

London School of Economics and Political Science

Three Essays on Firms and International Trade

Hanwei Huang

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Abstract

The first chapter of the thesis investigates the resilience of Chinese manufacturing importers to supply chain disruptions by exploiting the 2003 SARS epidemic as a natural experiment. I show both in theory and empirics that geographical diversification is crucial in building a resilient supply chain. I also find that reduction in trade costs induces firms to further diversify. Connectivity to the transportation network facilitates diversification in input sourcing and reduces the negative impact of SARS. Infrastructure is therefore useful not only in improving the efficiency of the economy, but also in increasing its resilience to shocks.

The second chapter studies how changes in factor endowments, technologies, and trade costs jointly determine structural adjustments, which are defined as changes in the distributions of production and exports. During 1999 to 2007, Chinese manufacturing production became more capital-intensive while exports did not. A structurally estimated Ricardian and Heckscher-Ohlin model with heterogeneous firms reconciles this seemingly puzzling pattern. Counterfactual simulations show that capital deepening made Chinese production more capital intensive, but technology changes that biased toward the labour-intensive sectors and trade liberalizations provided a counterbalancing force.

The last chapter examines how firm heterogeneity shapes comparative advantage. Drawing on matched customs and firm-level data from China, we find that export participation, exported product scope and product mix, and firm mix within industries vary systematically with firms' labour intensity. This is rationalized by a model in which firms from industries of comparative disadvantage face tougher competition in the export market. The competitive effect induces reallocation within and across firms and generates endogenous Ricardian comparative advantage, which dampens *ex ante* comparative advantage. Using sufficient statistics to measure and decompose comparative advantage, we find that the dampening mechanism is quantitatively important in shaping comparative advantage for a calibrated Chinese economy.

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Chapter 1

Germs, Roads and Trade: Theory and Evidence on the Value of Diversification in Global Sourcing

1.1 Introduction

Global sourcing has allowed firms to find the best input in a global market but also exposed them to foreign shocks. For example, the 2011 Tōhoku earthquake in Japan caused severe disruptions to affiliates of Japanese multinationals in the US (Boehm et al., forthcoming). Despite the conventional wisdom suggesting firms to diversify and the fact that firms are increasing the priority of supply chain management, there is little rigorous evidence on how diversification in global sourcing shapes the impact of supply chain disruptions on firms and the extent to which infrastructure affects the size of the impact.¹

In this paper I study the value of diversification in global sourcing for Chinese manufacturing importers by exploiting the 2003 SARS epidemic as a natural experiment. I show both theoretically and empirically that geographical diversification is crucial in building a resilient supply chain.² By doing this I make the following three contributions. First, I find that high productivity firms are more *geographically* diversified in input sourcing than low productivity firms. Second, I find that sourcing diversifications make firms more resilient to adverse shocks on sourcing if sourcing decisions exhibit complementarities across trade

¹More than 90% of the firms surveyed by the World Economic Forum (2012) indicated that supply chain and transport risk management had become a greater priority for them. A Financial Times article (2014) advocates that diversification is still at the heart of supply chain management. However, management and operation scientists mostly rely on simulations to evaluate supply chain disruptions and have problems estimating model parameters according to the review by Snyder et al. (2016).

²A firm is defined to be more resilient if pass-throughs of adverse shocks on trade routes to firm outcomes (such as marginal costs or revenues) are smaller. Ponomarov and Holcomb (2009) survey other notions of resilience.

routes. Finally, I find that connectivity to transportation networks increases sourcing diversification by inducing firms to source via more trade routes, which helps dampen the negative impact of adverse shocks.

The 2003 SARS epidemic provides the empirical setting to investigate supply chain disruptions. Unlike the recent outbreaks of Ebola and Zika, Severe Acute Respiratory Syndrome (SARS) was an unknown disease when it first struck southern China in late 2002. It rapidly hit several other countries/regions, and reached its peak in the second quarter of 2003. The epidemic ended in July 2003, after affecting more than 8,000 and taking away the lives of 774 people. The rapid spread, coupled with scant information disclosed by the Chinese government, shocked the global community. Major trading partners of mainland China such as Canada, Hong Kong, Taiwan and Singapore, and trade hubs in China such as Beijing and Guangdong were severely affected. Given its deadliness and infectiousness, governments took stringent measures to combat SARS, including travel bans,³ vessel controls at ports,⁴ and health check-points on roads, which inevitably disrupted trade. For example, the number of visitors to the 2003 spring session of Canton Fair, the largest trade fair in China, dropped by 81%, and the total business turnover dropped by 74% year-on-year.⁵

To guide the empirical analysis, I built a model in which firms source inputs from different origins via various trade routes to assemble final goods. When making sourcing decisions, a firm first chooses the trade routes. Conditional on its established routes, the firm then chooses imports across this set of routes. The model has the following key testable predictions. First, given the assumption that adding new trade routes incurs fixed costs, only high productivity firms can afford to source via more routes if sourcing decisions are complementary across trade routes. I further show that they are more diversified in sourcing than low productivity firms as measured by the Herfindahl-Hirschman Index which takes into account how intensively firms source inputs via each route. Second, more diversified firms are more resilient to adverse shocks if sourcing decisions are complementary across trade routes. I find that the pass-through of an adverse shock on trade routes to marginal cost is proportional to the input expenditure share of the route hit by the shock, which tends to be smaller for more diversified firms. The rise in marginal costs drives down input demands if sourcing decisions are complementary across trade routes.

³The World Health Organization (WHO) issued rare travel advice warning travellers against visiting regions with local outbreaks (Heymann, Mackenzie and Peiris, 2013).

⁴The WHO also provided guidelines to port authorities if cruise vessels had suspected cases on board. The number of vessels arriving in Hong Kong dropped by about 5% in the first half of 2003. A Malaysian chemical cargo vessel heading to Guangzhou was held in quarantine for 10 days when the crew members started developing SARS-like symptoms. More than two months elapsed before the sick crew members were given the all-clear.

⁵Source: Historical statistics of the Canton Fair.

Such a feedback effect from marginal cost to imports is again smaller for a more diversified firm. Finally, the model predicts that reduction in trade costs induces firms to further diversify by sourcing via more trade routes.

I test the model prediction on diversification and resilience by estimating the response of Chinese manufacturing firm imports to SARS using matched customs and firm-level data from 2000-2006. The data allow me to identify the date, the location of the importer, the Chinese entry customs, and the origin of each transaction. To capture the spatial and time variations of the epidemic, I construct a treatment variable which measures the exposure of Chinese importers to SARS by trade route. A trade route is defined as treated if the origin or the entry customs was on the WHO's list of areas with local SARS outbreaks. Since the model predicts that the pass-through of a trade cost shock into the route-specific import depends on the pre-shock input expenditure share of the affected route, I include an interaction term between the treatment variable and the average input expenditure share by trade route before SARS to capture such heterogeneous treatment effect. The baseline estimate implies that the average effect of the SARS shock on imports was about -7.9%. Crucially, the impact increased with the pre-SARS input expenditure share which suggests that sourcing decisions were complementary and diversification brought resilience. For a firm that solely relied on a route hit by SARS, my estimation implies that its imports would fall by as much as 52%.

More diversified firms saw smaller impacts on their route-specific imports, but the overall impact might not be smaller if a larger number of trade routes were affected. To see if that was the case, I use the model to account for the effect of SARS on other firm level outcomes. Despite the fact that I only observe firms' international sourcing behaviours which prevents me from fully identifying and estimating the model, I show that we can gauge the effect on firm marginal costs and outputs using a sufficient statistic approach.⁶ The idea is to combine the "hat algebra" approach (Jones, 1965; Dekle, Eaton, and Kortum, 2007) and the technique from Feenstra (1994).⁷ Using this new method, I find that the marginal cost of firms whose imports were hit by SARS increased by about 0.7% on average. The rise in marginal costs tended to be smaller for firms with more trade routes. Conversely, if pass-throughs were homogeneous, firms with more trade routes would be more heavily affected. Aggregating across firms, total Chinese manufacturing

⁶Sufficient statistic approach is increasingly popular in the trade literature, with most notable contribution by Arkolakis et al. (2012). Recent contributions include Blaum et al. (2016), and Fajgelbaum and Redding (2014).

⁷In a CES model, Feenstra (1994) found that we can estimate changes in the Sato-Vartia price index even if there are new or disappearing varieties as long as there are varieties which are available both before and after. Similarly, I estimate changes in firms' marginal cost relying on overlapping trade routes prior and post the shock.

output decreased by about 0.7% at the peak of SARS.⁸

The model predicts that high productivity firms are more geographically diversified which is confirmed by the data. Conditional on firm productivity, the model also predicts that firms' sourcing strategies expand weakly if trade costs decline. Therefore, improving infrastructures reduces trade costs and induces firms to become more diversified. This might make them more resilient to adverse shocks given the finding that diversification brings resilience. To test these model implications, I utilize the expansion of Chinese highway and railway networks from 2000-2006 and examine whether or not firms further diversify their sourcing strategy after connecting to railways or highways. Indeed, I find that firms located in regions connected to highways started to source via more trade routes, but connectivity to railways only had significant effects on the intensive margin. To deal with the potential endogeneity of highway or railway placements, I follow the "inconsequential unit approach" to exclude regions located on nodes of the transportation network and focus on the periphery regions (Chandra and Thompson, 2000). The effect of connectivity to transportation networks on diversification remains robust and significant. Finally, I provide evidence that connectivity to railways dampened the negative impact of SARS on imports for firms in the periphery regions while the effect of highway connection was insignificant.

I conduct various robustness checks on the baseline result. First, to deal with concerns over omitting export demand shocks, I extend the benchmark model by allowing firms to export, and derived a new structural equation incorporating export demand shocks. Guided by the extended model, I construct controls for export demand shocks. The estimated effect of export demand shocks turns out to be small and insignificant. Second, I ensure that the SARS shock was as good as random to firms in order to estimate its effect consistently. To test this assumption, I employ a Difference-In-Difference strategy to show that the growth trends of the never-treated and eventually-treated imports were similar before SARS. Third, to deal with concerns about the peculiar feature of processing trade and its prominence in Chinese imports, I estimate the response of importers Processing with Inputs (PI) and Pure Assembly (PA) importers, separately. PA firms do not decide where to source or own the imported inputs but must have written contracts approved by the customs authority in advance (Feenstra and Hanson, 2005). There is little scope for them to adjust sourcing in the face of SARS. Indeed, I find no significant treatment effect or differential treatment effect for PA firms, while the diversification channel still works for PI firms. Finally, I examine the possibility of alternative mechanisms cushion-

⁸It is about two thirds of the GDP loss estimated by Lee and McKibbin (2004) using a CGE model. I do not consider input-output linkages which could amplify the effect as in Carvalho et al. (2016).

ing firms from negative shocks. I construct variables to measure firms' inventories, access to finance and liquidity, and include them with the diversification channel. The diversification channel remains robust but these alternative mechanisms are insignificant. To deal with multi-plant firms diversifying productions in multiple locations, I focus on firms importing/exporting in a single location and find the diversification mechanism remains significant for them.⁹

Related Literature

My paper is related to several strands of the literature. It first contributes to studies on trade in intermediate inputs and global value chains. There is a large body of literature studying the productivity and welfare gains from sourcing foreign intermediate inputs (Hummels et al., 2001; Goldberg et al., 2010; Gopinath and Neiman, 2013; Halpern et al., 2015; Yu, 2015; Blaum et al., 2016). This paper builds on the work by Antràs, Fort, and Tintelnot (2017, hereafter AFT) and highlights another benefit of global sourcing, namely allowing firms to diversify their sourcing strategies and increase their resilience to adverse shocks.¹⁰ While firm heterogeneity has been shown to affect their organizational forms (Antràs and Helpman, 2004) and the productivity gains of sourcing (Blaum et al., 2016), I show that it also shapes firms' output volatilities and resilience to supply chain disruptions.¹¹

My study is also related to the literature on diversification and trade. The mechanism of my model is similar to the “technological diversification” channel in Koren and Tenreyro (2013). They show that it can explain the differential country-level output volatilities in a close-economy model with endogenous growth. I show how it can generate resilience to supply chain disruptions and heterogeneous firm-level volatility in open economies.¹² While only the extensive margin is active in their model, I look at diversification in both the intensive and extensive margins. Allen and Atkin (2016) investigate how the expansion of Indian highways has shaped farmers' revenue volatility and crop allocations through the lens of a model with risk-averse agents, but diversification is achieved by risk-neutral agents in my model. Similarly, using models with risk-averse agents, Fillat and Garetto (2015)

⁹Neither the firm survey nor the customs data report the number of plants that a firm has. I use a proxy which counts the distinct number of Chinese locations associated with each firm in the customs data.

¹⁰Similar to AFT, Bernard et al. (forthcoming), Blaum et al. (2016), and Furusawa et al. (2015) also study firms' extensive margin choice in sourcing but with different focuses from mine.

¹¹AFT investigates the heterogeneous response of US firms to a large long-term shock which increases the potential of China in supplying intermediate inputs. Berman et al. (2012) and Amiti et al. (2014) both study how firm heterogeneity matters for exporters' response to exchange rate shocks. I focus on importers' heterogeneous response to a negative temporal real shock.

¹²Di Giovanni and Levchenko (2012), and Caselli et al. (2014) study country-level volatility in open economies. Vannoorenberghe et al. (2016), Kurz and Senses (2016) also found firm-level volatilities are related to exporting and importing. Kramarz et al. (2016) examine diversification and the volatility of French exports, focusing on the role of micro and macro level shocks.

and Esposito (2016) examine demand diversifications for multinationals and exporters, respectively. I focus on diversification in sourcing and test its implication on the resilience of supply chains using a natural experiment.

The paper also contributes to the lively literature evaluating the impact of natural disasters or epidemics on economic activities (Young 2005; Hsiang and Gina 2014; Boehm et al., forthcoming; Barrot and Sauvagnat 2016; Carvalho et al. 2016). Similar to Boehm et al. (forthcoming), Barrot and Sauvagnat (2016), and Carvalho et al. (2016), I also study how shocks affect the rest of the economy or other economies through the input channel. The key difference is that I focus on firms' heterogeneous response and how diversification can serve as a mechanism to mitigate negative shocks. While the detrimental effect of Ebola on trade has been noted (FAO, 2016; World Bank, 2016), there is little concrete estimation of this effect. This paper is the first to evaluate the impact of an epidemic on trade in intermediate inputs.

Finally, the paper is related to studies on infrastructure and trade. While most of the literature focuses on how infrastructure reduces trade costs and brings productivity or welfare gains,¹³ my study highlights an additional benefit of better infrastructure, that is, allowing firms to diversify sourcing and increase their resilience to shocks. Similar effects of infrastructure are also featured in Burgess and Donaldson (2010, 2012) who find that the arrival of railways in India reduced the damage of weather shocks on local economies.

The remainder of the paper is organized as follows. Section 2 presents the motivating evidence. Section 3 sets up the model and develops its main predictions. Section 4 studies the resilience of firms to SARS. Section 5 accounts for the effect on marginal costs and revenues. Section 6 examines the effect of roads on diversification and resilience. Section 7 concludes.

1.2 Motivating Evidence

This section establishes three new stylized facts on global sourcing which motivates the theoretical model in the next section. I use two datasets to generate these facts. The first is the Chinese Annual Industry Survey (CAIS) for year 1999-2007. It covers all state owned enterprises and other firms with sales above 5 million Chinese Yuan (around US\$60,000). It provides firms' financial statements, name, address, phone number, post code, etc.. The other data that I use are the Chinese Customs data for year 2000-2006 which cover all Chinese import and export transactions. For each transaction, the data record the value, quantity, origin, destination, the Chinese customs district for clearance, and information

¹³Recent contributions include Donaldson (2018), Allen and Arkolakis (2014), Fajgelbaum and Redding (2014), Atkin and Donaldson (2014), Bernard et al. (forthcoming), and Baum-Snow et al. (2016).

about the Chinese import/export entity. There is no common identifier between these two datasets. I match them using firm name, post code, and phone number.¹⁴ Because my focus is the production of goods, I limit the sample to manufacturing firms. Firms with fewer than 8 employees are excluded since they operate under different legal requirements. I also exclude firms with negative outputs or fixed assets. The matched sample represents about 38% of all Chinese imports in 2000 and 46% of those in 2006.

1.2.1 Output Volatility and Sourcing Diversification

Since the customs data record the origin, destination, and customs district, I can track the geographical trajectory of each transaction.¹⁵ For example, a firm from Beijing can import from Japan via the Shanghai or the Tianjin customs district.¹⁶

The combination of a sourcing origin and a customs district forms a geographically distinct route for sourcing. Using this information, I first identify the set of trade routes used by each Chinese importer. I then measure sourcing diversification for each firm using the Herfindahl-Hirschman Index (HHI) which sums over the squares of input expenditure share of all routes, while the input expenditure share is measured by the share of route-specific inputs in total inputs. Since domestic sourcing is not observed in my data, HHI is assigned as one for non-importers. At the same time, CAIS allows me to compute the volatility of outputs for firms. Following Koren and Tenreyro (2013), I define output volatility as the variance of (real) sales growth rate during the period 1999 to 2007.¹⁷ Since this is a relatively short time series, I also use the customs data to generate a relatively long time series of firms' quarterly exports and compute the volatility of exports for exporters from 2000-2006.¹⁸ I then examine how sales and exports volatility are associated with firms' sourcing diversification and find:

Stylized fact 1: *Importers which are more geographically diversified in sourcing are less volatile.*

This can first be seen from Figure 1.1. Panel (a) plots a local polynomial regression of (log) firm level sales volatility on sourcing diversification measured by the average HHI

¹⁴This matching method has been used in various papers including Yu (2015), and Manova and Yu (2016).

¹⁵In the Chinese customs regulations, importers are required to report the border customs district through which goods are actually imported. For the goods transferred between customs districts, the name of the customs district at the entry point is reported. For more details, please refer to section III of the Chinese *Standards on Completion of Customs Declaration Forms for Import/Export Goods*.

¹⁶In total, China was divided into 41 provincial level customs districts during the sample period. The majority of these customs districts overlap the provincial borders (see Figure A3 in the Appendix). A full list of the customs districts is given in Appendix Table A18.

¹⁷The price index is from Brandt et al. (2012). I focus on the balanced panel and exclude entry and exit to insure that I have relatively longer time series to compute volatility.

¹⁸There is no product level price index for exports. Instead, I use output price index to deflate exports. The results are similar without deflating.

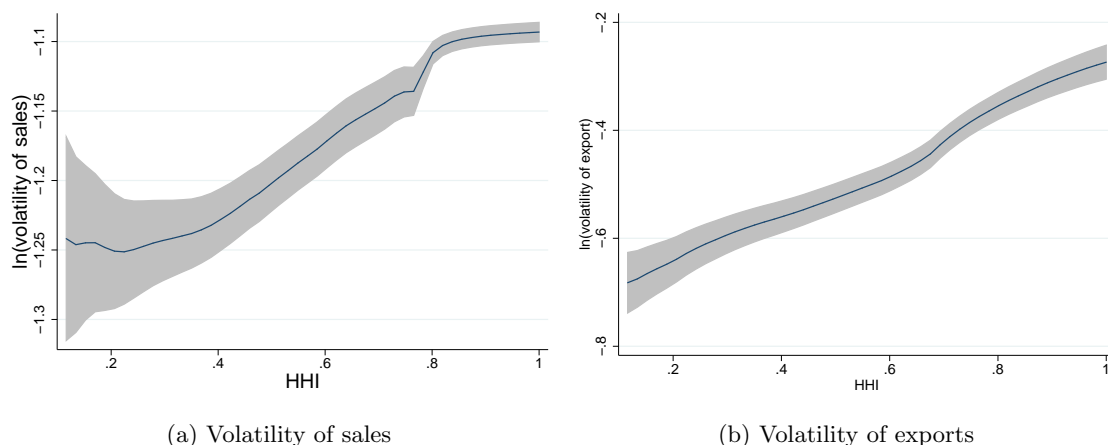


Figure 1.1: Sourcing diversification and firm-level volatility

between 2000 and 2006. Panel (b) looks at the volatility of exports and sourcing diversification. As can be seen, there is a general upward sloping trend in both figures: firms with more diversified sourcing strategies are associated with lower volatility. Of course, there may be confounders that lead to such a relationship. To handle such concern, I conduct a regression analysis regressing firms' output volatility on sourcing diversification, controlling for age, size in terms of average employment, and productivity measured in terms of average TFP during sample period for firms. I also control for diversification in the product margin by including the average number of imported products (Harmonized System 8 digit product), and geographically diversification on the demand side by adding the number of exporting routes used by the exporters. The results are shown in Appendix Table A7. The relationship remains stable: a higher HHI is associated with higher output volatility. It continues to hold when restricting the sample to importers and controlling for the number of products imported. The regressions on exports volatility lead to the same conclusion as in Appendix Table A8.

1.2.2 Customs District Heterogeneity and Gravity

Importers source inputs through geographically distinct customs districts. These customs districts show rich heterogeneity in terms of the number of firms they serve and the value of goods they process. This is captured in Figure 1.2 (a). The figure plots the share of Chinese imports through each customs district on the horizontal axis against the share of importers that import via each customs district on the vertical axis.¹⁹ The vertical axis captures the extensive margin while the horizontal axis captures both the intensive margin and the extensive margin. As is obvious from the figure, there are large variations between

¹⁹The sum of the values on the vertical axis does not add up to 1 because firms could import through multiple customs districts. The current result uses data from the year 2006 - results from other years are similar.

customs districts. The Shanghai customs district is the largest. Nearly 40% of Chinese importers import through Shanghai. Although the share of importers through Shenzhen is just about a third of Shanghai, the value of goods passing through is almost the same, about 20% of the total. Such divergence in the extensive margin and the intensive margin suggests that some customs districts may be easy to access but they are not as efficient in terms of sourcing foreign imports.

Part of Shanghai's advantage is probably its relatively central position on the Chinese coastline. Figure 1.2 (b) plots the share of firms importing via Shanghai for each prefecture city. Gravity clearly plays a role: there is a gradient originating from Shanghai. Closer firms are more likely to import through Shanghai. These findings can be summarized as:

Stylized fact 2: *Customs districts are heterogeneous in facilitating imports and firms tend to source via closer customs.*

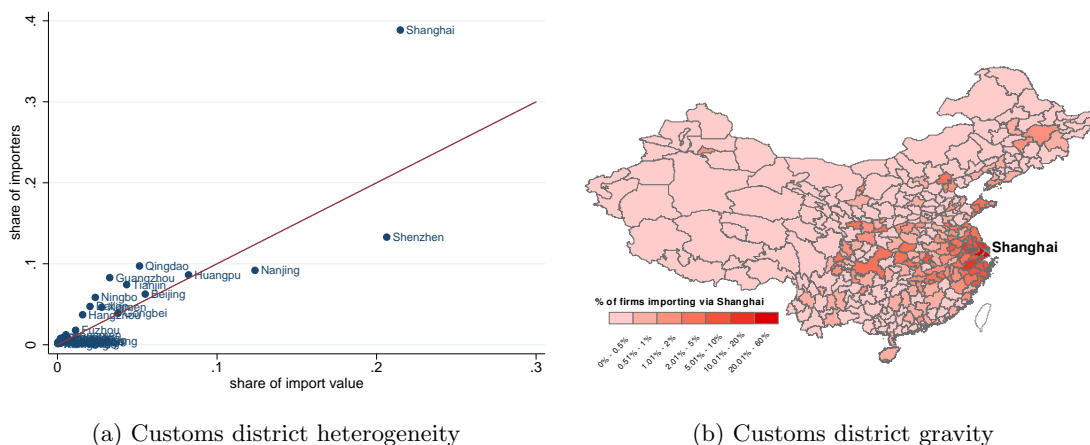


Figure 1.2: Customs district heterogeneity and gravity

1.2.3 Multi-customs-district Premium

Firms using different numbers of customs districts are also very different. Figure 1.3 (a) shows the distribution of customs use across importers. Importers using multiple customs districts are a minority but they import much more goods than single-customs-district importers. Only 30% of the importers import via more than one customs district. But they contribute about 60% of total imports. This suggests that the importers using multiple customs districts are probably larger. I next examine whether this is borne out by regression analysis.

It is well known that importers are larger than non-importers (Bernard, Jensen, Redding, and Schott, 2007; Kugler and Verhoogen 2009). AFT shows that the importer premium tends to rise with the number of countries that firms import from. I confirm this finding in the Chinese data and show that there is an additional premium: importers

importing through more customs districts tend to be larger and more productive. This is shown in Appendix Table A9 in which I use data from the year 2006 and regress firm characteristics on the number of customs districts that firms use, controlling for the number of origins. My focus is the dummies indicating the number of customs districts that importers use with single-customs-district firms as the benchmark group. Columns (1) to (4) focus on sales. Column (1) controls only for industry, prefecture and ownership fixed effects, and the premium of multi-customs-district firms is huge. Moreover, it increases with the number of customs districts. When the number of importing countries is included in column (2), which is the focus of AFT, the effect shrinks by around two thirds. Firm size as measured by employment is included in column (3). To address the concern that the premium could be due to multi-plant firms located in multiple customs districts, a measure controlling for multi-plant firms is added in column (4). Either CAIS or the customs data do not report the number of plants. Since the customs data report the destination and origin for each transaction, I count the number of distinct domestic destination/origin locations for each Chinese exporter/importer. If firms have separate plants in each location, this place count measure can be used to control for multi-plant firms. Adding this multi-plant measure, the premium decreases slightly but remains sizeable and significant. Similar results hold for imports in column (5), labour productivity as measured by real value added per worker in column (6) and Total Factor Productivity (TFP) in column (7).²⁰ The premium is also visualized in Figure 1.3 (b), with the dash lines indicating the 95% confidence intervals. The third stylized fact is summarized as:

Stylized fact 3: *Multi-customs-district sourcing firms are larger and more productive.*

In Appendix 1.C.1, I conduct various robustness checks on the premium, including an alternative measure for a multi-plant firm, excluding processing importers who are subject to place-based policy such as processing trade zone, and excluding importers from Guangdong province which is divided into seven customs districts. For all these robustness checks, the premium remains sizeable and highly significant. The premium is not particular to the year 2006 and found in data from other years as well.

1.3 Theoretical Framework

This section presents a model of global sourcing which reconciles the three stylized facts established in the previous section. More importantly, it provides theoretical predictions on sourcing diversification and resilience to supply chain disruptions, which will guide

²⁰I use the price indexes from Brandt et al. (2012) to construct real value added and real capital stock. TFP is estimated using the Levinsohn and Petrin (2003) method.

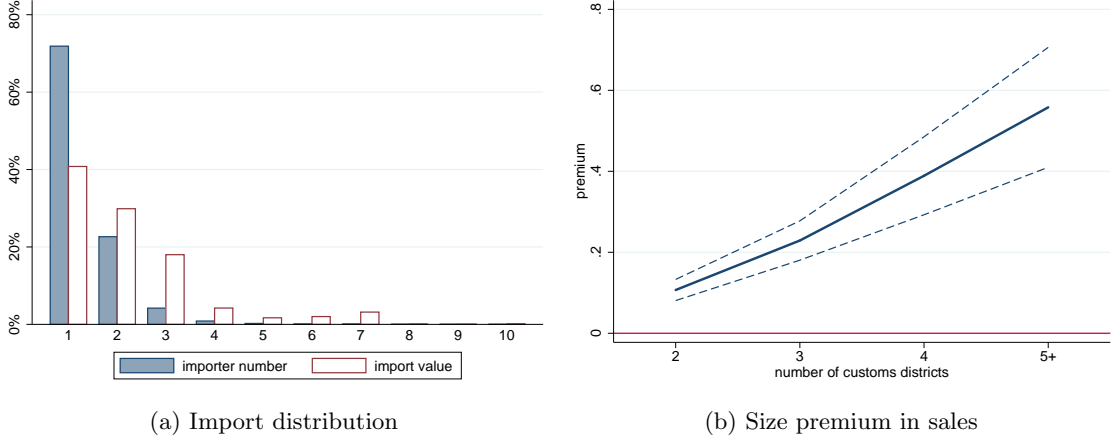


Figure 1.3: Multi-customs-district premium

my empirical analysis. I introduce multiple domestic regions, domestic trade costs, and customs services into the model by Antràs, Fort and Tintelnot (2017). While countries are singletons and goods arrive at factory doors directly in their model, the new features are necessary to identify domestic regions and customs districts hit by SARS. They also allow me to investigate the role of domestic infrastructure.

1.3.1 Demand

There are I regions at home. In each region, the representative consumer's preference for the manufacturing final goods is given by the following CES utility function

$$U_i = \left(\int_{\varpi \in \Omega_i} q(\varpi)^{\frac{\sigma-1}{\sigma}} d\varpi \right)^{\frac{\sigma}{\sigma-1}},$$

where $\sigma > 1$ is the demand elasticity, and Ω_i is the set of final-good varieties available at region i . The demand for final goods at region i is determined by

$$q_i(\varpi) = D_i p_i(\varpi)^{-\sigma},$$

where $D_i \equiv \frac{1}{\sigma} \left(\frac{\sigma}{\sigma-1} \right)^{1-\sigma} P_i^{\sigma-1} E_i$ is a region specific demand shifter; E_i and P_i are the local expenditure and price index, respectively; $p_i(\varpi)$ is the price of variety ϖ .

