattern. Counterfactual simulations show that capital deepening made Chinese production more capital-intensive, but technology changes that biased toward the labor-intensive sectors and trade liberalizations provided a counterbalancing force.

Key Words: Structural Adjustments, Comparative Advantage, Heterogeneous Firm

JEL Classification Numbers: F12 and L16

1 Introduction

We define structural adjustments as changes in the distribution of production and exports. In a world of multiple industries, economic structure evolves constantly. One familiar economic development pattern is that a country will first produce labor-intensive goods. Then, those industries decline and are gradually replaced with more capital-intensive industries. According to the Heckscher-Ohlin (HO) theory, as a country becomes more capital abundant, production and exports will become more capital-intensive. Yet the effects of trade liberalization and changes in Ricardian comparative advantage on structural adjustments have not been sufficiently investigated. Existing analysis in the literature focuses on adjustment across industries, like Romalis (2004), but largely ignores the effect of reallocation within industries across heterogeneous firms (Melitz, 2003). In this paper, we provide empirical, theoretical, and quantitative evidence on how changes in factor endowment, technology, and trade costs jointly determine structural adjustments both across and within sectors.

The first contribution of this paper is to document three seemingly puzzling facts on structural adjustments in China from 1999 to 2007. As one of the fastest-growing economies, China provides a good case for studying structural adjustments. Using firm-level data for the period 1999-2007, we find the following: 1) Manufacturing production became more capital-intensive in 2007 as compared with 1999. As China was clearly more capital abundant in 2007 than in 1999, according to classical HO theory, China should be producing and exporting more capital-intensive goods. Thus, the observed adjustment in the structure of production is consistent with classical HO theory. 2) Exports did not become more capital-intensive. Instead, the percentage of exporters and export intensity increased in labor-intensive industries and decreased in capital-intensive industries. This fact is at odds with HO theory (Romalis, 2004).[1] 3) Productivity in labor-intensive industries grew faster than those in capital-intensive industries during the period 1999-2007.[2]

The second contribution of this paper is to develop a unified theoretical model to study structural adjustments, especially the puzzling patterns in China. We introduce firm heterogeneity (Melitz, 2003) into the two-country continuous HO and Ricardian framework (Dornbusch, Fischer, and Samuelson 1977, 1980, hereafter DFS).[3] In our model, countries differ in endowment and technology, and we posit a continuum of industries with differing levels of capital intensity. An industry is made up of heterogeneous firms facing idiosyncratic productivity shock as in Melitz (2003). Two cut-off industries define most labor-intensive industries, intermediate labor (or capital) intensive industries, and most capital-intensive industries, and therefore determine the pattern of production and trade specialization between two countries. The labor (capital) abundant country completely specializes in most labor (capital) industries.

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[1]The failure of HO theory to pass empirical tests was first pointed out by Leontief (1953). For a synthesis of the literature, see Feenstra (2015).

[2]Work by Trefler (1993, 1995), Harrigan (1995, 1997), Davis and Weinstein (2001) point at the importance of recognizing cross country technology differences when we examine the prediction of HO theory.

[3]Existing theories of international trade mostly study comparative advantages due to factor endowment or technology, alone. Chor (2010) and Marrow (2010) are among the few exceptions. Furthermore, there is little theoretical predictions when more than two sectors are considered.

Both countries produce in intermediate labor-intensive industries. Trade is one-way for industries in which either country completely specializes and two-way in industries in which both countries produce.[4] We show that export participation, measured by the conditional probability of exporting, and export intensity, measured by the fraction of sales exported in each industry, are higher in industries with stronger comparative advantage.

We numerically solve the model to conduct comparative statics. Three main model properties are: 1) We confirm the "quasi-Rybczynski" theorem by Romalis (2004), which states that production and exports become more capital-intensive when a country becomes more capital abundant. Furthermore, the magnitude of changes is more pronounced in more capital-intensive industries. Export participation and export intensity increase in capital-intensive industries and decrease in labor-intensive industries. 2) Sector-biased technology changes that strengthen the Ricardian comparative advantage in labor-intensive industries increase export participation and export intensity in these industries and shift production toward them. The first two properties can be thought of as the single crossing property for sectoral distribution of production and exports. 3) Trade liberalization magnifies existing comparative advantages. The labor-abundant country will produce and export more in labor-intensive industries when trade costs are reduced.

The third contribution of this paper is to quantify the driving forces behind structural adjustments in China. Using the method of moments, we estimate the model's underlining parameters on endowment, technology, and trade costs for China during the period of 1999-2007. This quantitative analysis allows us to gauge the contribution of each driving force by conducting counterfactual experiments while considering general equilibrium effects. Our estimation results indicate that during the period of 1999-2007 the capital-to-labor ratio of China more than doubled, technology improved significantly and favored labor-intensive industries, and trade liberalization reduced variable trade costs by more than a quarter. By running counterfactual simulations that replace the model parameters of 1999 with the parameters of 2007, we find that factor endowment was the major force shifting Chinese production to capital-intensive industries. Changes in parameters governing trading costs and technology contributed much less to the adjustments in production patterns. At the same time, sector-biased technology change was the main driving force behind the adjustments in exports. Over time, China gained more Ricardian comparative advantage in labor-intensive industries due to faster productivity growth in these industries. Such technology changes induced more firms to select into exporting and endogenously amplified the Ricardian comparative advantage in labor industries, outweighing forces from endowment changes and leading to more exports in labor-intensive industries. Hence, the quantitative analysis helps to account for the empirical facts on the structural adjustments in China.

Our estimated model also allows us to separate the endogenous Ricardian comparative advantage from the ex-ante Ricardian comparative advantage (Bernard, Redding, and Schott, 2007a) and to evaluate the contribution of export selection to sectoral productivity growth (Melitz, 2003). We find that export

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[4] Unlike Helpman, Melitz and Rubinstein (2008), zeros in trade flow can be generated in our model even though productivity distribution is unbounded. This is possible since entry is endogenous and countries can specialize in production.

selection strongly shapes Ricardian comparative advantage and contributes 2.1% of overall productivity growth. We also evaluate welfare gains for China and the rest of the world (RoW) due to structural adjustments and find that although both China and RoW benefit from China's structural adjustments, China benefits relatively more. The rise of China relative to RoW is mostly driven by technology changes, less by endowment, and least by trade liberalization. This is consistent with the survey by Zhu (2012) in which he concludes that productivity growth is the main source of growth for China.[5]

Our paper is related to several strands of literature. First, we embrace the key insights from Trefler (1993, 1995), Harrigan (1995, 1997), Davis and Weinstein (2001), Chor (2010) and Morrow (2010) by incorporating cross-country and sectoral productivity differences into the HO model. We extend their analysis to allow for firm heterogeneity and reallocation within industries. Moreover, we structurally estimate model primitives to quantify the relative contribution of changes in endowment and technology to structural adjustments. Compared with analysis based on multivariate regressions, our study enables richer analysis via counterfactual simulations.[6]

We also contribute to the literature studying the interaction of firm heterogeneity and comparative advantage, most notably Bernard, Redding, and Schott (2007a). Recent contributions include Okubo (2009), Lu (2010), Fan et al. (2011), and Burstein and Vogel (2011, 2016). With the exception of Burstein and Vogel (2011, 2016), these papers include either HO or Ricardian comparative advantage alone. Whereas the focus of Burstein and Vogel (2011, 2016) is on the effect of trade liberalization on skill premium, we focus on structural adjustments. Moreover, our paper is the first to quantify endogenous Ricardian comparative advantage, a mechanism found in Bernard, Redding and Schott (2007a).

Our paper is also related to the literature that studies the effect of evolving comparative advantage. Redding (2002) studies the role of technology and endowment in the evolution of specialization patterns. Like his study, we also analyze how the distribution of economic activity across sectors changes over time. Romalis (2004) uses long-run data and finds evidence supporting the Rybczynski effect. Costinot *et al.* (2016), Levchenko and Zhang (2016) examine the welfare implications of evolving comparative advantage. We focus on how evolving comparative advantage shapes structures of production and exports, taking into account firm heterogeneity and changes in trade costs.

Finally, we also contribute to the literature studying China's trade growth and its implications for RoW. Rodrik (2006), Schott (2008), and Wang and Wei (2010) discovered that Chinese exports were getting more sophisticated. Despite that, Amiti and Freund (2010) find that the labor intensity of Chinese exports remains unchanged when processing trade is accounted for. Thus, China continues to specialize in labor-intensive industries, which is consistent with our findings. We show that this is possible in a

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[5]Our result is also consistent with Tombe and Zhu (2015) in which they find trade liberalization contributes modestly to the growth of China. That being said, we only capture the aggregate reallocation effects but not the within-firm changes. De Loecker and Goldberg (2014) provide an in-depth review of the various channels that trade liberalization affects productivity through within-firm changes.

[6]Structural approach is increasing popular in the field of international trade, especially since the seminal contribution by Eaton and Kortum (2002) which provides a tractable multi-country Ricardian model. Recent applications include Chor (2010), Costinot *et al* (2016) and Donaldson (forthcoming). We instead follow the two-country DFS set-up which is also seen in Gaubert and Itskhoki (2015). Different from us, they focus on the granularity of firms and its implication for comparative advantage.

more and more capital-abundant country because trade liberalization and sector-bias technology favor exports from labor-intensive industries. Autor, Dorn, and Hanson (2013) find negative effects of Chinese import competition on US local employment and have ignited vibrant research evaluating welfare gains from trading with China. Hsieh and Ossa (2011), and di Giovanni, Levchenko, and Zhang (2014) both study the welfare effect of productivity growth in China. We include changes in endowment and trade liberalization and quantify the welfare effect of each channel individually.

The remainder of the paper is organized as follows. Section 2 presents the data patterns we observed from Chinese firm-level data. Section 3 develops the model, and our equilibrium analysis is presented in section 4. Section 5 provides numerical solutions for the model and conducts several numerical comparative statics. Section 6 structurally estimates the model and presents the quantitative results, including the counterfactual experiments and welfare analysis. Section 7 concludes.

2   Motivating Evidence

Structural adjustments take place in all economies gradually but surely as sector distribution evolves. In this section, we document stylized facts about adjustments in production and trade structure over time. We focus on China because of its fast economic development and the availability of good firm-level data. We use data from the Chinese Annual Industrial Survey for the period 1999-2007 that covers all State Owned Enterprise (SOE) and non-SOEs with annual sales higher than 5 million RMB Yuan.[7] The dataset provides information on balance sheet, profit and loss, cash flow statements, firm identification, ownership, exports, employment, etc. We focus on manufacturing firms and exclude utility and mining firms. To clean the data, we follow Brandt *et al.* (2012), dropping firms with missing, zero, or negative capital stock, exports or value added, and only include firms with more than eight employees. Summary statistics of the basic variables after cleaning are shown in the Appendix Table A.1.

Guided by HO theory, we focus on sectors that have different capital intensities. We define capital intensity as $1 - \frac{wage}{value\ added}$.[8] Since the focus of this paper is on changes in sectoral distribution over time, we mostly compare the data from 1999 to that from 2007.

Table 1 presents the basic empirical features of Chinese manufacturing firms in terms of factor allocation and export participation. The average capital share of manufacturing firms increased by four percentage points.[9] So overall manufacture production is more capital-intensive in 2007 than in 1999. At the same time, the average capital share of exporters stays almost unchanged. The fraction of exporting firms remained at around 25%. The share of goods exported increased by about three percentage points,

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[7]We do not look at years after 2007 due to the lack of data. The aftermath of the financial crisis is also of great concern.

[8]We drop firms with capital intensity larger than one or less than zero. Wage is defined as the sum of payable wage, labor and employment insurance fee, and total employee benefits payable. The 2007 data also reports housing fund and housing subsidy, endowment insurance and medical insurance, and employee educational expenses provided by the employers. Adding these three variables increase the average labor share slightly. To make it consistent, we do not include them.

[9]Hsieh and Klenow (2009) point out that labor share generated out of the firm level survey is significantly less than the numbers reported in the Chinese input-output tables and the national accounts (roughly 50%). They argue that it can be explained by non-wage compensation. But even in the aggregate numbers, capital share is increasing over time, as documented by Karabarbounis and Neiman (2014) and Chang, Chen, Waggoner and Zha (2015).

from 18% to 21%.

Table 1: Capital Share and Export Participation

Variables	mean in 1999	mean in 2007
capital share of all manufacturers	0.667	0.707
capital share of exporters	0.623	0.619
proportion of exporters	0.253	0.249
exports/gross sales	0.181	0.208

2.1 Definition of Industry

To study structural adjustments, we need to measure the industrial distribution of production and exports. However, conventional sector classification potentially fails to appropriately group products. As Schott (2003, page 687) argues, "*testing the key insight of Heckscher-Olin theory ... requires grouping together products that are both close substitutes and manufactured with identical techniques. Traditional aggregates can fail on both counts.*" Table A.2 in the Appendix shows that there are large variations of capital share within the two-digit Chinese Industry Classification (CIC) of industries in 2007. The standard deviation of capital intensity across firms within each industry is around 0.22. Moreover, the capital intensity between exporters and non-exporters differs significantly. Except for Manufacture of Tobacco (industry 16), the capital share of exporters is significantly lower than non-exporters. These differences persist even when we use the four-digit CIC industry classification, which includes more than 400 industries.[10]

Given the large variation of capital intensity within each industry and the systematic differences between exporters and non-exporters, we follow Schott's idea to define industry as "HO aggregate" and regroup firms according to their capital intensity. For example, firms with capital share from 0 to 0.01 are lumped together and defined as industry 1, for a total of 100 industries.[11]

2.2 Production

We first examine how Chinese production structure changes over time. Panel (a) in Figure 1 plots the distribution of production across "industries". Each dot on the left panel represents the share of firms operating in each industry defined according to capital intensity. The share of firms producing in capital-intensive industries increases over time as the whole distribution shifts to the right in 2007. Thus, there is significant reallocation of resources to capital-intensive industries. Panel (b) plots the distribution of outputs in terms of the real value added at industry level. Firms in capital-intensive industries accounted

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[10]For brevity, the results are not reported but available upon request. Alvarez and López (2005) and Bernard, Redding and Schott (2007b) found that exporters are more capital intensive than non-exporters for Chilean and American firms, respectively. Bernard, Redding and Schott (2007b) speculated that exporters in developing countries should be more labor intensive than non-exporters given their comparative advantage in labor intensive goods. For the same data, Ma *et al.*(2014) use capital labor ratio (capital divided by wage payments) as the indicator of factor intensity. They also find Chinese exporters are less capital intensive than non-exporters.

[11]Such an industry definition has also been used by Ju, Lin and Wang (2015) to study industry dynamics.

for larger fractions in 2007 than in 1999.[12] Table 2 summarizes the information in Figure 1, comparing capital-intensive industries in which firms' capital intensities are higher than 0.5 with other industries. As the first column indicates, the share of capital-intensive firms increased by 5.3 percentage points, from 76.5% in 1999 to 81.8% in 2007. Those firms' employment and output shares also increased by 9.0 and 6.0 percentage points, respectively, as shown in the last two columns.

Stylized fact 1: *The Chinese manufacturing production became more capital intensive over time.*

Table 2: Structural Adjustment of Production

Year	share of firms in capital intensive industries	share of employment in capital intensive industries	share of value added by capital intensive industries
1999	0.765	0.672	0.879
2007	0.818	0.762	0.938
Difference	0.053	0.090	0.059

Notes: Capital intensive industries are industries with capital intensity larger than 0.5. The row "Difference" is the difference between year 1999 and 2007.
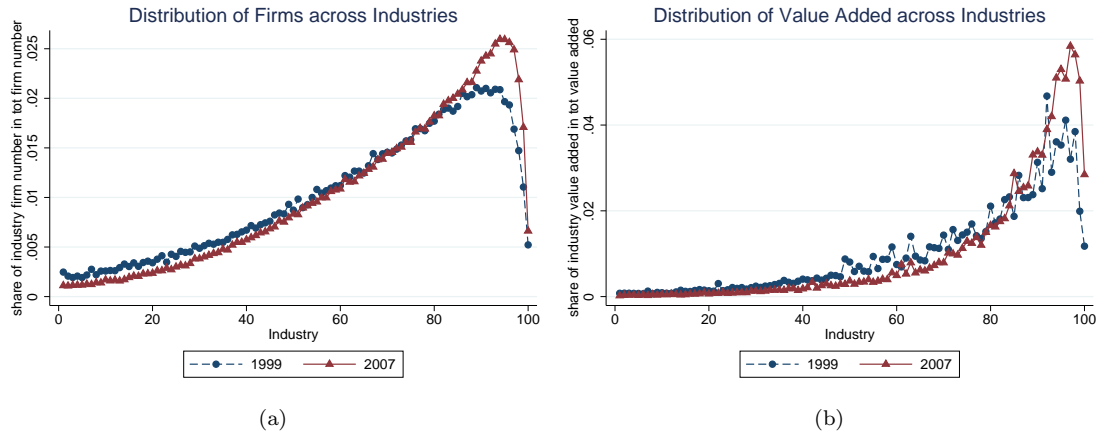

(a)   (b)

Figure 1: Distribution of outputs

2.3   Trade Patterns

Next, we examine China's structure of exports. Figure 2 plots the distribution of exports across industries. The left panel plots the distribution of exporters (defined by the ratio of number of exporters in the industry to total number of exporters) in 1999 and 2007, and shows that the distribution stays almost unchanged.[13] The right panel plots the distribution of export sales (defined by the ratio of the export sales in the industry to total export sales), and we can see that distribution patterns for the two years

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[12]Real value added is calculated using the input and output pricing index constructed by Brandt *et al* (2012).

[13]If anything, it shifts towards the labor intensive industries.

are almost indistinguishable. So, there is no noticeable change in aggregate exports. This result is at odds with the Rybczynski theorem that predicts that a country's production and exports will become more capital-intensive when the country becomes more capital abundant. At the same time we find that export participation for different industries changes over time. Figure 3 plots export participation within each industry. The left panel plots the share of exporters for each industry (defined by the ratio of number of exporters to total number of firms in the industry), and we can see that over time it increases in labor-intensive industries and drops in capital-intensive industries. The right panel plots export intensity, which is the value of exports divided by total sales for each industry. It increases for most industries, especially labor-intensive industries. However, it drops for the more capital-intensive industries.

These adjustments are also shown in Table 3. As the first column indicates, the fraction of capital-intensive exporters dropped by 0.5% during the period 1999-2007. These exporters contributed to 81.4% of total exports in 1999. The fraction of export sales by capital-intensive industries dropped by 0.3%, to 81.1% in 2007, as shown in the second column. Finally, according to the third column, in capital intensive industries, 23.4% of firms were exporters in 1999, while that fraction dropped to 21.4% in 2007.

Stylized fact 2: *The average capital intensity of Chinese exports stayed almost unchanged over time. Export participation increased in labor-intensive industries and decreased in capital-intensive industries.*

Table 3: Structural Adjustment of Exports

Year	fraction of exporters from capital intensive industries	fraction of export sales by capital intensive industries	share of exporting firms in capital intensive industries
1999	0.708	0.814	0.234
2007	0.703	0.811	0.214
Difference	-0.005	-0.003	-0.020

Notes: Capital intensive industries are industries with capital intensity larger than 0.5. The row "Difference" is the difference between year 1999 and 2007.

Putting Stylized facts 1 and 2 together, we have a seemingly puzzling observation. Production clearly became more capital-intensive in 2007 than in 1999, while exports did not.[14] According to the standard HO theory, one should expect exports to become more capital-intensive when production becomes more capital-intensive. However, the HO theory assumes away the role of productivity. This leads us to the next stylized fact.

2.4 Productivity

We now look at productivity growth from 1999 to 2007 across industries, as in Trefler (1993, 1995), Harrigan (1995, 1997), Davis and Weinstein (2001), which point at the importance of examining technology.