1.3.2 Production and Trade

The final-good producers compete in a monopolistically competitive market with free entry. They are endowed with a core productivity φ which is drawn from a distribution $G_i(\varphi)$, $\varphi \in [\bar{\varphi}_i, \infty]$. Following Melitz (2003), such productivity is learned only after paying the fixed entry cost of f_{ei} . To produce the non-tradable final goods, firms assemble

intermediate inputs which are sourced from intermediate input producers located in different origins. The bundle of intermediate inputs has a continuum of measure one and is assumed to have a symmetric elasticity of substitution ρ .²¹

While AFT assumes that the final-good producers trade directly with the intermediate input producers and there are no domestic trade costs, I assume that it requires customs services when sourcing the foreign inputs, and trade is also costly at home. The reason for making these assumptions is twofold. First, importers use services provided by the customs bureau at various stages of the transaction. Even services which are not directly provided by the customs bureau, such as searching for the right suppliers, translating documents, or making payments, are usually provided by intermediaries located in the vicinity of the customs bureau. The cost and efficiency of the service vary across customs districts, which can help explain the large customs district heterogeneity observed in the second stylized fact.²² Second, domestic trade costs are particularly high in developing countries. Atkin and Donaldson (2015) estimate that the distance elasticity for domestic trade costs is four to five times larger in Ethiopia or Nigeria than in the US. In the case of China, as pointed out by Young (2000), interregional competition leads to severe market segregation. It is important to understand how domestic trade costs shape firms' sourcing behaviour and how improvement in infrastructure might help firms in sourcing.

To keep the model as tractable as possible and at the same time retaining these additional features, I assume that firms' input sourcing follows a two-stage process, as illustrated in Figure 1.4. Intermediate inputs are first sourced by intermediaries located in each customs district. Inputs are then shipped to the final-good producers.²³ The iceberg trade costs of shipping inputs from origin k to the customs district j , and from j to the final destination i are denoted as τ_{jk} and τ_{ij} , respectively. In order to source inputs through trade route jk , the final-good producers from region i need to pay a fixed cost in terms of f_{ijk} units of labour in region i . I use $J_i(\varphi)$ to denote the set of customs districts, and $K_{ij}(\varphi)$ the set of origins for which the firm with productivity φ located in region i has paid the associated fixed cost of sourcing $w_i f_{ijk}$. I will refer $J_i(\varphi)$ and $K_{ij}(\varphi)$ as the *sourcing strategy*.

The intermediate input producers use constant return to scale technologies for production with labour as the only input, and sell their outputs competitively. At each origin, there is a continuum of intermediate input producers. The unit labour requirement is de-

²¹The assumption of non-tradable final goods is not crucial. It is relaxed later in one of the robustness checks. The measure of intermediate inputs can also be endogenized without changing the main predictions. Similar to AFT, ρ turns out to play little role in the model.

²²Customs broker is a typical type of intermediary. Alibaba, the largest Chinese B2B platform, provides an online platform for customs brokers. The prices and services listed vary across locations.

²³This is similar to the "hub and spoke" structure used by Head, Jing and Ries (2017) for sourcing. It also resembles the idea of international gateway in Coşar and Demir (2016).

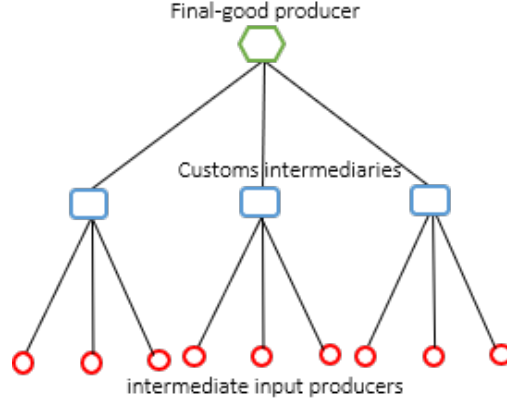


Figure 1.4: Illustration of firms' sourcing process

noted as $a_k(\varphi, v)$ for the input producer $v \in [0, 1]$ locating in region k who supplies inputs for a firm with productivity φ . Following AFT, I assume that the firm-specific $a_k(\varphi, v)$ is drawn from the following Fréchet distribution:

$$\Pr(a_k(\varphi, v) > a) = e^{-A_k a^\theta}, \quad A_k > 0,$$

where A_k is the average efficiencies of intermediate input producers from origin k . At each customs district, there is a continuum of intermediaries which use constant return to scale technologies providing the customs service. The unit labour requirement for the intermediary $\omega \in [0, 1]$ locating in customs district j trading with the firm having productivity φ is denoted as $b_j(\varphi, \omega)$. Again, it is assumed that $b_j(\varphi, \omega)$ is drawn from a Fréchet distribution:

$$\Pr(b_j(\varphi, \omega) > b) = e^{-B_j b^\theta}, \quad B_j > 0,$$

where B_j is the average efficiency of the intermediaries in customs district j . Under these assumptions, the marginal cost of firms is given by

$$c_i(\varphi) = \frac{1}{\varphi} \left(\int_0^1 [\tau_{ij} b_j(\varphi, \omega) w_j (\int_0^1 (\tau_{jk} a_k(\varphi, v) w_k)^{1-\rho} dv)^{\frac{1}{1-\rho}}]^{1-\rho} d\omega \right)^{\frac{1}{1-\rho}}.$$

1.3.3 Optimal Sourcing

The final-good producers' problem in sourcing has two layers: the sourcing strategy, i.e., the extensive margin problem in choosing which trade routes to be used in sourcing inputs, and the intensive margin, i.e., how much inputs to source from each route. I first solve the intensive margin problem for a given sourcing strategy, then characterize the optimal sourcing strategy.

The cost of sourcing input v from origin k via intermediary ω at customs district j to

destination i for firm φ is: $\tau_{ij}\tau_{jk}a_k(\varphi, v)b_j(\varphi, \omega)w_kw_j$. If $a_k(\varphi, v)$ and $b_j(\varphi, \omega)$ were learnt simultaneously and the final-good producer sought to $\min_{j,k}\{\tau_{ij}\tau_{jk}a_k(\varphi, v)b_j(\varphi, \omega)w_kw_j\}$, there is no explicit solution as in the Eaton-Kortum (2002) model. This is because the product of two Fréchet distributed random variables is not Fréchet distributed. To make progress, I impose the the following assumption on timing: the final-good producers do not observe the realized unit labour requirement at the origins when making the sourcing decision across customs districts; they can only predict these costs given the productivity distribution of potential suppliers in different origin countries.²⁴ Suppose the expected unit cost of intermediate inputs shipped to customs district j for firm φ is $c_i^j(\varphi)$. The customs district picked by final-good producer is determined by solving the following problem:

$$\min_{j \in J_i(\varphi)} \{\tau_{ij}b_j(\varphi, \omega)c_i^j(\varphi)w_j\}.$$

Since $1/b_j(\varphi, \omega)$ is Fréchet distributed, according to Eaton and Kortum (2002), the probability of sourcing through customs district j is given by

$$\chi_{ij}(\varphi) = \frac{B_j(\tau_{ij}w_jc_i^j(\varphi))^{-\theta}}{\sum_{l \in J_i(\varphi)} B_l(\tau_{il}w_l c_i^l(\varphi))^{-\theta}}. \quad (1.1)$$

The problem at customs district j in choosing intermediate input producers across origins is:

$$\min_{k \in K_{ij}(\varphi)} \{\tau_{jk}a_k(\varphi, v)w_k\}.$$

Again, given the Fréchet distributed $1/a_k(\varphi, v)$, the probability of sourcing from region k at customs district j is given by

$$\chi_{k|j}(\varphi) = \frac{A_k(\tau_{jk}w_k)^{-\theta}}{\Theta_j(\varphi)},$$

where $\Theta_j(\varphi) \equiv \sum_{n \in K_{ij}(\varphi)} A_n(\tau_{jn}w_n)^{-\theta}$. The expected unit cost $c_i^j(\varphi)$ is given by $c_i^j(\varphi) = (\gamma\Theta_j(\varphi))^{-\frac{1}{\theta}}$, where γ is a constant defined by the Gamma function. Similar to the Nested Logit model in discrete choice theory, the probability of sourcing from origin k using customs district j for final-good producer from region i with productivity φ , which I will call *sourcing intensity* for the rest of the paper, is given by:

$$\chi_{ijk}(\varphi) = \chi_{ij}(\varphi)\chi_{k|j}(\varphi) = \frac{B_j A_k (\tau_{ij}\tau_{jk}w_jw_k)^{-\theta}}{\Psi_i(\varphi)}, \quad (1.2)$$

²⁴Antràs and de Gortari (2017) make a similar assumption in a model of global value chain with multi-stage production. They show that this assumption of incomplete information with stage specific randomness is isomorphic to an alternative assumption of complete information but with randomness ascribed to the *overall costs* of a given route.

where $\Psi_i(\varphi) \equiv \sum_{l \in J_i(\varphi)} B_l \Theta_l(\varphi) (\tau_{il} w_l)^{-\theta} = \sum_{l \in J_i(\varphi), n \in K_{ij}(\varphi)} \phi_{iln}$ is the *sourcing capability* of the firm, and $\phi_{iln} = B_l A_n (\tau_{il} \tau_{ln} w_l w_n)^{-\theta}$ is the *sourcing potential* of origin n through customs district l . Then Equation (1.1) can also be rewritten as

$$\chi_{ij}(\varphi) = \frac{B_j \Theta_j(\varphi) \tau_{ij}^{-\theta} w_j^{-\theta}}{\Psi_i(\varphi)}.$$

Thus the customs districts which have lower costs trading with the destination are more likely to be used. This is consistent with Stylized fact 2 on customs district gravity. Following Eaton and Kortum (2002), the Fréchet assumptions implies that

$$c_i(\varphi) = \frac{1}{\varphi} (\gamma^2 \Psi_i(\varphi))^{-1/\theta}. \quad (1.3)$$

Up till now, the sourcing strategies given by $J_i(\varphi)$ and $K_{ij}(\varphi)$ have been taken as given. They are characterized by the following problem:

$$\max_{\substack{I_{ijk} \in \{0,1\} \\ j=1 \\ k=1}}^{J,K} \pi_i(\varphi, \{I_{ijk}\}_{j=1}^{J,K}) = D_i \varphi^{\sigma-1} (\gamma^2 \sum_{j=1}^{J,K} \sum_{k=1}^{J,K} I_{ijk} B_j A_k (\tau_{ij} \tau_{jk} w_j w_k)^{-\theta})^{\frac{\sigma-1}{\theta}} - w_i \sum_{j=1}^{J,K} \sum_{k=1}^{J,K} I_{ijk} f_{ijk}, \quad (1.4)$$

where I_{ijk} is an indicating variable, J and K are the total number of customs districts and origins that firms could potentially choose. I_{ijk} takes value 1 if $j \in J_i(\varphi)$ and $k \in K_{ij}(\varphi)$, that is $J_i(\varphi) \equiv \{j : I_{ijk} = 1\}$ and $K_{ij}(\varphi) \equiv \{k : I_{ink} = 1, n = j\}$. As noted by AFT, there is no explicit solution to Problem (1.4). A brute force approach requires an evaluation of 2^{JK} combinations of customs district and origin for each firm. Nonetheless, the solution has the following properties.

Proposition 1.1. *The optimal sourcing strategy $I_{ijk}(\varphi) \in \{0, 1\}_{j=1, k=1}^{J,K}$ is such that*

- (a) *a firm's sourcing capability $\Psi_i(\varphi)$ is non-decreasing in φ ;*
- (b) *if $\sigma - 1 > \theta$, $J_i(\varphi_L) \subseteq J_i(\varphi_H)$, $K_{ij}(\varphi_L) \subseteq K_{ij}(\varphi_H)$ for $\varphi_H \geq \varphi_L$;*
- (c) *if $\sigma - 1 > \theta$, $\Theta_j(\varphi)$ is non-decreasing in φ .*

Proof. See Appendix 1.A.1. □

Conclusion (a) implies that firms with higher core productivities φ have even lower marginal costs given their higher sourcing capabilities. In the case that $\sigma - 1 > \theta$, sourcing decisions are complementary. According to conclusion (b), there is a pecking order in firms' sourcing strategies.²⁵ It implies that high productivity firms are more likely to source not

²⁵For the case that $\sigma - 1 = \theta$, the sourcing decisions across different trade routes are independent. For the case that $\sigma - 1 < \theta$, they are substitutable. In both cases, the sourcing strategies of firms do not necessarily follow a pecking order according to AFT. In the rest of the paper, I focus on the more empirically relevant case that sourcing decisions are complementary. Later, I provide an estimate for $\sigma - 1 - \theta$ which turns out to be positive.

only from more origins but also via more customs districts. This is consistent with Stylized fact 3 that multi-customs-district importers are more productive.

1.3.4 Industry and General equilibrium

Following AFT, I assume that consumers spend a fixed share of their income η on the manufacturing final goods. The remainder is spent on an outside good which is homogeneous and freely tradable across regions. The outside good thus serves as numeraire and pins down the wage for each region. Wages are thus taken as given in solving the sectoral equilibrium for the manufacturing sector. Since entry is free:

$$\int_{\bar{\varphi}_i}^{\infty} \pi_i(\varphi) dG(\varphi) = w_i f_{ei},$$

the measure of final-good producers in each region can be pinned down as

$$N_i = \frac{\eta L_i}{\sigma \left(\int_{\bar{\varphi}_i}^{\infty} \sum_{j \in J_i(\varphi), k \in K_{ij}(\varphi)} f_{ijk} dG_i(\varphi) + f_{ei} \right)}.$$

1.3.5 The Gravity Equation

For a firm with productivity φ , if it sources inputs from origin k via customs district j , the corresponding import is given by

$$M_{ijk}(\varphi) = (\sigma - 1) D_i \varphi^{\sigma-1} (\gamma^2 \Psi_i(\varphi))^{\frac{\sigma-1}{\theta}} \chi_{ijk}(\varphi). \quad (1.5)$$

Then the total imports of all firms in region i from origin k via customs district j is given by

$$\begin{aligned} M_{ijk}(\varphi) &= N_i \int_{\bar{\varphi}_{ijk}} M_{ijk}(\varphi) dG(\varphi) \\ &= (\sigma - 1) D_i \gamma^{\frac{2(\sigma-1)}{\theta}} B_j A_k (\tau_{ij} \tau_{jk} w_j w_k)^{-\theta} \Lambda_{ijk}, \end{aligned}$$

where $\Lambda_{ijk} = \int_{\bar{\varphi}_{ijk}} I_{ijk}(\varphi) \varphi^{\sigma-1} \Psi_i(\varphi)^{\frac{\sigma-1-\theta}{\theta}} dG(\varphi)$, and $\bar{\varphi}_{ijk}$ is the productivity cut-off for firms located in region i picking route jk .

1.3.6 Diversification, Resilience, and Volatility

The previous results are direct extensions of AFT, this subsection presents *new* results on firms' diversification in sourcing, resilience to shocks on supply chains, and output volatility. Proposition 1.1 implies that high productivity firms tend to be more diversified along the extensive margin since they source from more trade routes. However, it is not

necessarily true that their inputs are less concentrated. For example, consider two firms A and B , firm A is using two trade routes with each contributing $\frac{1}{2}$ of total inputs, while firm B is using three routes with one contributing $\frac{3}{4}$, and the other two each contributing $\frac{1}{8}$. The concentration of A 's sourcing strategy measured by the HHI is $(\frac{1}{2})^2 + (\frac{1}{2})^2 = \frac{1}{2}$, and $(\frac{3}{4})^2 + 2(\frac{1}{8})^2 = \frac{19}{32} > \frac{1}{2}$ for B . So B looks more diversified by the extensive margin, but less diversified after taking the intensive margin into account. The following proposition rules out such a possibility.

Proposition 1.2. *If sourcing decisions are complementary across trade routes, that is $\sigma - 1 > \theta$, the concentration of firms' sourcing strategies as measured by the Herfindahl-Hirschman Index $HHI_i(\varphi) \equiv \sum_{j,k} \chi_{ijk}(\varphi)^2$ is non-increasing in φ .*

Proof. See Appendix 1.A.2. □

Therefore, high productivity firms are more diversified even after considering the intensive margin. The intuition is that if a certain trade route is dominant for a firm, it must be less or equally dominant for a more productive firm. This is because the high productivity firms have greater sourcing capability and more alternatives. For the example above, it cannot be that B 's most dominant option takes a share greater than $\frac{1}{2}$ when it has one more option than A .

So far, I have characterized the properties of the optimal sourcing strategy for given sourcing potentials and fixed costs. The following proposition considers a comparative statics on how the optimal source strategies respond to exogenous changes in these parameters.

Proposition 1.3. *If sourcing decisions are complementary across trade routes, that is $\sigma - 1 > \theta$, and market demands D_i are fixed, firms' sourcing strategies $J_i(\varphi)$ and $K_{ij}(\varphi)$ weakly expand whenever there is improvement in the sourcing potential $\vec{\phi}_i$ or reduction in the fixed costs of sourcing \vec{f}_i , where $\vec{\phi}_i' = \{\phi_{ijk}\}_{j=1,k=1}^{J,K}$ and $\vec{f}_i' = \{f_{ijk}\}_{j=1,k=1}^{J,K}$.*

Proof. See Appendix 1.A.3. □

The proposition implies that increasing sourcing potentials or reduction in the fixed costs of sourcing will induce firms to expand their sourcing strategies along the extensive margin.²⁶ The intuition behind the result is as follows. Since sourcing decisions are complementary, an increase of sourcing potential of any trade route is likely to raise the marginal benefit of including a route in the sourcing strategy. Reducing the cost of any

²⁶In a different model setup, Bernard et al. (forthcoming) discovers a similar result with respect to search costs and variable trade costs.

sourcing route is likely to lower the marginal cost of including a route. These make it more attractive for a firm to add a new route.

Now I examine the model prediction on firms' resilience to shocks. Resilience is measured by the pass-through of adverse shocks to firm performance. A firm is said to be more resilient if the pass-through is smaller. Since there is no explicit solution to the model, we might expect that it is difficult to know without numerical simulations. It turns out that we can gauge the effect without solving the whole model by using the "hat algebra" technique thanks to Jones (1965) and revitalized by Deckle, Eaton, and Kortum (2007). One complication is that my model has adjustments in the extensive margin. Firms can add or drop trade routes. In the Eaton-Kortum-type models, firms import from everywhere and there is only adjustment in the intensive margin. To solve the problem, I use a technique from Feenstra (1994) with which he estimates the welfare gains from new varieties. Applying his idea along with the hat algebra approach, I find:

Proposition 1.4. *For a small idiosyncratic trade cost shock which changes τ_{ijk} to τ'_{ijk} ($\tau_{ijk} \equiv \tau_{ij}\tau_{jk}$) such that the firm does not abandon route jk , we have:*

(a) *The pass-through to the marginal cost is given by*

$$\frac{\partial \ln(\widehat{c_i(\varphi)})}{\partial \ln(\widehat{\tau_{ijk}})} = \frac{\chi_{ijk}(\varphi)}{1 - \sum_{jk \in \mathcal{N}_i(\varphi)} \chi'_{ijk}(\varphi)},$$

where $\widehat{X} \equiv \frac{X'}{X}$ and $\mathcal{N}_i(\varphi)$ is the set of new routes chosen by the firm after the shock.

(b) *With complementarity of sourcing decisions across trade routes ($\sigma - 1 > \theta$) and adverse shocks ($\tau'_{ijk} \geq \tau_{ijk}$),*

$$\frac{\partial \ln(\widehat{c_i(\varphi)})}{\partial \ln(\widehat{\tau_{ijk}})} = \chi_{ijk}(\varphi),$$

$$\frac{\partial^2 \ln(\widehat{c_i(\varphi)})}{\partial \ln(\widehat{\tau_{ijk}}) \partial \varphi} \leq 0; \quad \frac{\partial^2 \ln(\widehat{c_i(\varphi)})}{\partial \ln(\widehat{\tau_{ijk}}) \partial \phi_{ijk}} > 0.$$

That is, high productivity firms are more resilient to adverse shocks, and firms are less resilient to shocks on more appealing trade routes.

Proof. See Appendix 1.A.4. □

The pass-through has two components according to conclusion (a): the intensive margin captured by $\chi_{ijk}(\varphi)$ and the extensive margin captured by $\frac{1}{1 - \sum_{jk \in \mathcal{N}_i(\varphi)} \chi'_{ijk}(\varphi)}$. Both depend on firm productivity φ .²⁷ However, it is difficult to know how pass-throughs vary with productivity φ for general shocks. Conclusion (b) instead focuses on adverse shocks

²⁷The pass-through depends only on the intensive margin and is homogeneous across all importers in Eaton-Kortum-type models with universal importing. Therefore, these models predict that firms are equally resilient.

which is more relevant to the discussion of resilience.²⁸ In this case, the pass-through depends only on the intensive margin. This is because no firms will add *new* trade routes facing adverse shocks, according to Proposition 1.3. The only possible adjustment along the extensive margin is to drop trade routes.²⁹ Then the term on extensive margin adjustment becomes $\frac{1}{1 - \sum_{jk \in \mathcal{N}_i(\varphi)} \chi'_{ijk}(\varphi)} = 1$ since $\sum_{jk \in \mathcal{N}_i(\varphi)} \chi'_{ijk}(\varphi) = 0$. The impact of the shock is determined by the intensive margin and increases with $\chi_{ijk}(\varphi)$. If the firm is not diversified at all, and solely relies on the trade route hit by the shock, the pass-through is 100%. Conclusion (b) tells us that the pass-through decreases weakly with firm productivity. This is because high productivity firms are more diversified and source from more places. Their load of inputs on any particular route is smaller, and so is the pass-through. It also tells us that the pass-through is larger for routes with higher sourcing potential. Due to the pecking order, firms agree on the ranking of trade routes. The more appealing routes take larger shares for every firm. Shocks on these routes have higher pass-throughs and are more detrimental to firms.

Marginal costs are usually not directly observable. To generate empirically testable predictions, I study how the easily observed firm-level import flows given by Equation (1.5), will respond to an adverse shock. The model delivers the following result.

Proposition 1.5. (a) *For a small trade cost shock which increase τ_{imn} to τ'_{imn} such that firms do not abandon route mn , import flows respond according to*

$$-\frac{\partial \ln \widehat{M}_{ijk}(\varphi)}{\partial \ln \widehat{\tau}_{imn}} = \begin{cases} \theta + (\sigma - 1 - \theta)\chi_{imn}(\varphi), & \text{if } m=j, n=k, \\ (\sigma - 1 - \theta)\chi_{imn}(\varphi), & \text{otherwise.} \end{cases}$$

(b) *If sourcing decisions are complementary across trade routes, the size of the pass-through to imports decreases weakly with firm productivity.*

Proof. See Appendix 1.A.5. □

Again, the pass-through endogenously depends on firm productivity φ . Other than the usual Fréchet shape parameter θ which captures the direct impact of the shock, there is an additional term $(\sigma - 1 - \theta)\chi_{imn}(\varphi)$ which is positive if sourcing decisions are complementary ($\sigma - 1 > \theta$), and negative if inputs are substitutable ($\sigma - 1 < \theta$). This additional term highlights the interdependencies across trade routes and disappears in the knife-edge case of no interdependencies ($\sigma - 1 = \theta$). The cost shock reduces firms' sourcing capability and increases their marginal cost according to Proposition 1.4. This drives down

²⁸The bottleneck problem is that we cannot characterize how the set of new routes $\mathcal{N}(\varphi)$ varies with φ . For a favourable shock, the pass-through is non-monotonic with respect to firm productivity which I discuss in the proof.

²⁹The situation here is to the opposite of Proposition 1.3. When the sourcing potential of a certain route declines, firms' sourcing strategies either shrink or remain the same.

marginal demand curve for all inputs if the sourcing decisions are complementary. Such a feedback effect through interdependencies amplifies the initial cost shock and reduce imports further. In contrast, if the inputs are substitutable, the cost shock reduces firm output and drives up the marginal demand curve. Such increase in the marginal demand for the input dampens the initial negative shock. This difference will allow me to identify whether sourcing decisions are complementary or substitutable.

The pass-through also varies the sourcing intensity $\chi_{ijk}(\varphi)$. The feedback effect is stronger if the firm has a heavier load on inputs from the route being shocked, which tends to be the case for a less diversified firm. Finally, the interdependency is also reflected by the result that imports also respond to shocks on other routes in the firm's sourcing strategy.

I have shown that more productive firms can be more resilient to adverse shocks in Proposition 1.4. However, since high productivity firms are sourcing from more places, they may also be more exposed to shocks. There is no guarantee that they are less volatile. The following proposition provides conditions under which high productivity firms are also less volatile.

Proposition 1.6. (a) *If the shocks on trade routes are not perfectly correlated and have the same variance ξ^2 , opening to trade lowers the volatility of firms' sourcing capabilities.*

(b) *If sourcing decisions are complementary across trade routes and the adverse shocks are i.i.d., the volatility of firm revenue is:*

$$\text{var}(\widehat{R}_i(\varphi)) \propto \xi^2 HHI_i(\varphi)$$

which weakly decreases with productivity φ .

(c) *The volatility of importers is the same under universal importing.*

Proof. See Appendix 1.A.6. □

While the literature has shown extensively that trade in intermediate brings productivity gains for firms (Goldberg et al., 2010; Halpern et al., 2015; Blaum et al., 2016; AFT, 2017), we know less about the effect on higher moments of firm performance and how they vary with firm productivity. Result (a) indicates a potential additional benefit of opening to trade for intermediate inputs: lower firm-level volatility. Caselli et al. (2015) illustrate that opening to trade can lower countries' aggregate volatility by allowing countries to diversify and reducing the exposure to domestic shocks. A similar mechanism is present in my model at the firm level except that I allow firms to add or drop trade routes while countries import from everywhere in their model. They emphasize that the mechanism

hinges on the size of variance and covariance across countries. This is still true in my model. If the variance of domestic sourcing potential is negligible compared with the variance of the foreign sourcing potentials, sourcing autarky actually would lead to lower volatilities.³⁰ Result (b) spells out a scenario that more geographically diversified firms are less volatile. It provides a theoretical explanation for Stylized fact 1. The channel relies on diversification since the variation of volatility is all loaded on the variation of HHI. In a model with universal importing such as Eaton-Kortum, result (c) implies homogeneity in the volatility of all importers, regardless of the underlying structure of shocks. This is at odds with Stylized fact 1 and highlights the importance of adjustment in the extensive margin in generating volatility heterogeneity across firms.

1.4 Diversification and Resilience to the SARS Epidemic

This section tests Proposition 1.5 on diversification and resilience by exploiting the 2003 SARS epidemic as a natural experiment. During my sample period, SARS was one of the most significant events which disrupted the supply chains of China.³¹ As I will argue, it was an unexpected exogenous shock to Chinese importers which made it more difficult for them to source inputs.

1.4.1 The SARS Epidemic

SARS was the first easily transmissible epidemic to emerge in the new millennium. It broke out in Southern China in November 2002 and ended in July 2003. It was an unknown disease which has respiratory symptoms similar to an influenza and could not be cured by existing antivirals and antibiotics at that time. Given its severity and infectiousness, governments and intergovernmental organizations took unprecedented measures to prevent it becoming a global pandemic (Heymann et al. 2013). Other than travel advice warning people against travelling to areas with local outbreaks, the WHO also issued procedures to hold cargo vessels in check at ports in case there were probable cases on board.³² The International Civil Aviation Organization (ICAO) set up the “Anti-SARS Airport Evaluation Project” to impose checks on flights from SARS infected areas.³³ These measures necessarily created frictions in the flow of people and goods. For example, the number of

³⁰This may explain why Kurz and Senses (2016) find that US importers are more volatile than non-importers. As a matured economy, US is probably less volatile than other countries.

³¹While Japan is one of the key suppliers for China and there are many recent studies on the effect of the 2011 earthquake (Boehm et al 2015; Todo, et al., 2015; Carvalho et al., 2016), my data do not cover this period.

³²For example, *Travel advice - Hong Kong Special Administrative Region of China, and Guangdong Province, China* was issued on 2 April 2003. *Procedures for prevention and management of probable cases of SARS on international cargo vessels* was issued on 23 May 2003.

³³ICAO Airport Evaluation for Anti-SARS Protective Measures.

air passengers around the Asia-Pacific dropped almost by 50% in the second quarter of 2003 compared with 2002 (Hollingsworth et al., 2006), while the freight traffic in Asia and North American stayed below the 2002 level for most of the year.³⁴

Important suppliers of mainland China such as Canada, Hong Kong, Taiwan, Singapore and Vietnam were severely affected. These five regions topped the list of SARS cases, just behind mainland China itself (see Appendix Table A17). Imports from these regions alone made up about 20.5% of all Chinese imports in 2002. SARS struck these regions on different dates and lasted for different periods, such spatial and time variations help to identify the effect of the epidemic. To capture these variations, I use lists of *Areas with recent local transmission of SARS* provided by the WHO which it identified as risky to travel to. These lists are summarized in Appendix Table A12, in which I indicate the period that each region was listed as risky. Using this list, I construct a dummy $SARS_{jk,t}$ indicating whether a trade route was hit by SARS or not at period t . It takes the value one as long as a Chinese customs district j or origin k remained on the list at time t .³⁵ Since the listing depended not only on the development of the epidemic but also the discretion of WHO, it is very likely to be exogenous to Chinese importers and their foreign suppliers.

1.4.2 The Resilience of Firms to SARS

Proposition 1.5 predicts that the effect of an adverse shock on imports varies with the pre-shock sourcing intensity. To capture such a differential treatment effect, I run the following regression:

$$\begin{aligned} \ln Import_{ijk}^{nt} = & D_i + C_j + O_k + F^{nt} + \sum_k b_k X_k^{nt} + \alpha_1 \chi_{ijk}^{n,t-1} \\ & + \alpha_2 SARS_{jk,t} + \beta \chi_{ijk}^{n,t-1} SARS_{jk,t} + \gamma CoSARS_{ijk}^{nt} + \epsilon_{ijk}^{nt}, \end{aligned} \quad (1.6)$$

in which I examine how firm n 's imports flowing from origin k through customs district j at time t , $Import_{ijk}^{nt}$, would respond if trade route jk was hit by SARS. The customs data are at monthly frequency which I aggregate to quarter-level to deal with the lumpiness of monthly data. According to Proposition 1.5, the pass-through depends on the sourcing intensity before shock $\chi_{ijk}^{n,t-1}$, which is measured by the average expenditure share of firm n for inputs from route jk before the SARS epidemic. I add an interaction term between the SARS shock $SARS_{jk,t}$ and the pre-SARS sourcing intensity $\chi_{ijk}^{n,t-1}$ to capture the heterogeneous pass-through, while controlling for the main effects. The main coefficient of interest is β . It has a structural interpretation of $-(\sigma - 1 - \theta)$ and is expected to be

³⁴IATA International Traffic Statistics: December 2003.

³⁵A customs district is defined as affected if its local province is on the list.

negative if sourcing decisions are complementary. I also control for the interdependence of trade flows across routes by adding a dummy $CoSARS_{ijk}^{nt}$ indicating whether other trade routes used by firm n were hit by SARS or not at period t . This is because Proposition 1.5 predicts that trade flows also respond to shocks hitting other routes. At the same time, I control for D_i the destination fixed effect, C_j the customs district fixed effect, and O_k the origin fixed effect, respectively. Finally, and most importantly, I control for firm characteristics X_k^{nt} and firm-time fixed effect F^{nt} to deal with idiosyncratic firm-level time-varying shocks, including demand shocks and disruptions in production due to the SARS epidemic.

The results are presented in Table 1.1, where I add the independent variables one by one. Unsurprisingly, the pre-shock sourcing intensity is positive and highly significant in all columns; trade flow is larger for routes with higher sourcing intensity. The main effect of the SARS shock is negative and highly significant as indicated in column (2). Firm imports fell by 7.9% on average if the route was hit by SARS. However, there are significant variations across firms and routes. The pass-through is much smaller for more diversified firms. When the interaction term between the sourcing intensity and SARS shock is introduced in column (3), the main effect of the SARS shock is reduced to about 5.6%, and the coefficient of the interaction term is negative and highly significant at -0.465. Then for a firm without any diversification before the epidemic such that $\chi_{ijk}^{n,t-1} = 1$, the overall effect of the SARS shock was $-0.0555 + (-0.465) * 1 = -0.52$. That is, its imports fell as much as 52%. In contrast, if the firm was very diversified such that $\chi_{ijk}^{n,t-1} \simeq 0$, the overall effect the SARS shock would just be the main effect at -5.6%. Moreover, the fact that the estimated β is negative implies $\sigma - 1 > \theta$, and the sourcing decisions are complementary. In column (4), I further include the dummy indicating whether other routes were hit by SARS or not to capture the interdependence across trade routes. The effect turns out to be very small and not significantly different from zero while the other coefficients remain robust.

1.4.3 Robustness Checks

Export Demand Shocks

So far, I have assumed that firms do not export, but in fact many importers are simultaneously exporters. If export demand shocks due to the SARS epidemic are correlated with import cost shocks, the omitted variable problem will lead to a bias in the estimation. To understand how export demand shocks translate into import demand, I extend the model and allow firms to export final goods following the Melitz (2003) setup. This is shown in

Table 1.1: Resilience of firms to the SARS epidemic

| Dependent Variable: | firm imports by route $\ln(\text{imp}_{ijk,t})$ | | | |
|---|---|------------------------|-----------------------|-----------------------|
| | (1) | (2) | (3) | (4) |
| pre SARS sourcing intensity | 9.461*** (0.0970) | 9.461*** (0.0970) | 9.493*** (0.0953) | 9.493*** (0.0953) |
| trade route hit by SARS=1 | | -0.0794*** (0.0229) | -0.0555** (0.0244) | -0.0557** (0.0241) |
| trade route hit by SARS=1 x pre SARS sourcing intensity | | | -0.465*** (0.133) | -0.464*** (0.133) |
| other routes hit by SARS=1 | | | | 0.00454 (0.0197) |
| firm-time FE | Y | Y | Y | Y |
| industry FE | Y | Y | Y | Y |
| ownership type FE | Y | Y | Y | Y |
| origin FE | Y | Y | Y | Y |
| destination FE | Y | Y | Y | Y |
| customs area FE | Y | Y | Y | Y |
| R^2 | 0.472 | 0.472 | 0.472 | 0.472 |
| No. of observations | 2019727 | 2019727 | 2019727 | 2019727 |

Notes: A trade route is a combination of an origin and a customs district. It is defined as hit by SARS if the origin or the customs district is listed by the WHO as regions with local transmission of SARS. The pre shock sourcing intensity is constructed as the route-specific input expenditure share averaged before the SARS epidemic. The numbers in parentheses are standard errors clustered at region-industry level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

Appendix 1.A.8. The key result is that the pass-through of a shock affecting both exports and imports to import flow is given by

$$-\frac{\partial \ln \widehat{M}_{ijk}(\varphi)}{\partial \ln \widehat{\tau}_{imn}} = \begin{cases} \theta + (\sigma - 1 - \theta)\chi_{imn}(\varphi) + (\sigma - 1)\mu_{imn}(\varphi), & \text{if } m=j, n=k, \\ (\sigma - 1 - \theta)\chi_{imn}(\varphi) + (\sigma - 1)\mu_{imn}(\varphi), & \text{otherwise,} \end{cases}$$

where $\mu_{imn}(\varphi)$ is the intensity of final goods exported through trade route mn , which captures the diversification on the demand side. The pass-through is smaller for a more diversified exporter who has a smaller share of goods exported through route mn . Moreover, if $\text{cov}(\chi_{imn}(\varphi), \mu_{imn}(\varphi)) > 0$ and $\sigma - 1 > \theta$, so that imports and exports are positively correlated, the effect of diversification in sourcing is overestimated when diversification on the demand side is omitted.³⁶ To control for export demand shocks, I follow the theory to add an interaction term between the epidemic shock and the pre-SARS export intensity for each route. The export intensity is constructed as the average share of outputs exported through each route before the epidemic. The results are presented in Appendix Table A1. Column (1) is the benchmark which only includes the sourcing diversification channel. Column (2) instead only includes the export diversification channel and omits the sourcing diversification channel. The coefficient for the export intensity is positive. So indeed firms tend to import more through the trade routes which have higher export

³⁶ $\sigma - 1 > \theta$ naturally implies $\sigma - 1 > 0$ because θ is greater than zero.

intensity. Moreover, the interaction term between the SARS shock and export intensity has a significant negative coefficient. Thus, without looking at sourcing diversification, it looks as if imports are more resilient when the export intensity is lower. However, only diversification on the import side matters when I put the two channels together in column (3): the magnitude of the interaction term between the SARS shock and export intensity drops dramatically and is not significantly different from zero. At the same time, the baseline result of sourcing diversification remains robust and significant.

Alternatively, we expect that importers who do not export should not be exposed to export demand shocks. In Appendix Table A14, I split the sample into exporters and non-exporters. For importers who do not export, the differential treatment effect remains robust and significant.³⁷

No Pre-Trend Assumption

Although I have controlled for a rich set of fixed effects and even firm-time fixed effect which should alleviate much concern on selection. It might still be of concern that the routes hit by SARS were selected within a firm in such a way that made them more or less resilient to the SARS shock. To show that this is not the case and the SARS shock was as good as random, I employ a Difference-In-Difference strategy to estimate firm imports by route, and include the interaction terms of the time dummies and the treated dummy, controlling for firm characteristics including firm size, age, and firm, industry fixed effects, ownership type, and origin-customs-destination fixed effects. A firm-route is defined as treated if it was eventually affected by SARS during the sample period. The coefficients for the interaction terms of the treated dummy and the time dummies are plotted in Figure 1.5. As we can see, there was no pre-existing trend before the epidemic.

Processing Trade

During the past three decades, China has adopted policies which encourage local firms to form processing trade relationships with foreign firms. Processing trade accounted for about half of total imports in the early 2000s (Yu, 2015). For Chinese processing traders, there are two important regimes (Feenstra and Hanson, 2005; Manova and Yu, 2016): processing with supplied inputs (PI) under which firms independently source and pay for imported inputs, and pure assembly (PA) under which firms receive inputs at no cost from foreign partners.³⁸ As argued by Feenstra and Hanson (2005), PA firms play little part

³⁷The effect is much larger than the full sample. But these non-exporters are less productive than the exporters. They are less diversified and should have higher pass-throughs.

³⁸As long as the finished outputs are re-exported, both types of processing trade are exempted from import duties. If the processed goods are sold domestically, the exempted import tariffs must be returned.



Figure 1.5: SARS on imports: difference-in-difference estimation

Notes: The figure plots the coefficients of the interaction terms of the time dummy and the treated dummies in a difference-in-difference regression on firm imports by route. A firm-route is treated if either the importing origin or the customs district was affected by SARS during the sample period. Dash lines indicate 95% confidence intervals while standard errors are clustered at firm level.

in sourcing and incur no costs using the imported inputs. Their sourcing decisions are at the discretion of their foreign partners. Moreover, the terms of the transaction with the foreign partner must be written in contracts and presented to the customs authority in advance. Given these institutional constraints, there is little scope for them to adjust their sourcing strategy in the face of unexpected shocks compared with normal firms. In contrast, PI firms take ownership of the imported inputs. They actively search for the right inputs and pay for the associated costs. Other than paying zero duties, the problem that PI firms face can still be described by my model. Thus their response to the SARS shock should still be in line with the model prediction.

To see whether this is the case, I examine the effect of SARS on *pure* PI processing importers and *pure* PA processing importers separately. These are processing firms that only engage in processing imports.³⁹ The results are presented in Appendix Table A2. Columns (1) and (2) include only the sample of PI importers while columns (3) and (4) include only the sample of PA importers. As expected, the response of PI firms is in line with the model. The coefficient of the interaction term is negative and significant, although the average effect is not significant. In contrast, the coefficient of the interaction term is positive but not significantly different from zero for PI firms. The main effect of the SARS is also not significantly different from zero. These results implies that the PA firms were not responsive in sourcing when affected by SARS, regardless of their diversification in sourcing.

³⁹I also examine importers who partially participate in processing imports. The results are qualitatively the same as presented in Appendix Table A13. As noted by Yu (2015), there are hybrid firms which have both PI imports and PA imports. To make the test as clean as possible, these hybrid firms are excluded.

Alternative Cushioning Mechanisms

Finally, I examine whether the diversification channel under examination is robust to alternative mechanisms that might make firms more resilient to the SARS shock. The main alternative channels that I consider include liquidity, finance, and inventory. The idea is that firms with more liquidity, better access to credit or more inventory may also be more resilient to the SARS shock. These favourable conditions provide buffers for firms to absorb and counteract adverse shocks. If these firms at the same time are also more diversified, I would overestimate the effect of diversification. To rule out such a possibility, I construct measures to capture these various channels. Following Manova and Yu (2016), I measure the liquidity available to each firm as $(\text{current assets} - \text{current liabilities})/\text{total assets}$. For access to credit, I use the leverage ratio which is measured as $\text{liabilities}/\text{assets}$. Finally, I use the ratio of the inventory in intermediate inputs relative to total intermediate inputs to capture the inventory channel. These variables are added as additional controls to the baseline regression. Since these measures are firm-year specific and will be fully absorbed by the firm-time fixed effect, the firm-time fixed effect is replaced by a county-time fixed effect. The results are presented in Appendix Table A3. Column (1) is the baseline which includes only the import diversification channel. Columns (2) to (4) focus on the alternative channels. Column (5) puts them together with the baseline channel. As we can see, these alternative channels do not appear have significant effect in cushioning the SARS shock on imports and the diversification channel remains significant.

There is concern that multi-plant firms, which produce in multiple locations and naturally import via more routes, are more resilient because of diversification in production. To deal with such concern, I focus on firms importing/exporting in a single location, which make up about 80% of the importers in my sample, and are likely to be single-plant firms. The results are presented in Appendix Table A15. The baseline result still holds for these firms importing/exporting in a single place, while the effect is not significant for firms with multiple importing/export locations.

1.5 Accounting for the Effect of the SARS Shock

SARS reduced imports, more strongly for less diversified firms. The question that remains unanswered is how much the SARS shock on imports had raised firms' marginal costs and reduced aggregate output. The lack of domestic sourcing data prevents me from doing a full-fledged structural estimation to uncover all underlying parameters. I have only estimated firms' response in the intensive margin. Despite these, as argued by Chetty (2009), sufficient statistic approach can bridge the gap between reduced form and struc-

tural estimation. The following proposition shows that answering the question requires only estimating the demand elasticity, observing the pre-shock sourcing behaviour, and the estimated effects on imports in the intensive margin.

Proposition 1.7. *If sourcing decisions are complementary across trade routes, the change in firms' marginal cost in the face of adverse shocks to inputs can be inferred as:*

$$\widehat{c}_i(\varphi) = \left(\sum_{j \times k \in \mathcal{C}(\varphi)} \chi_{ijk}(\varphi) \widehat{M}_{ijk}(\varphi) \right)^{\frac{1}{1-\sigma}},$$

where $\chi_{ijk}(\varphi)$ is the pre-shock sourcing intensity, $\widehat{M}_{ijk}(\varphi)$ is the estimated change in trade flow, σ is the demand elasticity, and $\mathcal{C}(\varphi)$ is the set of common routes used by the firm both before and after shocks.

Proof. See Appendix 1.A.7 □

Although marginal cost is not directly observable and cannot be easily estimated. This result tells us that $\chi_{ijk}(\varphi)$, $\widehat{M}_{ijk}(\varphi)$ and σ are *sufficient statistics* to estimate the effect of adverse shocks on marginal cost. $\chi_{ijk}(\varphi)$ is available from the data. $\widehat{M}_{ijk}(\varphi)$ can be calculated given the estimates from the previous section. The only unknown is the demand elasticity σ . As I have estimated, $\sigma - 1 - \theta = 0.464$ from the interaction term of Column (4) in Table 1.1 corresponds to the coefficient β in Equation (1.6). According to Proposition 1.5, β 's theoretical counterpart is $-(\sigma - 1 - \theta)$. If θ is estimated, σ can also be inferred. I next estimate θ by exploring firms' sourcing decision with respect to tariff variations across markets.

1.5.1 Estimating the Efficiency Dispersion Parameter θ

The key relationship that I use to estimate θ is $\chi_{ijk}(\varphi) = \frac{B_j A_k (\tau_{ij} \tau_{jk} w_j w_k)^{-\theta}}{\Psi_i(\varphi)}$, which is the sourcing intensity from origin k through customs district j for a firm in region i with productivity φ . Suppose $\chi_i^d(\varphi) \equiv \frac{\phi_i^d(\varphi)}{\Psi_i(\varphi)}$ is the intensity of domestic sourcing where $\phi_i^d(\varphi)$ is the capability of domestic sourcing, a ratio-type estimator can be formulated:

$$\begin{aligned} \ln \chi_{ijk}(\varphi) - \ln \chi_i^d(\varphi) &= \ln \frac{B_j A_k (\tau_{ij} \tau_{jk} w_j w_k)^{-\theta}}{\Psi_i(\varphi)} - \ln \frac{\phi_i^d(\varphi)}{\Psi_i(\varphi)} \\ &= \underbrace{\ln B_j w_j^{-\theta}}_{\text{customs FE}} + \underbrace{\ln A_k w_k^{-\theta}}_{\text{origin FE}} - \theta \ln \tau_{ij} - \theta \ln \tau_{jk} - \ln \phi_i^d(\varphi). \end{aligned} \quad (1.7)$$

AFT normalize $\phi_i^d(\varphi)$ to be the value one which implies that all importers have the same domestic sourcing capability. Hence $\ln \phi_i^d(\varphi) = 0$ and disappears from the equation

above. Since I observe the locations of firms and other firm variables, I allow it to vary cross firms by controlling for firm characteristics and firm fixed effect.⁴⁰

Compared with AFT, I also allow for domestic trade costs τ_{ij} and intermediation efficiencies at customs district $B_j w_j^{-\theta}$ to affect firms' sourcing behaviour. In the equation above, I control for $\ln B_j w_j^{-\theta}$ and $\ln A_k w_k^{-\theta}$ by customs fixed effect and origin fixed effect, respectively. For domestic and international trade costs, I assume that $\ln \tau_{ij}^\theta = \alpha_0 + \alpha_1 \ln \text{dist}_{ij} + \alpha_2 \text{comLang}_{ij} + \alpha_3 \text{comCustoms}_{ij} + \epsilon_{ij}$, and $\ln \tau_{jk}^\theta = \beta_0 + \beta_1 \ln \text{dist}_{jk} + \beta_2 \text{coCHN}_{jk} + \beta_3 t_k + \epsilon_{jk}$. Domestic distances dist_{ij} are measured in great circle distance between the prefecture where the firm is located and the importing customs district. The coordinates of the Chinese prefectures are measured in ArcGIS as the centroid of each prefecture. The coordinates of the customs districts are measured as the centroid of the major gateway city within the customs district.⁴¹ Distances between Chinese customs districts and sourcing origins dist_{jk} are measured in terms of great circle distances between the centroids of major gateways as well.⁴² comLang_{ij} is a dummy variable indicating whether the domestic destination i shares the same language as the customs district j . This variable is coded using the Language Atlas of China in Lively (2000) which provides data at county level. I further aggregate the data to prefecture city and customs district level. comCustoms_{ij} is a dummy indicating whether destination i is within the customs district j or not. It is meant to capture the trade costs imposed by the customs administrative boundaries. Next, since Rauch and Trindade (2002) find that ethnic Chinese networks facilitate trade between countries, I construct the variable coCHN_{jk} which is the share of ethnic Chinese in origin k multiplied by the share of overseas Chinese for customs district j . Historically, some Chinese regions such as Guangdong had more emigrants bound for other countries. These regions may have formed a better network with foreign suppliers and enjoyed lower trade costs than other regions in China. The share of ethnic Chinese for each origin is from Poston Jr et al. (1994).⁴³ The share of overseas Chinese for customs districts is constructed using the Chinese City Yearbook 1995. The Yearbook reports the number of overseas Chinese for each prefecture.⁴⁴ I aggregate it up to customs

⁴⁰Firms with high domestic sourcing capability are very likely to have high global sourcing capability. The global sourcing capability will be overestimated unless $\phi_i^d(\varphi)$ is controlled. Yet firms in regions with poor access to foreign markets may source more from the domestic market. In a different context, Baum-Snow *et al* (2016) show that domestic and foreign market access have different implications for Chinese urban growth.

⁴¹When there is more than one major gateway city, the minimum of the distances from the ports is used. The list of major gateways for each customs district is in Appendix A18.

⁴²For coastal countries, I identify the largest port. For inland countries, the capital city is used. I also seek a robustness check with maritime distance. It is computed as using a map of maritime shipping from Halpern et al. (2015) to extract the shortest path connecting the ports. I then calculate the length of the path. The result is quantitatively similar.

⁴³The sample used by Rauch and Trindade (2002) is limited to a smaller number of countries for which the gravity variables are available. I use the full sample from Poston Jr et al. (1994).

⁴⁴In the data they are called "Hua2qiao2" in Pinyin, which means 'overseas Chinese'.

district level and divide it by the local population. The result is reported in the last column of Appendix Table A18. Finally, I construct firm-market import tariffs using data from TRAINS following Fitzgerald and Haller (2014). The tariff is constructed as $t_k^n = \sum_p \frac{ps_t^n + ps_{t-1}^n}{2} \ln(1 + t_{k,p})$ where ps_t^n is the product share in firm n 's import basket at period t and $t_{k,p}$ is the import tariff imposed by China on product p from origin k . It varies by market since product tariffs vary by market. Such variations shift the cost of sourcing and allow me to identify the dispersion parameter θ .

In the end, the equation that I estimate is:

$$\begin{aligned} \ln \chi_{ijk}^n - \ln \chi_i^{d^n} &= a + C_j + O_k - \alpha_1 \ln dist_{ij} - \alpha_2 comLang_{ij} - \alpha_3 comCustoms_{ij} \\ &\quad - \beta_1 \ln dist_{jk} - \beta_2 coCHN_{jk} - \beta_3 \ln(t_k^n) + X_i^n \delta + F^n + \xi_{ijk}^n, \end{aligned}$$

where C_j and O_k are custom area and origin fixed effects respectively. Firm characteristics X_i^n and firm fixed effect F^n capture the unobserved domestic sourcing capability $\ln \phi_i^d(\varphi)$ in Equation (1.7). β_3 is the coefficient of interest which corresponds to θ . The results for the estimation using year 2006 data are reported in Appendix Table A4.⁴⁵ The main specification of interest is shown in Column (4) where we have $\hat{\theta} = 5.50$. This is close to the value in the literature as surveyed by Head and Mayer (2014). They find a median trade elasticity of 5.03 for structural estimations using tariff variations.⁴⁶ To address the concern that current product share is endogenous to current tariff in Fitzgerald and Haller (2014), I also use a tariff measure which only use the lagged product shares as weights. Instead of controlling for gravity variables, I use origin-customs district-destination fixed effect to fully absorb the iceberg trade costs. I also try other specifications and the elasticity remains robust as in the Appendix Table A16. Given the estimate that $\hat{\theta} = 5.50$, the demand elasticity is $\hat{\sigma} = 5.50 + 1 + 0.465 = 6.965$.

The estimated origin fixed effect captures the efficiency of each origin $\ln A_k w_k^{-\theta}$. I plot it against total imports from each origin in Appendix Figure A2 (a). The estimated customs district fixed effect captures the efficiency of each customs $\ln B_j w_j^{-\theta}$. Panel (b) plots it against total imports through each customs. Both show an upward sloping relationship. The estimated efficiency of Shenzhen is about 1.9 times higher than Shanghai. This probably partly explains why imports through Shenzhen were almost the same as Shanghai even though the number of importers imported via Shenzhen was just about 1/3 of Shanghai.

⁴⁵There was not much variation in import tariffs across markets for China before 2006. Most Chinese trade agreements took effect after 2005. Before that, China imposed homogeneous import tariffs across markets except several least developed African countries.

⁴⁶This is also their preferred value. AFT estimate θ using the variation in wages across sourcing origins and get a much lower elasticity at 1.789.

1.5.2 Effect of SARS on Firms' Marginal Cost and Aggregate Output

With the estimated demand elasticity σ , we can now estimate the effect on firms' marginal cost using Proposition 1.7. Using the estimated effect of SARS on imports from the previous section, I compute the point estimate of changes in imports by $\widehat{M}_{ijk}(\varphi) = \tilde{\alpha}_2 SARS_{jk,t} + \tilde{\beta} \chi_{ijk} SARS_{jk,t} + \tilde{\gamma} CoSARS_{ijk}^{nt}$ with $\tilde{\alpha}_2 = -0.0555$, $\tilde{\beta} = -0.464$, and $\tilde{\gamma} = 0.00454$ according to column (4) of Table 1.1. Figure 1.6 (a) plots the estimated changes in marginal cost against the number of trade routes for the affected firms.⁴⁷ The average effect on marginal cost is about 0.7%. Interestingly, there is a general downward sloping trend: firms sourcing from more routes appear less affected. However, if the homogeneous pass-through specification is used to compute $\widehat{M}_{ijk}(\varphi) = \tilde{\alpha}_2 SARS_{jk,t}$ where $\tilde{\alpha}_2 = -0.0794$ according to column (2) of Table 1.1, the result plotted in panel (b) shows an opposite trend: the more diversified firms appear less resilient. This highlights the role of heterogeneous pass-through in generating resilience for more diversified firms.

With the estimated effect on marginal cost, the effect on firm revenue is:

$$\widehat{R}_i(\varphi) = \widehat{c}_i(\varphi)^{1-\sigma}. \quad (1.8)$$

Therefore, given that $\sigma = 6.965$, an 1% increase in marginal cost translates to a loss of $(1 - \sigma)\% = -5.965\%$ in revenue.⁴⁸ Before showing the aggregate effect, I examine whether these firm-level revenue shocks are meaningful. I regress the actual firm revenue growth rates in year 2003 on the accumulated revenue shocks over the quarters that the firm was affected in 2003.⁴⁹ The result is shown in Table 1.2. Columns (1) to (3) include both importers and non-importers. Zeros are assigned for the accumulated shocks for non-importers. Columns (4) and (5) only include importers. As we can see, in all regressions, firms which had larger revenue shocks due to SARS had a lower growth rate in 2003. So the constructed shocks are indeed correlated with the actual growth rates.

I then aggregate the loss in revenue across firms using

$$\widehat{R} = \sum \frac{R_i(\varphi)}{R} \widehat{c}_i(\varphi)^{1-\sigma},$$

where $\frac{R_i(\varphi)}{R}$ is the observed output share of firm i from the data. This is computed for each quarter that SARS was affecting the Chinese economy, and the result is plotted in

⁴⁷The figure is generated using local polynomial regression, dropping the top 1% firms in terms of the number of trade routes used.

⁴⁸To the extent that σ might be different across firms, it has been investigated by Yeh (2016). He found that larger firms face smaller price elasticities. This is an additional channel that they might respond less to shocks.

⁴⁹Quarterly level firm outputs are not observable since CAIS reports firm revenues at annual frequency. I sum the inferred revenue shocks over the quarters that firms were affected. For example, if a firm had a revenue shock of 1% in Spring and 2% in Summer, the overall shock is 3%.

Figure 1.7. At the peak of the epidemic 2003Q2, SARS led to a loss of about 0.7% in Chinese manufacturing output. It quickly subsided to just 0.2% when the epidemic ended in 2003Q3.⁵⁰

Table 1.2: Verifying the firm level revenue shock

| Dependent Variable: | All Firms | | | Importers Only | |
|--|----------------------|-----------------------|-----------------------|----------------------|-----------------------|
| | (1) | (2) | (3) | (4) | (5) |
| firm revenue growth rate in year 2003 | | | | | |
| accumulated revenue loss due to SARS shocks on imports | -0.881*** (0.207) | -0.705*** (0.204) | -0.770*** (0.214) | -0.569*** (0.119) | -0.410*** (0.109) |
| ln firm age | | -0.319*** (0.0445) | -0.344*** (0.0472) | | -0.535*** (0.0787) |
| ln firm employment | | | 0.100*** (0.0305) | | 0.0415** (0.0197) |
| Prefecture FE | Y | Y | Y | Y | Y |
| industry FE | Y | Y | Y | Y | Y |
| Ownership FE | Y | Y | Y | Y | Y |
| R^2 | 0.00570 | 0.00614 | 0.00623 | 0.0573 | 0.0724 |
| No. of observations | 140081 | 140081 | 140081 | 11585 | 11585 |

Notes: The dependent variable is the the growth rate of firm revenue in 2003. Columns (1) to (3) include both importers and non-importers. Columns (4) and (5) only include importers. The numbers in parentheses are standard error clustered at industry-prefecture level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

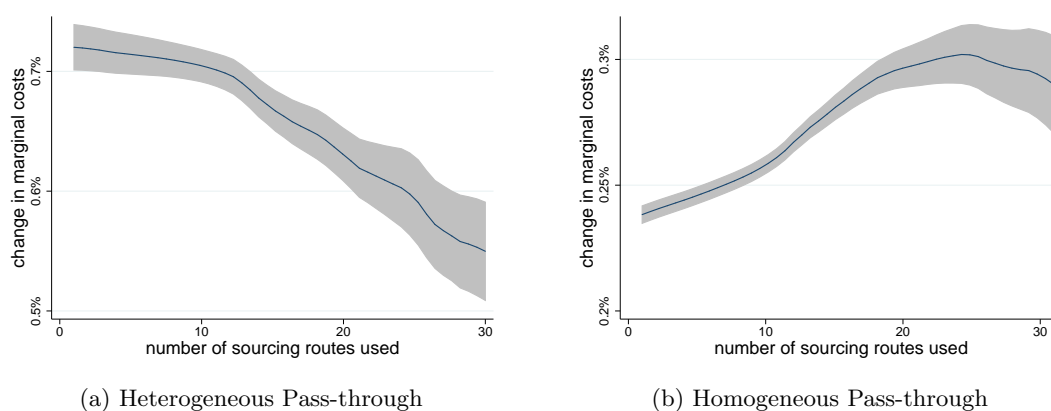


Figure 1.6: Effect on marginal costs

1.6 Roads, Diversification, and Resilience

I have provided evidence showing that sourcing diversification made firms more resilient to the SARS epidemic. But the questions remained are: (a) who are more diversified, and (b) can we improve firms' resilience by making them more diversified in sourcing? I will address these two questions in this section. Answering these two questions not only

⁵⁰Lee and McKibbin (2004) simulate a CGE model to estimate the economic impact of SARS. They find a reduction of Chinese GDP by 0.37%. Since manufacturing is about 32.5% of Chinese GDP in 2003, my estimation implies that GDP fell by $32.5\% \times 0.7\% = 0.23\%$ at the peak of SARS due to shocks on imports.