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[14]This does not contradict earlier work on the rising sophistication of Chinese exports (Rodrik 2006, Schott 2008, Wang and Wei 2010). China might have exported more sophisticated products but only engaged in the labor intensive assembling. As found by Amiti and Freund (2010), the labor intensity of Chinese exports remain unchanged from 1992 to 2005 once processing trade is accounted for.
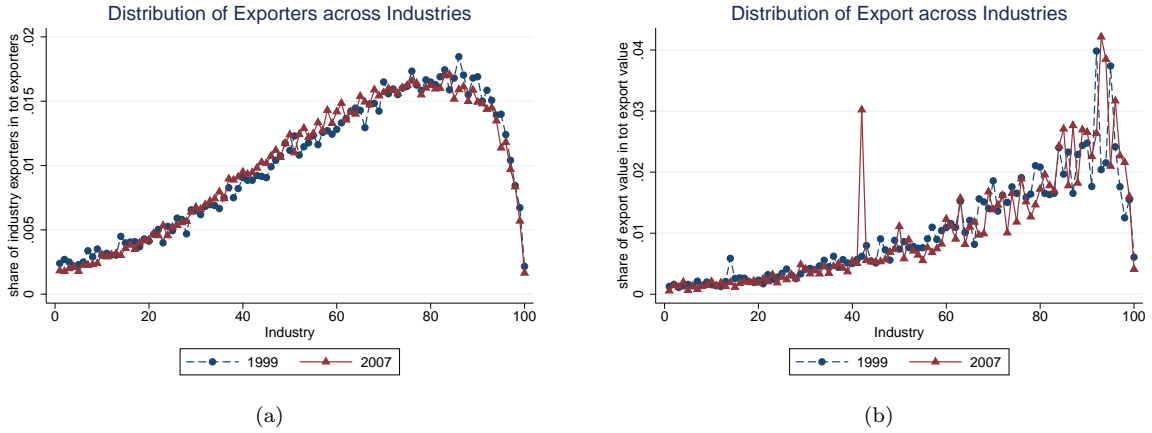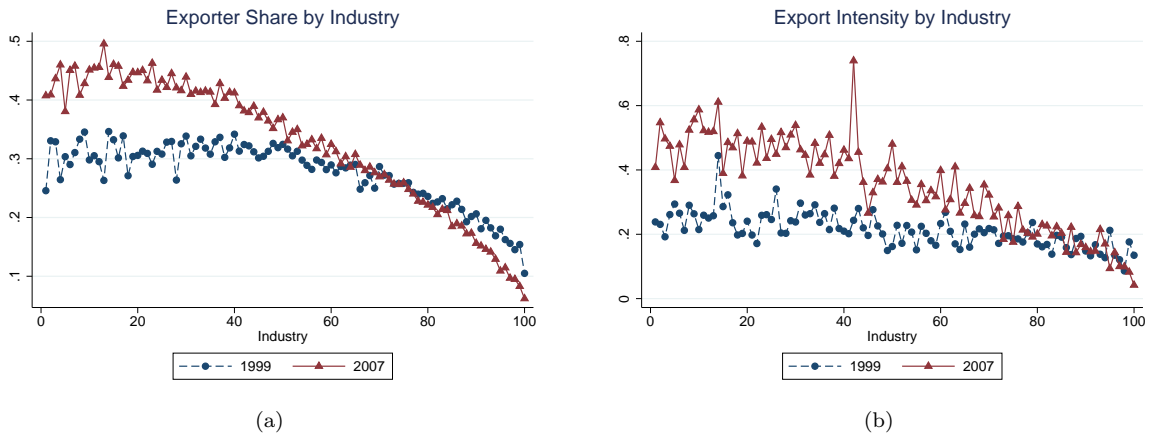
Figure 2: Distribution of exports

Figure 3: Export participation by industry

First, we gather firm-level data over nine years to estimate the firm level total factor productivity (TFP) using the Levinsohn and Petrin (2003) method.[15] Then we compute the average TFP for each industry weighted by firm outputs, trimming the top and bottom one percent to remove outliers. Figure 4 shows the estimated average TFP for each industry. There are two basic observations. First, TFP rises from 1999 to 2007 for all industries. Second, TFP grows faster in labor-intensive industries. In other words, productivity growth is biased toward labor-intensive industries.

Stylized fact 3: *Productivity grew faster in labor intensive industries.*

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[15]The panel is constructed using the method by Brandt *et al* (2012). Their price indexes and program to construct the panel are available at http://feb.kuleuven.be/public/N07057/China/. Real output is measured by real value added. Real output and input are all constructed using the input and output price indexes provided by them. Capital stock is constructed using the perpetual inventory method. Labor is measured as employment. We estimate the TFP by 2-digit CIC industries. For brevity, the estimate results are not reported here but available upon request. Our results are robust to the Olley and Pakes (1996) method or labor productivity measured as real value added per worker. This is shown in the Appendix 8.7.
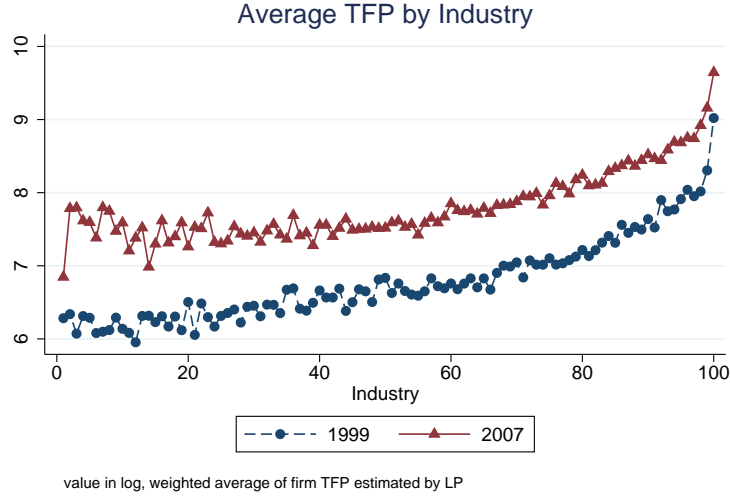
Figure 4: Total Factor Productivity

2.5 Robustness of the Stylized Facts

We explore the robustness of the stylized facts in this subsection. To show that the stylized facts are robust using data from periods other than the years of 1999 and 2007, we use all the data and look at the annual differences. The results are presented in Table 4. Our baseline specification below studies how annual changes of outcome are systematically related to the capital intensity of each industry.

$$\Delta Y_{it} = \alpha Z_i + \beta X_{it} + \epsilon_{it}$$

where ΔY_{it} is the change of industry outcome Y from period t-1 to t: $\Delta Y_{it} = Y_{it} - Y_{it-1}$, t=2000,2001,...,2007. The outcomes include the share of firm number, output, sales, exporter number, export volume, export intensity and average TFP. Z_i is the capital intensity of sector i and X_{it} includes other controls. Table 4 presents the baseline results. From column (1) to (3), we find that production becomes capital-intensive over time as the share of firms, value added, and sales all increase with capital intensity. However, the distribution of exports across industries does not really move; the share of exporters and export volume basically are not correlated with capital intensity at all, as shown in columns (4) and (5). Instead, changes in export propensity and export intensity tend to be smaller for capital-intensive industries, which we can see in columns (6) and (7). Finally, TFP growth tends to be lower in more capital-intensive industries as shown in column (8).

Another concern is whether the findings are driven purely by the "HO aggregate". In Appendix 8.7, we show that this is not the case. We use the four-digit CIC industry classification to regenerate all facts. As is evident from the figures, our findings that a) Chinese production became more capital-intensive but exports did not, b) export participation increased in labor-intensive sectors but declined

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Table 4: Structural Adjustments China 1999-2007

	(1) Firm #	(2) Value added	(3) Sales	(4) Exporter #	(5) Export Volume	(6) Export Propensity	(7) Export Intensity	(8) TFP
capital intensity	0.000623^a	0.00105^a	0.00107^a	-0.0000558	0.000238	-0.0276^a	-0.0382^a	-0.0530^a
	(0.0000866)	(0.000356)	(0.000310)	(0.0000385)	(0.000266)	(0.00139)	(0.00304)	(0.00761)
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
R^2	0.0734	0.0126	0.0142	0.000350	0.000201	0.272	0.0340	0.359
No. of observations	800	800	800	800	800	800	800	800

Notes: The dependent variables of columns (1) to (5) are first-difference in the share of firm number, value added, sales, exporter number and export volume for each industry, respectively. The dependent variable of column (6) is the first-difference of export propensity (defined as the number of exporters divided by firm number within each industry). The dependent variable of column (7) is the first-difference of export intensity (defined as the value of exports divided by total sales within each industry). The dependent variable of column (8) is the growth rate of average sectoral TFP weighted by value added. The estimation method is OLS. Robust standard errors clustered at industry level are reported in the parentheses. The constants are absorbed by the year fixed effects. Significance levels are indicated by a, b, c at 0.1, 0.05 and 0.01 respectively.

in capital-intensive sectors, and c) productivity growth is faster in labor-intensive sectors, all hold under CIC industry classification.

Finally, to check whether our results are driven by any peculiar Chinese institution, we regenerate the facts using various sub-samples. To address the concern of the expiration of the Multi Fiber Agreement in 2005 and rising exports in the labor-intensive textile industries, we exclude the corresponding two-digit CIC industry categories 17 and 18 as per Khandelwal, Schott, and Wei (2013). To address the effect of reform of Chinese SOEs in the late 1990s, which might favor certain industries over others, we exclude all SOEs from our sample. Finally, to address the effects of processing trade and export subsidies, we exclude all pure exporters that are predominantly processing exporters and thus benefit from export subsidies.[16] In these various sub-samples, our basic findings are qualitatively preserved, as shown in Appendix 8.7.

3 Model Setup

To account for the empirical features of the data, we now build a model that incorporates Ricardian comparative advantage, HO comparative advantage, and firm heterogeneity. The model embeds heterogeneous firms (Melitz 2003) into a Ricardian and HO theory within a continuum of industries (Dornbusch, Fisher, and Samuelson 1977, 1980). There are two countries: home and foreign, which differ only in technology and factor endowment. Without loss of generality, we assume that the home country is labor abundant, that is: $L/K > L^*/K^*$, and has Ricardian comparative advantage in labor-intensive industries.[17] There is a continuum of industries z on the interval of $[0, 1]$. z denotes the industry capital intensity, so that higher z stands for higher capital intensity. Each industry is inhabited by heterogeneous firms which produce different varieties of goods and sell in a market with monopolistic competition.

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[16]Pure exporters are defined as exporters with export intensity greater than 70% following Defever and Riaño (2017).

[17]Variables with "*" are for the foreign. We will discuss what happens if HO and Ricardian comparative advantage favor different industries.

3.1 Demand Side

There is a continuum of identical and infinitely lived households that can be aggregated into a representative household. The representative household's preference over different goods is given by the following utility function:

$$U = \int_0^1 b(z) \ln Q(z) dz,$$

where $b(z)$ is the expenditure share on each industry and satisfies $\int_0^1 b(z)dz = 1$, and $Q(z)$ is the lower-tier utility function over the consumption of individual varieties $q_z(\omega)$ given by the following CES aggregator:[18]

$$Q(z) = (\int_{\omega \in \Omega_z} q_z(\omega)^\rho d\omega)^{1/\rho}$$

where Ω_z is the varieties available for industry z. We assume $0 < \rho \leq 1$ so that the elasticity of substitution $\sigma = \frac{1}{1-\rho} > 1$. The demand function for individual varieties is given by:

$$q_z(\omega) = Q(z)(\frac{p_z(\omega)}{P(z)})^{-\sigma} \tag{3.1}$$

where $P(z) = (\int_{\omega \in \Omega_z} p_z(\omega)^{1-\sigma} d\omega)^{\frac{1}{1-\sigma}}$ is the dual price index defined over price of different varieties $p_z(\omega)$.

3.2 Production

Following Melitz (2003), we assume that production incurs a fixed cost during each period which is the same for all firms in the same industry, and that variable cost varies with firm productivity. Firm productivity $A(z)\varphi$ has two components: $A(z)$ is a common component for all firms from the same industry z; φ is an idiosyncratic component drawn from a common continuous and increasing distribution $G(\varphi)$, with probability density function $g(\varphi)$. Following Romalis (2004) and Bernard *et al.* (2007a), we assume that fixed costs are paid using capital and labor with a factor intensity that matches that of production in that industry. Specifically, we assume that the total cost function is:

$$\Gamma(z, \varphi) = \left(f_z + \frac{q(z, \varphi)}{A(z)\varphi} \right) r^z w^{1-z} \tag{3.2}$$

where r and w are rents for capital and labor respectively. The relative industry-specific productivity for home and foreign $\varepsilon(z)$ is assumed to be:

$$\varepsilon(z) \equiv \frac{A(z)}{A^*(z)} = \lambda A^z, \lambda > 0, \ A > 0. \tag{3.3}$$

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[18]Such a preference structure is also used in the survey paper to quantify gains from trade by Costinot and Rodriguez-Clare (2014). In the Appendix 9.3, we generalize our main theoretical results to a nested-CES preferences structure.

Under this assumption, λ captures the absolute advantage and A captures the comparative advantage. Higher λ leads the home country to be relatively more productive in all industries. If $A > 1$, the home country is relatively more productive in capital-intensive industries and has Ricardian comparative advantages in those industries. If $A = 1$, $\varepsilon(z)$ does not vary with z, and there is no role for Ricardian comparative advantage. Under the assumption that home has Ricardian comparative advantage in labor-intensive industries, we have $0 < A < 1$.

Trade is costly. Firms that export need to pay a per-period fixed cost $f_{zx}r^z w^{1-z}$ which requires both labor and capital. In addition, there are variable iceberg trade costs. Firms need to ship τ units of goods for 1 unit of goods to arrive in the foreign market. Profit maximization implies that the equilibrium price is a constant mark-up over the marginal cost. Hence, the exports and domestic prices satisfy:

$$p_{zx}(\varphi) = \tau p_{zd}(\varphi) = \tau \frac{r^z w^{1-z}}{\rho A(z) \varphi} \tag{3.4}$$

where $p_{zx}(\varphi)$ and $p_{zd}(\varphi)$ are the export and domestic price, respectively. Given the pricing rule, firms' revenues from domestic and foreign market $r_{zd}(\varphi)$ and $r_{zx}(\varphi)$ are:

$$r_{zd}(\varphi) = b(z)R \left(\frac{\rho A(z) \varphi P(z)}{r^z w^{1-z}} \right)^{\sigma - 1} \tag{3.5}$$

$$r_{zx}(\varphi) = \tau^{1-\sigma} \left(\frac{P(z)^*}{P(z)} \right)^{\sigma - 1} \frac{R^*}{R} r_{zd}(\varphi) \tag{3.6}$$

where R and R^* are aggregate revenues for home and foreign, respectively. Then the total revenue of a firm is:

$$r_z(\varphi) = \begin{cases} r_{zd} & \text{if it sells only domestically;} \\ r_{zx} + r_{zd} & \text{if it exports.} \end{cases}$$

Therefore, the firm's profit can be divided into the two portions, profit earned from domestic markets and profit earned from foreign markets:

$$\pi_{zd}(\varphi) = \frac{r_{zd}}{\sigma} - f_z r^z w^{1-z}$$
$$\pi_{zx}(\varphi) = \frac{r_{zx}}{\sigma} - f_{zx} r^z w^{1-z} \tag{3.7}$$

Thus, the total profit $\pi_z(\varphi)$ is given by:

$$\pi_z(\varphi) = \pi_{zd}(\varphi) + \max\{0, \pi_{zx}(\varphi)\} \tag{3.8}$$

A firm with productivity φ produces if its revenue at least covers the fixed cost. That is $\pi_{zd}(\varphi) \geq 0$. Similarly, it exports if $\pi_{zx}(\varphi) \geq 0$. These define the productivity cut-off for zero-profit $\bar{\varphi}_z$ and the

productivity cut-off for exporting profit to be zero $\bar{\varphi}_{zx}$, which satisfy:

$$r_{zd}(\bar{\varphi}_z) = \sigma f_z r^z w^{1-z} \tag{3.9}$$

$$r_{zx}(\bar{\varphi}_{zx}) = \sigma f_{zx} r^z w^{1-z} \tag{3.10}$$

Using the two equations above, we can derive the relationship between the two productivity cut-offs:

$$\bar{\varphi}_{zx} = \Lambda_z \bar{\varphi}_z, \text{ where } \Lambda_z = \frac{\tau P(z)}{P(z)^*} \left[\frac{f_{zx} R}{f_z R^*} \right]^{\frac{1}{\sigma-1}}. \tag{3.11}$$

$\Lambda_z > 1$ implies selection into the export market: only the most productive firms export. The empirical literature strongly supports selection into exporting. Therefore, we focus on parameters where exporters are always more productive, following Melitz (2003) and Bernard *et al.* (2007a).[19] Firms' production and export decisions are shown in Figure 5. Each period, $G(\bar{\varphi}_z)$ fraction of firms exit upon entry because they do not earn positive profit. And $1 - G(\bar{\varphi}_{zx})$ fraction of firms export because they have sufficiently high productivity and earn positive profit from both domestic and foreign sales. Firms whose productivity is between $\bar{\varphi}_{zx}$ and $\bar{\varphi}_z$ sell only in the domestic market. So the *ex ante* probability of exporting conditional on successful entry χ_z is

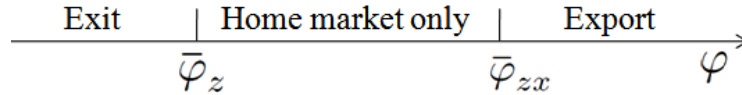$$\chi_z = \frac{1 - G(\bar{\varphi}_{zx})}{1 - G(\bar{\varphi}_z)} \tag{3.12}$$

Figure 5: Productivity Cut-offs and Firm Decisions

3.3 Free entry

If a firm does produce, it faces a constant probability δ of bad shock every period in which it is forced to exit. The steady-state equilibrium is characterized by a constant mass of firms entering an industry M_{ez} and a constant mass of firms producing M_z. The mass of firms entering equals the mass of firms exiting:

$$(1 - G(\bar{\varphi}_z))M_{ez} = \delta M_z. \tag{3.13}$$

The entry cost is given by $f_{ez} r^z w^{1-z}$. The expected profit of entry V_z comes from two parts: the *ex ante* probability of successful entry times the expected profit from domestic market until death and the *ex ante* probability of export times the expected profit from the export market until death. Free entry

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[19]Lu(2010) explores the possibility that $\Lambda_z < 1$ and documents that in the labor intensive sectors of China, exporters are less productive. Dai *et al* (2011) argue for the importance of accounting for processing exporters. And using TFP as the productivity measure instead of value added per worker, even including processing exporters still support that exporters are more productive.

implies

$$V_z = \frac{1 - G(\bar{\varphi}_z)}{\delta} \left(\pi_{zd}(\widehat{\varphi}_z) + \chi_z \pi_{zx}(\widehat{\varphi}_{zx}) \right) = f_{ez} r^z w^{1-z} \tag{3.14}$$

where $\pi_{zd}(\widehat{\varphi}_z)$ and $\chi_z \pi_{zd}(\widehat{\varphi}_{zx})$ are the expected profit from serving the domestic and foreign markets, respectively. $\widehat{\varphi}_z$ is the average productivity of all producing firms and $\widehat{\varphi}_{zx}$ is the average productivity of all exporting firms. They are defined as:

$$
\begin{aligned}
\widehat{\varphi}_z &= \left(\frac{1}{1 - G(\bar{\varphi}_z)} \int_{\bar{\varphi}_z}^{\infty} \varphi^{\sigma-1} g(\varphi) d\varphi \right)^{\frac{1}{\sigma-1}} \\
\widehat{\varphi}_{zx} &= \left(\frac{1}{1 - G(\bar{\varphi}_{zx})} \int_{\bar{\varphi}_{zx}}^{\infty} \varphi^{\sigma-1} g(\varphi) d\varphi \right)^{\frac{1}{\sigma-1}}
\end{aligned}
\tag{3.15}
$$

Combining the free entry condition (3.14) with the zero profit conditions (3.9), (3.10), the productivity cut-offs $\bar{\varphi}_z$ and $\bar{\varphi}_{zx}$ satisfy:

$$\frac{f_z}{\delta} \int_{\bar{\varphi}_z}^{\infty} \left[(\frac{\varphi}{\bar{\varphi}_z})^{\sigma-1} - 1 \right] g(\varphi) d\varphi + \frac{f_{zx}}{\delta} \int_{\bar{\varphi}_{zx}}^{\infty} \left[(\frac{\varphi}{\bar{\varphi}_{zx}})^{\sigma-1} - 1 \right] g(\varphi) d\varphi = f_{ez} \tag{3.16}$$

3.4 Market Clearing

In equilibrium, the sum of domestic and foreign spending on domestic varieties equals the value of total industry revenue:

$$R_z = b(z) R M_z \left(\frac{p_{zd}(\widehat{\varphi}_z)}{P(z)} \right)^{1-\sigma} + \chi_z b(z) R^* M_z \left(\frac{p_{zx}(\widehat{\varphi}_{zx})}{P(z)^*} \right)^{1-\sigma} \tag{3.17}$$

where the price index $P(z)$ is given by the equation below. R and R^* are home and foreign aggregate revenues. R_z^* and $P(z)^*$ are defined in a symmetric way.

$$P(z) = \left[M_z p_{zd}(\widehat{\varphi}_z)^{1-\sigma} + \chi_z^* M_z^* p_{zx}^*(\widehat{\varphi}_{zx}^*)^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \tag{3.18}$$

The factor market clearing conditions are:

$$
\begin{aligned}
L &= \int_0^1 l(z) dz, \ L^* = \int_0^1 l^*(z) dz \\
K &= \int_0^1 k(z) dz, \ K^* = \int_0^1 k^*(z) dz
\end{aligned}
\tag{3.19}
$$

3.5 Equilibrium

The equilibrium consists of the vector of $\{\bar{\varphi}_z, \bar{\varphi}_{zx}, P(z), p_z(\varphi), p_{zx}(\varphi), r, w, R, \bar{\varphi}_z^*, \bar{\varphi}_{zx}^*, P(z)^*, p_z(\varphi)^*,$ $p_{zx}(\varphi)^*, r^*, w^*, R^*\}$ for $z \in [0,1]$. It is determined by the following conditions:

(a) Firms' pricing rule (3.4) for each industry and each country;

(b) Free entry condition (3.14) and the relationship between two zero profit productivity cut-offs (3.11) for each industry and both countries;

(c) Factor market clearing condition (3.19);

(d) The pricing index (3.18) implied by consumer and producer optimizations;

(e) The world goods market clearing condition(3.17).