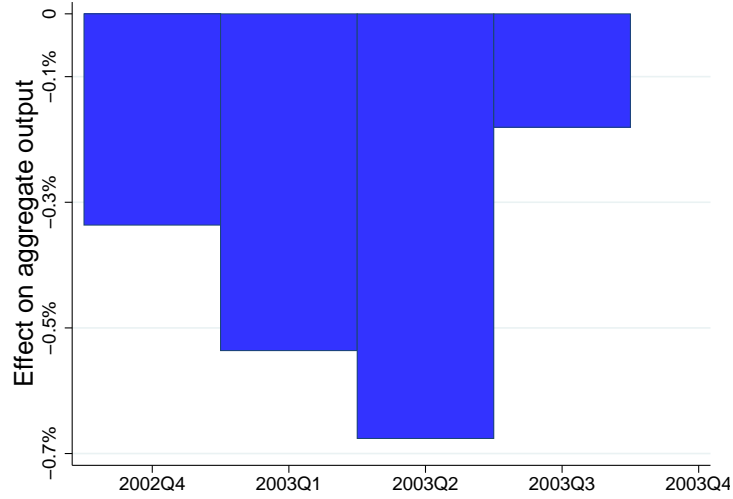


Figure 1.7: Effect on aggregate output

provides further tests on the model, but also helps us to identify barriers that keep firms from being resilient and find policies to improve their resilience.

1.6.1 Productivity and Diversification

Proposition 1.2 predicts that diversification depends on productivity: high productivity firms are more diversified as measured by the HHI of their sourcing diversification. To test this prediction, I run the following regression:

$$HHI_{nt} = a_0 + a_1 \ln F_{nt} + \sum_k \beta_k X_k^n + \epsilon_{nt},$$

where HHI_{nt} is the HHI of firm n at period t , F_{nt} is the firm productivity, and X_k^n includes other firm characteristics. a_1 is the main coefficient of interest. According to the proposition, we should expect $a_1 < 0$. As mentioned before, HHI is constructed as the sum over the squares of input expenditure share in each trade route for each firm.⁵¹ It is assigned as one for non-importers when I look at the full sample of firms since I do not observe domestic sourcing.

The results are reported in Table 1.3. Columns (1) and (2) use the full sample, including importers and non-importers. Columns (3) and (4) only look at importers. The controls include year, ownership, industry, and region fixed effects in all columns, and firm fixed effect in columns (2) and (4). Across all columns, we find that the estimated \hat{a}_1 is negative and highly significant. So indeed, consistent with the model, high productivity firms are more diversified in sourcing. This finding implies that it is important to control

⁵¹Following AFT, firms with imports more than its total inputs are excluded from the sample. Imports on fuels and mineral products are not counted. Wage bills are included as total inputs to address the concern on home sourcing.

for firm productivity when examining sourcing diversification.

Table 1.3: Firm productivity and diversification of sourcing: all firms

| Dependent Variable: | All Firms | | Importers Only | |
|---------------------------------|---------------------------|----------------------------|-------------------------|-------------------------|
| | (1) | (2) | (3) | (4) |
| sourcing diversification in HHI | | | | |
| ln TFP | -0.00839*** (0.000168) | -0.000853*** (0.000118) | -0.0835*** (0.00113) | -0.0223*** (0.00156) |
| Year FE | Y | Y | Y | Y |
| Ownership FE | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y |
| Region FE | Y | Y | Y | Y |
| Firm FE | N | Y | N | Y |
| R^2 | 0.367 | 0.860 | 0.160 | 0.597 |
| No. of observations | 1328727 | 1224458 | 185957 | 165863 |

Notes: The numbers in parentheses are standard error clustered at firm level. The number of observations varies across regressions as I use the *reghdfe* command in Stata which gets rid of singletons for fixed effects nested with each other. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

1.6.2 Roads and Diversification

I now examine the role of infrastructure, specifically railways and highways which have been shown to reduce trade costs (e.g., Donaldson, 2018), in shaping firms' sourcing diversification. According to Proposition 1.3, firms' sourcing strategies become more diversified along the extensive margin if there is reduction in trade costs. To test this proposition, I explore the expansion of the Chinese highway and railway network from 2000-2006. I examine whether firms in regions connected to highways or railways expand their sourcing strategies or not by running the following regression:

$$\ln(1 + N_{it}^n) = b_0 + b_1 Highway_{it} + b_2 Railway_{it} + \delta_i + \delta_n + \delta_t + \sum_k \beta_k X_k^{nt} + \zeta_{it}^n,$$

N_{it}^n counts the extensive margin of the sourcing strategy for firm n at period t . $Highway_{it}$ and $Railway_{it}$ are dummies indicating region i 's connection to highways and railways, respectively. δ_i , δ_n and δ_t capture region, firm, and time fixed effects, respectively. X_k^{nt} is added to control for various firm characteristics, including firm productivity. ζ_{it}^n is the error term.

To implement this regression, I construct dummies indicating whether or not a region was connected to highways or railways using China GIS data provided by the ACASIAN Data Center at Griffith University. The data provide year 1999 county boundaries and transportation data for the years 2000, 2004 and 2007. To construct the highway and railway network for each year between 2000 and 2006, I manually collect the opening date of Chinese highway and railway by section according to news reports, government reports,

and other online sources that I collect.⁵² The complete networks for years 2000 and 2006 are illustrated in Figure A4 and A5. As we can see, the railway network was already quite dense in 2000.⁵³ The highway network was mostly confined to the coastal provinces in 2000, but expanded quickly to most of the country in 2006. The geographical unit of my analysis is a county.⁵⁴ I use the region code in CAIS to identify the county that each firm is located.⁵⁵

The results presented in Appendix Table A5 include counts of customs districts, origins, and customs district-country pairs as outcome variables. Columns (1) to (3) use the full sample of importers. A well-known issue in the literature on infrastructure evaluation is the endogenous placement of roads. If roads were built to connect importers, the estimated effect would be upward biased. To handle this issue, I follow the “inconsequential unit approach” (Chandra and Thompson, 2000) to exclude firms located on the end nodes of the network.⁵⁶ The idea is that the unobserved characteristics of the units between the nodes of the network should be inconsequential to the placement the roads. These units got connected simply because they lie between the nodes. Thus I exclude importers located in urban units within each city and provincial capital cities, since highways or railways were built to connect these regions. The results are presented in columns (4) to (6). As is obvious across all the columns, connection to the highway increases the number of customs districts, sourcing origins, and customs district-origin pairs in importers’ sourcing strategy. The effect is significant and robust across different samples and outcomes. However, connection to railways does not appear to have a significant effect.

Although Proposition 1.3 only makes prediction about diversification along the extensive margin, firms are likely be more diversified as measured by HHI if they have a wider sourcing strategy. I expect firms got connected by highways or railways to have a lower HHI. This is formally tested by regressing HHI on dummies of highway and railway connections. The results are presented in Appendix Table A6. Connections to railways and highways are indeed associated with more diversification, as indicated in columns (1) to (3). In column (4), I show that the same result holds after excluding the firms from the urban units and provincial capitals. Although railways do not appear to have a significant effect on the extensive margin, they help firms to diversify when the intensive margin is taken into account.

⁵²If there is a conflict with ACASIAN data on the opening date, I follow the sources that I have collected.

⁵³The recent impressive development of high speed railways was mostly part of the stimulation package after the 2008 financial crisis.

⁵⁴The base map from ACASIAN combines the urban districts into a single urban unit for each prefecture. I include these urban units in my baseline result and exclude them in the robustness checks.

⁵⁵I use the region code (in Chinese) from the Ministry of Civil Affairs to link region codes over time.

⁵⁶Redding and Turner (2015) synthesise the literature that addresses the endogenous placement of roads.

1.6.3 Roads and Resilience

I have shown that diversification makes firms more resilient to the SARS epidemic and roads help to increase diversification. The remaining question is: do roads increase firms' resilience to the SARS epidemic? The idea is that if firms in regions with railway or highway connection are more diversified, this should make them more resilient. To see if this is the case, I run the following regression:

$$\ln Import_{ijk}^{nt} = c_0 + c_1 Highway_{it} + c_2 Railway_{it} + \gamma_0 SARS_{jk,t} + \gamma_1 Highway_{it} SARS_{jk,t} + \gamma_2 Railway_{it} SARS_{jk,t} + \sum \beta_k X_{kt}^n + \epsilon_{nt},$$

where $Highway_{it}$ and $Railway_{it}$ are the connection dummies and $SARS_{jk,t}$ is the dummy indicating whether route jk was affected by SARS or not at period t . The key coefficients of interest are γ_1 and γ_2 . If connectivity to roads indeed increases resilience, we expect them to be positive. The results are presented in Table 1.4. One difference from the previous section is that I cannot control for the firm-time fixed effect because the connectivity dummies $Highway_{it}$ and $Railway_{it}$ are defined at region-time level. Firm-time fixed effect and region-time fixed effect are fully multi-collinear with these dummies. Instead, I control for province-time fixed effect to handle demand or productivity shocks due to SARS.

Table 1.4: Roads and resilience

| Dependent Variable: | Full sample | | Excluding nodes of the road network | |
|---|------------------------|-----------------------|-------------------------------------|-----------------------|
| | (1) | (2) | (3) | (4) |
| firm imports by route $\ln(imp_{ijk})$ | | | | |
| trade route hit by SARS=1 | -0.0924*** (0.0195) | -0.168*** (0.0475) | -0.121*** (0.0244) | -0.198*** (0.0547) |
| highway connected=1 | | 0.0332 (0.0337) | | 0.000513 (0.0392) |
| trade route hit by SARS=1 x highway connected=1 | | 0.0476 (0.0388) | | 0.0382 (0.0434) |
| railway connected=1 | | 0.0414 (0.0357) | | 0.133** (0.0622) |
| trade route hit by SARS=1 x railway connected=1 | | 0.0432 (0.0307) | | 0.0637* (0.0350) |
| province-time, Destination, Origin, Customs, Ownership, Industry FE | Y | Y | Y | Y |
| R^2 | 0.111 | 0.111 | 0.123 | 0.123 |
| No. of observations | 2231882 | 2231882 | 1348241 | 1348241 |

Notes: A firm is defined as connected to highway if the county that the firm located is connected to the highway in each year. Columns (1) to (2) include full sample while columns (3) and (4) exclude firms located in urban units or provincial capitals. The numbers in parentheses are standard error clustered at industry and prefecture level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

The results are shown in Table 1.4. Column (1) shows the average effect of the SARS shock. Columns (2) study the connectivity to highways and railways. Both highways and

railways appear to dampen the effect of the SARS shock but the effect is not significant. When I exclude firms located in urban units and provincial capitals in column (4). The dampening effect of railways appears to be larger and marginally significant.⁵⁷ Overall, connection to railways reduced the negative impact of SARS on imports by about 6%. However, the effect of highway connectivity remains insignificant.

1.7 Conclusion

This paper studies how diversification shapes firms' resilience to supply chain disruptions. The Chinese firms which are more geographically diversified in their input sourcing appear less volatile. However, diversification is not a free lunch. Gravity drags firms to source through closer customs districts. Only the more productive firms manage to source through more customs districts. I build a model to account for these facts based on the work by Antràs, Fort, and Tintelnot (2017). The model predicts that high productivity firms are more diversified, hence more resilient to adverse shocks if sourcing decisions are complementary across trade routes. It also predicts that trade liberalization or improvement in infrastructure facilitates diversification. I explore the 2003 SARS epidemic as a natural experiment to test the model predictions and find that, the damage on imports is indeed smaller if the firm is more diversified hence need not rely so much on trade routes hit by SARS. Moreover, connection to highways and railways appears to facilitate diversification in sourcing and reduce the impact of the SARS shock. This is a benefit of infrastructure that should not be overlooked by policy makers.

⁵⁷To contain the spread of SARS, local Chinese governments set up check-points on highways to examine the temperature of drivers and passengers. While such checks were also applied to passengers travelling by railway before boarding, they were unlikely to disrupt trains, which follow fixed schedules, especially those only carrying goods. In contrast, so many check-points were set up on roads that the Ministry of Public Security had to issue an executive order called "Five Forbidden Practices" (in Chinese) in May 2003: no interruptions of traffic were allowed in the name of fighting against SARS; no traffic controls at provincial borders; no road blocks to stop traffic; no forced U-turns for vehicles in the normal course; and no traffic jams in the name of quarantine. Such a difference probably explains the different effect of railways and highways connection.

Appendix

1.A Proofs

1.A.1 Proof of Proposition 1.1

Suppose there are two firms from region i with different productivities which are denoted as φ_H and φ_L such that $\varphi_H > \varphi_L$. Their sourcing strategies are given by $\mathcal{I}_i(\varphi_H) = \{\{j, k\}, I_{ijk}(\varphi_H) = 1\}$ and $\mathcal{I}_i(\varphi_L) = \{\{j, k\}, I_{ijk}(\varphi_L) = 1\}$ respectively. If $\mathcal{I}_i(\varphi_H) = \mathcal{I}_i(\varphi_L)$, conclusion (a) naturally holds as it implies $\Psi(\varphi_H) = \Psi(\varphi_L)$. On the other hand, if $\mathcal{I}_i(\varphi_H) \neq \mathcal{I}_i(\varphi_L)$, it must be the case that:

$$D_i \varphi_H^{\sigma-1} (\gamma^2 \Psi(\varphi_H))^{\frac{\sigma-1}{\theta}} - \sum_{\{jk\} \in I_{ijk}(\varphi_H)} f_{ijk} > D_i \varphi_H^{\sigma-1} (\gamma^2 \Psi(\varphi_L))^{\frac{\sigma-1}{\theta}} - \sum_{\{jk\} \in I_{ijk}(\varphi_L)} f_{ijk},$$

$$D_i \varphi_L^{\sigma-1} (\gamma^2 \Psi(\varphi_L))^{\frac{\sigma-1}{\theta}} - \sum_{\{jk\} \in I_{ijk}(\varphi_L)} f_{ijk} > D_i \varphi_L^{\sigma-1} (\gamma^2 \Psi(\varphi_H))^{\frac{\sigma-1}{\theta}} - \sum_{\{jk\} \in I_{ijk}(\varphi_H)} f_{ijk}.$$

Combining the two inequalities above, we have

$$D_i \gamma^{\frac{2(\sigma-1)}{\theta}} (\varphi_H^{\sigma-1} - \varphi_L^{\sigma-1}) (\Psi(\varphi_H)^{\frac{\sigma-1}{\theta}} - \Psi(\varphi_L)^{\frac{\sigma-1}{\theta}}) > 0.$$

Since $\varphi_H > \varphi_L$ and $\sigma > 1$, it must be the case that

$$\Psi(\varphi_H) > \Psi(\varphi_L).$$

So conclusion (a) is established.

For conclusion (b), we note that if $\sigma - 1 > \theta$, the profit function specified in problem (1.4) features increasing differences in (I_{ijk}, I_{imn}) , with $j \neq m$ or $k \neq n$. It also features increasing differences in (I_{ijk}, φ) for any j and k . Using the Topkis's monotonicity theorem, we conclude that $I_{ijk}(\varphi_H) \geq I_{ijk}(\varphi_L)$ for any $\varphi_H \geq \varphi_L$. It naturally implies $J_i(\varphi_L) \subseteq J_i(\varphi_H)$ and $K_{ij}(\varphi_L) \subseteq K_{ij}(\varphi_H)$.

Then from the definition of $\Theta_j(\varphi) \equiv \sum_{n \in K_{ij}(\varphi)} A_n (\tau_{jn} w_n)^{-\theta}$, given that $K_{ij}(\varphi_L) \subseteq$

$K_{ij}(\varphi_H)$, naturally we have

$$\Theta_j(\varphi_H) \geq \Theta_j(\varphi_L)$$

which is conclusion (c).

1.A.2 Proof of Proposition 1.2

Since the sourcing decisions are complementary, firms' sourcing strategies follow a pecking order. Suppose the sourcing potential of trade routes faced by firms in region i are ranked as $\phi_{i1} \geq \phi_{i2} \geq \dots \geq \phi_{iN}$. The least productive firm would only source from option 1 and its $HHI_1 = 1$. For two firms with different sourcing strategies such that one is sourcing from n options while the other is sourcing from $n+1$, their HHI for sourcing are $HHI_n = \frac{\sum_{s=1}^n \phi_{is}^2}{(\sum_{s=1}^n \phi_{is})^2}$ and $HHI_{n+1} = \frac{\sum_{s=1}^{n+1} \phi_{is}^2}{(\sum_{s=1}^{n+1} \phi_{is})^2}$, respectively. Therefore, we have

$$\begin{aligned} HHI_{n+1} - HHI_n &= \frac{(\sum_{s=1}^{n+1} \phi_{is}^2)(\sum_{s=1}^n \phi_{is})^2 - (\sum_{s=1}^n \phi_{is}^2)(\sum_{s=1}^{n+1} \phi_{is})^2}{(\sum_{s=1}^n \phi_{is})^2(\sum_{s=1}^{n+1} \phi_{is})^2} \\ &= \frac{\phi_{in+1}^2(\sum_{s=1}^n \phi_{is})^2 - \phi_{in+1}^2 \sum_{s=1}^n \phi_{is}^2 - 2\phi_{in+1}(\sum_{s=1}^n \phi_{is})(\sum_{s=1}^n \phi_{is}^2)}{(\sum_{s=1}^n \phi_{is})^2(\sum_{s=1}^{n+1} \phi_{is})^2} \\ &= \frac{\phi_{in+1}(\sum_{s=1}^n \phi_{is})[\sum_{s=1}^n \phi_{in+1}\phi_{is} - \sum_{s=1}^n \phi_{is}^2] - \phi_{in+1}^2 \sum_{s=1}^n \phi_{is}^2 - \phi_{in+1}(\sum_{s=1}^n \phi_{is})(\sum_{s=1}^n \phi_{is}^2)}{(\sum_{s=1}^n \phi_{is})^2(\sum_{s=1}^{n+1} \phi_{is})^2}. \end{aligned}$$

Since $\phi_{is} \geq \phi_{in+1}$, it must be the case that $\phi_{is}^2 \geq \phi_{in+1}\phi_{is}$, $\forall s \leq n$. Then we have $\sum_{s=1}^n \phi_{in+1}\phi_{is} \leq \sum_{s=1}^n \phi_{is}^2$. Thus the first term in the numerator of the third line in the equation above is non-positive. Given that the other two terms are also negative, the numerator of the third line must be negative. Thus we have

$$HHI_{n+1} < HHI_n,$$

and the concentration of the sourcing strategy tends to lower for more productive firms.

1.A.3 Proof of Proposition 1.3

If sourcing decisions are complementary across trade routes ($\sigma - 1 > \theta$), the profit function specified in problem (1.4) features increasing difference between (I_{ijk}, ϕ_{imn}) between any $j \neq m, k \neq n$. It also features increasing difference between $(I_{ijk}, -f_{imn})$ between any $j \neq m, k \neq n$. Again, using the Topkis's monotonicity theorem, we have $I_{ijk}(\vec{\phi}'_i) \geq I_{ijk}(\vec{\phi}_i)$ for $\vec{\phi}'_i > \vec{\phi}_i$. Naturally, it implies $J_i(\varphi, \vec{\phi}_i) \subseteq J'_i(\varphi, \vec{\phi}'_i)$, $K_{ij}(\varphi, \vec{\phi}_i) \subseteq K'_{ij}(\varphi, \vec{\phi}'_i)$.

Similarly, we have $I_{ijk}(\vec{f}'_i) \geq I_{ijk}(\vec{f}_i)$ for $\vec{f}'_i < \vec{f}_i$ which implies $J_i(\varphi, \vec{f}_i) \subseteq J'_i(\varphi, \vec{f}'_i)$, $K_{ij}(\varphi, \vec{f}_i) \subseteq K'_{ij}(\varphi, \vec{f}'_i)$.

1.A.4 Proof of Proposition 1.4

According to Equation (1.3), in case there is any shock to any supplier, the change in unit cost for the firm is given by

$$\hat{c}_i \equiv \frac{c'_i}{c_i} = \widehat{\Psi}_i(\varphi)^{-\frac{1}{\theta}}.$$

Thus, we have:

$$\frac{\partial \ln \hat{c}_i}{\partial \ln \widehat{\Psi}_i(\varphi)} = -\frac{1}{\theta}. \quad (\text{E.1.1})$$

On the other hand, we have

$$\widehat{\Psi}_i(\varphi) \equiv \frac{\sum_{j \in J'(\varphi), k \in K'(\varphi)} \phi'_{ijk}}{\sum_{j \in J(\varphi), k \in K(\varphi)} \phi_{ijk}}.$$

Suppose $\Omega(\varphi) = J(\varphi) \otimes K(\varphi)$ which is the set of routes picked by the firm before the shock and $\Omega'(\varphi) = J'(\varphi) \otimes K'(\varphi)$ is the one after the shock, and $\mathcal{C}(\varphi) = \Omega \cap \Omega' \neq \emptyset$ is the set of routes continued to be used by the firm. The set of new routes used by the firm is denoted as $\mathcal{N}(\varphi) \equiv \Omega' \setminus \mathcal{C}$. Then we have,

$$\begin{aligned} \widehat{\Psi}_i(\varphi) &= \frac{\sum_{j,k \in \mathcal{C}} \phi'_{ijk} + \sum_{j,k \in \mathcal{N}} \phi'_{ijk}}{\Psi_i(\varphi)} \\ &= \sum_{j,k \in \mathcal{C}} \frac{\phi'_{ijk}}{\phi_{ijk}} \frac{\phi_{ijk}}{\Psi_i(\varphi)} + \sum_{j,k \in \mathcal{N}} \frac{\phi'_{ijk}}{\Psi'_i(\varphi)} \frac{\Psi'_i(\varphi)}{\Psi_i(\varphi)} \end{aligned} \quad (\text{E.1.2})$$

$$= \sum_{j,k \in \mathcal{C}} \widehat{\phi}_{ijk} \chi_{ijk} + \widehat{\Psi}_i(\varphi) \sum_{j,k \in \mathcal{N}} \chi'_{ijk}. \quad (\text{E.1.3})$$

Rearranging the equation above, we have

$$\widehat{\Psi}_i(\varphi) = \frac{\sum_{j,k \in \mathcal{C}} \chi_{ijk} \widehat{\phi}_{ijk}}{1 - \sum_{j,k \in \mathcal{N}} \chi'_{ijk}}.$$

So one unit change in ϕ_{ijk} translates into $\frac{\chi_{ijk}}{1 - \sum_{j,k \in \mathcal{N}} \chi'_{ijk}}$ unit change in $\widehat{\Psi}_i(\varphi)$. Formally, for a small change in x , we know $\ln(x) \approx x - 1$. Thus $\widehat{\Psi}_i(\varphi) \approx 1 + \ln(\widehat{\Psi}_i(\varphi))$ and $\widehat{\phi}_{ijk} \approx 1 + \ln(\widehat{\phi}_{ijk})$. Then we have

$$\ln \widehat{\Psi}_i(\varphi) \approx \frac{\sum_{j,k \in \mathcal{C}} \chi_{ijk} \ln \widehat{\phi}_{ijk}}{1 - \sum_{j,k \in \mathcal{N}} \chi'_{ijk}} + \frac{\sum_{j,k \in \mathcal{C}} (\chi_{ijk} - \chi'_{ijk})}{1 - \sum_{j,k \in \mathcal{N}} \chi'_{ijk}}$$

which implies

$$\frac{\partial \ln \widehat{\Psi}_i(\varphi)}{\partial \ln \widehat{\phi}_{ijk}} \approx \frac{\chi_{ijk}}{1 - \sum_{j,k \in \mathcal{N}} \chi'_{ijk}}.$$

Finally, since $\phi_{ijk} = B_j A_k (\tau_{ijk} w_j w_k)^{-\theta}$, we have $\frac{\partial \ln \hat{\phi}_{ijk}}{\partial \ln \hat{\tau}_{ijk}} = -\theta$. This implies that the pass-through of cost shock $\hat{\tau}_{ijk}$ to marginal cost of the firm is given by:

$$\begin{aligned} \frac{\partial \ln \hat{c}_i}{\partial \ln \hat{\tau}_{ijk}} &= \frac{\partial \ln \hat{c}_i}{\partial \ln \hat{\Psi}_i(\varphi)} \frac{\partial \ln \hat{\Psi}_i(\varphi)}{\partial \ln \hat{\phi}_{ijk}} \frac{\partial \ln \hat{\phi}_{ijk}}{\partial \ln \hat{\tau}_{ijk}} \\ &\approx \frac{\chi_{ijk}(\varphi)}{1 - \sum_{j,k \in \mathcal{N}} \chi'_{ijk}(\varphi)}. \end{aligned}$$

The proof of conclusion (b) has two steps. First, from proposition 1, we know that sourcing capabilities $\Psi(\varphi)$ is an increasing function of productivity φ . Thus the probability of sourcing from route ijk $\chi_{ijk}(\varphi) = \frac{B_j A_k (\tau_{ijk} w_j w_k)^{-\theta}}{\Psi(\varphi)}$ is decreasing with φ . Second, for the denominator $1 - \sum_{j,k \in \mathcal{N}} \chi_{ijk}$, according to Proposition 1.3, we have $\sum_{j,k \in \mathcal{N}} \chi_{ijk} = 0$ in the case of adverse shocks, and $\sum_{j,k \in \mathcal{N}} \chi_{ijk} \geq 0$ in the case of favourable shock. Alternatively, this result can be derived by studying how the productivity cut-offs respond to the shocks as follows.

In the case of an adverse shock such that τ_{ijk} increases, it can be shown that no firms would like to increase the number of trade routes. To show that, we know that there is a pecking order in the case of complementarity and we could rank different trade routes according to their sourcing potential. The most appealing option would be sourced by all firms. This is option 1. The least appealing option would only be sourced by the most productive firms. This is option N. Suppose the productivity cut-offs for these different options are $\tilde{\varphi}_{i1} \leq \tilde{\varphi}_{i2} \leq \dots \leq \tilde{\varphi}_{iN}$ and suppose the route which is shocked currently ranked at r . We can know that the cut-offs are determined by

$$\begin{aligned} \tilde{\varphi}_{i1}^{\sigma-1} &= \frac{w_{if_{i1}}}{\gamma^{\left(\frac{2(\sigma-1)}{\theta}\right)} D_i \phi_{i1}^{\left(\frac{\sigma-1}{\theta}\right)}} \\ \tilde{\varphi}_{in}^{\sigma-1} &= \frac{w_{if_{in}}}{\gamma^{\left(\frac{2(\sigma-1)}{\theta}\right)} D_i \left(\left(\sum_{l=1}^n \phi_{il} \right)^{\left(\frac{\sigma-1}{\theta}\right)} - \left(\sum_{l=1}^{n-1} \phi_{il} \right)^{\left(\frac{\sigma-1}{\theta}\right)} \right)}, n > 1. \end{aligned}$$

when the trade costs using route r increases, it will not affect cutoffs $\tilde{\varphi}_{i1}, \tilde{\varphi}_{i2}, \dots, \tilde{\varphi}_{ir-1}$. Firms with productivity lower than $\tilde{\varphi}_{ir-1}$ will keep their trade routes as they are. However, as τ_{ir} increases, the sourcing potential of route r : ϕ_{ir} will decrease. This will decrease the difference between sourcing capabilities through n routes v.s. $n-1$ routes for $n \geq r$ as $\frac{\sigma-1}{\theta} \geq 1$.⁵⁸ Then for all $n \geq r$, we have $\tilde{\varphi}_{in}$ increases. This is illustrated in Figure A1 (a). Thus no firms would like to add trade routes. Instead, they would decrease the

⁵⁸It can be shown that $f(x) = f(x+a) \frac{\sigma-1}{\theta} - x \frac{\sigma-1}{\theta}$ is an increasing function of x as $\frac{\sigma-1}{\theta} \geq 1$.

number of sourcing routes. So we have $1 - \sum_{j,k \in \mathcal{N}} \chi_{ijk} = 1$ for all firms and

$$\frac{\partial \ln \widehat{c}_i}{\partial \ln \widehat{\tau}_{ijk}} \approx \chi_{ijk}(\varphi).$$

which declines with φ . So we have

$$\frac{\partial^2 \ln(\widehat{c}_i(\varphi))}{\partial \ln(\widehat{\tau}_{ijk}) \partial \varphi} = \frac{\partial \chi_{ijk}(\varphi)}{\partial \varphi} \leq 0.$$

$$\frac{\partial^2 \ln(\widehat{c}_i(\varphi))}{\partial \ln(\widehat{\tau}_{ijk}) \partial \phi_{ijk}} = \frac{\partial \chi_{ijk}(\varphi)}{\partial \phi_{ijk}} = \frac{1}{\Psi_i(\varphi)} > 0.$$

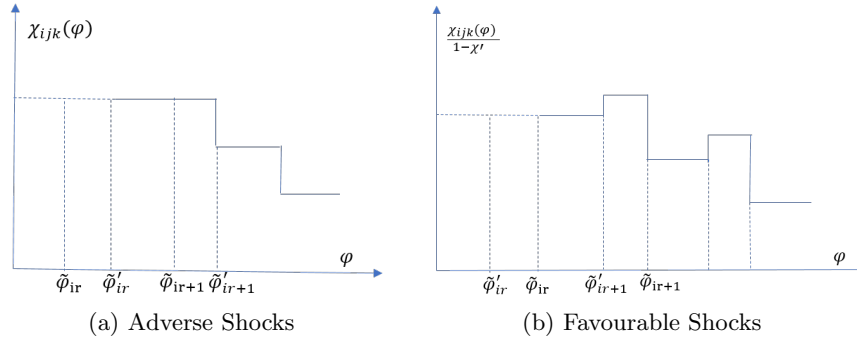


Figure A1: Pass-through of shocks

In the case that τ_{ijk} decreases. Following the previous case, it is easy to see that $\tilde{\varphi}_{i1}, \tilde{\varphi}_{i2}, \dots, \tilde{\varphi}_{ir-1}$ are not affected and firms with productivity $\varphi \leq \tilde{\varphi}_{ir-1}$ do not change their sourcing strategies. Intuitively, they do not include r in their sourcing options and are not affected by the cost shock. On the other hand, $\tilde{\varphi}_{in}$ will decrease to $\tilde{\varphi}'_{in}$ for all $n \geq r$. Then for firms with productivity within $[\tilde{\varphi}'_{i,n+1}, \tilde{\varphi}_{i,n+1}]$, they would like to include $n + 1$ in their sourcing strategies. The pass-through of the shock would be

$$\frac{\partial \ln \widehat{c}_i}{\partial \ln \widehat{\tau}_{ijk}} \approx \frac{\chi_{ir}(\varphi)}{1 - \chi_{i,n+1}(\varphi)'}$$

Firms with productivity in $[\tilde{\varphi}_{in}, \tilde{\varphi}'_{i,n}]$ fix their sourcing strategies and we still have

$$\frac{\partial \ln \widehat{c}_i}{\partial \ln \widehat{\tau}_{ijk}} \approx \chi_{ijk}(\varphi).$$

In this case, the pass-through is not universally declining with productivity as illustrated by Figure A1 (b).