Proposition 1 *There exists a unique equilibrium given by* $\{\bar{\varphi}_z, \bar{\varphi}_{zx}, P(z), p_z(\varphi), p_{zx}(\varphi), r, w, R, \bar{\varphi}_z^*, \bar{\varphi}_{zx}^*,$ $P(z)^*, p_z(\varphi)^*, p_{zx}(\varphi)^*, r^*, w^*, R^*\}.$

Proof. *See Appendix 8.1.*

4 Equilibrium Analysis

The presence of trade cost, multiple factors, heterogeneous firms, asymmetric countries, and infinite industry make it difficult to find a closed-form solution to the model. Therefore, we make two assumptions to simplify the algebra. First, we assume that the idiosyncratic productivity is Pareto distributed with the following density function:

$$g(\varphi) = a\theta^a \varphi^{-(a+1)}, a + 1 > \sigma$$

where θ is a lower bound of productivity: $\varphi \geq \theta$. [20] Second, we assume that the coefficients of fixed costs are the same for all industries:

$$f_z = f_{z'}, \ f_{zx} = f_{z'x}, \ f_{ez} = f_{ez'}, \ \forall z \neq z'.$$

Proposition 2 *(a) As long as the home country and the foreign country are sufficiently different in endowment or technology, then there exist two factor-intensity cut-offs* $0 \leq \underline{z} < \overline{z} \leq 1$ *such that the home country specializes in production within* $[0, \underline{z}]$ *whereas the foreign country specializes in production within* $[\overline{z}, 1]$, *while both countries produce within* $(\underline{z}, \overline{z})$. *(b) If there is no variable trade cost ($\tau = 1$) and fixed cost of export equals fixed cost of production for each industry ($f_{zx} = f_z, \forall z$), then we have $\underline{z} = \overline{z}$ so that two countries completely specialize.*

Proof. *See Appendix 8.2.*

---

[20]Some of our results do not depend on the assumption of Pareto distribution. We will point it out if this is the case.

Given our assumptions that $\frac{L}{K} > \frac{L^*}{K^*}$ and $A < 1$, the home country has comparative advantage in labor-intensive industries. Proposition 2 and Figure 6 illustrate the production and trade pattern under this scenario. Countries engage in inter-industry trade for industries within $[0, \underline{z}]$ and $[\overline{z}, 1]$, due to specialization.[21] This is where the comparative advantage in factor abundance or technology (classical trade theory) dominates trade costs and the power of increasing return and imperfect competition (new trade theory). Countries engage in intra-industry trade in industries within $(\underline{z}, \overline{z})$, where the power of increasing return to scale and imperfect competition dominate the power of comparative advantage (Romalis, 2004). Thus, if the two countries are very similar in terms of technology and endowment, the strength of comparative advantage would be relatively weak, and there would be no specialization and only intra-industry trade between the two countries. That is to say, $\underline{z} = 0$ and $\overline{z} = 1$. However, if trade is totally free, the classical trade force dominates and full specialization arises as $\underline{z} = \overline{z}$, following the specialization pattern in the classical DFS model. Finally, if $A \geq 1$, it is possible that the Ricardian comparative advantage is strong enough to overturn the HO comparative advantage. In that case, the pattern of production and trade will be reversed. The home country will specialize in $[\overline{z}, 1]$ and foreign country will specialize in $[0, \underline{z}]$.
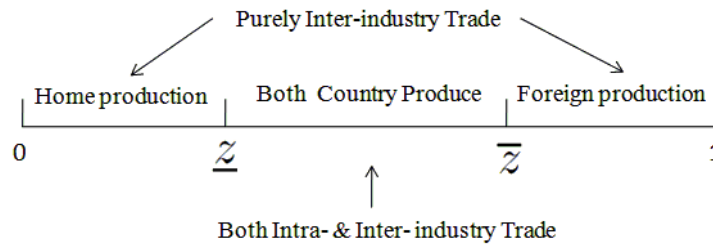

Figure 6: Production and Trade Pattern

In the classical DFS model with zero transportation costs, factor price equalization (FPE) prevails, and geographic patterns of production and trade are not determined when the two countries are similar. With costly trade and departure from FPE, we can determine the pattern of production. Our model thus inherits all the model properties in Romalis (2004). However, his assumption of homogeneous firms leads to the stark feature that all firms export. With the assumption of firm heterogeneity, export participation varies across industries in our model as shown in the following two propositions.

Proposition 3 (a) Under a general productivity distribution $g(\varphi) > 0$, the zero-profit productivity cut-off decreases with the capital intensity, while the export cut-off increases with the capital intensity within $(\underline{z}, \overline{z})$ in the home country. The converse holds in the foreign country.

(b) The cut-offs remain constant in product intervals which either country specializes.

Proof. *See Appendix 8.3.*

---

[21]For the industries that countries specialize, half of the potential trade flows are zeros. Helpman, Melitz and Rubinstein (2008) generate zeros in trade flow assuming bounded productivity distribution. Due to specialization, zeros in trade flows arise even with unbounded productivity distribution in our model.

The proposition does not rely on the assumption of Pareto distribution and is an extension of Bernard *et al.* (2007a). Their discussion is limited to the cases that both countries produce within the diversification cone and no specialization occurs. Our conclusion (b) extends the property to the cases of specialization. Figure 7 illustrates these results for both home and foreign countries.
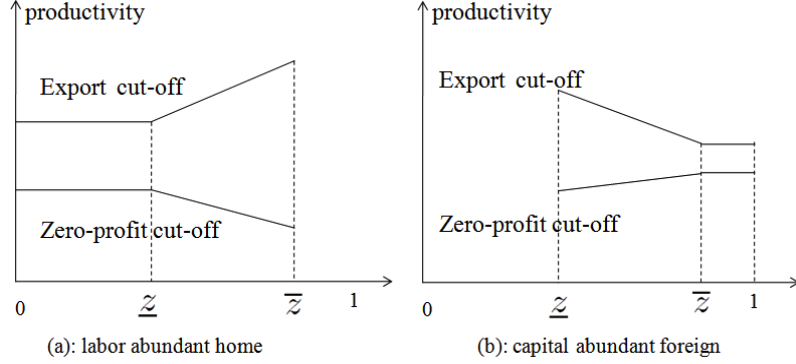

Figure 7: Productivity cut-offs

Proposition 4 *(a) Under the general productivity distribution $g(\varphi) > 0$, the probability of exporting χ_z is constant for industries in which either country specializes and decreases with capital intensity in home country within $(\underline{z}, \overline{z})$, and vice versa for the foreign country. If the productivity distribution is Pareto, we have*

$$\chi_z = \begin{cases} \frac{R^*}{fR} & z \in [0, \underline{z}] \\ \frac{\widetilde{\tau}^{-a} f - \varepsilon^a h(z)}{\varepsilon^a f h(z) - \widetilde{\tau}^a} & z \in (\underline{z}, \overline{z}) \end{cases}$$

where $h(z) \equiv \left(\frac{w}{w^*} (\frac{r/w}{r^*/w^*})^z \right)^{\frac{a\sigma}{1-\sigma}}$, $\widetilde{\tau} \equiv \tau(f)^{\frac{1}{\sigma-1}}$ and for $z \in (\underline{z}, \overline{z})$

$$\frac{\partial \chi_z}{\partial z} = B(z) \left[\ln(A) - \frac{\sigma}{\sigma - 1} \ln \left(\frac{r/w}{r^*/w^*} \right) \right], \ B(z) > 0.$$

(b) The export intensity is: $\gamma_z = \frac{f\chi_z}{1 + f\chi_z}$ which follows the same pattern as χ_z.

Proof. *See Appendix 8.4.*

Proposition 4 is a straightforward implication of Proposition 3. It says that the stronger the comparative advantage is, the larger the share of firms that participate in international trade. For industries that countries specialize, goods are supplied by only one country and export participation is a constant. This is illustrated in Figure 8. The left panel shows that export participation decreases with capital intensity in the home country. The right panel shows an opposite pattern for the foreign country.

Now we add the assumption that the idiosyncratic shock is drawn from a Pareto distribution. The assumption of Pareto distribution leads to explicit expressions and allows us to examine the sign of
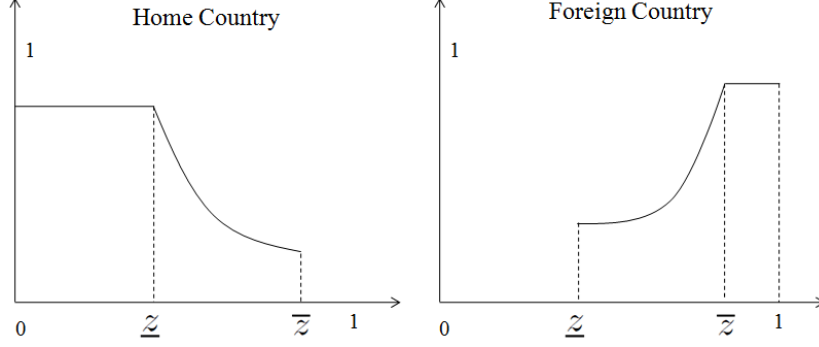
Figure 8: Export participation

$\frac{\partial \chi_z}{\partial z}$ within $(\underline{z}, \overline{z})$: it depends on the *Ricardian comparative advantage* $\ln(A)$ and the *Heckscher-Ohlin Comparative Advantage* $\ln\left(\frac{r/w}{r^*/w^*}\right)$. The magnitude of the HO comparative advantage depends on σ, the elasticity of substitution between varieties: the smaller σ is, the more that industries differ in their export participation. Since $A < 1$ and $\frac{K}{L} < \frac{K^*}{L^*}$, home country has both Ricardian comparative advantage and HO comparative advantage in labor-intensive industries. Thus we expect $\frac{\partial \chi_z}{\partial z} < 0$, and the probability of export decreases with capital intensities in the home country. However, if $A > 1$ and the home country has Ricardian comparative advantage in capital-intensive industries, then the sign of $\frac{\partial \chi_z}{\partial z}$ depends on which comparative advantage is stronger. If Ricardian comparative advantage is strong enough to overturn the HO advantage, then the home country will export more in capital-intensive industries.

The key insight from the Melitz model is that selection into exports leads to within-sector resource reallocation and brings productivity gains. Bernard *et al.* (2007a) find that the strength of reallocation is stronger in the industry that the country has comparative advantage. Such differential reallocation effects will generate productivity differences across sectors and countries. They refer to such a mechanism as "the endogenous Ricardian comparative advantage". In the following proposition, we show how to quantify such a mechanism.

Proposition 5 *(a) The average idiosyncratic firm productivity in each industry is*

$$\widehat{\varphi}_z = C(1 + f\chi_z)^{1/a}$$

where C is a constant. Within $(\underline{z}, \overline{z})$, it increases with the strength of comparative advantage as reflected by χ_z. Within the specialization zone $[0, \underline{z}]$, it is a constant.

(b) For sectors within $(\underline{z}, \overline{z})$, that both countries produce, so that the Ricardian comparative advantage can be decomposed into two components as:

$$\frac{\widehat{A(z)}}{\widehat{A^*(z)}} = \underbrace{\lambda A^z}_{exogenous} \underbrace{(\frac{1 + f\chi_z}{1 + f\chi_z^*})^{1/a}}_{endogenous}$$

19

Proof. *See Appendix 8.5.*

According to conclusion (a), opening to trade brings productivity gains, because χ_z would increase from zero to some positive number. The productivity gains will be larger if the share of exporters is higher. In conclusion (b), the relative industry productivity between home and foreign country is decomposed into an exogenous component and an endogenous component that varies with the relative extent of export selection. The home country can be relatively more productive either because industry-wide productivity is higher or because relatively more firms are selected to export.

Moreover, the endogenous Ricardian comparative advantage can amplify or dampen the exogenous component, depending on how the relative share of exporters varies across industries. If the HO comparative advantage is so strong that the share of exporters is relatively lower in industries with strong exogenous Ricardian comparative advantage, then the exogenous Ricardian comparative advantage would be dampened. For example, suppose $A > 1$ and λA^z increases with z. Hence, the home country has exogenous Ricardian comparative advantage in capital-intensive industries. However, if $\frac{L}{K} / \frac{L^*}{K^*}$ is so high that home country has strong HO comparative advantage in the labor-intensive industries and $\ln(A) < \frac{\sigma}{\sigma-1} \ln(\frac{r}{w} / \frac{r^*}{w^*})$. Then, according to Proposition 4, $\frac{\partial \chi_z}{\partial z}$ is negative and χ_z is lower in the capital-intensive industries. Conversely, χ_z^* is higher in the capital intensive industries. Then $(\frac{1+f\chi_z}{1+f\chi_z^*})^{1/a}$ declines with z and the endogenous Ricardian comparative advantage is weaker in capital-intensive industries.

5 Numerical Solution

In this subsection, we parametrize the model and solve it numerically. The purpose of this section is twofold. The first is to visualize the equilibrium. The second is to study how the equilibrium responds to changes in endowment, technology, and trade costs.

The parametrization of the model is shown in Table 5, following Bernard *et al.* (2007a). We set the initial endowment such that the home country has HO advantage in labor-intensive industries. Initial technology parameters are chosen such that there is no Ricardian comparative advantage. We normalize the expenditure function $b(z)$ to be 1 for all industries so that the variation of outputs and firm mass is driven only by comparative advantage. Figure 9 plots the conditional probability of exporting and firm mass distribution across industries. Given our symmetric parameters, the two countries produce and export symmetrically; countries produce and export more in industries in which they have stronger comparative advantage.

5.1 Comparative Statics

It is hard to get general results for comparative statics in this model. Instead, to better understand the mechanics of the model, we conduct a few numerical comparative statics by changing one parameter at a time. We consider effects of increasing K (capital deepening in home country), decreasing A (strength-

Table 5: Numerical solution: parametrization

| Variables	Definition	Value
K	home capital stock	100
L	home labor stock	300
K^*	foreign capital stock	300
L^*	foreign labor stock	100
f_{zx}/f_z	relative fixed cost of export	1.5
f_{ez}/f_z	relative fixed cost of entry	30
τ	iceberg trade cost	1.8
a	shape parameter of Pareto Distribution	3.8
θ	lower bound of Pareto Distribution	0.2
δ	exogenous death probability of firms	0.025
σ	elasticity of substitution	3.4
A	strength of comparative advantage	1
λ	strength of absolute advantage	1
$b(z)$	expenditure share	1
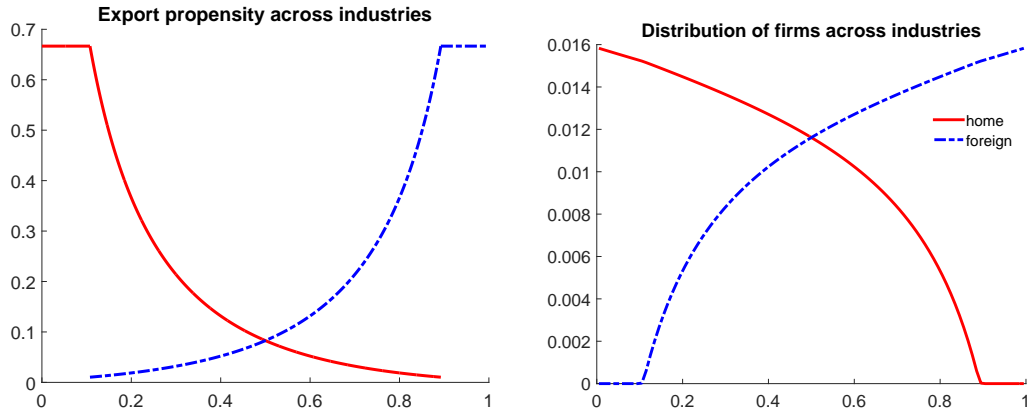
Notes: The figures are generated using the parameters specified in Table 5.

Figure 9: Benchmark Solution

ening Ricardian comparative advantage in labor-intensive industries), and reducing trade costs (trade liberalization). We are interested in the effects on production, exports, and productivity.

The first exercise is to increase K from 100 to 200. The results shown in Figure 10 indicate that: 1) $\overline{z}$ increases and $\underline{z}$ decreases. That is, as two countries become similar in endowment, the measure of industries in which both counties produce $[\underline{z}, \overline{z}]$ increases. 2) For firm mass $M(z)$, we have $\frac{\partial \left(M'(z) - M(z) \right)}{\partial z} > 0$. Furthermore, as Figure 10 (a) indicates, there exists a sector cut-off z_1 such that $M(z)$ increases for $z \geq z_1$ while decreases for $z < z_1$. These results are consistent with the well-known Rybczynski theorem that production shifts to capital-intensive industries as the home country becomes more capital abundant. 3) As z increases, sectoral export probability increases. That is, $\frac{\partial (\chi'_z - \chi_z)}{\partial z} > 0$. Furthermore, as panel (b) indicates, there exists a sector cut-off z_2 such that χ_z increases for $z \geq z_2$ while decreases for $z < z_2$. Similar results hold for the sectoral export intensity. 4) The selection effect changes the sectoral

productivity. Using result (a) of Proposition 5, we immediately see that changes in export probability induce changes in sectoral productivity. Thus, as z increases, sectoral productivity increases, and sectoral productivity increases for $z \geq z_2$ whereas sectoral productivity decreases for $z < z_2$. To summarize, these results indicate that distributions of firms' mass, export probability/intensity, and productivity across industries all follow the "single crossing property" when the relative endowment changes.
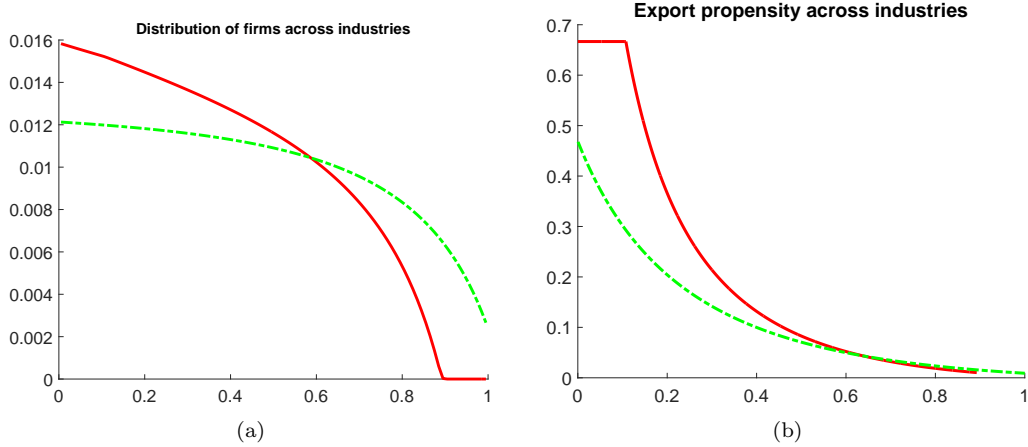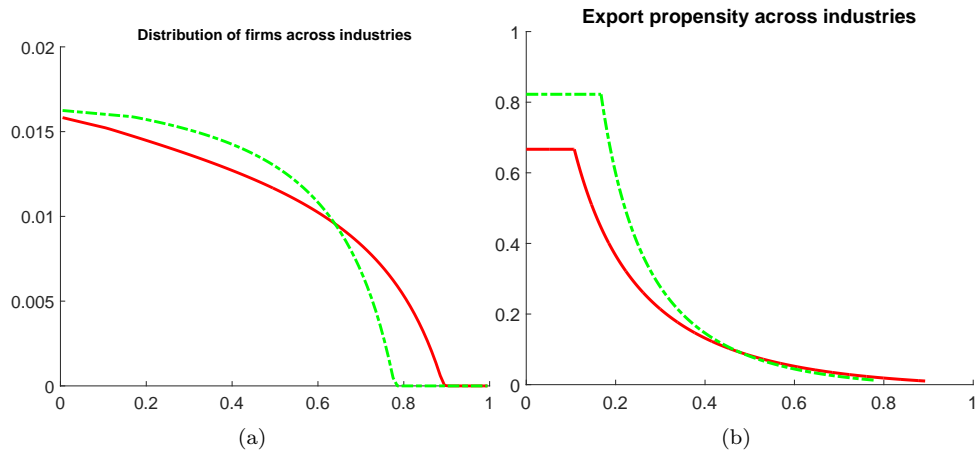

Notes: The solid lines are for the benchmark case with $K = 100$. The dash lines are for the case with $K = 200$.

Figure 10: Capital deepening

The second exercise reduces A, the parameter capturing Ricardian comparative advantage, from 1 to 0.5, which we call sector-bias technology change. Such a sector-bias technology change favors labor-intensive industries at home by making them relatively more productive to RoW. The results are presented in Figure 11, which indicate that 1) $\overline{z}$ decreases and $\underline{z}$ increases, so that the home country specialize more in labor-intensive industries; 2) $\frac{\partial (M'(z) - M(z))}{\partial z} < 0$; 3) $\frac{\partial (\chi'_z - \chi_z)}{\partial z} < 0$; and 4) Because the productivity in labor-intensive industries increases more, the selection effect reinforces the comparative advantage in labor-intensive industries. Note that results 2), 3) and 4) also follow a "single crossing property", however, in the opposite direction to the case of capital deepening.

The third exercise reduces the iceberg trade cost τ from 1.8 to 1.5. From Proposition 2 we know that free trade will lead to complete specialization. Thus, a reduction in τ tends to result in more specialization. That is, $\underline{z}$ would (weakly) increase and $\overline{z}$ decreases. That is indeed the case in Figure 12. As expected, trade liberalization increases export probability and export intensity. Moreover, production shifts to the comparative advantage industries.

So far, we have only shown the numerical comparative statics for two specific parameters in each experiment. We now present the aggregate moments from the model over a wider range of parameters. These moments include the share of capital-intensive firms (capital intensity $z \geq 0.5$), the average export propensity for labor-intensive industries ($z \leq 0.5$) and capital-intensive industries. The results are shown in Figure 13. In panel (a), we simulate capital deepening by increasing K from 40 to 300. The share of

Notes: The solid lines are for the benchmark case with $A = 1$. The dash lines are for the case with $A = 0.5$.

Figure 11: Sector-bias technology change
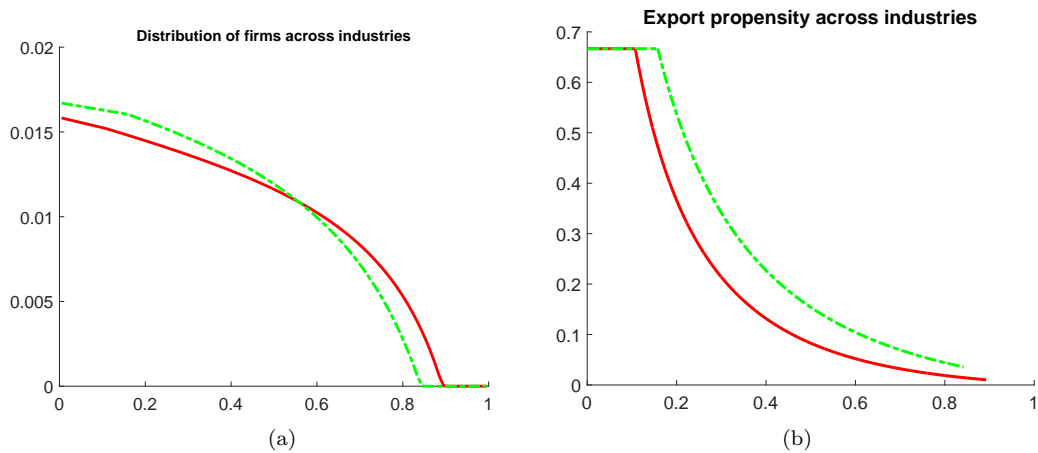
Notes: The solid lines are for the benchmark case with $\tau = 1.8$. The dash lines are for the case with $\tau = 1.5$.

Figure 12: Trade liberalization

capital-intensive firms increases as home country becomes more capital abundant. The average export propensity for labor-intensive industries drops and vice versa for capital-intensive industries. Panel (b) simulates sectoral bias technology change by increasing A from 0.3 to 1.5. As the home country gains Ricardian comparative advantage in capital-intensive industries, the share of capital-intensive firms and their export propensity both increase. Panel (c) simulates trade liberalization with τ varying from 1.1 to 2.2. Still, trade liberalization favors the comparative advantage industries and boosts their production and exports. Our numerical results are summarized together in Table 6. The key lessons we have learned are:

Property 1: As the capital endowment increases in the labor abundant home country, distributions of firms' mass, export probability/intensity, and productivity across industries all follow the "single
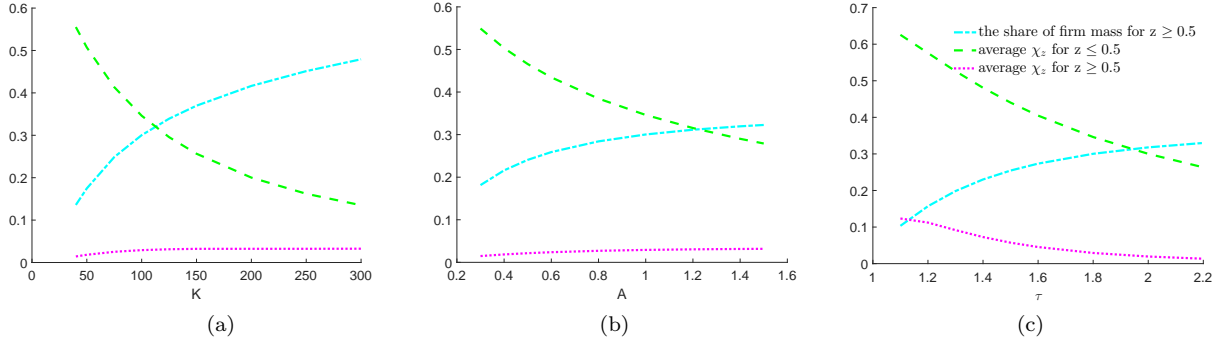
Notes: Panel (a) simulates capital deepening by increasing K from 40 to 300. Panel (b) simulates sectoral technology bias by varying A from 0.3 to 1.5. Panel (c) simulates trade liberalization with τ decreasing from 2.2 to 1.1.

Figure 13: Numerical comparative statics on aggregate moments

crossing property". That is, there exist cut-off capital intensities for industries such that firms' mass, export probability/intensity, and productivity increase for more capital-intensive industries, but decrease for more labor-intensive industries.

Property 2: For the sector-bias technology change that strengthens Ricardian comparative advantage in labor intensive industries, distributions of firms' mass, export probability/intensity, and productivity across industries also follow the "single crossing property", but in the opposite direction to the case of capital deepening.

Property 3: Trade liberalization strengthens existing comparative advantage by widening the range of industries in which each country specializes. Countries become more specialized as output and export both shift to comparative advantage industries.

Table 6: Numerical comparative statics

	share of capital intensive firms $(z \geq z_1)$	average χ_z for labor intensive industries $(z \leqslant z_2)$	average χ_z for capital intensive industries $(z \geq z_2)$	cut-off industry for home specialization $\underline{z}$	cut-off industry for foreign specialization $\overline{z}$
capital deepening $(K \uparrow)$	+	−	+	−	+
sector-bias technology change $(A \downarrow)$	−	+	−	+	−
trade liberalization $(\tau \downarrow)$	−			+	−

Notes: The variables are for the labor abundant home country. For the capital deepening experiment, we keep all the benchmark parameters except K. Similarly, only A varies for the experiment of sector-bias technology change and τ varies for the experiment of trade liberalization. z_1 is is the cut-off industry which the share of firm mass does not change in the comparative statics. z_2 is the cut-off industry which the export probability does not change in the comparative statics.

5.2   Discussion

If we believe capital had been deepening in China during the period 1999-2007, panel (a) of Figure 10 is consistent with the Stylized fact 1 that Chinese production became more capital-intensive. However,

panel (b) is to the opposite of the Stylized fact 2 that the share of exporters increased in labor-intensive industries and dropped in capital-intensive industries. If trade liberalization was the main story and China had comparative advantage in labor-intensive industries, the Stylized fact 1 is at odds with panel (a) of Figure 12. According to Figure 11, if sector-bias technology change was the sole driving force, production and exports should have both become more labor-intensive or capital-intensive, depending on which industries the bias was favoring. However, this cannot be reconciled with stylized facts 1 and 2. In sum, none of these forces alone can explain all the stylized facts. We need to estimate and gauge the movement of each force over time to disentangle their individual effect. This is what we do in the next section.

6   Quantitative Analysis

In this section, we conduct a quantitative analysis of the model economy. We treat China as the home country and RoW as the foreign country. We first calibrate and structurally estimate the model parameters by fitting the model to the Chinese data. To disentangle the driving forces behind the pattern of structural adjustments that we observe in Section 2, we run counterfactual experiments by turning on different channels in the estimated model. The estimated model also allows us to decompose the Ricardian comparative advantage and productivity growth. Finally, we analyze the source of welfare gains and check the robustness of the estimation results.

6.1   Parametrization and Estimation

A subset of the parameters is based on data statistics or estimates from the literature. As first proved by Chaney (2008) and also in Arkolakis et al. (2012), trade elasticity in the Melitz model with Pareto distribution assumption is governed by the Pareto shape parameter. Thus we set the Pareto shape parameter $a = 3.43$, the median trade elasticity estimated by Broda *et al* (2006) for China. We will later test the robustness of our estimates by varying the trade elasticity from the lower end to the higher end of the estimates in the literature. Next, to infer the elasticity of substitution σ, we regress the logarithm of an individual firm's rank in sales on the logarithm of firm sales.[22] The estimated coefficient is 0.774, with a standard error of 0.001. According to Helpman, Melitz and Yeaple (2004), this coefficient would be $a - (\sigma - 1)$. Thus, the elasticity of substitution is $\sigma = 3.43 + 1 - 0.774 = 3.66$.

We normalize the labor supply for China to be 1. The relative labor endowment $\frac{L^*}{L}$ is calculated for both 1999 and 2007 using data from the World Bank as the ratio of industrial employment.[23] Next, from Proposition 8.4, export intensity and probability of export for each industry are related to each other as $\gamma_z = \frac{f\chi_z}{1+f\chi_z}$. Thus we can infer the relative fixed cost of exports as $f = \frac{\gamma_z}{\chi_z(1-\gamma_z)}$ for each industry.

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[22]The coefficient is estimated by polling the data from two years together using OLS, controlling year-industry fixed effects.

[23]Industrial employment is computed by multiplying the total labor force with the share industrial employment and employment rate. World Bank Database doesn't provide industrial employment share for the whole world in year 1999 and 2007. We take data from the closest available year: year 2000 and 2005 respectively.

Our estimation for f is the average across all industries. The estimated results are 1.00 and 1.77 for 1999 and 2007, respectively.[24] Finally, the expenditure share function is estimated as the consumption share for each industry where consumption is accounted as output plus net imports. We observe only output and exports from the firm survey. To infer imports, we match the firm survey data with the customs data from 2000 to 2006.[25] For each of the 100 industries, we compute the ratio of aggregate imports to aggregate exports of the matched firms. Then the imports of each industry are estimated as the aggregate exports of all firms multiplied by the ratio. We then compute expenditure as the output plus next exports for each industry, and then compute the expenditure function b(z) as the average of expenditure share during the period of 2000 and 2006. The estimated $b(z)$ is shown in the Appendix 9.2. These are all the parameters calibrated before the main estimation, which is also summarized in Table 7.

Table 7: Calibrated Parameters

Parameters	Value	Source
Pareto shape a	3.43	Broda *et al* (2006)
Elasticity of substitution σ	3.66	Estimated according to Helpman *et al* (2004)
relative labor size L^*/L	$year_{1999} : 2.49$ $year_{2007} : 2.22$	Ratio of industrial labor force (World Bank).
Relative fixed cost of export f	$year_{1999} : 1.00$ $year_{2007} : 1.77$	Inferred from $\gamma_z = \frac{f\chi_z}{1+f\chi_z}$
Expenditure share $b(z)$		Consumption share while C(z)=Y(z)-EXP(z)+IMP(z) with imports inferred from matched firm and customs data

Notes: The estimated f is the average across industries for each year. b(z) is averaged over 2000 and 2006. They are plotted in the Appendix 9.2.

Turning to the remaining parameters $\{\frac{K^*}{K}, K/L, A, \lambda, \tau\}$, we estimate them using method of moments. The first target moment is the relative size of China and RoW, measured by the aggregation revenue ratio R^*/R. It is calculated using the ratio of manufacturing output between RoW and China using World Bank data.[26] Secondly, we target the empirical feature on industry-level exporter share and capital intensity. The average share of exporters for the capital-intensive industries ($z \geq 0.5$) and labor-intensive industries ($z \leq 0.5$) are chosen as the estimation target moments. Finally, average capital intensity and capital intensity for exporters are also included. Thus, we use five moments to estimate five parameters.[27]

We estimate the model parameters separately for the years 1999 and 2007. Table 8 reports the estimated parameters. First, China became more capital abundant in 2007. The relative capital stock of RoW to China dropped from 3.50 to 2.54, and the capital labor ratio of China more than doubled its level in 1999 from 0.907 to 2.03. Second, China became more productive compared with RoW, especially

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[24]This does not mean the fixed cost of export was increasing from 1999 to 2007. It can be the case both the fixed costs of sales at home and export were declining but the fixed cost of export was falling slower. Appendix 9.2 plots the estimated f by industry.

[25]The customs data uses different firm identifier from the firm survey. We match them by firm name, address, post code and phone number. About 30%-40% of the exporters in the firm data are matched. The distribution of export across industries is almost identical for the matched exporters and all exporters from the firm data. Thus the matched firms are unlikely to be selected.

[26]Manufacturing output is estimated as nominal GDP multiplied by the share of manufacturing in aggregate GDP.

[27]Appendix 9.4 provides more details about the estimation method. Appendix 9.5 shows that the lower bound θ of the Pareto distribution, the exogenous death probability of firms δ, the fixed entry cost f_{ez} and fixed cost production f_z are irrelevant for the these moments.

in labor-intensive industries. As we can see, the parameter capturing the absolute advantage λ increased from 0.125 to 0.355. Thus the gap in sectoral TFP between China and RoW shrank in every industry.[28] More importantly, the parameter capturing exogenous Ricardian comparative advantage A switched from > 1 to < 1. This implies that the productivity growth in China must have been relatively faster in the labor-intensive industries during this period.[29] Although we cannot observe the TFP for RoW in each industry or directly measure the Ricardian comparative advantage, we do observe that TFP growth is relatively faster in the labor-intensive industries in China, as is shown in Figure 4 in the Stylized fact 3. Finally, the variable iceberg trade cost τ decreased by about 25%, from 2.38 to 1.76. This is not surprising given the trade liberalization that China experienced after joining the WTO in 2001.

Table 8: Estimation Results

Parameters	$\frac{K^*}{K}$	K/L	A	λ	τ
Year 1999	3.50	0.907	1.31	0.125	2.38
	(0.004)	(0.02)	(0.001)	(0.0002)	(0.001)
Year 2007	2.54	2.03	0.739	0.355	1.76
	(0.02)	(0.015)	(0.009)	(0.0002)	(0.001)

Notes: This table presents the estimation results. $\frac{K^*}{K}$ is the relative endowment of home and RoW. K/L is the capital labor ratio at home. A captures the Ricardian comparative advantage. λ captures the absolute comparative advantage. τ measures the iceberg trade cost. The numbers in the parentheses are bootstrapped standard errors. In each boostrap, we use a sample with replacement from the data to generate the target moments and redo the estimation. We perform 25 boostraps for each year.

We then examine the fitting of our model. Table 9 shows the fitting of the targeted moments. As can be seen in the table, we match the target moments reasonably well. Table 10 shows the fitting of non-targeted aggregate moments. The model matches the aggregate exporter share and aggregate export intensity relatively well. The aggregate export intensity in the model has a slightly higher level and shows a bigger increase compared with the data. The model also predicts a significant wage growth in China relative to RoW. In 1999, average wage for RoW was about 6.5 times that of China, declining to around 3 times in 2007. Such relative wage growth is close to what we observe.[30] As we will show in the counterfactual, such wage growth is mostly driven by technology change favoring labor-intensive industries, less by the increasing scarcity of labor to capital, least by the trade liberalization. The model also generates distribution of firm and exporter shares across industries. The fitting is illustrated in Figure 14. The estimated model closely matches not only the static patterns but also the changes over time. In sum, our model estimation can quantitatively account for both the changes in the aggregate

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[28]Our estimate of the relative productivity between China and RoW is close to the estimate by di Giovanni *et al.* (2014). They estimate that average productivity of China relative to RoW is about 0.34 in the 2000s. According to our estimate, the weighted average of relative productivity of China to the RoW is 0.16 in 1999 and 0.30 in 2007.

[29]This is consistent with the finding by Levchenko and Zhang (2016) that productivity tends to grow faster in industries with greater initial comparative disadvantage.

[30]According to ILO (2013, 2014), the world real wage growth between 1999 and 2007 is 20.4%. The world CPI grew by 33.5% during 1999-2007 according to World Bank data. Thus the nominal wage grew by 60.7% ((1+20.4%)(1+33.5%)-1). For the same period, the nominal wage of China grew by 168%. So the relative wage growth of the World to China is $\frac{w_{2007}^W/w_{2007}^C}{w_{1999}^W/w_{1999}^C} = \frac{w_{2007}^W}{w_{1999}^W}/\frac{w_{2007}^C}{w_{1999}^C} = (1 + 60.7\%)/(1 + 168\%) = 60.0\%$. If we are willing to accept that the wage of RoW is very close to the whole world, the same calculation using our estimate is $\frac{w_{2007}^*/w_{2007}}{w_{1999}^*/w_{1999}} = \frac{2.89}{6.43} = 44.9\%$. Thus our estimate of the relative wage growth of China to RoW from our model accounts a significant proportions of wage growth in China.

economy as well as the structural adjustment in Chinese production and exports from 1999 to 2007.

Table 9: Model fit: target moments

	Data		Model	
Year	1999	2007	1999	2007
R^*/R	16.74	7.47	16.74	7.47
exporter share: $z \leq 0.5$	0.312	0.42	0.315	0.423
exporter share: $z \geq 0.5$	0.241	0.234	0.238	0.228
capital intensity for all firms	0.667	0.707	0.659	0.688
capital intensity for all exporters	0.623	0.619	0.630	0.633

Notes: The current table demonstrates the fitting of the moments that are included in the estimation.

Table 10: Model fit: non-target moments

	Data		Model	
Year	1999	2007	1999	2007
aggregate exporter share	0.253	0.249	0.241	0.230
aggregate export intensity	0.181	0.208	0.189	0.284
relative wage: w*/w			6.43	2.89

Notes: The current table computes moments that are not included in the estimation using estimation results from Table 8 and compares them against data.
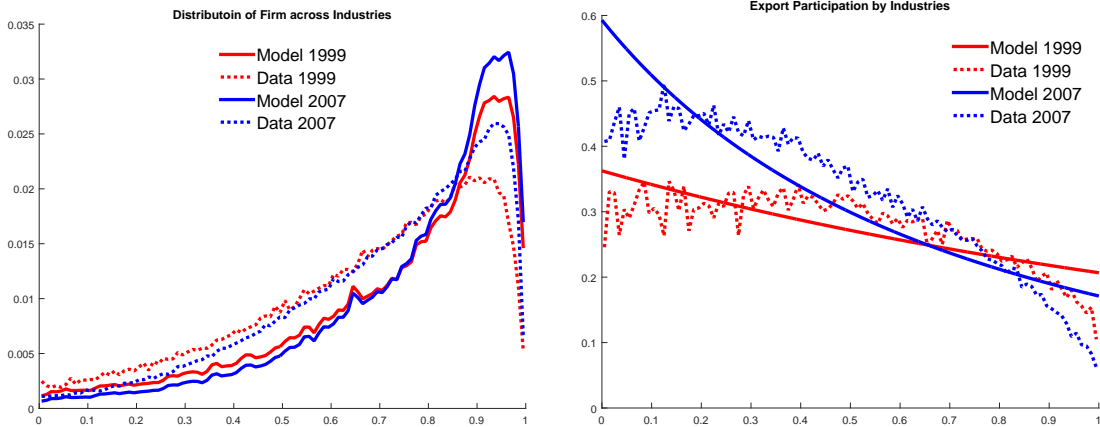

Figure 14: Model fit: non-targeted production and export

6.2 Counterfactual

In this subsection, we conduct counterfactual experiments to investigate the driving forces behind the structural adjustments of Chinese production and exports discussed in Section 2. In each experiment, we replace the estimated parameters of 1999 with those of 2007, one subset of parameters at a time. The first experiment replaces the technology parameters $\{A, \lambda\}$. The second one replaces the trade cost

parameters $\{\tau, f\}$. The last one replaces the endowment parameters $\{\frac{L^*}{L}, \frac{K^*}{K}, K/L\}$. The results are presented in Table 11 and Figure 15.