1.A.5 Proof of Proposition 1.5

The gravity equation at firm level determining the trade flow is given by Equation (1.5). Facing a supply shock, the change in trade flow is determined by

$$\begin{aligned}\widehat{M}_{ijk}(\varphi) &\equiv \frac{M'_{ijk}(\varphi)}{M_{ijk}(\varphi)} = \widehat{\Psi}_i(\varphi)^{\frac{(\sigma-1)}{\theta}} \widehat{\chi}_{ijk}(\varphi) \\ &= \widehat{\Psi}_i(\varphi)^{\frac{\sigma-1}{\theta}-1} \widehat{\phi}_{ijk},\end{aligned}$$

which implies $\ln \widehat{M}_{ijk}(\varphi) = (\frac{\sigma-1}{\theta} - 1) \ln \widehat{\Psi}_i(\varphi) + \ln \widehat{\phi}_{ijk}$. From the previous proof, we know that for an adverse shock

$$\frac{\partial \ln \widehat{\Psi}_i(\varphi)}{\partial \ln \widehat{\phi}_{ijk}} \approx \chi_{ijk}.$$

And since $\frac{\partial \ln \widehat{\phi}_{i.mn}}{\partial \ln \widehat{\tau}_{i.mn}} = -\theta$, we have

$$-\frac{\partial \ln \widehat{M}_{ijk}(\varphi)}{\partial \ln \widehat{\tau}_{imn}} = \begin{cases} \theta + (\sigma - 1 - \theta)\chi_{imn}, & \text{if } m=j, n=k \\ (\sigma - 1 - \theta)\chi_{imn}, & \text{otherwise.} \end{cases}$$

This establishes conclusion (a). If sourcing decisions are complementary across trade routes, as mentioned in the previous proof, the sourcing probability $\chi_{ijk}(\varphi)$ of each trade route is weakly decreasing in firm productivity φ . Then, the size of the pass-through should follow the same pattern if sourcing decisions are complementary across trade routes. This establishes conclusion (b).

1.A.6 Proof of Proposition 1.6

From the proof of Proposition 1.4, we know that the change in sourcing capability $\Psi = \sum \phi_r$ for a particular firm is given by ⁵⁹

$$\widehat{\Psi}(\varphi) = \frac{\sum_{r \in \mathcal{C}(\varphi)} \chi_r(\varphi) \widehat{\phi}_r}{1 - \sum_{r \in \mathcal{N}} \chi'_r(\varphi)},$$

where $\mathcal{C}(\varphi) \subset \Omega(\varphi)$ and $\mathcal{N} \subset \Omega'(\varphi)$ are the sets of continued and new trade route for the firm respectively while $\Omega(\varphi)$ and $\Omega'(\varphi)$ are the set of trade routes before and after the shocks. They all depend firm level productivity φ . I further simplify the notations as

$$\widehat{\Psi}(\varphi) = \sum_{r \in \Omega(\varphi)} \chi_r(\varphi) \Delta_r,$$

⁵⁹To simplify the notation, I omit the location subscript i .

while $\Delta_r = \widehat{\phi}_r \delta_r(\varphi, \widehat{\phi})$ with $\delta_r(\varphi, \widehat{\phi})$ being an indicator function defined as

$$\delta_r(\varphi, \widehat{\phi}) = \begin{cases} \frac{1}{1 - \sum_{r \in \mathcal{N}} \chi_r(\varphi)}, & \text{if } r \in \mathcal{C}(\varphi, \widehat{\phi}); \\ 0, & \text{otherwise,} \end{cases}$$

which captures to extensive margin shock of sourcing capabilities. Under the assumption that Δ_r has the same variance ξ^2 across trade routes, we have

$$\begin{aligned} \text{var}(\widehat{\Psi}(\varphi)) &= \text{var}\left(\sum_{r \in \Omega(\varphi)} \chi_r(\varphi) \Delta_r\right) \\ &= \sum_{r \in \Omega(\varphi)} \chi_r(\varphi)^2 \text{var}(\Delta_r) + \sum_{m \neq n, m, n \in \Omega(\varphi)} \chi_m(\varphi) \chi_n(\varphi) \text{cov}(\Delta_m, \Delta_n) \\ &= \xi^2 \left(\sum_{r \in \Omega(\varphi)} \chi_r(\varphi)^2 + \sum_{m \neq n, m, n \in \Omega(\varphi)} \chi_m(\varphi) \chi_n(\varphi) \rho_{mn} \right) \\ &\leq \xi^2. \end{aligned}$$

The last inequality holds because $\left(\sum_{r \in \Omega(\varphi)} \chi_r(\varphi)\right)^2 = \sum_{r \in \Omega(\varphi)} \chi_r(\varphi)^2 + \sum_{\substack{m \neq n \\ m, n \in \Omega(\varphi)}} \chi_m(\varphi) \chi_n(\varphi) =$

1. As long as the correlation of shocks $\rho_{ij} \equiv \frac{\text{cov}(\Delta_m, \Delta_n)}{\xi^2} < 1$ for any i and j , that is the shocks are not perfectly correlated across trade routes, we have $\text{var}(\widehat{\Psi}(\varphi)) < \xi^2$. On the other hand, if firms are under sourcing autarky, firms are subject to local shocks with volatility ξ^2 . This establishes conclusion (a).

If the shocks are i.i.d. such that $\rho_{mn} = 0$, we have:

$$\begin{aligned} \text{var}(\widehat{\Psi}(\varphi)) &= \text{var}\left(\sum_{r \in \Omega(\varphi)} \chi_r(\varphi) \Delta_r\right) \\ &= \xi^2 \sum_{r \in \Omega(\varphi)} \chi_r(\varphi)^2 \\ &= \xi^2 HHI(\varphi). \end{aligned}$$

From Proposition 1.2, we know that HHI decreases weakly with firm productivity. Then the volatility of firms' sourcing capabilities should decrease weakly with firm productivity as well. Since firm revenue is given by $R_i(\varphi) = D_i \varphi^{\sigma-1} \gamma^{\frac{2(\sigma-1)}{\theta}} \Psi_i(\varphi)^{\frac{\sigma-1}{\theta}}$, we have⁶⁰

$$\widehat{R}_i(\varphi) = \widehat{\Psi}_i(\varphi)^{\frac{\sigma-1}{\theta}}.$$

⁶⁰The demand D_i does not show up because we focus on cost shock on inputs.

Using the delta method, we have

$$\begin{aligned} \text{var}(\widehat{R}_i(\varphi)) &\approx \left[\frac{\partial \widehat{R}_i(\widehat{\Psi}_i(\varphi))}{\partial \widehat{\Psi}_i(\varphi)} \Big|_{\widehat{\Psi}_i(\varphi)=E[\widehat{\Psi}_i(\varphi)]} \right]^2 \text{var}(\widehat{\Psi}_i(\varphi)) \\ &= \frac{(\sigma-1)^2}{\theta^2} E[\widehat{\Psi}_i(\varphi)]^{\frac{2(\sigma-1-\theta)}{\theta}} \text{var}(\widehat{\Psi}_i(\varphi)). \end{aligned}$$

Since Δ_r is i.i.d., $E[\widehat{\Psi}_i(\varphi)] = E[\sum_{r \in \Omega(\varphi)} \chi_r(\varphi) \Delta_r] = \sum_{r \in \Omega(\varphi)} \chi_r(\varphi) E[\Delta_r] = E[\Delta_r]$ is a constant. The last equality holds as $\sum_{r \in \Omega(\varphi)} \chi_r(\varphi) = 1$. Given that $\text{var}(\widehat{\Psi}(\varphi)) = \xi^2 HHI(\varphi)$, we have

$$\text{var}(\widehat{R}_i(\varphi)) \propto \xi^2 HHI(\varphi),$$

which declines weakly with firm productivity φ in the same way as $HHI(\varphi)$. This establishes conclusion (b).

Under universal importing, the change to the sourcing capabilities of a firm is given by

$$\widehat{\Psi} = \sum_{r \in \Omega} \chi_r \widehat{\phi}_r,$$

where Ω is set of available trade routes to all importers. Given the universal importing assumption, Ω is the same for each firm, so is the sourcing intensity χ_r . Then the variance of $\widehat{\Psi}$ should be the same for all importers. So is firm revenue. This establishes conclusion (c).

1.A.7 Proof of Proposition 1.7

From Equation (1.3), the change in marginal costs in response to sourcing potentials is given by

$$\widehat{c}_i(\varphi) = \widehat{\Psi}_i(\varphi)^{-\frac{1}{\theta}} \tag{E.1.4}$$

which is inversely related to the change in the sourcing capability of the firm. On the other hand, from the proof of Proposition 1.4, the change in sourcing capability to an adverse shock is related to change sourcing potential and pre-shock sourcing probability as

$$\widehat{\Psi}_i(\varphi) = \sum_{j,k \in \mathcal{C}} \chi_{ijk} \widehat{\phi}_{ijk}. \tag{E.1.5}$$

if sourcing decisions are complementary across trade routes. Although $\widehat{\phi}_{ijk}$ is still not observable, according to Equation (1.5), the change in the trade flow is given by

$$\begin{aligned}\widehat{M}_{ijk}(\varphi) &= \widehat{\Psi}_i(\varphi)^{\frac{\sigma-1}{\theta}} \frac{\widehat{\phi}_{ijk}(\phi)}{\widehat{\Psi}_i(\varphi)} \\ &= \widehat{\Psi}_i(\varphi)^{\frac{\sigma-1}{\theta}-1} \widehat{\phi}_{ijk}(\phi)\end{aligned}$$

which implies

$$\widehat{\phi}_{ijk}(\phi) = \frac{\widehat{M}_{ijk}(\varphi)}{\widehat{\Psi}_i(\varphi)^{\frac{\sigma-1}{\theta}-1}}.$$

Substitute the equation above into Equation (E.1.5), we have

$$\widehat{\Psi}_i(\varphi) = \left(\sum_{j \times k \in C} \chi_{ijk}(\varphi) \widehat{M}_{ijk}(\varphi) \right)^{\frac{\theta}{\sigma-1}},$$

together with Equation (E.1.4), immediately we know

$$\widehat{c}_i(\varphi) = \left(\sum_{j \times k \in C} \chi_{ijk}(\varphi) \widehat{M}_{ijk}(\varphi) \right)^{\frac{1}{1-\sigma}}.$$

1.A.8 Tradable Final Goods and Demand Shocks

Suppose final goods are tradable. Exporting to market k through customs district j incurs a variable iceberg trade cost τ_{ijk}^X , and a fixed cost in terms of f_{ijk}^X unit of labour from region i . Then firms' profit function in Equation (1.4) now becomes:

$$\max_{I_{ijk}, I_{ijk}^X \in \{0,1\}} \pi(\varphi, \{I_{ijk}\}, \{I_{ijk}^X\}) = \varphi^{\sigma-1} (\gamma^2 \Psi_i(\varphi))^{\frac{\sigma-1}{\theta}} D_i(\varphi) - w_i \sum_{j=1, k=1}^{J,K} I_{ijk} f_{ijk} - w_i \sum_{j=1, k=1}^{J,K} I_{ijk}^X f_{ijk}^X$$

where I_{ijk} and I_{ijk}^X are indicator variables for import and export through route jk respectively, and $D_i(\varphi) \equiv \sum_{j=1, k=1}^{J,K} I_{ijk}^X (\tau_{ijk}^X)^{1-\sigma} D_k$ is the demand shifter. The model features increasing difference in (I_{ijk}^X, φ) , so more productive firms tend to export to more places. It also features increasing difference in $(I_{ijk}^X, \Psi_i(\varphi))$, thus any reduction in trade costs would lead firms to expand their export along the extensive margin, *vice versa* if trade costs increase.

The gravity equation at firm level determining the import flow is still given by Equation (1.5) except that the demand shifter D_i is now firm specific. Suppose $\widehat{\tau}_{ijk}^X = \widehat{\tau}_{ijk}$, thus the cost shock affects imports and exports along the same route at the same time, then

$$\widehat{M}_{ijk}(\varphi) = \widehat{\Psi}_i(\varphi)^{\frac{(\sigma-1)}{\theta}-1} \widehat{\phi}_{ijk} \widehat{D}_i(\varphi).$$

Compared with the proof in Appendix 1.A.5, there is an extra term $\widehat{D}_i(\varphi)$ which captures

the demand shock given by:

$$\begin{aligned}
\widehat{D}_i(\varphi) &= \frac{\sum_{j,k \in \mathcal{C}^{\mathcal{X}}(\varphi)} d'_{ijk} + \sum_{j,k \in \mathcal{N}^{\mathcal{X}}(\varphi)} d'_{ijk}}{D_i(\varphi)} \\
&= \sum_{j,k \in \mathcal{C}^{\mathcal{X}}(\varphi)} \frac{d'_{ijk}}{d_{ijk}} \frac{d_{ijk}}{D_i(\varphi)} + \sum_{j,k \in \mathcal{N}^{\mathcal{X}}(\varphi)} \frac{d'_{ijk}}{D'_i(\varphi)} \frac{D'_i(\varphi)}{D_i(\varphi)} \\
&= \sum_{j,k \in \mathcal{C}^{\mathcal{X}}(\varphi)} \widehat{d}_{ijk} \mu_{ijk} + \widehat{D}_i(\varphi) \sum_{j,k \in \mathcal{N}^{\mathcal{X}}(\varphi)} \mu'_{ijk},
\end{aligned}$$

where $\mathcal{C}^{\mathcal{X}}(\varphi)$ is the set of destinations that the firm continues to serve after the shock, and $\mathcal{N}^{\mathcal{X}}(\varphi)$ is the set of destinations that are newly included. Rearranging the equation above, we have

$$\widehat{D}_i(\varphi) = \frac{\sum_{j,k \in \mathcal{C}^{\mathcal{X}}} \mu_{ijk} \widehat{d}_{ijk}}{1 - \sum_{j,k \in \mathcal{N}^{\mathcal{X}}} \mu'_{ijk}},$$

where $\mu_{ijk}(\varphi) \equiv \frac{d_{ijk}}{D_i(\varphi)}$ is the intensity of exporting through route jk , and $d_{ijk} \equiv (\tau_{ijk}^X)^{1-\sigma} D_k$ is the residual demand for route jk . For negative shocks on trade costs, as argued above, firms would like to reduce exports along the extensive margin. Thus $\sum_{j,k \in \mathcal{N}^{\mathcal{X}}(\varphi)} \mu'_{ijk} = 0$ and

$$\widehat{D}_i(\varphi) = \sum_{j,k \in \mathcal{C}^{\mathcal{X}}(\varphi)} \mu_{ijk} \widehat{d}_{ijk}.$$

Then we have

$$\begin{aligned}
\frac{\partial \ln \widehat{D}_i}{\partial \ln \widehat{\tau}_{ijk}} &= \frac{\partial \ln \widehat{D}_i}{\partial \ln \widehat{d}_{ijk}} \frac{\partial \ln \widehat{d}_{ijk}}{\partial \ln \widehat{\tau}_{ijk}} \\
&= (1 - \sigma) \mu_{ijk}(\varphi),
\end{aligned}$$

combined with the fact that $\frac{\partial \ln \widehat{M}_{ijk}(\varphi)}{\partial \ln \widehat{\tau}_{imn}} = (\frac{\sigma-1}{\theta} - 1) \frac{\partial \ln \widehat{\Psi}_i(\varphi)}{\partial \ln \widehat{\tau}_{imn}} + \frac{\partial \ln \widehat{\phi}_{ijk}}{\partial \ln \widehat{\tau}_{imn}} + \frac{\partial \ln \widehat{D}_i(\varphi)}{\partial \ln \widehat{\tau}_{imn}}$, we have

$$-\frac{\partial \ln \widehat{M}_{ijk}(\varphi)}{\partial \ln \widehat{\tau}_{imn}} = \begin{cases} \theta + (\sigma - 1 - \theta) \chi_{imn}(\varphi) + (\sigma - 1) \mu_{imn}(\varphi), & \text{if } m=j, n=k, \\ (\sigma - 1 - \theta) \chi_{imn}(\varphi) + (\sigma - 1) \mu_{imn}(\varphi), & \text{otherwise.} \end{cases}$$

1.B Main Tables

Table A1: Resilience to the SARS shock: export demand shock

| Dependent Variable: firm import by route $\ln(\text{imp}_{ijk,t})$ | import cost shocks only (1) | export demand shocks only (2) | both export demand and import cost shocks (3) |
|---|-----------------------------------|-------------------------------------|---|
| trade route hit by SARS=1 | -0.0557** (0.0241) | -0.0696*** (0.0244) | -0.0549** (0.0242) |
| pre SARS sourcing intensity | 9.493*** (0.0953) | | 9.470*** (0.0982) |
| trade route hit by SARS=1 x pre SARS sourcing intensity | -0.464*** (0.133) | | -0.463*** (0.132) |
| pre SARS export intensity | | 1.277*** (0.0579) | 0.0725** (0.0362) |
| trade route hit by SARS=1 x pre SARS export intensity | | -0.261*** (0.0741) | 0.0285 (0.0519) |
| other routes hit by SARS=1 | 0.00454 (0.0197) | -0.0111 (0.0224) | 0.00467 (0.0197) |
| firm-time, industry, ownership, origin, destination, customs FE | Y | Y | Y |
| R^2 | 0.472 | 0.396 | 0.472 |
| No. of observations | 2019727 | 2019284 | 2019284 |

Notes: A trade route is a combination of an origin and a customs district. It is defined as hit by SARS if the origin or the customs district are listed by the WHO as regions with local transmission of SARS. Pre shock export intensity is constructed as the average share of outputs exported through each route before the SARS epidemic. It is zero for non-exporters. The pre shock sourcing intensity is constructed as the input expenditure share averaged before the SARS epidemic. The numbers in parentheses are standard errors clustered at region-industry level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

Table A2: Resilience of processing importers

| Dependent Variable: | Processing with inputs | | | Pure Assembly | | |
|---|------------------------|----------------------|----------------------|---------------------|---------------------|---------------------|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| firm import by route $\ln(\text{imp}_{ijk})$ | | | | | | |
| pre SARS sourcing intensity | 7.744*** (0.189) | 7.819*** (0.192) | 7.819*** (0.192) | 6.368*** (0.383) | 6.364*** (0.378) | 6.364*** (0.377) |
| trade route hit by SARS=1 | -0.0327 (0.0499) | 0.0238 (0.0494) | 0.0568 (0.0655) | 0.0438 (0.148) | 0.0406 (0.158) | 0.107 (0.162) |
| trade route hit by SARS=1 x pre SARS sourcing intensity | | -0.648*** (0.195) | -0.643*** (0.195) | | 0.0423 (0.744) | 0.0432 (0.739) |
| other routes hit by SARS=1 | | | 0.0487 (0.0616) | | | 0.147 (0.144) |
| firm-time, industry, ownership, origin, destination, customs FE | Y | Y | Y | Y | Y | Y |
| R^2 | 0.530 | 0.530 | 0.530 | 0.529 | 0.529 | 0.529 |
| No. of observations | 267005 | 267005 | 267005 | 17556 | 17556 | 17556 |

Notes: Pure processing importers are firms which have no ordinary imports subject to tariffs. Columns (1) and (3) include the sample of importers which only engage in processing with supplied inputs (PI). Column (4) and (6) include the sample of importers only engaged in pure assembly (PA). PA firms do not decide where to source or pay for the sourced inputs while PI firms do. The numbers in parentheses are standard error clustered at region-industry level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

Table A3: Robustness check: the liquidity, finance, and inventory channels

| Dependant Variable: | firm imports by route $\ln(\text{imp}_{ijk,t})$ | | | | |
|---|---|-----------------------|-----------------------|-----------------------|------------------------|
| | (1) | (2) | (3) | (4) | (5) |
| pre SARS sourcing intensity | 9.124*** (0.0900) | 9.124*** (0.0900) | 9.124*** (0.0900) | 9.138*** (0.0902) | 9.141*** (0.0906) |
| trade route hit by SARS | -0.0404** (0.0197) | -0.0391* (0.0201) | -0.0391* (0.0227) | -0.0405** (0.0206) | -0.0105 (0.0375) |
| trade route hit by SARS x pre shock sourcing intensity | -0.321*** (0.0955) | -0.320*** (0.0954) | -0.321*** (0.0953) | -0.321*** (0.0956) | -0.312*** (0.0954) |
| liquidity | | 0.00681 (0.0201) | | | -0.0840** (0.0366) |
| trade route hit x liquidity | | -0.0101 (0.0277) | | | -0.0568 (0.0586) |
| leverage ratio | | | -0.0131 (0.00860) | | -0.0435*** (0.0153) |
| trade route hit x leverage ratio | | | -0.00151 (0.0138) | | -0.0237 (0.0289) |
| inventory | | | | -0.324*** (0.0179) | -0.329*** (0.0192) |
| trade route hit x inventory | | | | 0.000131 (0.0286) | -0.0162 (0.0310) |
| firm, destination-time, ownership, industry, origin, customs FE | Y | Y | Y | Y | Y |
| R^2 | 0.403 | 0.403 | 0.403 | 0.403 | 0.403 |
| No. of observations | 2143515 | 2143515 | 2143515 | 2143515 | 2140168 |

Notes: Following Manova and Yu (2016), liquidity available to firms is measured by (current assets - current liabilities)/total assets. Inventory is measured as the ratio of intermediate inputs relative to total inputs. In all regressions, we control for time, destination region, origin, customs region and ownership fixed effects. The numbers in parentheses are standard errors clustered at region-industry level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

Table A4: Estimating the efficiency dispersion parameter θ

| Dependent Variable: | | | | |
|--|-----------------------|------------------------|------------------------|------------------------|
| foreign sourcing relative to home sourcing $\ln(\chi_{ijk}) - \ln \frac{\phi^d}{\Phi}$ | (1) | (2) | (3) | (4) |
| ln geodist customs district-destination | -0.166*** (0.0125) | -0.0977*** (0.0156) | -0.0521*** (0.0159) | -0.0522*** (0.0159) |
| ln geodist origin-customs district | -0.437*** (0.0141) | -0.435*** (0.0140) | -0.408*** (0.0153) | -0.411*** (0.0153) |
| common customs district | | 0.473*** (0.0682) | 0.446*** (0.0673) | 0.446*** (0.0673) |
| common language customs district-destination | | | 0.842*** (0.0880) | 0.845*** (0.0880) |
| co-Chinese | | | 10.55*** (2.630) | 10.48*** (2.627) |
| FH firm-market import tariff | | | | -5.500*** (0.797) |
| Firm, Industry, Ownership, Origin, Customs, Region FE | Y | Y | Y | Y |
| R^2 | 0.456 | 0.457 | 0.458 | 0.458 |
| No. of observations | 121742 | 121742 | 121742 | 121742 |

Notes: The dependent variable is the the log difference of probability in sourcing from a route relative to sourcing at home. The sample only includes importers in year 2006 that are not entrants in year 2005. “co-Chinese” is the share of ethnic Chinese in the origin multiplied by the share overseas Chinese in the Chinese customs district. “FH firm-market import tariff” a firm market specific tariff constructed following Fitzgerald and Haller (2014). It is a weighted average of product tariffs using the basket goods in current and lagged years. The numbers in parentheses are standard error clustered at firm level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

Table A5: Roads and sourcing diversification: the extensive margin

| Dependent variable: $\ln(N + 1)$ in | Full sample | | | Excluding nodes of road network | | |
|-------------------------------------|--------------------------|-------------------------|----------------------------------|---------------------------------|-------------------------|----------------------------------|
| | (1) customs districts | (2) origins | (3) customs districts-origins | (4) customs districts | (5) origins | (6) customs districts-origins |
| highway connected | 0.00531*** (0.000938) | 0.00514*** (0.00142) | 0.00499*** (0.00150) | 0.00414*** (0.00102) | 0.00444*** (0.00157) | 0.00414** (0.00165) |
| rail connected | -0.00105 (0.00137) | 0.00146 (0.00220) | 0.000790 (0.00229) | -0.00169 (0.00154) | 0.00179 (0.00239) | 0.00109 (0.00250) |
| ln TFP | 0.00771*** (0.000280) | 0.0159*** (0.000468) | 0.0168*** (0.000491) | 0.00717*** (0.000329) | 0.0144*** (0.000557) | 0.0151*** (0.000580) |
| ln age | 0.00949*** (0.000457) | 0.0162*** (0.000732) | 0.0170*** (0.000773) | 0.00815*** (0.000493) | 0.0136*** (0.000797) | 0.0141*** (0.000832) |
| Year FE | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | Y | Y | Y | Y | Y |
| Ownership FE | Y | Y | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y | Y | Y |
| region FE | Y | Y | Y | Y | Y | Y |
| R^2 | 0.811 | 0.873 | 0.871 | 0.806 | 0.873 | 0.872 |
| No. of observations | 1223731 | 1223731 | 1223731 | 832414 | 832414 | 832414 |

Notes: Columns (1) to (3) use the full sample while columns (4) to (6) exclude firms located in urban units and provincial capitals. The numbers in parentheses are standard error generated from observed information matrix. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

Table A6: Roads and sourcing diversification: HHI

| Dependent variable: HHI | Full sample | | | Excluding nodes of road network |
|-------------------------|----------------------------|----------------------------|----------------------------|---------------------------------|
| | (1) | (2) | (3) | (4) |
| connected to highway | -0.00310*** (0.000315) | | -0.00305*** (0.000315) | -0.00258*** (0.000354) |
| connected to railway | | -0.00168*** (0.000490) | -0.00139*** (0.000490) | -0.00249*** (0.000516) |
| ln TFP | -0.000831*** (0.000118) | -0.000826*** (0.000118) | -0.000827*** (0.000118) | -0.000417*** (0.000145) |
| ln firm age | -0.000716*** (0.000144) | -0.000717*** (0.000144) | -0.000720*** (0.000144) | -0.000768*** (0.000163) |
| Year FE | Y | Y | Y | Y |
| Ownership FE | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y |
| Region FE | Y | Y | Y | Y |
| Firm FE | Y | Y | Y | Y |
| R^2 | 0.860 | 0.860 | 0.860 | 0.865 |
| No. of observations | 1223731 | 1223731 | 1223731 | 832414 |

Notes: The dependent variable is firms' concentration of sourcing measured by the Herfindahl-Hirschman Index (HHI). Columns (1) to (3) use the full sample while column (4) excludes importers located in urban units and provincial capitals which are the nodes of the road network. The numbers in parentheses are standard error clustered at firm level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

1.C Complementary Tables and Figures

1.C.1 Complementary Tables

Output Volatility and sourcing diversification

This subsection provides robustness tests on the firms' output volatility and input diversification. The first exercise looks at the volatility of firms' export which is generated out of a relatively long time series of firms' quarterly export. I then regress the volatility of exports on the number of trade routes, controlling for firm age, firm size and output diversification captured by the number of exporting routes. The results are shown in Table A8. As can be seen from the table, firms with more diversified sourcing strategies continue to have lower volatility in exports.