Table 11: Counterfactual

	Baseline Model		Counterfactual		
	(1)	(2)	(3)	(4)	(5)
year	1999	2007	A and λ	τ and f	endowments
R^*/R	16.74	7.47	10.31	16.22	12.31
exporter share: $z \leq 0.5$	0.315	0.423	0.559	0.435	0.196
exporter share: $z \geq 0.5$	0.238	0.228	0.193	0.352	0.196
capital intensity for all firms	0.659	0.688	0.659	0.655	0.694
capital intensity for all exporters	0.630	0.633	0.538	0.634	0.694
aggregate exporter share	0.241	0.230	0.221	0.357	0.196
aggregate export intensity	0.189	0.284	0.161	0.381	0.164
relative wage: w*/w	6.43	2.89	3.44	6.04	5.81

Notes: Column (1) and (2) are model results using the parameters estimated in Table 8. Column (3) replaces the estimated technology parameters $\{A, \lambda\}$ of 1999 by the estimates of 2007 and keeps other parameters unchanged. Column (4) replaces $\{\tau, f\}$ of 1999 by the estimates of 2007 and keeps other parameters unchanged. Column (5) replaces $\{\frac{L^*}{L}, \frac{K^*}{K}, \frac{K}{L}\}$ of 1999 by the estimates of 2007 and keeps other parameters unchanged.

Our first finding is that the rise of China is mostly driven by productivity growth, less by changes in endowment, and least by trade liberalization. The relative size of RoW to China $\frac{R^*}{R}$ drops from 16.74 to 10.29 when we change $\{A, \lambda\}$ in column (3) of Table 11. This change in the relative size of RoW to China is about 70% of actual change from 16.74 to 7.47. The magnitude is significantly smaller in column (4) and (5) when we run the other two counterfactuals. This is consistent with the findings by Zhu (2012) and Tombe and Zhu (2015), who also find that the growth of China is mostly driven by productivity growth.[31] Similar to us, Tombe and Zhu (2015) also find that trade liberalization with RoW only contributes a small fraction to the growth of China. A similar conclusion holds for relative wage $\frac{w^*}{w}$. It drops by about a half when we replace $\{A, \lambda\}$.

Our second finding is that, change in endowment is the primary driver of more capital-intensive production. The capital intensity of all firms barely changes when we replace $\{A, \lambda\}$ or $\{\tau, f\}$ but increases from 0.659 to 0.694 when we replace the endowment parameters. As China became more capital abundant in 2007, China's comparative disadvantage in the capital-intensive industries was weakened. Hence, expected profit rose in capital-intensive industries. Furthermore, as capital became relative cheaper, fixed entry costs in capital-intensive industries also decreased. In the end, more firms entered capital-intensive industries. However, according to our estimates China gained Ricardian comparative advantage in labor-intensive industries in 2007. Given the changes in $\{A, \lambda\}$, expected profit of operating in the labor-intensive industries increased. Wages also increased, however, this drove up the fixed entry costs for labor-intensive industries. Rising expected profit and rising fixed entry costs balanced out, leaving firm mass distribution almost unchanged.

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[31]Zhu (2012) uses a growth accounting approach. Tombe and Zhu(2015) calibrate a general equilibrium model of trade and migration.

Because trade liberalization benefited comparative advantage industries more, we would expect an expansion of the labor-intensive industries. But the effect turned out to be quite small. These results are also demonstrated in the left panel of Figure 15. Only in the counterfactual experiment with endowment can we see the firm mass distribution shifting to capital-intensive industries.

Finally, technological changes drove the phenomena whereby exporters did not become more capital-intensive, and export participation increased in labor-intensive industries but dropped in capital-intensive ones. As is evident from Table 11, only when $\{A,\lambda\}$ is replaced does the average capital intensity of exporters fall. This is due to a significant rise of exporters in labor-intensive industries and a decline in the capital-intensive ones. Export participation increases universally when we replace $\{\tau, f\}$. When replacing the endowment parameters, exporter share declines everywhere, more so in the labor-intensive industries, making exporters more labor-intensive on average.
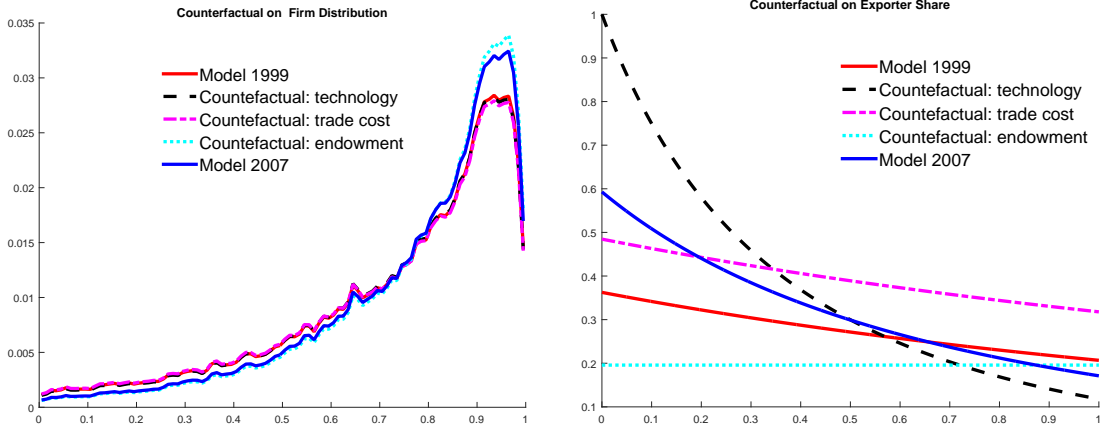

Figure 15: Counterfactuals

6.3 Decompose the Ricardian Comparative Advantage and Productivity Growth

With the estimated parameters, we can decompose Ricardian comparative advantage into exogenous and endogenous components using results from Proposition 5. This channel is first discovered in Bernard *et al.* (2007a) which prove the theoretical possibility of such a channel. Proposition 5 allows us to evaluate its quantitative relevance. According to Proposition 5, the Ricardian comparative advantage can be decomposed as:

$$\frac{\widehat{A(z)}}{A^*(z)} = \underbrace{\lambda A^z}_{exogenous}\underbrace{(\frac{1+f\chi_z}{1+f\chi_z^*})^{1/a}}_{endogenous}.$$

The exogenous component can be readily estimated using λ and A from Table 8. We measure the endogenous component directly using the share of exporter for each industry χ_z and χ_z^*. Although χ_z^* is

not observable, we can show that $\chi_z^* = \chi_z^{-1} \left(\tau f^{\frac{1}{\sigma-1}} \right)^{-2a}$. So χ_z^* can be calculated given the observed χ_z, and σ, a, τ, and f.[32] Figure 16 illustrates the decomposition for both 1999 and 2007. The red triangle lines capture the exogenous component λA^z and the blue dotted lines captures both the exogenous and endogenous components. The difference between the two lines is due to the endogenous component. The estimated exogenous Ricardian comparative advantage favored the labor-intensive industries in 2007. Since the exporter share is relatively higher in labor-intensive industries, the endogenous Ricardian comparative advantage also favors labor-intensive industries. Thus, the exogenous Ricardian comparative advantage is amplified by the endogenous component. Therefore, the blue dotted line for 2007 is steeper than the red triangle line. The situation is exactly reversed in 1999. The estimated exogenous Ricardian comparative advantage favored the capital-intensive industries and was dampened by the endogenous component.
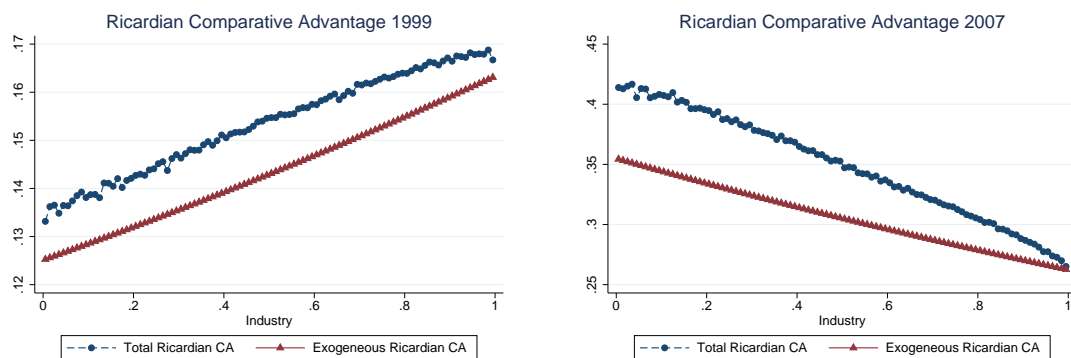

Figure 16: Decomposition of Ricardian comparative advantage

We can apply such decomposition not only for cross sectional productivity differences but also productivity growth over time. Let x and x' denote variable x for current period and next period, respectively. Sectoral productivity growth is decomposed as: [33]

$$\frac{E(A(z)'\varphi|\varphi \geq \bar{\varphi}_z')}{E(A(z)\varphi|\varphi \geq \bar{\varphi}_z)} = \frac{A(z)'}{A(z)} \frac{\widehat{\varphi}_z'}{\widehat{\varphi}_z} = \frac{A(z)'}{A(z)} \left(\frac{1 + f'\chi_z'}{1 + f\chi_z}\right)^{\frac{1}{a}}$$

where $\frac{A(z)'}{A(z)}$ absorbs the industry-wide productivity growth and $\left(\frac{1+f'\chi_z'}{1+f\chi_z}\right)^{\frac{1}{a}}$ captures productivity growth

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[32]The estimated χ_z^* is plotted in Figure A5 in the Appendix. The share of exporters to China in RoW is significantly lower than the share of exporters in China to RoW, driven by the fact that RoW is much larger than China. It increases with capital intensity, consistent with RoW's comparative advantage in the capital-intensive industries. It also increases over time, especially for the capital-intensive industries, due to the trade liberalization and the growing size of China. This identification result is similar to the Head-Ries index (Head and Ries, 2001) where they trade costs for given ratios of export to domestic absorption while we infer export participation for given trade costs.

[33]The results is immediately from conclusion (a) of proposition 5 by assuming that the constant C is the same over time. C depends on δ the exogenous death shock for firms, θ the lower bound of the support of Pareto Distribution, and $\tilde{f}$ the relative fixed entry cost. Any changes in these 3 parameters will be absorbed by the industry-wise productivity change in our accounting setting. If we could identify these 3 parameters, we can further decompose the productivity growth.

due to change in export selection. Figure 17 (a) plots the estimated productivity growth by industry.[34] As noted earlier, the productivity growth is higher in the labor-intensive industries. The right panel plots $(\frac{1+f'\chi_z'}{1+f\chi_z})^{\frac{1}{a}}$. Since χ_z increased in the labor-intensive industries, selection to export will lead to a disproportionally higher productivity growth in these industries. Although exporter share declined for the capital-intensive industries, the relative higher fixed costs of exports f in 2007 still implies tougher export selection. Overall, export selection leads to productivity growth almost in every industry. We find that the average productivity growth rate weighted by value added across all industries is about 144%. However, the weighted average of productivity growth rate driven by the export selection is about 3.1%. Hence, export selection contributes about 2.1% of the overall productivity growth.[35]
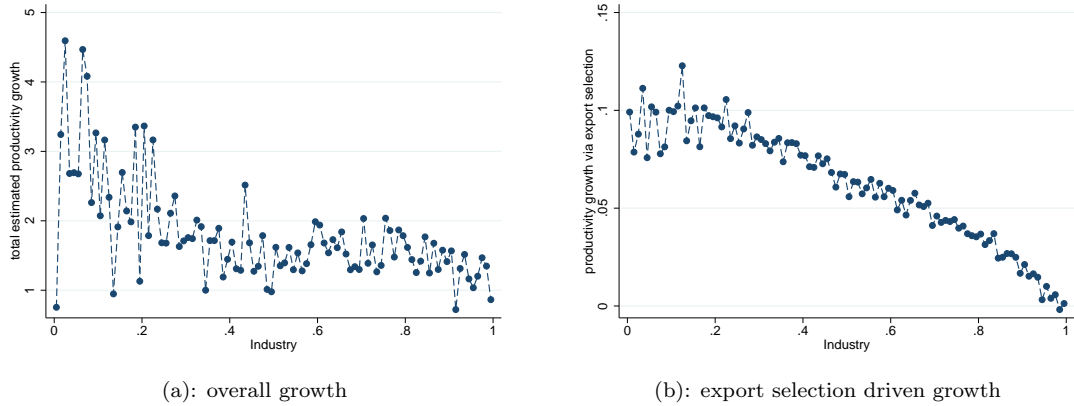

(a): overall growth   (b): export selection driven growth

Figure 17: Export selection and productivity growth

6.4 Welfare Analysis

An estimated model also allows us to provide welfare analysis for China and RoW. Given the logarithm utility we use, we measure welfare using equivalent real consumption given by $W \equiv \exp(U)$. The exact welfare formula is specified in Appendix 8.6. Armed with estimated parameters and the welfare formula, we first compare the welfare level of China with RoW, and find

$$\frac{W_{1999}}{W_{1999}^*} = 8.2\%, \quad \frac{W_{2007}}{W_{2007}^*} = 20\%.$$

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[34]We do not observe growth in industry-wide productivity $\frac{A(z)'}{A(z)}$ directly. So we need to measure the left-hand side of the equality in order to evaluate the contribution of endogenous selection given by $(\frac{1+f'\chi_z'}{1+f\chi_z})^{\frac{1}{a}}$. We estimate $\frac{E(A(z)\varphi|\varphi\geq\bar{\varphi}_z)'}{E(A(z)\varphi|\varphi\geq\bar{\varphi}_z)}$ as the growth of average sectoral productivity from 1999 to 2007. The sectoral productivity is computed as the weighted average of firm level TFP as estimated by the Levinsohn and Petrin (2003) method.

[35]The small contribution of export selection to overall productivity growth is not unique to this study. For example, Baldwin and Gu (2003) find that Canadian plants entering the export market contribute very little overall growth.

Though the welfare of China is much lower than RoW, it is catching up quickly. To gauge the speed of welfare growth in China and RoW, we estimate the changes in real consumption over time.[36] The result is presented in column (1) of Table 12. We have $\frac{W_{2007}}{W_{1999}} = 5.84$ and $\frac{W_{2007}^*}{W_{1999}^*} = 2.43$, implying that in 1999 real consumption grows 24.7% for China and 11.7% for RoW [37] To understand the source of these welfare gains, we compute the corresponding welfare number in the counterfactual experiment discussed in the previous subsection. The results are reported from column (2) to (4) in Table 12. [38] As can be seen, the welfare gain of China mostly comes from changes in endowment and productivity growth, not from the trade liberalization. For RoW, the welfare gain mostly comes from changes in endowment, less from productivity growth, and least from the trade liberalization.

Table 12: Counterfactual Welfare

welfare	(1)	Counterfactual		
		(2)	(3)	(4)
change	Baseline	$A(z)$ and $A(z)^*$	τ and f	endowments
$\frac{W_{2007}}{W_{1999}}$	5.84	2.32	1.02	2.38
$\frac{W_{2007}^*}{W_{1999}^*}$	2.43	1.31	1.01	1.84

Notes: Column (1) corresponds to the welfare growth rate computed using the estimated parameters from Table 8, assuming the death shock δ, lower bound of productivity θ and the relative fixed cost of entry $\widetilde{f}$ do not change between 1999 and 2007. Column (2) computes the hypothetical welfare growth if only $A(z)$ and $A(z)^*$ have changed between 1999 and 2007. Similarly, columns (3) and (4) only change the trade costs and endowments, respectively.

6.5 Robustness

In this subsection, we conduct the robustness check of our estimation result. In our baseline, we set the trade elasticity $a = 3.43$ based on the literature. We would like to know whether our estimate is robust to alternative values. In Table 13, we vary the trade elasticity from 2.5 which is at the lower end of the estimate in the literature to 7.5, which is at the higher end. By the nature of our calibration, the elasticity of substitution σ also varies accordingly. It turns out that the point estimate of each parameter varies with trade elasticity. However, the direction of the changes in the estimated parameters are the same as our baseline estimation: across all cases, $\frac{K^*}{K}$, A and τ decrease from 1999 to 2007, *vice versa* for $\frac{K}{L}$ and λ.

7 Conclusion

In this paper, we first document the seemingly puzzling patterns of structural adjustments in production and export based on comprehensive Chinese firm-level data: overall manufacturing production be-

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[36]As explained in Appendix 8.6, we assume the relative fixed entry cost $\widetilde{f}$, death probability δ and the lower bound of the Pareto distribution θ are constant over time.

[37]To put these numbers into perspective, the real GDP per capita grows at 12.5% for China and 4.9% for RoW. But since we only capture the manufacturing sector, these numbers are not directly comparable.

[38]In column (2), instead of replacing A, λ, we replace the estimated year 1999 sectoral productivity for China $A(z)$ and RoW $A(z)^*$ by those estimated for 2007. If we only replace A, λ, only changes the relative productivity between China and RoW would be captured. And we would miss out the productivity growth over time in China and RoW.

Table 13: Robustness checks on trade elasticity

Given Parameters			Estimated Parameters				
a	σ	year	K*/K	K/L	A	λ	τ
2.5	2.73	1999	3.88	0.91	1.56	0.10	3.28
		2007	2.88	2.03	0.82	0.33	2.10
5	5.23	1999	4.09	0.91	1.59	0.14	1.81
		2007	2.76	2.03	0.89	0.36	1.49
7.5	7.73	1999	4.21	0.91	1.63	0.15	1.49
		2007	2.34	2.03	0.77	0.36	1.31

Notes: Our baseline estimation result in Table 8 is obtained by setting the Pareto shape $a = 3.43$. This table provides estimation results with a varying from 2.5 to 7.5.

came more capital-intensive whereas exports did not during the period 1999-2007; export participation increased in labor-intensive industries but dropped in capital-intensive ones, which counters our understanding from the Rybczynski Theorem of HO theory. To explain these findings, we embed a Melitz-type heterogeneous firm model into the Ricardian and HO trade theory with continuous industries.

We structurally estimate the model and find that China became relatively more capital abundant over time, technology improved significantly and favored labor-intensive industries between 1999 and 2007. Trade liberalization reduced the variable trade costs by about a quarter. By running counterfactual simulations, we find that the adjustment in production pattern is mainly driven by changes in endowment whereas changes in export participation are mostly driven by changes in technology. Using the estimated model, we find that export selection shapes the Ricardian comparative advantage extensively but contributes only about 2.1% of productivity growth over time. Finally, growth of output and welfare in China is driven mostly by technology change, less by endowment and trade liberalization.

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8   Appendix

8.1   Proof of Proposition 1

The proof is similar to the proof of Proposition 3 in Bernard, Redding and Schott (2007a). The complication is that we allow for specialization while they focus on cases within the diversification cone.[39] The idea of the proof is as follows. We first write factor demands as functions of the factor prices $\{w, w^*, r, r^*\}$. Then the factor market clearing conditions determine the equilibrium factor prices. Once the factor prices are known, all the other equilibrium variables are also determined.

For given factor prices, the total revenue for home country and foreign country are $R = wL + rK$ and $R^* = w^* L^* + r^* K^*$, respectively. For industries that home country specializes, the factor demands are $l(z) = (1 - z)b(z)(R + R^*)/w$, $k(z) = zb(z)(R + R^*)/r$. Factor demands in foreign country are symmetric. For industries that both countries produce, the industry revenue function is given by Equation (3.17),

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[39]We will show how to determine the specialization pattern in proposition 2.

thus we need to know the firm mass M_z and M_z^*, the pricing index $P(z)$ and $P(z)^*$, and industry average productivity $\widehat{\varphi}_z$ and $\widehat{\varphi}_z^*$ in order to settle their factor demands. We will use the model conditions to substitute for these terms. Starting from Equation (3.17), we find that:

$$\frac{r(\widehat{\varphi}_z)}{r(\widehat{\varphi}_z^*)} = \widetilde{p}_z^{1-\sigma} \frac{(\frac{P(z)}{P(z)^*})^{\sigma-1} + \frac{R^*}{R}\tau^{1-\sigma}\chi_z^{\frac{a+1-\sigma}{a}}}{\frac{R^*}{R} + \chi_z^{*\frac{a+1-\sigma}{a}}\tau^{1-\sigma}(\frac{P(z)}{P(z)^*})^{\sigma-1}} \tag{8.1}$$

where $r(\widehat{\varphi}_z) = \frac{R_z}{M_z}$ is the average firm revenue, and $\widetilde{p}_z \equiv \frac{p_{zd}(\widehat{\varphi}_z)}{p_{zd}(\widehat{\varphi}_z^*)} = \frac{\widehat{\varphi}_z^* w}{\varepsilon(z)\widehat{\varphi}_z w^*}(\frac{r/w}{r^*/w^*})^z$ is the relative average domestic price between the two countries, with $\varepsilon(z) \equiv \frac{A(z)}{A^*(z)}$.

At the same time, using the zero profit conditions Equations (3.9) and (3.10), and the fact that $\frac{r(\widehat{\varphi}_z)}{r(\check{\varphi}_z)} = (\frac{\widehat{\varphi}_z}{\check{\varphi}_z})^{\sigma-1}$, we find $r(\widehat{\varphi}_z) = (f_z(\frac{\widehat{\varphi}_z}{\check{\varphi}_z})^{\sigma-1} + \chi_z f_{zx}(\frac{\widehat{\varphi}_{zx}}{\check{\varphi}_{zx}})^{\sigma-1})\sigma r^z w^{1-z}$. Combined with the free entry condition, it can be shown that the average productivity between home and foreign country is $\frac{\widehat{\varphi}_z^*}{\widehat{\varphi}_z} = (\frac{1+f\chi_z^*}{1+f\chi_z})^{\frac{1}{a}}$ while $f \equiv \frac{f_{zx}}{f_z}$. Using the Pareto distribution assumption, we find that $\frac{\widehat{\varphi}_z}{\check{\varphi}_z} = \frac{\widehat{\varphi}_{zx}}{\check{\varphi}_{zx}} = (\frac{a}{a+1-\sigma})^{\frac{1}{\sigma-1}}$, and $\chi_z = \frac{1-G(\check{\varphi}_{zx})}{1-G(\check{\varphi}_z)} = \Lambda_z^{-a}$, while Λ_z is the productivity cut-off ratio defined in Equation (3.11). Combining these results, it can be shown that:

$$\frac{r(\widehat{\varphi}_z)}{r(\widehat{\varphi}_z^*)} = \varepsilon\widetilde{p}_z(\frac{1+f\chi_z}{1+f\chi_z^*})^{\frac{a+1}{a}}, \tag{8.2}$$

Using the definition of $\widetilde{p}_z$ and combining Equation (8.1) and (8.2), we have:

$$\chi_z = \frac{\widetilde{\tau}^{-a}f - \varepsilon^a h(z)}{\varepsilon^a f h(z) - \widetilde{\tau}^a}, \tag{8.3}$$

where $h(z) = (\frac{w}{w^*}(\frac{r/w}{r^*/w^*})^z)^{\frac{a\sigma}{1-\sigma}}$ and $\widetilde{\tau} = \tau f^{\frac{1}{\sigma-1}}$. From Equation (8.3), we find that χ_z is a function of the factor prices. From Equation (3.11) we have $\Lambda_z = \chi_z^{-1/a} = \frac{\tau P(z)}{P(z)^*}(\frac{fR}{R^*})^{1/(\sigma-1)}$, then $\frac{P(z)}{P(z)^*} = \frac{\chi_z^{-1/a}}{\tau}(\frac{R^*}{fR})^{1/(\sigma-1)}$. which is also function of the factor prices. Combined with Equations (3.17) and (3.18), the revenue for those industries that both countries produce are :

$$R_z = b(z)[\frac{R}{1 - \widetilde{\tau}^{-a}\varepsilon^a f h(z)} - \frac{fR^*}{\widetilde{\tau}^a\varepsilon^a h(z) - f}], \tag{8.4}$$

$$R_z^* = b(z)\varepsilon^a h(z)[\frac{R^*}{\varepsilon^a h(z) - f\widetilde{\tau}^{-a}} - \frac{fR}{\widetilde{\tau}^a - \varepsilon^a f h(z)}]. \tag{8.5}$$

Both equations above are functions of factor prices. Using $l(z) = (1 - z)b(z)R_z/w$ and $k(z) = zb(z)R_z/r$, the factor market clearing conditions for home country are given by:

$$\int_{I(s)} (1 - z)\frac{b(z)(R + R^*)}{w}dz + \int_{I(b)} (1 - z)\frac{R_z}{w} = L,$$

$$\int_{I(s)} z\frac{b(z)(R + R^*)}{r}dz + \int_{I(b)} z\frac{R_z}{r} = K.$$

Another two symmetric equations can be written for the foreign country. I(s) is set of the industries

that home country specializes and while I(b) is the set of industries that both countries produce. They are determined by cut-off industries where either the domestic or foreign firm mass is zero using the result $\frac{M_z}{M_z^*} = \widetilde{p}_z^{\sigma-1} \frac{(\frac{P(z)}{P(z)^*})^{1-\sigma} - \chi_z^{-\frac{a+1-\sigma}{a}} \widetilde{\tau}^{-2(a+1-\sigma)} \tau^{1-\sigma}}{1 - \chi_z^{\frac{a+1-\sigma}{a}} \tau^{1-\sigma} (\frac{P(z)}{P(z)^*})^{1-\sigma}}$ [40], which is also determined by factor prices. These four factor demand equations together determine the four factor prices $\{w, r, w^*, r^*\}$.

Once the factor prices are known, χ_z is pinned down for all industries which in turn determines the productivity cut-offs $\bar{\varphi}_z$, and $\bar{\varphi}_{zx}$. Once the cut-offs are known, average revenue for each industry is given by $r(\widehat{\varphi}_z) = (f_z(\frac{\widehat{\varphi}_z}{\bar{\varphi}_z})^{\sigma-1} + \chi_z f_{zx}(\frac{\widehat{\varphi}_{zx}}{\bar{\varphi}_{zx}})^{\sigma-1})\sigma r^z w^{1-z}$. Then we use the goods market clearing condition Equation (3.17) to determine the firm mass for each industry. The price index for each industry is also pinned down using Equation (3.18). ∎

8.2 Proof of Proposition 2

Suppose $M_z^* \neq 0$, the relative firm mass between home and foreign can be extracted from Equation (3.18) as:

$$\frac{M_z}{M_z^*} = \widetilde{p}_z^{\sigma-1} \frac{(\frac{P(z)}{P(z)^*})^{1-\sigma} - \chi_z^{-\frac{a+1-\sigma}{a}} \widetilde{\tau}^{-2(a+1-\sigma)} \tau^{1-\sigma}}{1 - \chi_z^{\frac{a+1-\sigma}{a}} \tau^{1-\sigma} (\frac{P(z)}{P(z)^*})^{1-\sigma}},$$

where we have used a result that $\chi_z \chi_z^* = \widetilde{\tau}^{-2a}$ to replace χ_z^* by $\chi_z^{-1} \widetilde{\tau}^{-2a}$. Since $\frac{P(z)}{P(z)^*} = \frac{\chi_z^{-1/a}}{\tau}(\frac{R^*}{fR})^{1/(\sigma-1)}$ and $\widetilde{p}_z = \frac{\widehat{\varphi}_z w}{\varepsilon(z)\widehat{\varphi}_z w^*}(\frac{r/w}{r^*/w^*})^z$, we have:

$$\frac{M_z}{M_z^*} = \varepsilon^{1-\sigma}(\frac{1 + f\chi_z^*}{1 + f\chi_z})^{\frac{\sigma-1}{a}}[\frac{w}{w^*}(\frac{r/w}{r^*/w^*})^z]^{\sigma-1} \frac{\frac{fR}{R^*} - \chi_z^{-1}\widetilde{\tau}^{-2a}f^2}{1 - \chi_z \frac{fR}{R^*}} \tau^{\sigma-1} \chi^{\frac{\sigma-1}{a}}.$$

If $\chi_z = \frac{R^*}{fR}(\frac{f}{\widetilde{\tau}^a})^2$, we have $\frac{M_z}{M_z^*} = 0$. Since $M_z^* > 0$, it must be that $M_z = 0$. If χ_z decreases such that $\chi_z < \frac{R^*}{fR}(\frac{f}{\widetilde{\tau}^a})^2$, we have $\frac{M_z}{M_z^*} < 0$. Since M_z cannot be negative, we should have $M_z = 0$ and foreign will specialize in these industries. On the other hand, if χ_z increases such that χ_z approaches $\frac{R^*}{fR}$ and $\frac{M_z}{M_z^*} \to +\infty$, or say $\frac{M_z^*}{M_z} \to 0$, which implies $M_z^* = 0$. If χ_z further increases such that $\chi_z > \frac{R^*}{fR}$, we again have $\frac{M_z^*}{M_z} < 0$. Since M_z^* cannot be negative, M_z^* stays at zero and home will specialize in these industries. In summary, to maintain positive firm mass for both countries in each industry, we must have:

$$\frac{R^*}{fR}(\frac{f}{\widetilde{\tau}^a})^2 < \chi_z < \frac{R^*}{fR},$$

where $\frac{f}{\widetilde{\tau}^a} = \frac{f}{\tau^a f^{\frac{a}{\sigma-1}}} < \frac{f}{f^{\frac{a}{\sigma-1}}} < 1$. If χ_z falls out of this range, one country's firm mass is zero and the other is positive. This is when specialization happens. For industries that both produce, we have

$$\chi_z = \frac{\widetilde{\tau}^{-a}f - \varepsilon^a h(z)}{\varepsilon^a f h(z) - \widetilde{\tau}^a}, \tag{8.6}$$

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[40]This is derived from Equation (3.18) defining price index

which is a continuous and monotonic between $[\underline{z}, \overline{z}]$.[41] For the boundary industries $\underline{z}$ and $\overline{z}$, since we have

$$\chi_{\underline{z}} = \frac{R^*}{fR} \text{ and } \chi_{\overline{z}} = \frac{R^*}{fR}(\frac{f}{\widetilde{\tau}^a})^2,$$

evaluating Equation (8.6) at $\underline{z}$ and $\overline{z}$, we have:

$$\underline{z} = \frac{\ln(\frac{\chi_{\underline{z}}\widetilde{\tau}^a + f\widetilde{\tau}^{-a}}{1 + f\chi_{\underline{z}}}) - \frac{a\sigma}{1-\sigma}\ln(\frac{w}{w^*}) - a\ln(\lambda)}{\frac{a\sigma}{1-\sigma}\ln(\frac{r/w}{r^*/w^*}) + a\ln(A)},$$

$$\overline{z} = \frac{\ln(\frac{\chi_{\overline{z}}\widetilde{\tau}^a + f\widetilde{\tau}^{-a}}{1 + f\chi_{\overline{z}}}) - \frac{a\sigma}{1-\sigma}\ln(\frac{w}{w^*}) - a\ln(\lambda)}{\frac{a\sigma}{1-\sigma}\ln(\frac{r/w}{r^*/w^*}) + a\ln(A)},$$

which are also determined given the factor prices. If we have free trade such that $\tau = f = 1$, we have $\chi_{\underline{z}} = \chi_{\overline{z}} = \frac{R^*}{R}$, and $\underline{z} = \overline{z}$. The two countries completely specialize. $\blacksquare$

8.3 Proof of Proposition 3

Let's focus on the home country. For any two industries z and z', suppose $z < z'$, using the definition of Λ_z Equation (3.11), and the assumption that variable trade costs and fixed costs are the same for all industries, we have:

$$\frac{\Lambda_z}{\Lambda_{z'}} = \frac{P(z)/P(z')}{P(z)^*/P(z')^*}.$$

If $\frac{P(z)}{P(z')} < \frac{P(z)^*}{P(z')^*}$, that is labor intensive products are relatively cheaper in home country, then $\Lambda_z < \Lambda_{z'}$. This is exactly what we will prove next. The idea is that if $\frac{P(z)}{P(z')} < \frac{P(z)^*}{P(z')^*}$ under autarky and $\frac{P(z)}{P(z')} = \frac{P(z)^*}{P(z')^*}$ under free trade, then the costly trade case will fall between.

Under free trade, all firms export. The price of each variety and number of varieties are the same for both countries. Thus the pricing index $P(z) = P(z)^*$ for all industries and we have $\frac{P(z)}{P(z')} = \frac{P(z)^*}{P(z')^*}$.

At the other extreme of close economy, no firms export and from Equation (3.18) we have $P(z) = M_z^{\frac{1}{1-\sigma}} p_{zd}(\widehat{\varphi}_z)$. Firm mass for each industry is $M_z = \frac{b(z)R}{r(\widehat{\varphi}_z)} = \frac{b(z)R}{r(\bar{\varphi}_z)}(\frac{\bar{\varphi}_z}{\widehat{\varphi}_z})^{\sigma-1}$. So $\frac{P(z)}{P(z')} = (\frac{w}{r})^{(z'-z)/\rho}(\frac{b(z)}{b(z')})^{\frac{1}{1-\sigma}}\frac{A(z')\bar{\varphi}_{z'}}{A(z)\bar{\varphi}_z}$. Using Equation (3.16) we have homogeneous cut-offs for all industries under autarky: $\bar{\varphi}_{z'} = \bar{\varphi}_z$. Then it can be verified that

$$\frac{P(z)/P(z')}{P(z)^*/P(z')^*} = (\frac{w/r}{w^*/r^*})^{\frac{z'-z}{\rho}} A^{z'-z}.$$

Since $z' > z$ and $A < 1$, then $\frac{w}{r} < \frac{w^*}{r^*} \iff \frac{P(z)}{P(z')} < \frac{P(z)^*}{P(z')^*}$. We just need to show that $\frac{w}{r} < \frac{w^*}{r^*}$ under autarky. Using the factor market clearing condition, given the Cobb-Douglas forms for production

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[41] This is proved in proposition 4.

function, entry costs, and payments of fixed costs, we find that:

$$\frac{K}{L} = \frac{w}{r} \frac{\int_0^1 zb(z)dz}{\int_0^1 (1-z)b(z)dz}, \quad \frac{K^*}{L^*} = \frac{w^*}{r^*} \frac{\int_0^1 zb(z)dz}{\int_0^1 (1-z)b(z)dz}.$$

Thus $\frac{K}{L} < \frac{K^*}{L^*} \Longleftrightarrow \frac{w}{r} < \frac{w^*}{r^*}$ and we establish that $\Lambda_z < \Lambda_{z'}$, or say Λ_z increases with z in home country.

For industries that both countries produce, Equation (3.16) determines the cut-offs. It is easy to see that the first term in the left hand side of the equation is a decreasing function of $\bar\varphi_z$, and the second term is a decreasing function of $\bar\varphi_{zx}$, given that $g(\varphi) > 0$, $\bar\varphi_z \le \varphi$ and $\bar\varphi_{zx} \le \varphi$. Since Λ_z increases with z, it can be shown that either $\frac{\partial \bar\varphi_z}{\partial z} > 0$ or $\frac{\partial \bar\varphi_z}{\partial z} = 0$ cannot maintain the equality of the equation.[42] So it must be the case that $\frac{\partial \bar\varphi_z}{\partial z} < 0$. Then the first term of equation (3.16) increases with z. To maintain the equation the second term must decrease with z. Thus $\bar\varphi_{zx}$ should be an increasing function of z. Similar logic applies for the foreign country: $\frac{\partial \bar\varphi_z^*}{\partial z} > 0$ and $\frac{\partial \bar\varphi_{zx}^*}{\partial z} < 0$.

For industries that home country specializes: $M_z^* = 0$ and $M_z > 0$. Thus the price indexes at home and foreign are: $P(z) = M_z^{\frac{1}{1-\sigma}} p_{zd}(\widehat\varphi_z)$ and $P(z)^* = \chi_z^{\frac{1}{1-\sigma}} M_z^{\frac{1}{1-\sigma}} p_{zx}(\widehat\varphi_{zx})$. So we have $\Lambda_z = \frac{\tau P(z)}{P(z)^*}(\frac{fR}{R^*})^{\frac{1}{\sigma-1}} = \chi_z^{\frac{1}{\sigma-1}} \frac{\widehat\varphi_{zx}}{\widehat\varphi_z}(\frac{fR}{R^*})^{\frac{1}{\sigma-1}}$. Using the definition of $\widehat\varphi_z$ and $\widehat\varphi_{zx}$, we have $\Lambda_z = \left(\chi_z \dfrac{\frac{1}{1-G(\bar\varphi_{zx})}\int_{\bar\varphi_{zx}}^\infty \varphi^{\sigma-1}g(\varphi)d\varphi}{\frac{1}{1-G(\bar\varphi_z)}\int_{\bar\varphi_z}^\infty \varphi^{\sigma-1}g(\varphi)d\varphi}\right)^{\frac{1}{\sigma-1}}$

$(\frac{fR}{R^*})^{\frac{1}{\sigma-1}} = \left(\dfrac{\int_{\Lambda_z\bar\varphi_z}^\infty \varphi^{\sigma-1}g(\varphi)d\varphi}{\int_{\bar\varphi_z}^\infty \varphi^{\sigma-1}g(\varphi)d\varphi}\right)^{\frac{1}{\sigma-1}} (\frac{fR}{R^*})^{\frac{1}{\sigma-1}}$ which is an implicit function of Λ_z and $\bar\varphi_z$. Moreover, the free entry condition $\frac{f_z}{\delta} \int_{\bar\varphi_z}^\infty \left[(\frac{\varphi}{\bar\varphi_z})^{\sigma-1} - 1\right] g(\varphi)d\varphi + \frac{f_{zx}}{\delta} \int_{\Lambda_z\bar\varphi_{zx}}^\infty \left[(\frac{\varphi}{\bar\varphi_{zx}})^{\sigma-1} - 1\right] g(\varphi)d\varphi = f_{ez}$ is also an implicit function of Λ_z and $\bar\varphi_z$. Solving these two equations together we would have Λ_z and $\bar\varphi_z$. Since these two functions hold for all the industries that home specializes, the solution would be the same for all these industries within $[0, \underline z]$ under our assumption that f_z, f_{zx} and f_{ez} do not vary with z.∎

8.4   Proof of Proposition 4

The conditional probability of export is given by $\chi_z = \frac{1-G(\bar\varphi_{zx})}{1-G(\bar\varphi_z)}$. From Proposition 3, we know that $\frac{\partial \bar\varphi_z}{\partial z} < 0$ and $\frac{\partial \bar\varphi_{zx}}{\partial z} > 0$ for $z \in (\underline z, \bar z)$. Thus we have $\frac{\partial G(\bar\varphi_z)}{\partial z} < 0$ and $\frac{\partial G(\bar\varphi_{zx})}{\partial z} > 0$ as long as the cumulative distribution function $G(\varphi)$ is continuous and $G(\varphi)' > 0$. Then it is easy to see that $\frac{\partial \chi_z}{\partial z} < 0$ for $z \in (\underline z, \bar z)$. For $z \in [0, \underline z]$, we know that $\frac{\partial \bar\varphi_z}{\partial z} = 0$ and $\frac{\partial \bar\varphi_{zx}}{\partial z} = 0$ from Proposition 3, so $\frac{\partial \chi_z}{\partial z} = 0$.

Under the assumption that $G(\varphi)$ is Pareto distributed, we have $\chi_z = \Lambda_z^{-a}$ and the $\Lambda_z = \frac{\bar\varphi_{zx}}{\bar\varphi_z} = \frac{\widehat\varphi_{zx}}{\widehat\varphi_z}$. Thus using the result that $\Lambda_z = \chi_z^{\frac{1}{\sigma-1}} \frac{\widehat\varphi_{zx}}{\widehat\varphi_z}(\frac{fR}{R^*})^{\frac{1}{\sigma-1}}$ from the proof of Proposition 3, we have $\chi_z = \frac{R^*}{fR}$ for industries that home specializes. For industries that both countries produce, we know that $\chi_z =$

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[42]This is a proof by contradiction. Suppose $\frac{\partial \bar\varphi_z}{\partial z} > 0$, so will $\bar\varphi_{zx}$ given $\frac{\partial \Lambda_z}{\partial z} > 0$. Then the left hand side of Equation (3.16) will decrease with z. But the right hand side is a constant. Contradiction. Similar argument applies if $\frac{\partial \bar\varphi_z}{\partial z} = 0$.