Table A7: Volatility of sales

| Dependent variable: ln(sales volatility) | (1) | (2) | (3) | (4) | (5) |
|--|----------------------|------------------------|-------------------------|-------------------------|-------------------------|
| Sourcing Diversification measured by HHI | 0.288*** (0.0315) | 0.369*** (0.0306) | 0.270*** (0.0310) | 0.218*** (0.0328) | 0.180*** (0.0414) |
| ln age of firm | | -0.207*** (0.00750) | -0.176*** (0.00763) | -0.188*** (0.00789) | -0.228*** (0.0154) |
| ln employment | | | -0.0708*** (0.00472) | -0.0448*** (0.00592) | -0.0288*** (0.00928) |
| ln TFP | | | | -0.0438*** (0.00665) | -0.0360*** (0.0105) |
| ln number of exporting routes | | | | -0.00991** (0.00462) | -0.0159** (0.00733) |
| ln number of imported products | | | | | -0.0158** (0.00697) |
| Industry FE | Y | Y | Y | Y | Y |
| Prefecture FE | Y | Y | Y | Y | Y |
| R^2 | 0.0556 | 0.0806 | 0.0878 | 0.0895 | 0.0958 |
| No. of observations | 44454 | 44451 | 44451 | 44432 | 14356 |

Notes: Sales volatility is the variance of growth rate during 1999-2007. Herfindahl-Hirschman Index (HHI) is constructed over the shares of inputs sourced from different trade routes and averaged across years. For non-importers, it is assigned as 1. For exporting routes, it is assigned as 1 for non-exporters. Column (5) only includes importers. The numbers in parentheses are standard error clustered at industry and prefecture level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

Multi-customs-district importer premium

This section presents results on the various robustness checks on the multi customs district premium. First, I show that this is not a phenomenon particular to year 2006. Table A10 presents results year 2000. The premium is quite similar. Additional checks are shown in Table A11. First, an alternative measure of multi-plant firm is used. The measure is a variable in the CAIS data called “Dan1wei4shu4liang4” in Pinyin which means number of production unit. This is not the number of plants that a firm has but multiple-plant

Table A8: Volatility of exports

| Dependent variable: ln(exports volatility) | (1) | (2) | (3) | (4) | (5) |
|--|----------------------|----------------------|------------------------|------------------------|------------------------|
| Sourcing Diversification measured by HHI | 0.732*** (0.0669) | 0.740*** (0.0665) | 0.663*** (0.0681) | 0.685*** (0.0670) | 0.519*** (0.0844) |
| ln age of firm | | -0.0703* (0.0385) | -0.000882 (0.0386) | 0.00268 (0.0386) | -0.0119 (0.0410) |
| ln employment | | | -0.0950*** (0.0153) | -0.101*** (0.0209) | -0.0881*** (0.0218) |
| ln TFP | | | | 0.0462** (0.0215) | 0.0650*** (0.0229) |
| ln number of exporting routes | | | | -0.0514*** (0.0166) | -0.0552*** (0.0169) |
| ln number imported products | | | | | -0.0586*** (0.0177) |
| Industry FE | Y | Y | Y | Y | Y |
| Prefecture FE | Y | Y | Y | Y | Y |
| R^2 | 0.0846 | 0.0853 | 0.0931 | 0.0957 | 0.0987 |
| No. of observations | 5887 | 5887 | 5887 | 5884 | 5716 |

Notes: Volatility of exports is the variance of quarterly exports growth rate between 2000 and 2006. Herfindahl-Hirschman Index (HHI) is constructed over the shares of inputs sourced from different trade routes and averaged across years. Only firms that are both importer and exporter are included in column (5). The numbers in parentheses are standard error clustered at industry and prefecture level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

firms should have more production units. The results is shown in column (1) and (2). There is worry that some regions might have place-based policy such as processing trade zone. It might induce firms importing from certain places. I exclude firms that purely engage in processing imports.⁶¹ The result is shown in column (3) and (4). Finally, given that Guangdong Province is divided into 7 custom areas, significantly more than other provinces. To address the concern that the result is driven importers from Guangdong, I exclude importers from Guangdong. The result is presented in column (5) and (6). The multi-customs-district premium remains robust.

⁶¹Processing import is defined as pure assembly (14 in the 2-digit shipment id code) and processing with imported materials (15 in the 2-digit shipment id code).

Table A9: Multi-customs-district premium: 2006

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|--------------------------|----------------------|----------------------|-----------------------|-----------------------|----------------------|-----------------------|-----------------------|
| | Sales | Sales | Sales | Sales | Import | labor productivity | TFP |
| 2 customs districts | 0.593*** (0.0187) | 0.151*** (0.0180) | 0.118*** (0.0134) | 0.107*** (0.0133) | 0.599*** (0.0304) | 0.109*** (0.0146) | 0.0906*** (0.0151) |
| 3 customs districts | 1.115*** (0.0378) | 0.381*** (0.0353) | 0.263*** (0.0250) | 0.229*** (0.0247) | 0.828*** (0.0496) | 0.246*** (0.0285) | 0.269*** (0.0297) |
| 4 customs districts | 1.662*** (0.0763) | 0.627*** (0.0704) | 0.459*** (0.0489) | 0.389*** (0.0491) | 0.999*** (0.0825) | 0.458*** (0.0593) | 0.442*** (0.0613) |
| 5+ customs districts | 2.226*** (0.118) | 0.989*** (0.105) | 0.710*** (0.0768) | 0.558*** (0.0755) | 1.517*** (0.131) | 0.589*** (0.101) | 0.585*** (0.0961) |
| ln # of import countries | | 0.691*** (0.0117) | 0.280*** (0.00857) | 0.272*** (0.00861) | 1.620*** (0.0198) | 0.140*** (0.00843) | 0.424*** (0.00926) |
| ln Employment | | | 0.775*** (0.00591) | 0.769*** (0.00595) | 0.359*** (0.0117) | | |
| Industry FE | Y | Y | Y | Y | Y | Y | Y |
| Prefecture FE | Y | Y | Y | Y | Y | Y | Y |
| Ownership FE | Y | Y | Y | Y | Y | Y | Y |
| Multi-plant FE | N | N | N | Y | Y | Y | Y |
| R^2 | 0.291 | 0.419 | 0.681 | 0.683 | 0.569 | 0.410 | 0.403 |
| No. of observations | 37589 | 37589 | 37589 | 37571 | 37572 | 36324 | 36211 |

Notes: The estimation method is OLS with high dimensional FE using the Stata command *reghdfe* written by Correia (2015). It eliminates singletons nested within fixed effects. From column (3) on, we control for the multi-plant firms using the measure of firm unit number in the data. Industry fixed effect is controlled for at the 4-digit CIC level. Ownership fixed effect is controlled for using the registered firm type which distinguishes firms between state owned enterprises, private owned enterprises and foreign invested enterprises. The numbers in parentheses are standard error clustered at industry and prefecture level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

Table A10: Multi-customs-district premium: 2000

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|--------------------------|----------------------|----------------------|-----------------------|-----------------------|----------------------|----------------------|----------------------|
| | Sales | Sales | Sales | Sales | Import | labor productivity | TFP |
| 2 customs districts | 0.622*** (0.0267) | 0.221*** (0.0253) | 0.143*** (0.0190) | 0.135*** (0.0190) | 0.738*** (0.0442) | 0.103*** (0.0234) | 0.128*** (0.0241) |
| 3 customs districts | 1.058*** (0.0532) | 0.377*** (0.0491) | 0.325*** (0.0380) | 0.297*** (0.0379) | 1.023*** (0.0784) | 0.293*** (0.0501) | 0.261*** (0.0466) |
| 4 customs districts | 1.587*** (0.132) | 0.660*** (0.122) | 0.429*** (0.0986) | 0.424*** (0.0950) | 1.268*** (0.137) | 0.402*** (0.0980) | 0.502*** (0.101) |
| 5+ customs districts | 2.179*** (0.236) | 1.050*** (0.227) | 0.682*** (0.158) | 0.463*** (0.149) | 1.087*** (0.310) | 0.619*** (0.196) | 0.927*** (0.207) |
| ln # of import countries | | 0.611*** (0.0129) | 0.285*** (0.00992) | 0.278*** (0.00987) | 1.489*** (0.0274) | 0.144*** (0.0113) | 0.386*** (0.0118) |
| ln Employment | | | 0.708*** (0.00856) | 0.707*** (0.00855) | 0.343*** (0.0181) | | |
| Industry FE | Y | Y | Y | Y | Y | Y | Y |
| Prefecture FE | Y | Y | Y | Y | Y | Y | Y |
| Ownership FE | Y | Y | Y | Y | Y | Y | Y |
| Multi-plant FE | N | N | N | Y | Y | Y | Y |
| R^2 | 0.355 | 0.458 | 0.676 | 0.677 | 0.526 | 0.331 | 0.317 |
| No. of observations | 17984 | 17984 | 17984 | 17974 | 17980 | 17444 | 17407 |

Notes: The estimation method is OLS with high dimensional FE using the Stata command *reghdfe* written by Correia (2015). It eliminates singletons nested within fixed effects. From column (3) on, we control for the multi-plant firms using the measure of firm unit number in the data. Industry fixed effect is controlled for at the 4-digit CIC level. Ownership fixed effect is control using the registered firm type which distinguishes firms between state owned enterprises, private owned enterprises and foreign invested enterprises. The numbers in parentheses are standard error clustered at industry and prefecture level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

Table A11: Robustness of the multi-customs-district premium: 2006

| | (1) | (2) | (3) | (4) | (5) | (6) |
|--------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|----------------------|
| | Sales | TFP | Sales | TFP | Sales | TFP |
| 2 customs districts | 0.116*** (0.0134) | 0.104*** (0.0150) | 0.0870*** (0.0149) | 0.0646*** (0.0174) | 0.0401*** (0.0155) | 0.0397** (0.0182) |
| 3 customs districts | 0.256*** (0.0249) | 0.304*** (0.0299) | 0.190*** (0.0261) | 0.205*** (0.0326) | 0.123*** (0.0279) | 0.174*** (0.0345) |
| 4 customs districts | 0.453*** (0.0490) | 0.517*** (0.0607) | 0.331*** (0.0499) | 0.360*** (0.0628) | 0.223*** (0.0532) | 0.277*** (0.0677) |
| 5+ customs districts | 0.694*** (0.0772) | 0.740*** (0.0996) | 0.458*** (0.0766) | 0.414*** (0.0980) | 0.421*** (0.0781) | 0.463*** (0.101) |
| ln # of import countries | 0.280*** (0.00858) | 0.435*** (0.00924) | 0.314*** (0.00967) | 0.465*** (0.0103) | 0.321*** (0.00958) | 0.450*** (0.0104) |
| ln Employment | 0.771*** (0.00598) | | 0.776*** (0.00661) | | 0.764*** (0.00716) | |
| Industry FE | Y | Y | Y | Y | Y | Y |
| Prefecture FE | Y | Y | Y | Y | Y | Y |
| Ownership FE | Y | Y | Y | Y | Y | Y |
| Multi-plant FE | Y | Y | Y | Y | Y | Y |
| R^2 | 0.681 | 0.401 | 0.702 | 0.417 | 0.706 | 0.406 |
| No. of observations | 37571 | 36213 | 26265 | 25168 | 23896 | 22940 |

Notes: Column (1) and (2) use alternative measure of multi-plant firm. Column (3) and (4) exclude pure processing importers. Column (5) and (6) exclude importers from Guangdong province. The numbers in parentheses are standard error clustered at industry and prefecture level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

Table A12: Areas with local transmission of SARS

| Country | Area | From | To |
|-------------|----------------------|-----------|-----------|
| China | Beijing | 02-Mar-03 | 18-Jun-03 |
| China | Guangdong | 16-Nov-02 | 07-Jun-03 |
| China | Hebei | 19-Apr-03 | 10-Jun-03 |
| China | Hubei | 17-Apr-03 | 26-May-03 |
| China | Inner Mongolia | 04-Mar-03 | 03-Jun-03 |
| China | Jilin | 01-Apr-03 | 29-May-03 |
| China | Jiangsu | 19-Apr-03 | 21-May-03 |
| China | Shanxi | 08-Mar-03 | 13-Jun-03 |
| China | Shaanxi | 12-Apr-03 | 29-May-03 |
| China | Tianjin | 16-Apr-03 | 28-May-03 |
| China | Hong Kong | 15-Feb-03 | 22-Jun-03 |
| China | Taiwan | 25-Feb-03 | 05-Jul-03 |
| Canada | Greater Toronto Area | 23-Feb-03 | 02-Jul-03 |
| Canada | New Westminster | 28-Mar-03 | 05-May-03 |
| Mongolia | Ulaanbaatar | 05-Apr-03 | 09-May-03 |
| Philippines | Manila | 06-Apr-03 | 19-May-03 |
| Singapore | Singapore | 25-Feb-03 | 31-May-03 |
| Vietnam | Hanoi | 23-Feb-03 | 27-Apr-03 |

Notes: This table lists the areas identified by the WHO as regions with local transmission of SARS.

Table A13: Resilience of processing importers: partial processing traders

| Dependent Variable: | Processing with inputs | | Pure Assembly | |
|--|------------------------|----------------------|---------------------|---------------------|
| | (1) | (2) | (3) | (4) |
| firm import by route $\ln(\text{imp}_{ijk})$ | | | | |
| pre shock sourcing intensity | 9.456*** (0.117) | 9.510*** (0.114) | 7.542*** (0.222) | 7.532*** (0.220) |
| trade route hit by SARS=1 | -0.0650** (0.0281) | -0.0248 (0.0296) | -0.0596 (0.0757) | -0.0673 (0.0816) |
| trade route hit by SARS=1 x pre shock sourcing intensity | | -0.662*** (0.138) | | 0.150 (0.452) |
| other routes hit by SARS=1 | | -0.0103 (0.0249) | | 0.0204 (0.0705) |
| firm-time FE | Y | Y | Y | Y |
| industry FE | Y | Y | Y | Y |
| ownership type FE | Y | Y | Y | Y |
| origin FE | Y | Y | Y | Y |
| destination FE | Y | Y | Y | Y |
| customs area FE | Y | Y | Y | Y |
| R^2 | 0.470 | 0.470 | 0.487 | 0.487 |
| No. of observations | 1385724 | 1385724 | 78896 | 78896 |

Notes: Partial processing traders are importers which partially participate in processing trade. Column (1) and (2) use the sample of importers that engage both in Processing with Inputs (PI) and ordinary imports but not Pure Assembly (PA). Column (3) and (4) use the sample of importers that engage both in PA and ordinary imports but not PI. The numbers in parentheses are standard errors clustered at region-industry level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

Table A14: Resilience of importers: exporters and non-exporters

| Dependent Variable: | Importers but not exporters | | Importers and also exporters | |
|--|-----------------------------|----------------------|------------------------------|-----------------------|
| | (1) | (2) | (3) | (4) |
| firm imports by route $\ln(\text{imp}_{ijk})$ | | | | |
| pre shock sourcing intensity | 7.863*** (0.248) | 7.985*** (0.244) | 9.547*** (0.0987) | 9.574*** (0.0976) |
| trade route hit by SARS=1 | 0.00956 (0.0623) | 0.0733 (0.0646) | -0.0819*** (0.0238) | -0.0626** (0.0249) |
| trade route hit by SARS=1 x pre shock sourcing intensity | | -1.665*** (0.361) | | -0.375*** (0.128) |
| other routes hit by SARS=1 | | -0.0407 (0.0589) | | 0.00474 (0.0205) |
| firm-time FE | Y | Y | Y | Y |
| industry FE | Y | Y | Y | Y |
| ownership type FE | Y | Y | Y | Y |
| origin FE | Y | Y | Y | Y |
| destination FE | Y | Y | Y | Y |
| customs area FE | Y | Y | Y | Y |
| R^2 | 0.549 | 0.550 | 0.467 | 0.467 |
| No. of observations | 153627 | 153627 | 1866083 | 1866083 |

Notes: This table examines the resilience of importers which export and those that do not. Column (1) and (2) include importers that do not export. Column (3) and (4) include importers that are also exporters. The numbers in parentheses are standard errors clustered at region-industry level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

Table A15: Resilience of importers: single-location and multi-location importers

| Dependent Variable: | Single-location | | Multi-location | |
|---|------------------------|-----------------------|---------------------|---------------------|
| | (1) | (2) | (3) | (4) |
| firm import by route $\ln(\text{imp}_{ijk})$ | | | | |
| pre SARS sourcing intensity | 9.105*** (0.0960) | 9.135*** (0.0943) | 11.38*** (0.166) | 11.38*** (0.166) |
| trade route hit by SARS=1 | -0.0908*** (0.0262) | -0.0683** (0.0288) | -0.0389 (0.0478) | -0.0604 (0.0468) |
| trade route hit by SARS=1 x pre SARS sourcing intensity | | -0.396*** (0.134) | | 0.0727 (0.378) |
| other routes hit by SARS=1 | | -0.00554 (0.0222) | | 0.0540 (0.0438) |
| firm, destination-time, ownership, industry, origin, customs FE | Y | Y | Y | Y |
| R^2 | 0.483 | 0.483 | 0.439 | 0.439 |
| No. of observations | 1572882 | 1572882 | 446827 | 446827 |

Notes: This table examines the resilience of importers which has only single import/export location (roughly county level unit) in the customs data v.s. those have multiple. Column (1) and (2) include importers that only reports one single location. Column (3) and (4) include importers that reports multiple. The numbers in parentheses are standard errors clustered at region-industry level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

Table A16: Robustness of the trade elasticity

| Dependent Variable: foreign sourcing relative | | | | | |
|--|------------------------|------------------------|------------------------|-----------------------|----------------------|
| to home sourcing $\ln(\chi_{ijk}) - \ln \frac{\phi^d}{\Phi}$ | (1) | (2) | (3) | (4) | (5) |
| Weighted tariff, no log approximation | -5.180*** (0.748) | | | | |
| lagged share weighted ln(tariff) | | -5.087*** (0.759) | | | |
| current share weighted ln(tariff) | | | -5.121*** (0.770) | | |
| FH firm-market import tariff | | | | -4.989*** (0.800) | -5.676*** (0.830) |
| ln maritime distance | | | | -0.331*** (0.0145) | |
| ln geodist customs-destination | -0.0522*** (0.0159) | -0.0521*** (0.0159) | -0.0522*** (0.0159) | -0.253*** (0.0561) | |
| ln geodist origin-customs | -0.411*** (0.0153) | -0.411*** (0.0153) | -0.411*** (0.0153) | | |
| common customs | 0.446*** (0.0673) | 0.446*** (0.0673) | 0.446*** (0.0673) | 0.411*** (0.0799) | |
| common language: customs-destination | 0.845*** (0.0880) | 0.844*** (0.0880) | 0.844*** (0.0881) | 0.426*** (0.119) | |
| co-Chinese | 10.48*** (2.627) | 10.48*** (2.627) | 10.48*** (2.627) | 8.047*** (2.741) | |
| Firm FE | Y | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y | Y |
| Ownership type FE | Y | Y | Y | Y | Y |
| Origin FE | Y | Y | Y | Y | N |
| Customs district FE | Y | Y | Y | Y | N |
| Destination FE | Y | Y | Y | Y | N |
| Origin-Customs district-Destination FE | N | N | N | N | Y |
| R^2 | 0.458 | 0.458 | 0.458 | 0.460 | 0.504 |
| N | 121742 | 121742 | 121742 | 114732 | 115964 |

Notes: This table examines the robustness of θ with alternative measures and specifications. Column (1) uses the simple weighted average of tariff without log approximation as in Fitzgerald and Haller (2014). Column (2) uses only lagged shares in constructing the firm-market specific import tariff. Column (3) uses only current shares in constructing the tariff measure. Column (4) uses maritime distances between major ports instead of great circle distance to measure distances between customs districts and origins. Column (5) absorbs the gravity variables by a origin-custom district-destination fixed effect. The numbers in parentheses are standard errors clustered at firm level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01, respectively.

Table A17: SARS cases by regions

| Areas | Female | Male | Total | Number of deaths | fatality ratio (%) | Date onset first probable case | Date onset last probable case |
|---------------------|--------|------|-------|------------------|--------------------|--------------------------------|-------------------------------|
| China | 2674 | 2607 | 5327 | 349 | 7 | 16-Nov-02 | 03-Jun-03 |
| China, Hong Kong | 977 | 778 | 1755 | 299 | 17 | 15-Feb-03 | 31-May-03 |
| China, Taiwan | 218 | 128 | 346 | 37 | 11 | 25-Feb-03 | 15-Jun-03 |
| Canada | 151 | 100 | 251 | 43 | 17 | 23-Feb-03 | 12-Jun-03 |
| Singapore | 161 | 77 | 238 | 33 | 14 | 25-Feb-03 | 05-May-03 |
| Vietnam | 39 | 24 | 63 | 5 | 8 | 23-Feb-03 | 14-Apr-03 |
| United States | 14 | 15 | 29 | 0 | 0 | 24-Feb-03 | 13-Jul-03 |
| Philippines | 8 | 6 | 14 | 2 | 14 | 25-Feb-03 | 05-May-03 |
| Germany | 4 | 5 | 9 | 0 | 0 | 09-Mar-03 | 06-May-03 |
| Mongolia | 8 | 1 | 9 | 0 | 0 | 31-Mar-03 | 06-May-03 |
| Thailand | 5 | 4 | 9 | 2 | 22 | 11-Mar-03 | 27-May-03 |
| France | 1 | 6 | 7 | 1 | 14 | 21-Mar-03 | 03-May-03 |
| Australia | 4 | 2 | 6 | 0 | 0 | 26-Feb-03 | 01-Apr-03 |
| Malaysia | 1 | 4 | 5 | 2 | 40 | 14-Mar-03 | 22-Apr-03 |
| Sweden | 3 | 2 | 5 | 0 | 0 | 28-Mar-03 | 23-Apr-03 |
| Italy | 1 | 3 | 4 | 0 | 0 | 12-Mar-03 | 20-Apr-03 |
| United Kingdom | 2 | 2 | 4 | 0 | 0 | 01-Mar-03 | 01-Apr-03 |
| India | 0 | 3 | 3 | 0 | 0 | 25-Apr-03 | 06-May-03 |
| Republic of Korea | 0 | 3 | 3 | 0 | 0 | 25-Apr-03 | 10-May-03 |
| Indonesia | 0 | 2 | 2 | 0 | 0 | 06-Apr-03 | 17-Apr-03 |
| China, Macao | 0 | 1 | 1 | 0 | 0 | 05-May-03 | 05-May-03 |
| Kuwait | 1 | 0 | 1 | 0 | 0 | 09-Apr-03 | 09-Apr-03 |
| New Zealand | 1 | 0 | 1 | 0 | 0 | 20-Apr-03 | 20-Apr-03 |
| Republic of Ireland | 0 | 1 | 1 | 0 | 0 | 27-Feb-03 | 27-Feb-03 |
| Romania | 0 | 1 | 1 | 0 | 0 | 19-Mar-03 | 19-Mar-03 |
| Russian Federation | 0 | 1 | 1 | 0 | 0 | 05-May-03 | 05-May-03 |
| South Africa | 0 | 1 | 1 | 1 | 100 | 03-Apr-03 | 03-Apr-03 |
| Spain | 0 | 1 | 1 | 0 | 0 | 26-Mar-03 | 26-Mar-03 |
| Switzerland | 0 | 1 | 1 | 0 | 0 | 09-Mar-03 | 09-Mar-03 |
| Total | 4273 | 3779 | 8098 | 774 | 9.6 | | |

Notes: Data source: WHO.

Table A18: List of Chinese customs districts

| ID | Name | Province | largest gateway | 2 nd largest gateway | 3 rd largest gateway | share of overseas Chinese |
|------|--------------|----------------|-----------------|---------------------------------|---------------------------------|---------------------------|
| 100 | Beijing | Beijing | Beijing | | | 0.49% |
| 200 | Tianjin | Tianjin | Tianjin | | | 0.01% |
| 400 | Shijiazhuang | Hebei | Tangshan | Qinhuangdao | | 0.00% |
| 500 | Taiyuan | Shanxi | Taiyuan | | | 0.00% |
| 600 | Manchuri | Inner Mongolia | Manchuri | | | 0.00% |
| 700 | Mongolia | Inner Mongolia | Baotou | | | 0.00% |
| 800 | Shenyang | Liaoning | Shenyang | | | 0.00% |
| 900 | Dalian | Liaoning | Dalian | Yinkou | Dandong | 0.04% |
| 1500 | Changchun | Jilin | Changchun | | | 0.00% |
| 1900 | Harbin | Heilongjiang | Harbin | | | 0.00% |
| 2200 | Shanghai | Shanghai | Shanghai | | | 0.18% |
| 2300 | Nanjing | Jiangsu | Suzhou | Nanjing | Lianyungang | 0.04% |
| 2900 | Hangzhou | Zhejiang | Jiaxing | | | 0.08% |
| 3100 | Ningbo | Zhejiang | Ningbo-Zhoushan | | | 0.07% |
| 3300 | Hefei | Anhui | Wuhu | | | 0.01% |
| 3500 | Fuzhou | Fujian | Fuzhou | | | 0.20% |
| 3700 | Xiamen | Fujian | Xiamen | Quanzhou | | 1.14% |
| 4000 | Nanchang | Jiangxi | Nanchang | | | 0.01% |
| 4200 | Qingdao | Shandong | Qingdao | Rizhao | Yantai | 0.01% |
| 4600 | Zhengzhou | Henan | Zhengzhou | | | 0.01% |
| 4700 | Wuhan | Hubei | Wuhan | | | 0.01% |
| 4900 | Changsha | Hunan | Changsha | | | 0.02% |
| 5100 | Guangzhou | Guangdong | Huangpu | | | 2.75% |
| 5200 | Huangpu | Guangdong | Humen | | | 0.01% |
| 5300 | Shenzhen | Guangdong | Shenzhen | | | 2.07% |
| 5700 | Gongbei | Guangdong | Zhuhai | | | 1.19% |
| 6000 | Shantou | Guangdong | Shantou | | | 0.93% |
| 6400 | Haikou | Hainan | Haikou | | | 0.27% |
| 6700 | Zhanjiang | Guangdong | Zhanjiang | | | 0.01% |
| 6800 | Jiangmen | Guangdong | Jiangmen | | | 1.02% |
| 7200 | Nanning | Guangxi | Fanchenggang | | | 0.15% |
| 7900 | Chengdu | Sichuan | Chengdu | | | 0.01% |
| 8000 | Chongqing | Chongqing | Chongqing | | | 0.02% |
| 8300 | Guiyang | Guizhou | Guiyang | | | 0.04% |
| 8600 | Kunming | Yunnan | Kunming | | | 0.01% |
| 8800 | Lasa | Tibet | Lasa | | | 0.00% |
| 9000 | Xi'an | Shannxi | Xi'an | | | 0.29% |
| 9400 | Wulumuqi | Xinjiang | Wulumuqi | | | 0.01% |
| 9500 | Lanzhou | Gansu | Lanzhou | | | 0.00% |
| 9600 | Yinchuan | Ningxia | Yinchuan | | | 0.01% |
| 9700 | Xining | Qinghai | Xining | | | 0.00% |

Notes: The table lists the customs district as shown in Figure A3. It also lists the gateway city (cities) for each customs district. The column on overseas Chinese is constructed from Chinese City Yearbook 1995 and defined as the number of overseas Chinese divided by local population.

1.C.2 Complementary Figures

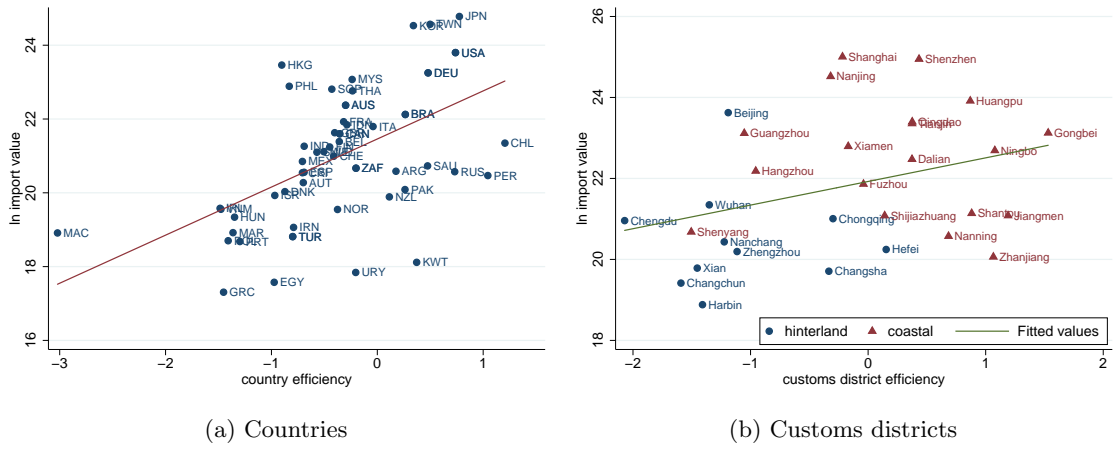
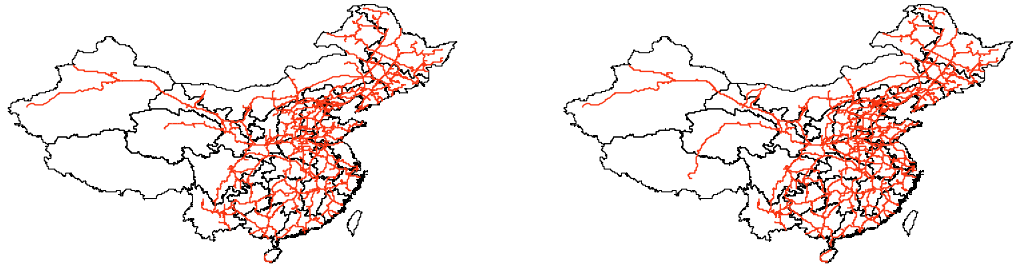


Figure A2: Countries and customs districts: efficiencies vs. imports



Figure A3: Map of Chinese customs districts

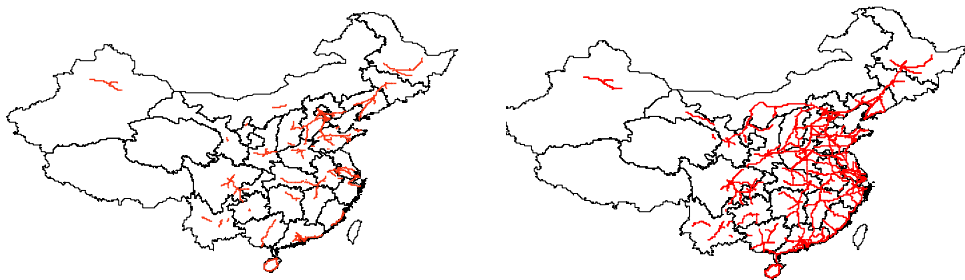


(a) Year 2000

(b) Year 2006

Notes: The base map is from the ACASIAN Data Center with finishing date cross-validated using news reports, government reports and other online sources.