$\frac{\tilde{\tau}^{-a}f - \varepsilon^a h(z)}{\varepsilon^a f h(z) - \tilde{\tau}^a}$ from the proof of Proposition 1. Using the chain rule, we have $\frac{\partial \chi_z}{\partial z} = \frac{(1 - \tilde{\tau}^{-2a}f^2)\varepsilon^a h(z)a}{(\varepsilon^a f h(z) - \tilde{\tau}^a)^2}(\ln(A) - \frac{\sigma}{\sigma-1}\ln(\frac{r/w}{r^*/w^*}))$. Let $B(z) = \frac{(1 - \tilde{\tau}^{-2a}f^2)\varepsilon^a h(z)a}{(\varepsilon^a f h(z) - \tilde{\tau}^a)^2}$ which is positive, immediately, we have

$$\frac{\partial \chi_z}{\partial z} = B(z)(\ln(A) - \frac{\sigma}{\sigma - 1}\ln(\frac{r/w}{r^*/w^*})),$$

whose sign depends only on $\ln(A)$ and $\frac{\sigma}{\sigma-1}\ln(\frac{r/w}{r^*/w^*})$.[43] For average export intensity for each sector is

$\gamma_z \equiv \frac{\chi_z r(\widehat{\varphi}_{zx})}{r(\widehat{\varphi}_z) + \chi_z r(\widehat{\varphi}_{zx})} = \frac{\chi_z f_{zx}(\frac{\widehat{\varphi}_{zx}}{\widehat{\varphi}_{zx}})^{\sigma-1}\sigma r^z w^{1-z}}{(f_z(\frac{\widehat{\varphi}_z}{\widehat{\varphi}_z})^{\sigma-1} + \chi_z f_{zx}(\frac{\widehat{\varphi}_{zx}}{\widehat{\varphi}_{zx}})^{\sigma-1})\sigma r^z w^{1-z}} = \frac{f_{zx}\chi_z}{f_z + f_{zx}\chi_z} = \frac{f\chi_z}{1 + f\chi_z}$, thus $\frac{\partial \gamma_z}{\partial \chi_z} = \frac{f}{(1+f\chi_z)^2} > 0$.
So γ_z is a monotonic increasing function of χ_z and should follow the same pattern as χ_z.∎

8.5 Proof of Proposition 5

From Equation (3.16) for free entry equation, we can calculate that the average of idiosyncratic firm productivity as

$$\widehat{\varphi}_z = (\frac{a}{a + 1 - \sigma})^{\frac{1}{\sigma-1}}\bar{\varphi}_z = (\frac{a}{a + 1 - \sigma})^{\frac{1}{\sigma-1}}[\frac{(\sigma-1)\theta^a}{(a+1-\sigma)\delta\tilde{f}}(1 + f\chi_z)]^{\frac{1}{a}}$$

where $\tilde{f} = \frac{f_{ez}}{f_z}$. Let $C = (\frac{a}{a+1-\sigma})^{\frac{1}{\sigma-1}}[\frac{(\sigma-1)\theta^a}{(a+1-\sigma)\delta\tilde{f}}]^{\frac{1}{a}}$, we immediately have

$$\widehat{\varphi}_z = C(1 + f\chi_z)^{1/a}.$$

From the equation above, $\widehat{\varphi}_z$ is monotonic increasing function of χ_z. As we have proved in Proposition 4, χ_z is higher in industries with larger comparative advantage, so is $\widehat{\varphi}_z$. Then measured average productivity for each industry is

$$\widehat{A(z)} = E_\varphi\{A(z)\varphi | \varphi > \bar{\varphi}_z\} = A(z)\tilde{\varphi}_z$$

Thus the measured Ricardian comparative advantage is given by $\frac{\widehat{A(z)}}{\widehat{A^*(z)}} = \frac{A(z)}{A^*(z)}\frac{\tilde{\varphi}_z}{\tilde{\varphi}_z^*}$. Under our assumption that $\frac{A(z)}{A^*(z)} = \lambda A^z$ and using the expression for $\widehat{\varphi}_z$ above, we have

$$\frac{\widehat{A(z)}}{\widehat{A^*(z)}} = \lambda A^z(\frac{1 + f\chi_z}{1 + f\chi_z^*})^{1/a},$$

which is the second result of the proposition. ∎

8.6 Welfare

Given the CES aggregation within each sector, the real consumption for each sector is $Q(z) = \frac{R(z)}{P(z)}$, where R(z)=b(z)R is the sectoral revenue and P(z) is the price index of sector z. Hence the welfare of

---

[43]$B(z)$ is positive as $\tilde{\tau}^{-a}f < 1$.

the representative household is given by

$$U = \int_0^1 b(z) \ln b(z) dz + \ln R - \int_0^1 b(z) \ln P(z) dz,$$

where the first term is a constant intrinsic to the Cobb-Douglas preferences. The sectoral price index $P(z)$ is given by Equation (3.18). Plugging in the average price of domestic varieties and average F.O.B price of foreign varieties respectively: $P_z(\widehat{\varphi}_z) = \frac{\sigma}{\sigma-1} \frac{r^z w^{1-z}}{A(z)\widehat{\varphi}_z}$ and $P_z(\widehat{\varphi}^*_{zx}) = \frac{\sigma}{\sigma-1} \frac{r^{*z} w^{*1-z}}{A(z)^* \widehat{\varphi}^*_{zx}}$, we have

$$P(z) = \frac{\sigma}{\sigma-1} \frac{1}{A(z)} [M_z(\frac{r^z w^{1-z}}{\widehat{\varphi}_z})^{1-\sigma} + \chi^*_z M^*_z(\tau \frac{r^{*z} w^{*1-z}}{\frac{A(z)^*}{A(z)}\widehat{\varphi}^*_{zx}})^{1-\sigma}]^{\frac{1}{1-\sigma}}.$$

where $\frac{A(z)^*}{A(z)}$ is estimated as the Ricardian Comparative Advantage λA^z. If we only care about relative welfare, then for the case of no specialization (which is the case for our estimated results):

$$
\begin{aligned}
U^* - U &= \ln \frac{R^*}{R} + \int_0^1 b(z) \ln \frac{P(z)}{P(z)^*} dz \\
&= \ln \frac{R^*}{R} + \int_0^1 b(z) [\ln \frac{A(z)^*}{A(z)} + \frac{1}{1-\sigma} \ln \frac{M_z(\frac{r^z w^{1-z}}{\widehat{\varphi}_z})^{1-\sigma} + \chi^*_z M^*_z(\tau \frac{r^{*z} w^{*1-z}}{\frac{A(z)^*}{A(z)}\widehat{\varphi}^*_{zx}})^{1-\sigma}}{M^*_z(\frac{r^{*z} w^{*1-z}}{\frac{A(z)}{A^*(z)}\widehat{\varphi}^*_z})^{1-\sigma} + \chi_z M_z(\tau \frac{r^z w^{1-z}}{\widehat{\varphi}_{zx}})^{1-\sigma}}] dz.
\end{aligned}
$$

This can be computed with our baseline estimation result. However, if we want to know the welfare change at home and foreign over time, we need to know $A(z)$ and $A(z)^*$, the exogenous sectoral level productivities which are not directly observed. However, we can first estimate the average sectoral TFP: $E(A(z)\varphi | \varphi \geq \bar{\varphi}_z) = A(z)\widehat{\varphi}_z$ while $\widehat{\varphi}_z$ can be computed from Proposition 5 as $\widehat{\varphi}_z = C(1 + f\chi_z)^{1/a}$.[44] Then an estimator of A(z) is:

$$A(z) = \frac{E(A(z)\varphi | \varphi \geq \bar{\varphi}_z)}{\widehat{\varphi}_z}.$$

Then $A(z)^*$ is inferred as $A(z)^* = \frac{A(z)}{\lambda A^z}$. We note that

$$\exp(U) = \exp(\int_0^1 b(z) \ln b(z) dz) \frac{R}{\exp(\int_0^1 b(z) \ln P(z) dz)}$$

---

[44]The limitation that we face here is that we cannot identify C. We have to assume that it is constant over time. Thus we cannot capture the welfare effect due to change in δ, θ or f.

is the real consumption, and the welfare change as measured by real consumption is given by:[45]

$$
\begin{aligned}
\widehat{U} &\equiv \exp(U' - U) = \exp(\ln \frac{R'}{R} - \int_0^1 b(z) \ln \frac{P(z)'}{P(z)} dz) \\
&= \frac{R'}{R} \exp(\int_0^1 b(z)[\ln(\frac{A(z)'}{A(z)}) - \frac{1}{1-\sigma} \ln \frac{M_z'(\frac{r'^z w'^{1-z}}{\widehat{\varphi}_z'})^{1-\sigma} + \chi_z^{*'} M_z^{*'}(\tau' \frac{r^{*'z} w^{*'1-z}}{\frac{A(z)^{*'}}{A(z)'} \widehat{\varphi}_{zx}^{*'}})^{1-\sigma}}{M_z(\frac{r^z w^{1-z}}{\widehat{\varphi}_z})^{1-\sigma} + \chi_z^* M_z^*(\tau \frac{r^{*z} w^{*1-z}}{\frac{A(z)^*}{A(z)} \widehat{\varphi}_{zx}^*})^{1-\sigma}}]dz).
\end{aligned}
$$

8.7 Robustness of the motivating evidence

In this subsection, we examine the robustness of our motivating evidence that productivity growth is faster in labor intensity industries, production becomes more capital intensive and export participation increases for labor intensive industries but falls for capital intensive industries.

First, two alternative measures of productivity are used: labor productivity, and TFP estimated by the Olley and Pakes (1996) method. The results are presented in Figure A1. Again, productivity growth is relatively faster in labor intensive industries.

Figure A1: robustness by productivity growth
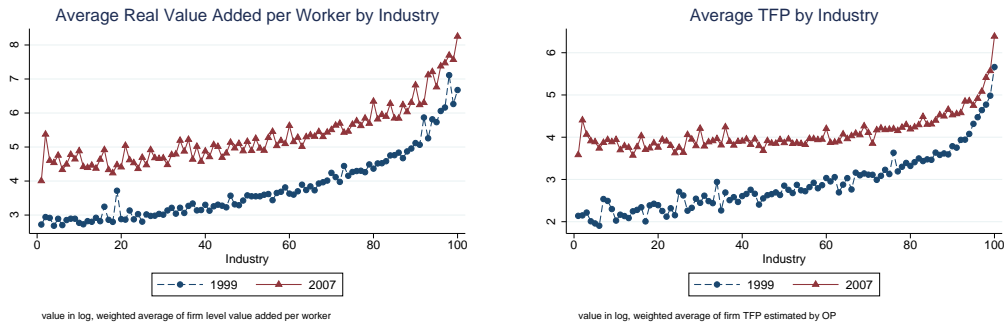
Notes: Labor productivity is measured as real valued added per worker. TFP is estimated as in Olley-Pakes (1996).

We then check whether our motivating evidence are driven by any institutional particular to China. We examine the role of Multi Fibre Agreement (MFA), State Owned Enterprise (SOE) and processing trade. Each time, we exclude firms subject to these institutions respectively and regenerate our basic motivating graphs. The results are shown in Figure A2. They are qualitatively consistent with the evidence in the main text. Next, we check whether our findings are driven by definition for industries. Instead of using the industry classification of "HO aggregate", we use the four-digit Chinese Industry Classification (CIC) to see whether our evidence still hold. The results are presented Figure A3. The results are consistent with our evidence using HO aggregate as industries classification.
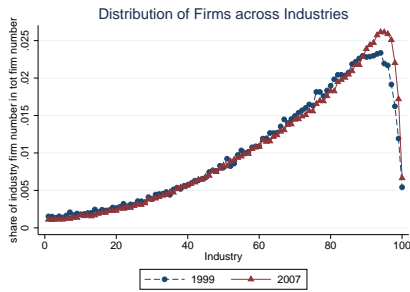
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[45]Since we normalize $L = 1$, R would be income per capita in China. We divide R^* by L^* to normalize the income to be a per capita measure as well whenever we compute the welfare for RoW.
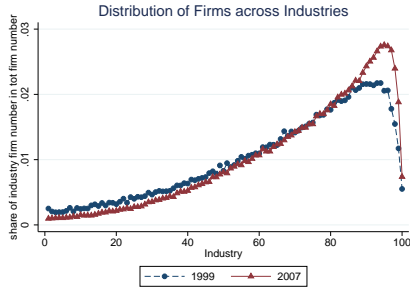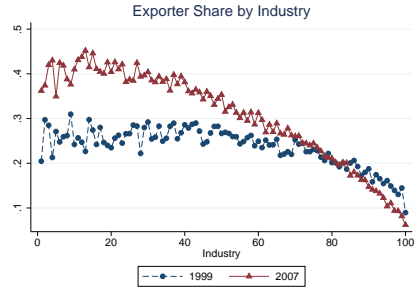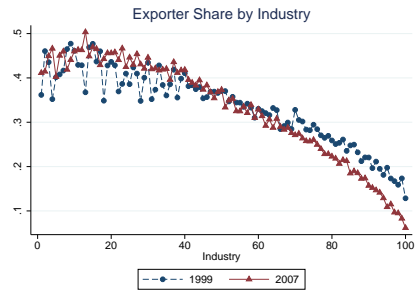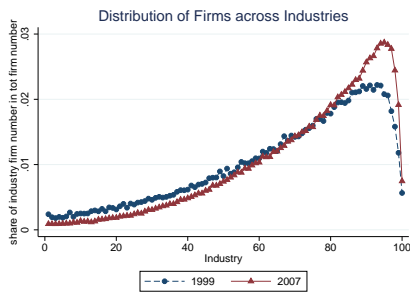
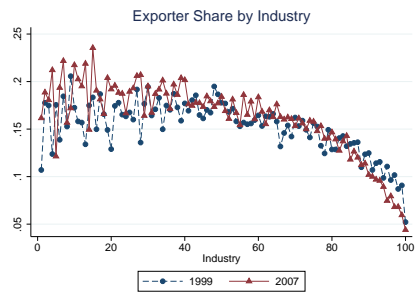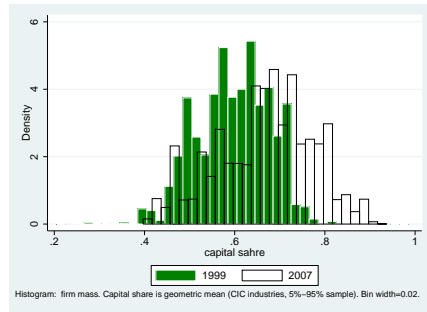MFA: firm mass   MFA: exporter share

SOE: firm mass   SOE: exporter share

Pure exporters: firm mass   Pure exporters: exporter share

Notes: (a) Industry classification is "HO aggregate" as in the main text. (b) The charts on MFA are produced by excluding the textile industries: 2-digit CIC industries of 17 and 18. (b) The charts on SOE are by excluding state owned firms. (c) The charts on Pure exporters are by excluding pure exporters, i.e., firms which export more than 70% of the outputs.
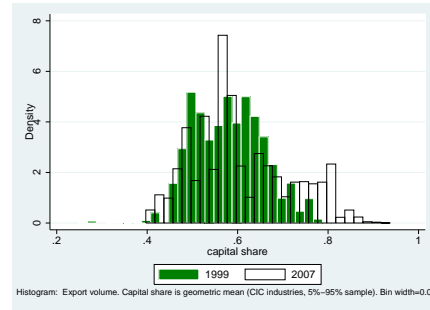
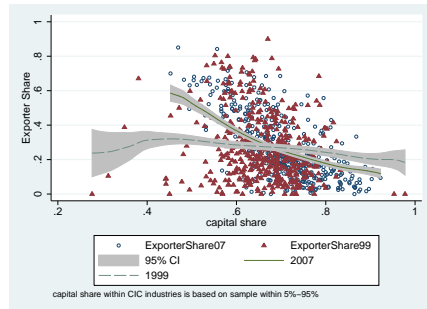Figure A2: robustness by excluding sub-samples
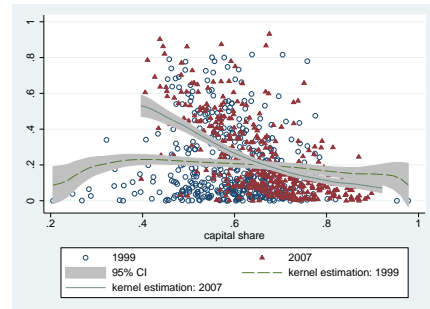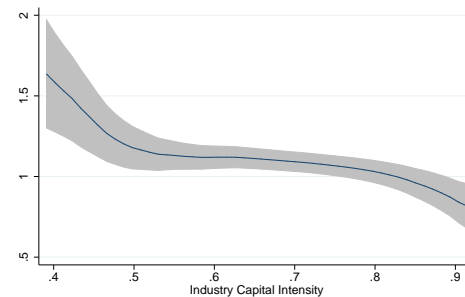
firm mass
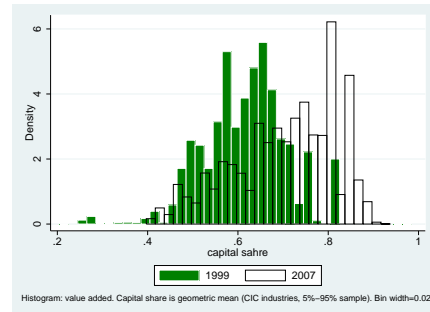
value added
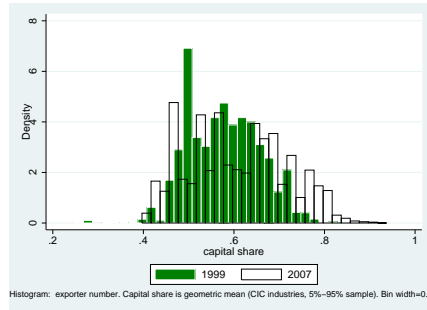
exporter distribution

export volume

exporter share

export intensity

Sectoral TFP growth

Notes: (a) Industry classification is four-digit CIC manufacturing industries. (b)Capital intensity is measured as the geometric mean across firms for each industry. (c) Non-parametric local polynomial is used to capture the trend in the data. (d) For the chart of TFP growth, capital intensity is measured as the average of 1999 and 2007 for each industry. Industry TFP is measured as the weighted average of firm level TFP, dropping the top and bottom 1% within each industry.

Figure A3: Motivating evidence in CIC industry classfication

9 Online Appendix (not for publication)

9.1 Basic Summary Statistics of the data

Table A.1: Statistical Summary of Main Variables

Variables	mean in 1999	mean in 2007
revenue(¥*1,000*)	50,932	117,888
value added(¥*1,000*)	14,130	31,983
sales(¥*1,000*)	49,306	115,413
export(¥*1,000*)	8,932	24,052
employee	329	219
total profit(¥*1,000*)	1,867	6,814
wage(¥*1,000*)	3,383	5,429

Notes: We followed Brandt et al (2012) to only include manufacturing firms with more than 8 employees, positive output and fixed assets, and drop firms with capital intensities less than zero or greater than one. We are left with 116,905 and 290,382 firms in 1999 and 2007 which represent about 80% and 93% of the original sample, respectively.

9.2 Additional Figures on Parametrization

The structural relationship $\gamma_z = \frac{f\chi_z}{1+f\chi_z}$ is used to estimate the relative fixed costs of export $f \equiv \frac{f_{zx}}{f_z}$. Using the observe γ_z and χ_z, f is estimated by sector using $f = \frac{\gamma_z}{\chi_z(1-\gamma_z)}$. The result is plotted in Figure A4 (a). The expenditure share b(z) is computed as the average of consumption share during 2000-2006. A ratio of aggregate imports to exports is estimated for the matched firms using the firm survey and the Customs Data. Imports of each industry is estimated as aggregate exports of all the firms in the survey multiplied by the ratio. Once imports are estimated, consumption is simply outputs plus imports minus exports. To infer the expenditure function across the whole support [0,1] as a continuous functions, we interpolate the expenditure function by linear projection. The result is shown in Figure A4 (b).
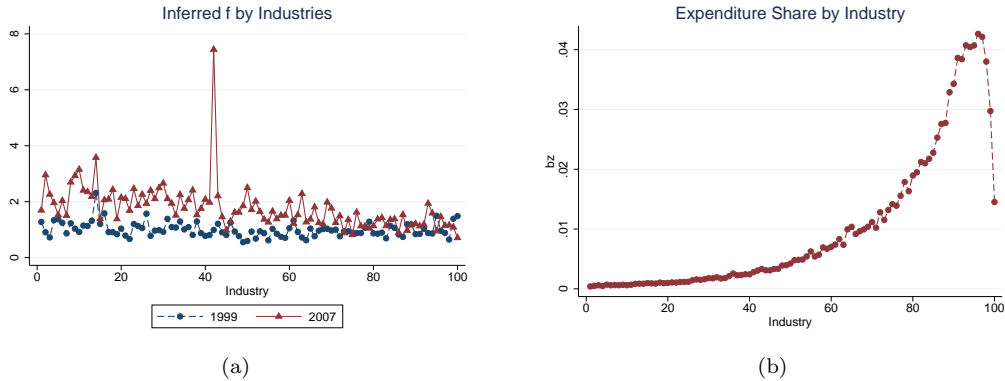

Figure A4: Relative fixed cost of export and expenditure function

To infer export propensity for RoW, we use the result that $\chi_z^* = \chi_z^{-1}\left(\tau f^{\frac{1}{\sigma-1}}\right)^{-2a}$, where χ_z is directly observable from the data; $a = 3.43$ and $\sigma = 3.66$ are calibrated; $f = 1$ for year 1999 and $f = 1.77$ for

Table A.2: Capital Share of Exporters and Non-Exporters in 2007

2-digit industry code	description	capital share of non-exporters		capital share of exporters	
		mean	std	mean	std
13	Processing of Foods	0.83	0.18	0.76	0.21
14	Manufacturing of Foods	0.76	0.20	0.71	0.22
15	Manufacture of Beverages	0.80	0.18	0.78	0.17
16	Manufacture of Tobacco	0.74	0.19	0.90	0.11
17	Manufacture of Textile	0.72	0.20	0.63	0.22
18	Manufacture of Apparel, Footwear & Caps	0.60	0.24	0.51	0.24
19	Manufacture of Leather, Fur, & Feather	0.64	0.25	0.53	0.23
20	Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm & Straw Products	0.74	0.20	0.69	0.21
21	Manufacture of Furniture	0.69	0.23	0.56	0.23
22	Manufacture of Paper & Paper Products	0.73	0.19	0.65	0.22
23	Printing, Reproduction of Recording Media	0.67	0.21	0.59	0.22
24	Manufacture of Articles For Culture, Education & Sport Activities	0.64	0.23	0.54	0.23
25	Processing of Petroleum, Coking, &Fuel	0.85	0.16	0.78	0.20
26	Manufacture of Raw Chemical Materials	0.79	0.19	0.75	0.19
27	Manufacture of Medicines	0.78	0.19	0.74	0.19
28	Manufacture of Chemical Fibers	0.80	0.17	0.77	0.20
29	Manufacture of Rubber	0.73	0.21	0.61	0.23
30	Manufacture of Plastics	0.72	0.21	0.60	0.23
31	Manufacture of Non-metallic Mineral goods	0.74	0.20	0.63	0.22
32	Smelting & Pressing of Ferrous Metals	0.82	0.17	0.82	0.15
33	Smelting & Pressing of Non-ferrous Metals	0.82	0.18	0.78	0.19
34	Manufacture of Metal Products	0.71	0.21	0.61	0.21
35	Manufacture of General Purpose Machinery	0.72	0.20	0.65	0.20
36	Manufacture of Special Purpose Machinery	0.72	0.21	0.63	0.21
37	Manufacture of Transport Equipment	0.70	0.21	0.65	0.21
39	Electrical Machinery & Equipment	0.73	0.21	0.61	0.23
40	Computers & Other Electronic Equipment	0.65	0.23	0.58	0.25
41	Manufacture of Measuring Instruments & Machinery for Cultural Activity & Office Work	0.69	0.22	0.56	0.23
42	Manufacture of Artwork	0.66	0.23	0.57	0.24
	All Industries	0.74	0.21	0.62	0.23

Notes: This table is generated using the Chinese firm survey for year 2007.

year 2007 are estimated above; τ =2.38 for year 1999 and τ =1.76 for year 2007 from the structural estimation. The results are plotted in Figure A5.
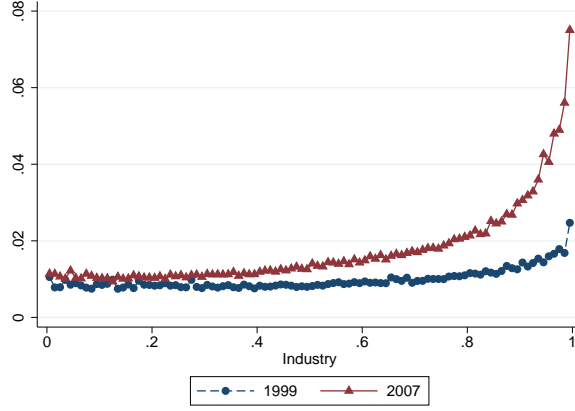

Figure A5: Inferred exporter share for RoW

9.3   CES preferences

Instead of assuming an aggregate Cobb-Douglas utility function, we assume that

$$
\begin{aligned}
U &= (\int_0^1 Q(z)^\mu dz)^{1/\mu} \\
Q(z) &= [\int_{\varpi \in \Omega_z} q_z(\varpi)^\rho d\varpi]^{1/\rho}
\end{aligned}
$$

where U is the upper-tier utility function and $Q(z)$ is the lower-tier utility function and $\mu \in (0,1], \rho \in (0,1]$. Then the elasticity of substitution between different industry and within each industry $\eta = \frac{1}{1-\mu} > 1$ and $\sigma = \frac{1}{1-\rho} > 1$. Then the demand for each industry and each variety are given by

$$
\begin{aligned}
Q(z) &= Q(\frac{P(z)}{P})^{-\eta} \\
q_z(\varpi) &= Q(z)(\frac{p_z(\varpi)}{P(z)})^{-\sigma}
\end{aligned} \tag{9.7}
$$

where P and $P(z)$ are pricing indexes. The revenues from domestic and foreign market are:

$$
\begin{aligned}
r_{zd}(\varphi) &= R(\frac{P(z)}{P})^{1-\eta}(\frac{p_z(\varphi)}{P(z)})^{1-\sigma} = RP^{\eta-1}P(z)^{\sigma-\eta}p_z(\varphi)^{1-\sigma} \\
r_{zx}(\varphi) &= R^* P^{*\eta-1}P^*(z)^{\sigma-\eta}p_{zx}(\varphi)^{1-\sigma}
\end{aligned}
$$

The profits from domestic and foreign sales are

$$
\pi_{zd}(\varphi) \;=\; \frac{r_{zd}(\varphi)}{\sigma} - f_z r^z w^{1-z}
$$

$$
\pi_{zx}(\varphi) \;=\; \frac{r_{zx}(\varphi)}{\sigma} - f_{zx} r^z w^{1-z}
$$

Using the zero-profit condition, we find $\Lambda_z \equiv \frac{\overline{\varphi}_{zx}}{\overline{\varphi}_z}$, the ratio between the cut-off productivity of export and survival is

$$
\Lambda_z = \tau \big(\frac{f_{zx}R}{f_z R^*}\big)^{\frac{1}{\sigma-1}} \big(\frac{P^*}{P}\big)^{\frac{1-\eta}{\sigma-1}} \big(\frac{P(z)}{P(z)^*}\big)^{\frac{\sigma-\eta}{\sigma-1}}
$$

where $P = [\int_0^1 P(z)^{1-\eta} dz]^{\frac{1}{1-\eta}}$ is the aggregate pricing index (P* for foreign). If $\eta = 1$, we are back to the Cobb-Douglas world. Using the equation above, we can prove that our propositions still hold. Especially, under the assumption of Pareto Distribution, the conditional probability of exporting is given by

$$
\chi_z = \begin{cases}
\left[\tau^{\eta-1} \frac{fR}{R^*} \big(\frac{P}{P^*}\big)^{\eta-1} \right]^{\frac{a(\sigma-1)}{(1-\eta)(\sigma-1)-a(\sigma-\eta)}} & z \in [0, \underline{z}] \\[2ex]
\frac{\widetilde{\tau}^{-a} f - \varepsilon^a g(z)}{\varepsilon^a f g(z) - \widetilde{\tau}^a} & z \in (\underline{z}, \overline{z})
\end{cases}
$$

9.4 Estimation Algorithm

For a given set of the exogenous parameters $\{\frac{K^*}{K}, \frac{L^*}{L}, \frac{K}{L}, A, \lambda, a, f, \tau, \sigma,\ b(z)\}$, we follow the idea of the proof for Proposition 1 to solve the endogenous factor prices $\{w, w^*, r, r^*\}$ using the factor market clearing conditions. First, the aggregate revenue for home and foreign are: $R = wL + rK$ and $R^* = w^*L^* + r^*K^*$. The factor intensity cut-offs are: $\underline{z} = \frac{\ln(\frac{\chi_{\underline{z}} \widetilde{\tau}^a + f \widetilde{\tau}^{-a}}{1 + f \chi_{\underline{z}}}) - \frac{a\sigma}{1-\sigma} \ln(\frac{w}{w^*}) - a \ln(\lambda)}{\frac{a\sigma}{1-\sigma} \ln(\frac{r/w}{r^*/w^*}) + a \ln(A)}$ and $\overline{z} = \frac{\ln(\frac{\chi_{\overline{z}} \widetilde{\tau}^a + f \widetilde{\tau}^{-a}}{1 + f \chi_{\overline{z}}}) - \frac{a\sigma}{1-\sigma} \ln(\frac{w}{w^*}) - a \ln(\lambda)}{\frac{a\sigma}{1-\sigma} \ln(\frac{r/w}{r^*/w^*}) + a \ln(A)}$, where $\chi_{\underline{z}} = \frac{R^*}{fR}$ and $\chi_{\overline{z}} = \frac{R^*}{fR}(\frac{f}{\widetilde{\tau}^a})^2$. The factor market clearing conditions for home country are

$$
\int_0^{\underline{z}} (1-z) \frac{b(z)(R+R^*)}{w} dz + \int_{\underline{z}}^{\overline{z}} (1-z) \frac{R_z}{w} = L, \quad \int_0^{\underline{z}} z \frac{b(z)(R+R^*)}{r} dz + \int_{\underline{z}}^{\overline{z}} z \frac{R_z}{r} = K.
$$

where R_z is given by equation (8.4). There are two similar equations for the foreign. So we have four equations to solve for the four unknown factor prices $\{w, w^*, r, r^*\}$.

Once $\{w, w^*, r, r^*\}$ are known, we compute domestic and foreign aggregate revenues R and R^*, the probability of export for each industry χ_z and the share of firms for each industry. This is done without the need to know other parameters of the model: $f_z, f_{zx}, f_{ez}, \delta$ and θ, which is shown in Appendix 9.5.

Then we compute our target moments $\frac{R^*}{R}$, exporter share for $z \geq 0.5$ and $z \leq 0.5$, capital intensity of all firms and capital intensity for all exporters. Our estimation takes $\{\frac{L^*}{L}, f, a, \sigma,\ b(z)\}$ as given and search for $\{\frac{K^*}{K}, \frac{K}{L}, A, \lambda, \tau\}$ to match these moments. In essence, there are basically two loops: an inter loop solving the factor prices and compute the model the moments, and an outer loop to search for model parameters that match the moments.

9.5 Identification

We first prove that given b(z), χ_z and $\frac{R^*}{R}$ only depend on $\{\frac{K^*}{K}, \frac{L^*}{L}, A, \lambda, a, f, \tau, \sigma\}$. Then we prove that firm mass distribution m_z depends on $\{\frac{K^*}{K}, \frac{L^*}{L}, A, \lambda, a, f, \tau, \sigma\}$ and $\frac{K}{L}$. Starting from factor market clearing condition, for sectors that are specialized by either country, we have

$$L_s = \int_0^{\underline{z}} l(z)dz = \frac{R+R^*}{w}\int_0^{\underline{z}}(1-z)b(z)dz = \frac{R+R^*}{w}N,$$

$$K_s = \int_0^{\underline{z}} k(z)dz = \frac{R+R^*}{r}\int_0^{\underline{z}}zb(z)dz = \frac{R+R^*}{r}B,$$

$$L_s^* = \int_{\overline{z}}^1 l^*(z)dz = \frac{R+R^*}{w^*}\int_{\overline{z}}^1(1-z)b(z)dz = \frac{R+R^*}{w^*}C,$$

$$K_s^* = \int_{\overline{z}}^1 k^*(z)dz = \frac{R+R^*}{r^*}\int_{\overline{z}}^1 zb(z)dz = \frac{R+R^*}{r^*}D,$$

where $N \equiv \int_0^{\underline{z}}(1-z)b(z)dz, B \equiv \int_0^{\underline{z}}zb(z)dz, C \equiv \int_{\overline{z}}^1(1-z)b(z)dz$ and $D \equiv \int_{\overline{z}}^1 zb(z)dz.$

For sectors that are produced by both countries, we have:

$$L_{int} = \frac{1}{w}\int_{\underline{z}}^{\overline{z}} b(z)(1-z)[\frac{R}{1-\widetilde{\tau}^{-a}\varepsilon^a fh(z)} - \frac{fR^*}{\widetilde{\tau}^a\varepsilon^a h(z)-f}]dz = \frac{R}{w}E - \frac{R^*}{w}F,$$

$$K_{int} = \frac{1}{r}\int_{\underline{z}}^{\overline{z}} b(z)z[\frac{R}{1-\widetilde{\tau}^{-a}\varepsilon^a fh(z)} - \frac{fR^*}{\widetilde{\tau}^a\varepsilon^a h(z)-f}]dz = \frac{R}{r}G - \frac{R^*}{r}H,$$

$$L_{int}^* = \frac{1}{w^*}\int_{\underline{z}}^{\overline{z}} b(z)(1-z)\varepsilon^a h(z)[\frac{R^*}{\varepsilon^a h(z)-f\widetilde{\tau}^{-a}} - \frac{fR}{\widetilde{\tau}^a-\varepsilon^a fh(z)}]dz = \frac{R^*}{w^*}I - \frac{R}{w^*}J,$$

$$K_{int}^* = \frac{1}{r^*}\int_{\underline{z}}^{\overline{z}} b(z)z\varepsilon^a h(z)[\frac{R^*}{\varepsilon^a h(z)-f\widetilde{\tau}^{-a}} - \frac{fR}{\widetilde{\tau}^a-\varepsilon^a fh(z)}]dz = \frac{R^*}{r^*}X - \frac{R}{r^*}Y,$$

where $E \equiv \int_{\underline{z}}^{\overline{z}}\frac{b(z)(1-z)}{1-\widetilde{\tau}^{-a}\varepsilon^a fh(z)}dz$, $F \equiv \int_{\underline{z}}^{\overline{z}}\frac{fb(z)(1-z)}{\widetilde{\tau}^a\varepsilon^a h(z)-f}dz, G \equiv \int_{\underline{z}}^{\overline{z}}\frac{b(z)z}{1-\widetilde{\tau}^{-a}\varepsilon^a fh(z)}dz, H \equiv \int_{\underline{z}}^{\overline{z}}\frac{fb(z)z}{\widetilde{\tau}^a\varepsilon^a h(z)-f}dz, I \equiv \int_{\underline{z}}^{\overline{z}}\frac{b(z)(1-z)\varepsilon^a h(z)}{\varepsilon^a h(z)-f\widetilde{\tau}^{-a}}dz, J \equiv \int_{\underline{z}}^{\overline{z}}\frac{fb(z)(1-z)\varepsilon^a h(z)}{\widetilde{\tau}^a-\varepsilon^a fh(z)}dz, X \equiv \int_{\underline{z}}^{\overline{z}}\frac{b(z)z\varepsilon^a h(z)}{\varepsilon^a h(z)-f\widetilde{\tau}^{-a}}dz$ and $Y \equiv \int_{\underline{z}}^{\overline{z}}\frac{fb(z)z\varepsilon^a h(z)}{\widetilde{\tau}^a-\varepsilon^a fh(z)}dz.$ Using fac-

tor market clearing condition,

$$L_s + L_{int} = L, K_s + K_{int} = K$$

$$L_s^* + L_{int}^* = L^*, K_s^* + K_{int}^* = K^*$$

We have

$$L = \frac{R}{w}(N + E) + \frac{R^*}{w}(N - F), K = \frac{R}{r}(B + G) + \frac{R^*}{r}(B - H)$$

$$L^* = \frac{R}{w^*}(C - J) + \frac{R^*}{w^*}(C + I), K^* = \frac{R}{r^*}(D - Y) + \frac{R^*}{r^*}(D + X)$$

Moreover, given $R = wL + rK$ and $R^* = w^*L^* + r^*K^*$, we have

$$\frac{R^*}{R} = \frac{1 - N - E - B - G}{N - F + B - H} = \frac{C + D - J - Y}{1 - C - D - X - I}.$$

Since N, B, C,..., I, J, X and Y only depend on $\{\frac{r^*}{r}, \frac{w^*}{w}, A, \lambda, a, f, \tau, \sigma\}^{46}$, according to the equation above, $\frac{R^*}{R}$ also depends on $\{\frac{r^*}{r}, \frac{w^*}{w}, A, \lambda, a, f, \tau, \sigma\}$ only.

Moreover,

$$\frac{L^*}{L} = \frac{w}{w^*}\frac{C - J + (C + I)\frac{R^*}{R}}{N + E + (N - F)\frac{R^*}{R}}$$

$$\frac{K^*}{K} = \frac{r}{r^*}\frac{(D - Y) + (D + X)\frac{R^*}{R}}{B + G + (B - H)\frac{R^*}{R}}$$

Then given $\{A, \lambda, a, f, \tau, \sigma\}$, there is an one to one mapping between $\{\frac{K^*}{K}, \frac{L^*}{L}\}$ and $\{\frac{r^*}{r}, \frac{w^*}{w}\}$.

So $\chi_z = \begin{cases} \frac{R^*}{fR} & z \in [0, \underline{z}] \\ \frac{\tilde{\tau}^{-a}f - \varepsilon^a h(z)}{\varepsilon^a f h(z) - \tilde{\tau}^a} & z \in (\underline{z}, \overline{z}) \end{cases}$ depends on $\{\frac{K^*}{K}, \frac{L^*}{L}, A, \lambda, a, f, \tau, \sigma\}$ only.

Next, we prove that firm mass distribution m_z depends on $\{\frac{K^*}{K}, \frac{L^*}{L}, A, \lambda, a, f, \tau, \sigma\}$ and $\frac{K}{L}$.

We define the firm mass distribution as

$$m_z = \frac{M_z}{\int_0^{\overline{z}} M_z dz}$$

For industries that home country specializes

$$b(z)(R + R^*) = M_z r(\widetilde{\varphi}_z)$$

$$= M_z \frac{a\sigma f_z r^z w^{1-z}(1 + f\chi_z)}{a + 1 - \sigma}$$

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[46]Given b(z), N, B, C, ..., I, J, X and Y are integrals of function of $\varepsilon^a h(z)$ defined over a intersection given by 0, $\underline{z}$, $\overline{z}$ and 1. $\varepsilon^a h(z)$, $\underline{z}$ and $\overline{z}$ are functions of $\{\frac{r^*}{r}, \frac{w^*}{w} \Psi, \lambda, a, f, \tau, \sigma\}$ only.

Thus

$$M_z\left(\frac{r}{w}\right)^z = \frac{b(z)(R+R^*)}{\frac{a\sigma f_z w}{a+1-\sigma}(1+f\chi_z)}$$

$$= b(z)L\frac{(1+\frac{rK}{wL})(1+\frac{R^*}{R})}{\frac{a\sigma f_z}{a+1-\sigma}(1+f\chi_z)}$$

Similarly, for industries that both countries produces:

$$M_z = \frac{b(z)L(1+\frac{rK}{wL})(1+\frac{R^*}{R})}{\frac{a\sigma f_z}{a+1-\sigma}(1+f\chi_z)(1+\frac{M_z^* r(\tilde{\varphi}_z^*)}{M_z r(\tilde{\varphi}_z)})(\frac{r}{w})^z}$$

Then, according to the definition of m(z), we have

$$m_z = \frac{M_z}{\int_0^{\bar{z}} M_z dz}$$

$$= \frac{b(z)L\frac{(1+\frac{rK}{wL})(1+\frac{R^*}{R})}{\frac{a\sigma f_z}{a+1-\sigma}(\frac{r}{w})^z(1+f\chi_z)}}{\int_0^{\underline{z}} b(z)L\frac{(1+\frac{rK}{wL})(1+\frac{R^*}{R})}{\frac{a\sigma f_z}{a+1-\sigma}(1+f\chi_z)(\frac{r}{w})^z}dz + \int_{\underline{z}}^{\overline{z}} \frac{b(z)L(1+\frac{rK}{wL})(1+\frac{R^*}{R})}{\frac{a\sigma f_z}{a+1-\sigma}(1+f\chi_z)(1+\frac{M_z^* r(\tilde{\varphi}_z^*)}{M_z r(\tilde{\varphi}_z)})(\frac{r}{w})^z}dz}$$

$$= b(z)\frac{(\frac{r}{w})^{-z}(1+f\chi_z)^{-1}}{\int_0^{\underline{z}} b(z)(\frac{r}{w})^{-z}(1+f\chi_z)^{-1}dz + \int_{\underline{z}}^{\overline{z}} \frac{b(z)(\frac{r}{w})^{-z}}{(1+\frac{M_z^* r(\tilde{\varphi}_z^*)}{M_z r(\tilde{\varphi}_z)})(1+f\chi_z)}dz}$$

for the industries that home specializes. As for industries that both countries produce:

$$m_z = \frac{M_z}{\int_0^{\overline{z}} M_z dz}$$

$$= b(z)\frac{\frac{(\frac{r}{w})^{-z}}{(1+\frac{M_z^* r(\tilde{\varphi}_z^*)}{M_z r(\tilde{\varphi}_z)})(1+f\chi_z)}}{\int_0^{\underline{z}} b(z)(\frac{r}{w})^{-z}(1+f\chi_z)^{-1}dz + \int_{\underline{z}}^{\overline{z}} \frac{b(z)(\frac{r}{w})^{-z}}{(1+\frac{M_z^* r(\tilde{\varphi}_z^*)}{M_z r(\tilde{\varphi}_z)})(1+f\chi_z)}dz}$$

It is obvious that m_z depends on $\frac{r}{w}$ which is determined by

$$\frac{r}{w} = \frac{L}{K}\frac{R(B+G)+R^*(B-H)}{R(N+E)+R^*(N-F)}$$

$$= \frac{L}{K}\frac{(B+G)+\frac{R^*}{R}(B-H)}{(N+E)+\frac{R^*}{R}(N-F)}$$

Thus $\frac{r}{w}$ depends not only on $\{\frac{K^*}{K}, \frac{L^*}{L}, A, \lambda, a, f, \tau, \sigma\}$ but also $\frac{K}{L}$. So does m_z.