Figure A4: Chinese railways 2000-2006



(a) Year 2000

(b) Year 2006

Notes: The base map is from the ACASIAN Data Center with finishing date cross-validated using news reports, government reports and other online sources.

Figure A5: Chinese highways 2000-2006

Chapter 2

Structural Adjustments and International Trade: Theory and Evidence from China

2.1 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 first produce labour-intensive goods. Those industries then decline and are gradually replaced by more capital-intensive industries. According to the Heckscher-Ohlin (HO) theory, as a country becomes more capital abundant, production and exports become more capital-intensive. Yet we know relatively less about the effect of trade liberalization and changes in Ricardian comparative advantage on structural adjustments. Moreover, existing analysis in the literature on structural adjustments focuses on reallocation across industries (e.g., Harrigan, 1995, 1997; Redding, 2002; Romalis, 2004), but largely ignores reallocation within industries across heterogeneous firms (Melitz, 2003). In this paper, we provide empirical, theoretical, and quantitative evidence on how changes in factor endowments, technology, and trade costs jointly determine structural adjustments both across and within industries.

We motivate our model by three new stylized 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, we find the following. 1) Manufacturing production became more capital-intensive in 2007 as compared with 1999. 2) Exports did not become more capital-intensive. Instead, the export intensity and percentage of firms that export increased in labour-intensive industries and decreased

in capital-intensive industries. 3) Productivity growth of labour-intensive firms was faster than capital-intensive firms during the period 1999-2007. China was clearly more capital abundant in 2007 than in 1999. According to the HO theory, China should be producing and exporting more capital-intensive goods. Thus, the observed adjustment in production in fact 1 is consistent with the HO theory. However, fact 2 seems to suggest that China had gained more comparative advantage in labour intensive sectors. Taken together, the first two facts are therefore at odds with the HO theory (not to say that the HO theory does not explain within-industry reallocations), while the third fact suggests that we need to consider productivity differences.

We develop a theoretical model to reconcile the stylized facts and study structural adjustments. We introduce firm heterogeneity (Melitz, 2003) into the two-country continuous HO and Ricardian framework (Dornbusch, Fischer, and Samuelson 1977, 1980, hereafter DFS) in the same manner as Bernard, Redding, and Schott (2007). There is a continuum of industries with different levels of capital intensity. Differences in factor endowments and technology between the two countries are the source of comparative advantage. The resulting pattern of production and trade is similar to Romalis (2004). If factor endowments are sufficiently different between the two countries, the labour (capital) abundant country specializes in labour (capital) intensive industries, while both countries produce in industries with intermediate labour intensity. Trade is one-way for industries in which either country specializes and two-way in industries in which both countries produce.¹ However, while all firms export in Romalis (2004), export propensity, measured by the conditional probability of exporting, is higher in industries of stronger comparative advantage in our model.

We numerically solve the model to conduct comparative statics and find the following three properties. Firstly, 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. On top of that, within-industry reallocations vary across industries. Export propensity and export intensity increase in capital-intensive industries and decline in labour-intensive industries. The magnitude of changes is more pronounced in more capital-intensive industries. Secondly, sector-biased technology change which strengthens the Ricardian comparative advantage of labour-intensive industries increase their export propensity and export intensity, and shift production toward these industries. The first two properties can be thought of as a “single crossing property” for

¹Unlike Helpman, Melitz, and Rubinstein (2008), and Lu (2010) in which firm entry is exogenous, we endogenize firm entry and allow for specialization. Zeros in trade flow can be generated in our model even though productivity distribution is unbounded. There is no specialization if factor endowments are within the “diversification cone” as in the two-sector model of Bernard et al. (2007), or if Ricardian comparative advantage is sufficiently weak.

sectoral distribution of production and exports. Finally, trade liberalization magnifies the existing comparative advantage. The labour-abundant country produce and export more in labour-intensive industries when trade costs are reduced.

To quantify the driving force behind structural adjustments in China, we estimate the model's underlining parameters by fitting the model moments to the data moments. The estimated model allows us to gauge the contribution of each driving force by conducting counterfactual experiments. Our estimation results indicate that during the period 1999-2007 the capital-to-labour ratio of China more than doubled, technology improved significantly and favoured labour-intensive industries, and trade liberalization reduced variable trade costs by more than a quarter. By running counterfactual simulations which replace the model parameters of 1999 by the parameters of 2007, we find that factor endowments were the major force shifting Chinese production toward capital-intensive industries. At the same time, sector-biased technology change was the main driving force behind the adjustment in exports. Over time, China gained more Ricardian comparative advantage in labour-intensive industries due to faster productivity growth in these industries. The technology change induced more firms to select into exporting and endogenously amplified the Ricardian comparative advantage in labour industries, outweighing changes in factor endowments, and leading to more exports in labour-intensive industries. The quantitative analysis therefore 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 et al., 2007), and to evaluate the contribution of export selection to productivity growth (Melitz, 2003). We find that Ricardian comparative advantage was dampened by export selection in 1999, but then got strengthened by export selection in 2007. Export selection contributed to about 2.1% of manufacturing productivity growth in China from 1999 to 2007. We also use the model to evaluate welfare gains and find that both China and the rest of the world (RoW) benefited from China's structural adjustments, but China benefited more. The rise of the Chinese economy was mostly driven by technology changes, less by factor endowments, 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 China's growth.²

Our paper makes contributions to several strands of literature. As far as we know, this is the first quantitative study on production and trade patterns which incorporates

²Our 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.

firm heterogeneity. Existing empirical studies on production and trade patterns mostly rely on industrial or product level data, and can generally be divided into two lines. The first is the Heckscher-Ohlin-Vanek literature which emphasizes cross-country differences in factor endowments.³ The other line of the literature focuses on the Ricardian model which emphasizes the role of productivity differences as the source of comparative advantage.⁴ We merge these two lines of analysis and introduce reallocation within industries by having heterogeneous firms. With the help of firm level data and a structurally estimated model, we not only quantify the importance of changes in factor endowments and technologies, but also show that within-industry reallocations shape comparative advantage and affect aggregate production and trade patterns considerably.

We also contribute to the literature studying the interaction of firm heterogeneity and comparative advantage. Our model is most closely related to Bernard et al. (2007). Recent contributions to this literature include Okubo (2009), Lu (2010), Fan et al. (2011), Gaubert and Itskhoki (2016), and Burstein and Vogel (2011, 2017). With the exception of Burstein and Vogel (2011, 2017), these papers include either HO or Ricardian comparative advantage alone. Whereas the focus of Burstein and Vogel (2011, 2017) is the effect of trade liberalization on skill premium, we focus on structural adjustments. Most importantly, our paper is the first to quantify the endogenous component of Ricardian comparative advantage due to firm heterogeneity, a mechanism first found in Bernard et al. (2007).

Our paper is also related to the literature on the evolution of comparative advantage. Redding (2002) studies the role of technology and factor endowments in the evolution of specialization patterns. Similar to his study, we also analyse 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 implication of evolving comparative advantage. We focus on how evolving comparative advantage shapes the structure 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 the RoW. Rodrik (2006), Schott (2008), and Wang and Wei (2010) discover that Chinese exports were getting more sophisticated. Despite that, Amiti and Freund (2010) find that the labour intensity of Chinese exports remained unchanged when processing trade is accounted for. China therefore continued to specialize in labour-intensive

³This is a large literature which dates back to Leontief (1953). Recent contributions include Treffer (1993, 1995), Harrigan (1995, 1997), Davis and Weinstein (2001), Romalis (2004), Schott (2004), Arezki et al. (2017), and among others.

⁴This line of literature has generated considerable amount of work since the seminal contribution by Eaton and Kortum (2002). Important contributions include Costinot et al. (2012) and Donaldson (2018). There are also papers which consider different sources of comparative advantage jointly, such as Chor (2010) and Morrow (2010).

industries, which is consistent with our finding. We show that this is possible in a more and more capital-abundant country since trade liberalization and sector-bias technology favour exports from labour-intensive industries. Autor, Dorn, and Hanson (2013) find negative effects of Chinese import competition on US local employment, which has ignited vibrant research evaluating welfare gains from trading with China. Hsieh and Ossa (2016), and Di Giovanni, Levchenko, and Zhang (2014) both study the welfare effect of productivity growth in China. We quantify the welfare effect of changes in factor endowments, technology, and trade liberalization 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. 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.

2.2 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.⁵ 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 Appendix Table B1.

Guided by HO theory, we focus on sectors that have different capital intensities. We define capital intensity as $1 - \frac{\text{labour costs}}{\text{value added}}$.⁶ 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.

⁵We do not look at years after 2007 due to the lack of data. The aftermath of the financial crisis is also of great concern.

⁶We drop firms with capital intensity larger than one or less than zero. Labour costs include payable wages, labour and employment insurance fees, and the total of 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 labour share slightly. To make it consistent, we do not include them.

Table 2.1 presents the basic empirical features of Chinese manufacturing firms in terms of factor allocation and export propensity. The average capital share of manufacturing firms increased by four percentage points.⁷ 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, from 18% to 21%.

Table 2.1: Capital share and exports

| Variables | mean in 1999 | mean in 2007 |
|------------------------------------|--------------|--------------|
| capital share of all manufacturers | 0.667 | 0.707 |
| capital share of exporters | 0.623 | 0.619 |
| percent of firms that export | 0.253 | 0.249 |
| exports/gross sales | 0.181 | 0.208 |

2.2.1 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 B2 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.⁸

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

⁷Hsieh and Klenow (2009) point out that labour 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).

⁸For brevity, the results are not reported but available upon request. Alvarez and López (2005), and Bernard, Jensen, Redding and Schott (2007) found that exporters are more capital intensive than non-exporters for Chilean and American firms, respectively. Bernard et al. (2007) speculated that exporters in developing countries should be more labour intensive than non-exporters given their comparative advantage in labour intensive goods. For the same data, Ma *et al.* (2014) use capital to labour ratio (capital divided by wage payments) as the indicator of factor intensity. They also find Chinese exporters are less capital intensive than non-exporters.

as “Heckscher-Ohlin aggregates” 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.⁹

2.2.2 Production

We first examine how Chinese production structure changes over time. Panel (a) in Figure C1 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 for larger fractions in 2007 than in 1999.¹⁰ Table 2.2 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 2.2: 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.

2.2.3 Trade Patterns

Next, we examine China’s structure of exports. Figure C2 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,

⁹Such an industry definition has also been used by Ju, Lin and Wang (2015) to study industry dynamics.

¹⁰Real value added is calculated using the input and output pricing index constructed by Brandt *et al.* (2012).

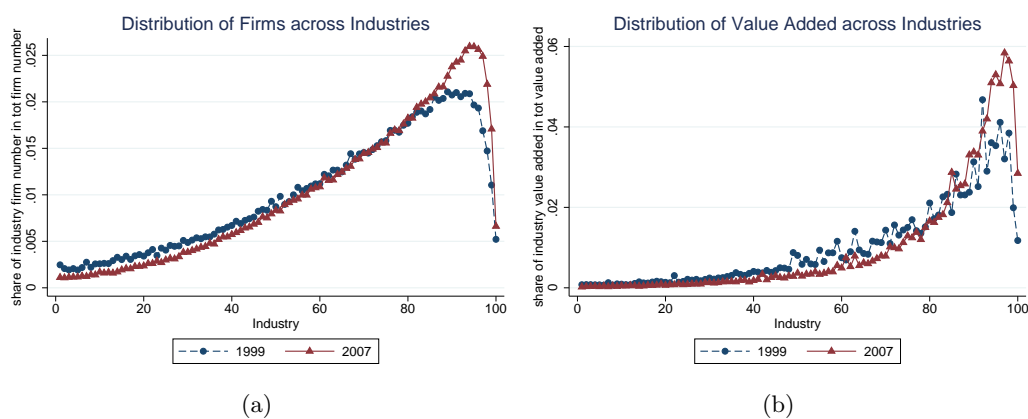


Figure 2.1: Distribution of outputs

and shows that the distribution stays almost unchanged.¹¹ 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 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 propensity for different industries changes over time. Figure C3 plots export propensity 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 labour-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 labour-intensive industries. However, it drops for the more capital-intensive industries.

These adjustments are also shown in Table 2.3. 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 propensity increased in labour-intensive industries and decreased in capital-intensive industries.*

¹¹If anything, it shifts towards the labour intensive industries.

Table 2.3: 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.

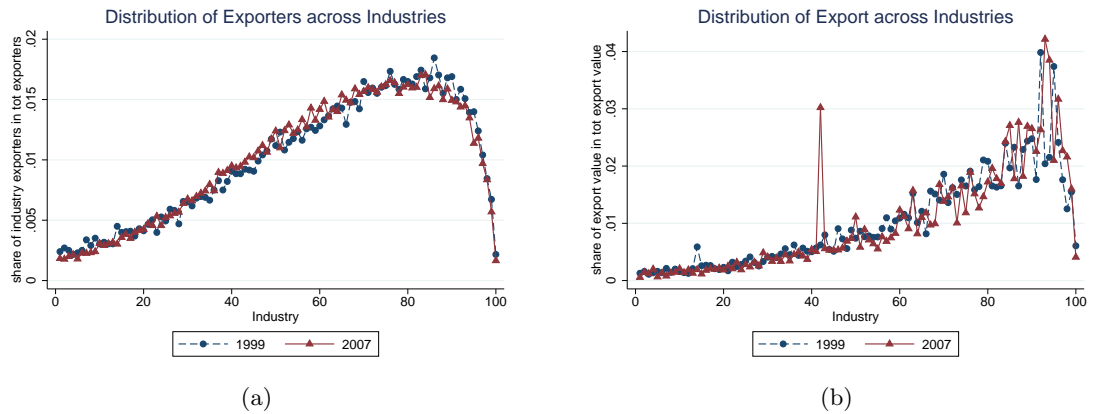


Figure 2.2: Distribution of exports

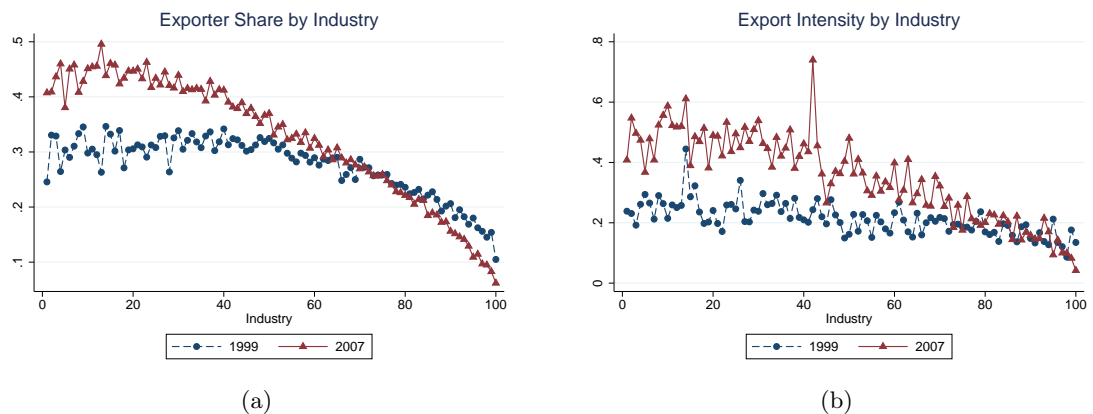


Figure 2.3: Export propensity and intensity by industry

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.¹² 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.

¹²This 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 labour intensive assembling. As found by Amiti and Freund (2010), the labour intensity of Chinese exports remained almost unchanged from 1992 to 2005 once processing trade is accounted for.

2.2.4 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. 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.¹³ Then we compute the average TFP for each industry weighted by firm outputs, trimming the top and bottom one percent to remove outliers. Figure 2.4 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 labour-intensive industries. In other words, productivity growth is biased toward labour-intensive industries.

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

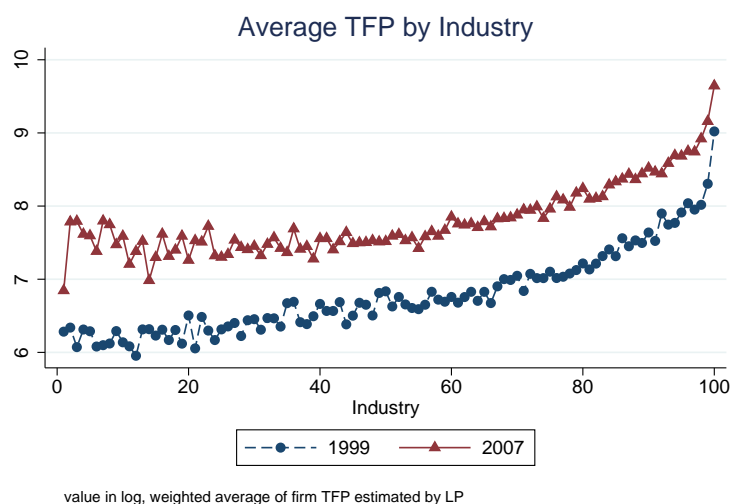


Figure 2.4: Industry productivity measured by weighted-average of firm TFP

2.2.5 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 following specification studies how annual

¹³The 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. labour 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 labour productivity measured as real value added per worker. This is shown in the Appendix 2.B.1.

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 : $\Delta Y_{it} = Y_{it} - Y_{it-1}$, $t=2000, 2001, \dots, 2007$. 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 2.4 presents the 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).

Table 2.4: Structural adjustments in China: 1999-2007

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---------------------|----------------------------------|--------------------------------|--------------------------------|-----------------------|--------------------|-------------------------------|-------------------------------|-------------------------------|
| | Firm # | Value added | Sales | Exporter # | Export Volume | Export Propensity | Export Intensity | TFP |
| capital intensity | 0.0006 ^a (0.00009) | 0.001 ^a (0.0004) | 0.001 ^a (0.0003) | -0.00006 (0.00004) | 0.0002 (0.0003) | -0.03 ^a (0.001) | -0.04 ^a (0.003) | -0.05 ^a (0.008) |
| Year FE | Y | Y | Y | Y | Y | Y | Y | Y |
| R^2 | 0.073 | 0.013 | 0.014 | 0.00035 | 0.00020 | 0.27 | 0.034 | 0.36 |
| 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 parentheses. The constants are absorbed by the year fixed effect. Significance levels are indicated by *a*, *b*, *c* at 0.1, 0.05 and 0.01 respectively.

Another concern is whether the findings are driven purely by “HO aggregates”. In Appendix 2.B.1, 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 propensity increased in labour-intensive sectors but declined in capital-intensive sectors, and c) productivity growth is faster in labour-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 labour-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 favour 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.¹⁴ In these various sub-samples, our basic findings are qualitatively preserved, as shown in Appendix 2.B.1.

2.3 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 endowments. Without loss of generality, we assume that the home country is labour abundant, that is: $L/K > L^*/K^*$, and has Ricardian comparative advantage in labour-intensive industries.¹⁵ 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.

2.3.1 Demand

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

¹⁴Pure exporters are defined as exporters with export intensity greater than 70% following Defever and Riaño (2017).

¹⁵Variables with “*” are for the foreign. We will discuss what happens if HO and Ricardian comparative advantage favour different industries.

by the following CES aggregator:¹⁶

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

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:

$$q_z(\omega) = Q(z) \left(\frac{p_z(\omega)}{P(z)} \right)^{-\sigma}, \quad (2.1)$$

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

2.3.2 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.* (2007), we assume that fixed costs are paid using capital and labour with a factor intensity that matches that of production in that industry. Specifically, we assume that the total cost function is:

$$\Gamma(z, \varphi) = \left(f_z + \frac{q(z, \varphi)}{A(z)\varphi} \right) r^z w^{1-z}, \quad (2.2)$$

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

$$\varepsilon(z) \equiv \frac{A(z)}{A^*(z)} = \lambda A^z, \lambda > 0, A > 0. \quad (2.3)$$

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 labour-intensive

¹⁶Such a preference structure is also used in the survey paper to quantify gains from trade by Costinot and Rodriguez-Clare (2014). In Appendix 2.A.7, we generalize our main theoretical results to a nested-CES preferences structure.

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 labour 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:

$$p_{zx}(\varphi) = \tau p_{zd}(\varphi) = \tau \frac{r^z w^{1-z}}{\rho A(z) \varphi}, \quad (2.4)$$

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:

$$r_{zd}(\varphi) = b(z)R \left(\frac{\rho A(z) \varphi P(z)}{r^z w^{1-z}} \right)^{\sigma-1}, \quad (2.5)$$

$$r_{zx}(\varphi) = \tau^{1-\sigma} \left(\frac{P(z)^*}{P(z)} \right)^{\sigma-1} \frac{R^*}{R} r_{zd}(\varphi), \quad (2.6)$$

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:

$$\begin{aligned} \pi_{zd}(\varphi) &= \frac{r_{zd}}{\sigma} - f_z r^z w^{1-z}, \\ \pi_{zx}(\varphi) &= \frac{r_{zx}}{\sigma} - f_{zx} r^z w^{1-z}. \end{aligned} \quad (2.7)$$

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

$$\pi_z(\varphi) = \pi_{zd}(\varphi) + \max\{0, \pi_{zx}(\varphi)\}. \quad (2.8)$$

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:

$$r_{zd}(\bar{\varphi}_z) = \sigma f_z r^z w^{1-z}, \quad (2.9)$$

$$r_{zx}(\bar{\varphi}_{zx}) = \sigma f_{zx} r^z w^{1-z}. \quad (2.10)$$

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

$$\bar{\varphi}_{zx} = \Lambda_z \bar{\varphi}_z, \text{ where } \Lambda_z = \frac{\tau P(z)}{P(z)^*} \left[\frac{f_{zx} R}{f_z R^*} \right]^{\frac{1}{\sigma-1}}. \quad (2.11)$$

$\Lambda_z > 1$ 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.* (2007).¹⁷ Firms' production and export decisions are shown in Figure 2.5. 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

$$\chi_z = \frac{1 - G(\bar{\varphi}_{zx})}{1 - G(\bar{\varphi}_z)}. \quad (2.12)$$

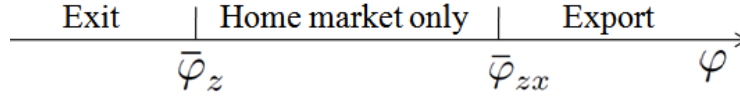


Figure 2.5: Productivity cut-offs and firm decisions

2.3.3 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:

$$(1 - G(\bar{\varphi}_z))M_{ez} = \delta M_z. \quad (2.13)$$

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 implies

$$V_z = \frac{1 - G(\bar{\varphi}_z)}{\delta} (\pi_{zd}(\bar{\varphi}_z) + \chi_z \pi_{zx}(\bar{\varphi}_{zx})) = f_{ez} r^z w^{1-z}, \quad (2.14)$$

¹⁷Lu(2010) explores the possibility that $\Lambda_z < 1$ and documents that in the labour 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.

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:

$$\begin{aligned}\widehat{\varphi}_z &= \left(\frac{1}{1 - G(\bar{\varphi}_z)} \int_{\bar{\varphi}_z}^{\infty} \varphi^{\sigma-1} g(\varphi) d\varphi \right)^{\frac{1}{\sigma-1}}, \\ \widehat{\varphi}_{zx} &= \left(\frac{1}{1 - G(\bar{\varphi}_{zx})} \int_{\bar{\varphi}_{zx}}^{\infty} \varphi^{\sigma-1} g(\varphi) d\varphi \right)^{\frac{1}{\sigma-1}}.\end{aligned}\quad (2.15)$$

Combining the free entry condition (2.14) with the zero profit conditions (2.9), (2.10), the productivity cut-offs $\bar{\varphi}_z$ and $\bar{\varphi}_{zx}$ satisfy:

$$\frac{f_z}{\delta} \int_{\bar{\varphi}_z}^{\infty} \left[\left(\frac{\varphi}{\bar{\varphi}_z} \right)^{\sigma-1} - 1 \right] g(\varphi) d\varphi + \frac{f_{zx}}{\delta} \int_{\bar{\varphi}_{zx}}^{\infty} \left[\left(\frac{\varphi}{\bar{\varphi}_{zx}} \right)^{\sigma-1} - 1 \right] g(\varphi) d\varphi = f_{ez}. \quad (2.16)$$

2.3.4 Market Clearing

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

$$R_z = b(z) R M_z \left(\frac{p_{zd}(\widehat{\varphi}_z)}{P(z)} \right)^{1-\sigma} + \chi_z b(z) R^* M_z \left(\frac{p_{zx}(\widehat{\varphi}_{zx})}{P(z)^*} \right)^{1-\sigma}, \quad (2.17)$$

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.

$$P(z) = \left[M_z p_{zd}(\widehat{\varphi}_z)^{1-\sigma} + \chi_z^* M_z^* p_{zx}^*(\widehat{\varphi}_{zx}^*)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}. \quad (2.18)$$

The factor market clearing conditions are:

$$\begin{aligned}L &= \int_0^1 l(z) dz, \quad L^* = \int_0^1 l^*(z) dz, \\ K &= \int_0^1 k(z) dz, \quad K^* = \int_0^1 k^*(z) dz.\end{aligned}\quad (2.19)$$

2.3.5 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 (2.4) for each industry and each country;

- (b) Free entry condition (2.14) and the relationship between two zero profit productivity cut-offs (2.11) for each industry and both countries;
- (c) Factor market clearing condition (2.19);
- (d) The pricing index (2.18) implied by consumer and producer optimizations;
- (e) The world goods market clearing condition(2.17).

Proposition 2.1. *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 2.A.1.

2.4 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 the lower bound of productivity: $\varphi \geq \theta$.¹⁸ 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 2.2. (a) *As long as the home country and the foreign country are sufficiently different in factor endowments or technology, then there exist two factor-intensity cut-offs $0 \leq \underline{z} < \bar{z} \leq 1$ such that the home country specializes in production within $[0, \underline{z}]$ whereas the foreign country specializes in production within $[\bar{z}, 1]$, while both countries produce within (\underline{z}, \bar{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 $\underline{z} = \bar{z}$ so that two countries completely specialize.*

Proof. See Appendix 2.A.2.

Given our assumptions that $\frac{L}{K} > \frac{L^*}{K^*}$ and $A < 1$, the home country has comparative advantage in labour-intensive industries. Proposition 2 and Figure 2.6 illustrate the production and trade patterns under this scenario. Countries engage in inter-industry trade

¹⁸Some of our results do not depend on the assumption of Pareto distribution. We will point it out if this is the case.

for industries within $[0, \underline{z}]$ and $[\bar{z}, 1]$, due to specialization.¹⁹ 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}, \bar{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 factor endowments, 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 $\bar{z} = 1$. However, if trade is totally free, the classical trade force dominates and full specialization arises as $\underline{z} = \bar{z}$, 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 $[\bar{z}, 1]$ and foreign country will specialize in $[0, \underline{z}]$.

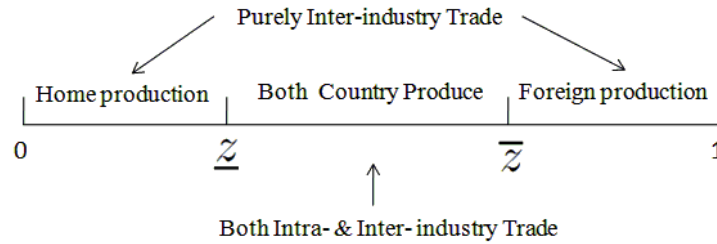


Figure 2.6: Production and trade patterns

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 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 propensity varies across industries in our model as shown in the following two propositions.

Proposition 2.3. (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}, \bar{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 2.A.3.

¹⁹For 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.* (2007). 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 2.7 illustrates these results for both home and foreign countries.

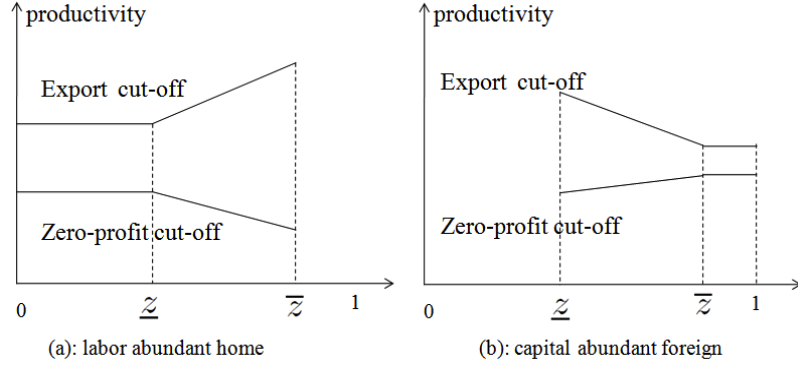


Figure 2.7: Productivity cut-offs

Proposition 2.4. (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}, \bar{z}) , and vice versa for the foreign country. If the productivity distribution is Pareto, we have

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

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

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

(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 2.A.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 propensity is a constant. This is illustrated in Figure 2.8. The left panel shows that export propensity decreases with capital intensity in the home country. The right panel shows an opposite pattern for the foreign country.

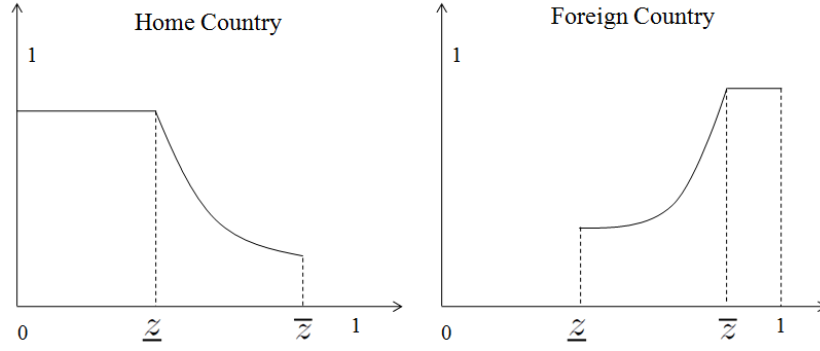


Figure 2.8: Export propensity

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 $\frac{\partial \chi_z}{\partial z}$ within (\underline{z}, \bar{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 propensity. Since $A < 1$ and $\frac{K}{L} < \frac{K^*}{L^*}$, home country has both Ricardian comparative advantage and HO comparative advantage in labour-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.* (2007) 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 2.5. (a) *The average idiosyncratic firm productivity in each industry is*

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

where C is a constant. Within (\underline{z}, \bar{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}, \bar{z}) , that both countries produce, so that the Ricardian com-*

parative advantage can be decomposed into two components as:

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

Proof. See Appendix 2.A.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 labour-intensive industries and $\ln(A) < \frac{\sigma}{\sigma-1} \ln\left(\frac{r}{w}/\frac{r^*}{w^*}\right)$. 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 $\left(\frac{1+f\chi_z}{1+f\chi_z^*}\right)^{1/a}$ declines with z and the endogenous Ricardian comparative advantage is weaker in capital-intensive industries.

2.5 Numerical Solution

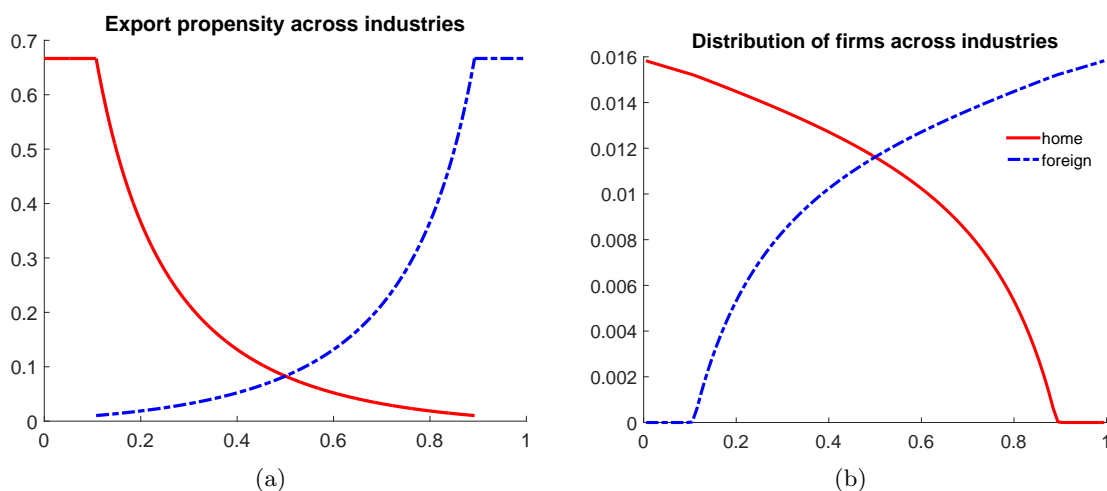
In this subsection, we parametrize the model and solve it numerically. The purpose of this section is twofold. The first is to visualize the equilibrium. The second is to study how the equilibrium responds to changes in factor endowments, technology, and trade costs.

The parametrization of the model is shown in Table 2.5, following Bernard *et al.* (2007). We set the initial factor endowments such that the home country has HO advantage in labour-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 2.9 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.

Table 2.5: Numerical solution: parametrization

| Variables | Definition | Value |
|--------------|--|-------|
| K | home capital stock | 100 |
| L | home labour stock | 300 |
| K^* | foreign capital stock | 300 |
| L^* | foreign labour 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 2.5.

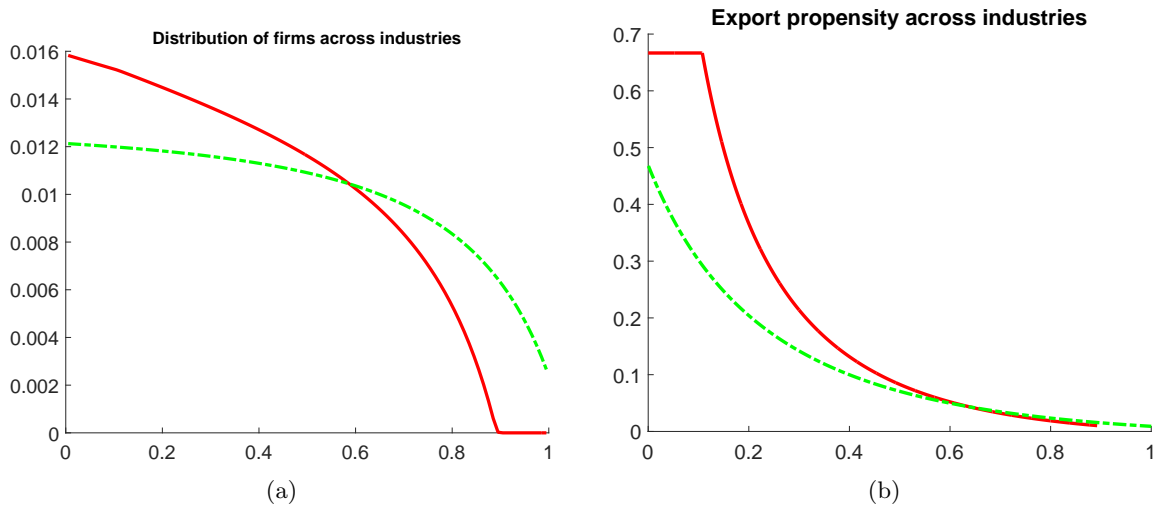
Figure 2.9: Benchmark solution

2.5.1 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 (strengthening Ricardian comparative advantage in labour-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 2.10 indicate that: 1) \bar{z} increases and \underline{z} decreases. That is, as two countries become similar in factor endowments, the measure of industries in which both countries produce $[\underline{z}, \bar{z}]$ increases. 2) For firm mass $M(z)$, we have $\frac{\partial(M'(z)-M(z))}{\partial z} > 0$. Furthermore, as Figure 2.10 (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 factor endowment changes.



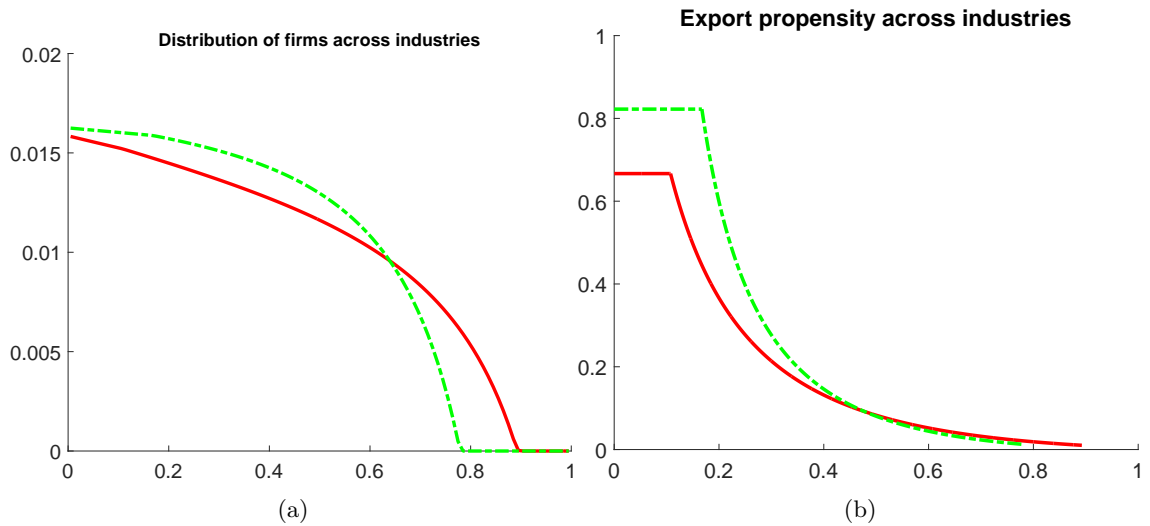
Notes: The solid lines are for the benchmark case with $K = 100$. The dashed lines are for the case with $K = 200$.

Figure 2.10: 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 favours labour-intensive industries at home by making them relatively more productive to the RoW. The results are presented in Figure 2.11, which indicate that 1) \bar{z} decreases and \underline{z} increases, so that the home country specialize more in labour-

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 labour-intensive industries increases more, the selection effect reinforces the comparative advantage in labour-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.

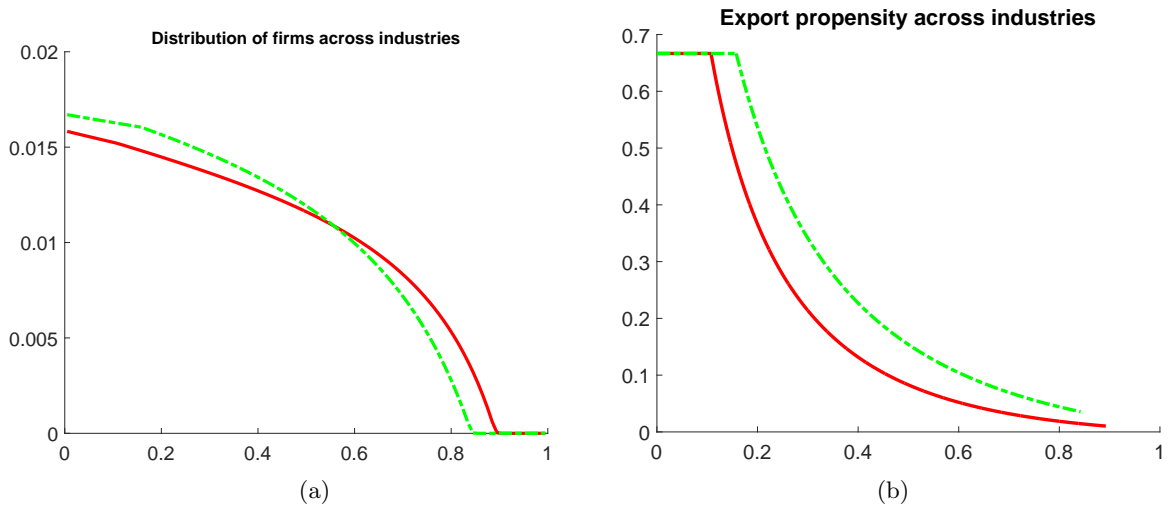
The third exercise reduces the iceberg trade cost τ from 1.8 to 1.5. From Proposition 2 we know that free trade will lead to complete specialization. Thus, a reduction in τ tends to result in more specialization. That is, \underline{z} would (weakly) increase and \bar{z} decreases. That is indeed the case in Figure 2.12. As expected, trade liberalization increases export probability and export intensity. Moreover, production shifts to the comparative advantage industries.



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

Figure 2.11: Sector-bias technology change

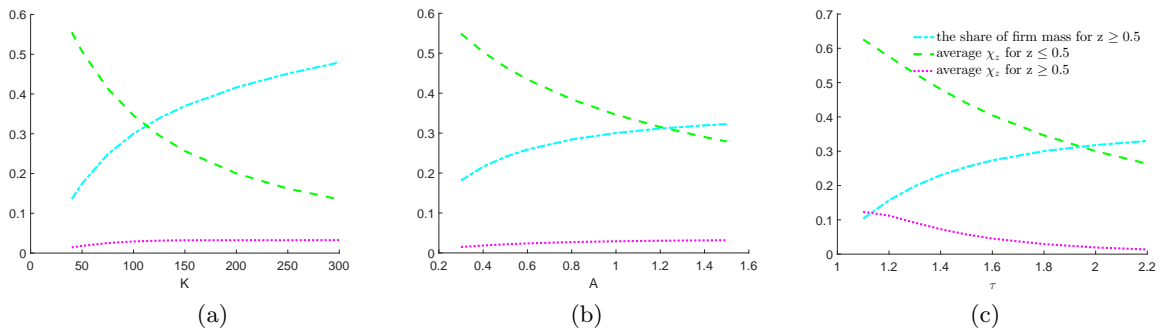
So far, we have only shown the numerical comparative statics for two specific parameters in each experiment. We now present the aggregate moments from the model over a wider range of parameters. These moments include the share of capital-intensive firms (capital intensity $z \geq 0.5$), the average export propensity for labour-intensive industries ($z \leq 0.5$) and capital-intensive industries. The results are shown in Figure 2.13. In panel (a), we simulate capital deepening by increasing K from 40 to 300. The share of capital-intensive firms increases as home country becomes more capital abundant. The average export propensity for labour-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 liber-



Notes: The solid lines are for the benchmark case with $\tau = 1.8$. The dashed lines are for the case with $\tau = 1.5$.

Figure 2.12: Trade liberalization

alization favours the comparative advantage industries and boosts their production and exports. Our numerical results are summarized together in Table 2.6. The key lessons we have learned are:



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 2.13: Numerical comparative statics on aggregate moments

Property 1: As the capital endowment increases in the labour abundant home country, distributions of firms’ mass, export probability/intensity, and productivity across industries all follow the “single 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 labour-intensive industries.

Property 2: For the sector-bias technology change that strengthens Ricardian comparative advantage in labour 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 2.6: Numerical comparative statics

| | share of capital intensive firms ($z \geq z_1$) | average χ_z for labour intensive industries ($z \leq z_2$) | 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 \bar{z} |
|--|---|---|--|--|---|
| capital deepening ($K \uparrow$) | + | - | + | - | + |
| sector-bias technology change ($A \downarrow$) | - | + | - | + | - |
| trade liberalization ($\tau \downarrow$) | - | | | + | - |

Notes: The variables are for the labour 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 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.

2.5.2 Discussion

If we believe capital had been deepening in China during the period 1999-2007, panel (a) of Figure 2.10 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 labour-intensive industries and dropped in capital-intensive industries. If trade liberalization was the main story and China had comparative advantage in labour-intensive industries, the Stylized fact 1 is at odds with panel (a) of Figure 2.12. According to Figure 2.11, if sector-bias technology change was the sole driving force, production and exports should have both become more labour-intensive or capital-intensive, depending on which industries the bias was favouring. 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.

2.6 Quantitative Analysis

In this section, we conduct a quantitative analysis of the model economy. We treat China as the home country and the 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.

2.6.1 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.²⁰ 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 labour supply for China to be 1. The relative labour endowment $\frac{L^*}{L}$ is calculated for both 1999 and 2007 using data from the World Bank as the ratio of industrial employment.²¹ Next, from Proposition 2.A.4, export intensity and probability of export for each industry are related to each other as $\gamma_z = \frac{fX_z}{1+fX_z}$. Thus we can infer the relative fixed cost of exports as $f = \frac{\gamma_z}{X_z(1-\gamma_z)}$ for each industry. Our estimation for f is the average across all industries. The estimated results are 1.00 and 1.77 for 1999 and 2007, respectively.²² 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 2006.²³ 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 net exports for each industry, and then compute the expenditure function $b(z)$ as the average of expenditure share during the period 2000-2006. The estimated $b(z)$ is shown in Appendix 2.B.2. These are all the parameters calibrated before the main estimation, which is also summarized in

²⁰The coefficient is estimated by pooling the data from two years together using OLS, controlling for year-industry fixed effect.

²¹Industrial employment is computed by multiplying the total labour 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.

²²This 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 2.B.2 plots the estimated f by industry.

²³The 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.

Table 2.7.

Table 2.7: Calibrated parameters

| Parameters | Value | Source |
|-------------------------------------|--|---|
| Pareto shape a | 3.43 | Broda <i>et al.</i> (2006) |
| Elasticity of substitution σ | 3.66 | Estimated according to Helpman <i>et al.</i> (2004) |
| relative labour size L^*/L | $year_{1999} : 2.49$ $year_{2007} : 2.22$ | Ratio of industrial labour 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 Appendix 2.B.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 the RoW, measured by the aggregation revenue ratio R^*/R . It is calculated using the ratio of manufacturing output between the RoW and China using World Bank data.²⁴ 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 labour-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.²⁵

We estimate the model parameters separately for the years 1999 and 2007. Table 2.8 reports the estimated parameters. First, China became more capital abundant in 2007. The relative capital stock of the RoW to China dropped from 3.50 to 2.54, and the capital to labour ratio of China more than doubled its level in 1999 from 0.907 to 2.03. Second, China became more productive compared with the RoW, especially in labour-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 the RoW shrank in every industry.²⁶ 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 labour-intensive industries during

²⁴Manufacturing output is estimated as nominal GDP multiplied by the share of manufacturing in aggregate GDP.

²⁵Appendix 2.A.8 provides more details about the estimation method. Appendix 2.A.9 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.

²⁶Our estimate of the relative productivity between China and the RoW is close to the estimate by di Giovanni *et al.* (2014). They estimate that average productivity of China relative to the 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.

this period.²⁷ Although we cannot observe the TFP for the RoW in each industry or directly measure the Ricardian comparative advantage, we do observe that TFP growth is relatively faster in the labour-intensive industries in China, as is shown in Figure 2.4 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 2.8: Estimation results

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

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

We then examine the fitting of our model. Table 2.9 shows the fitting of the targeted moments. As can be seen in the table, we match the target moments reasonably well. Table 2.10 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 the RoW. In 1999, average wage for the 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.²⁸ As we will show in the counterfactual, such wage growth is mostly driven by technology change favouring labour-intensive industries, less by the increasing scarcity of labour 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 2.14. 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 economy as well as the structural adjustment in Chinese production and

²⁷For supportive evidence, we look at reported R&D done by firms which are available in the data for the period 2005-2007. We find that the R&D intensity, measured by R&D costs divided by sales, tends to be higher for labour intensive Chinese firms. Levchenko and Zhang (2016) also find that productivity tends to grow faster in industries with greater initial comparative disadvantage.

²⁸According 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 $\frac{w_{2007}^W/w_{1999}^W}{w_{2007}^C/w_{1999}^C} = \frac{w_{2007}^W/w_{1999}^W}{w_{2007}^C/w_{1999}^C} = (1+60.7\%)/(1+168\%) = 60.0\%$. If we are willing to accept that the wage of the RoW is very close to the whole world, the same calculation using our estimate is $\frac{w_{2007}^*/w_{1999}^*}{w_{2007}^C/w_{1999}^C} = \frac{2.89}{6.43} = 44.9\%$. Thus our estimate of the relative wage growth of China to the RoW from our model accounts a significant proportions of wage growth in China.

exports from 1999 to 2007.

Table 2.9: Model fit: target moments

| Year | Data | | Model | |
|-------------------------------------|-------|-------|-------|-------|
| | 1999 | 2007 | 1999 | 2007 |
| Revenue of RoW/China: 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 2.10: Model fit: non-target moments

| Year | Data | | Model | |
|----------------------------|-------|-------|-------|-------|
| | 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 2.8 and compares them against data.

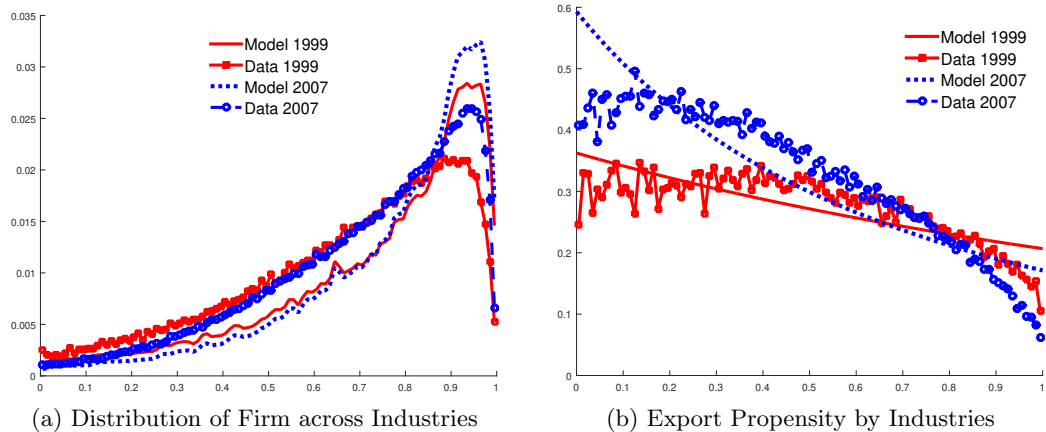


Figure 2.14: Model fit: non-targeted production and exports

2.6.2 Counterfactuals

In this subsection, we conduct counterfactual experiments to investigate the driving forces behind the structural adjustments of Chinese production and exports discussed in Section 2.2. 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 2.11 and Figure 2.15.

Table 2.11: Counterfactual simulations

| | Baseline Model | | Counterfactual simulation | | |
|-------------------------------------|----------------|-------|---------------------------|----------------|-------------------|
| | (1) | (2) | (3) | (4) | (5) |
| year | 1999 | 2007 | A and λ | τ and f | factor endowments |
| Revenue of RoW/China: 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 2.8. 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 factor endowments, and least by trade liberalization. The relative size of the RoW to China $\frac{R^*}{R}$ drops from 16.74 to 10.29 when we change $\{A, \lambda\}$ in column (3) of Table 2.11. This change in the relative size of the 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.²⁹ Similar to us, Tombe and Zhu (2015) also find that trade liberalization with the 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, changes in factor endowments are 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 labour-intensive industries in 2007. Given the changes in $\{A, \lambda\}$, expected profit of operating in the labour-intensive industries increased. Wages also increased, however, this drove up the fixed entry costs for labour-intensive industries. Rising

²⁹Zhu (2012) uses a growth accounting approach. Tombe and Zhu(2015) calibrate a general equilibrium model of trade and migration.

expected profit and rising fixed entry costs balanced out, leaving firm mass distribution almost unchanged.

Because trade liberalization benefited comparative advantage industries more, we would expect an expansion of the labour-intensive industries. But the effect turned out to be quite small. These results are also demonstrated in the left panel of Figure 2.15. Only in the counterfactual experiment with factor endowments that we see the firm mass distribution shifting toward capital-intensive industries.

Finally, technological changes drove the phenomena whereby exporters did not become more capital-intensive, and export propensity increased in labour-intensive industries but dropped in capital-intensive ones. As is evident from Table 2.11, only when $\{A, \lambda\}$ is replaced does the average capital intensity of exporters fall. This is due to a significant rise of exporters in labour-intensive industries and a decline in the capital-intensive ones. Export propensity increases universally when we replace $\{\tau, f\}$. When replacing the factor endowment parameters, exporter share declines everywhere, more so in the labour-intensive industries, making exporters more labour-intensive on average.

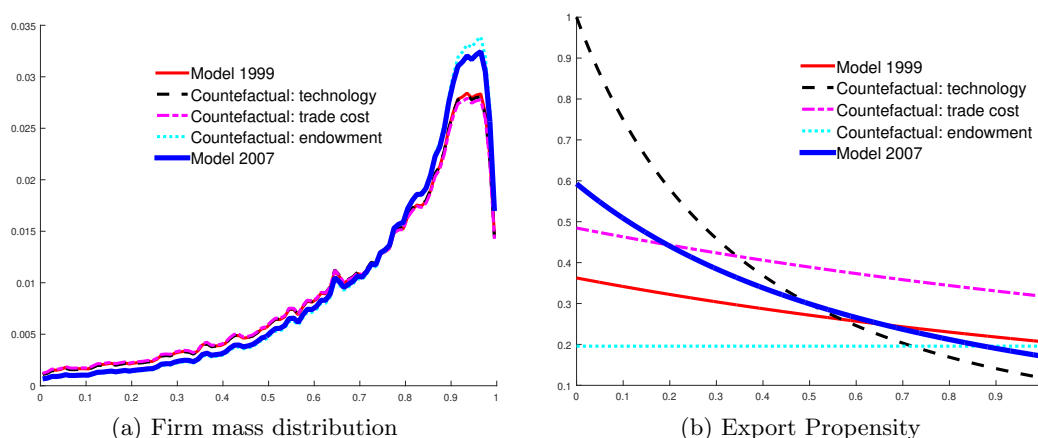


Figure 2.15: Counterfactuals

2.6.3 Decomposition of 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.* (2007) 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:

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

The exogenous component can be readily estimated using λ and A from Table 2.8. 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 .³⁰ Figure 2.16 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 favoured the labour-intensive industries in 2007. Since the exporter share is relatively higher in labour-intensive industries, the endogenous Ricardian comparative advantage also favours labour-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 favoured the capital-intensive industries and was dampened by the endogenous component.

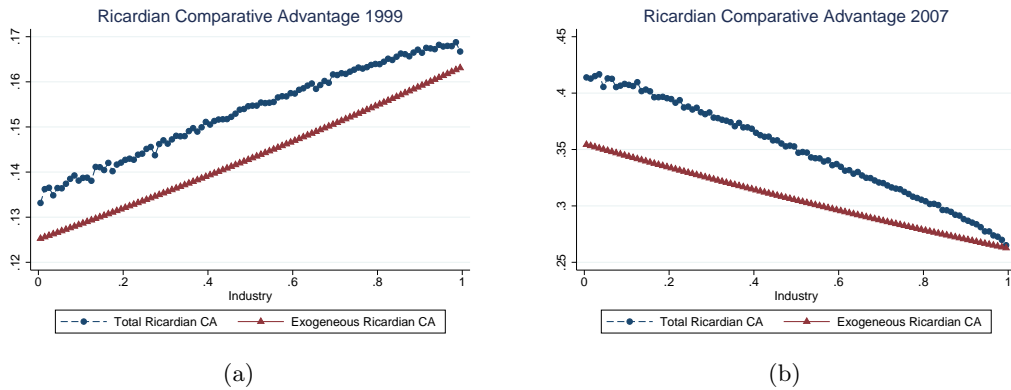


Figure 2.16: Decomposition of Ricardian comparative advantage

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

³⁰The estimated χ_z^* is plotted in Figure B5 in the Appendix. The share of exporters to China in the RoW is significantly lower than the share of exporters in China to the RoW, driven by the fact that the RoW is much larger than China. It increases with capital intensity, consistent with the 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 propensity for given trade costs.

and next period, respectively. Sectoral productivity growth is decomposed as:³¹

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

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 due to change in export selection. Figure 2.17 (a) plots the estimated productivity growth by industry.³² As noted earlier, the productivity growth is higher in the labour-intensive industries. The right panel plots $\left(\frac{1+f'\chi'_z}{1+f\chi_z}\right)^{\frac{1}{a}}$. Since χ_z increased in the labour-intensive industries, selection to export will lead to a disproportionately higher productivity growth in these industries. Although exporter share declined for the capital-intensive industries, the relative higher fixed costs of export 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.³³

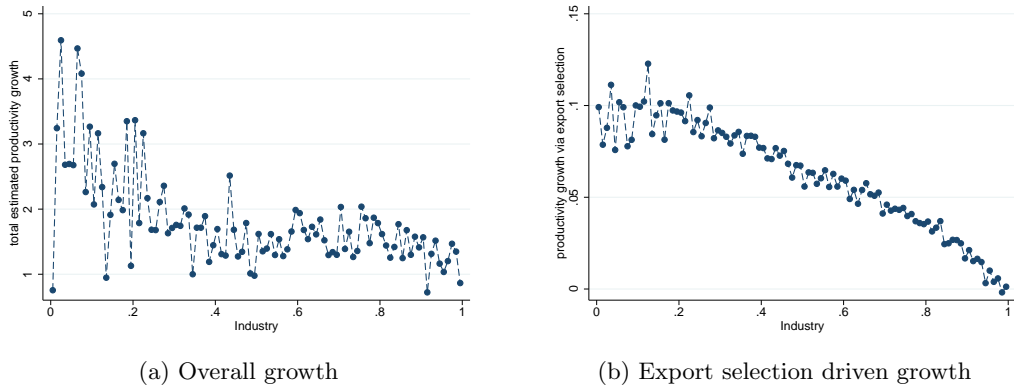


Figure 2.17: Export selection and productivity growth

³¹The 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.

³²We 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 $\left(\frac{1+f'\chi'_z}{1+f\chi_z}\right)^{\frac{1}{a}}$. 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.

³³The 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.

2.6.4 Welfare Analysis

An estimated model also allows us to provide welfare analysis for China and the 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 2.A.6. Armed with estimated parameters and the welfare formula, we first compare the welfare level of China with the RoW, and find

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

Though the welfare of China is much lower than the RoW, it is catching up quickly. To gauge the speed of welfare growth in China and the RoW, we estimate the changes in real consumption over time.³⁴ The result is presented in column (1) of Table 2.12. 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 the RoW.³⁵ 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 2.12.³⁶ As can be seen, the welfare gain of China mostly comes from changes in factor endowments and productivity growth, not from the trade liberalization. For the RoW, the welfare gain mostly comes from changes in factor endowments, less from productivity growth, and least from the trade liberalization.

Table 2.12: Counterfactual welfare

| | Baseline | Counterfactual | | |
|---------------------------------|----------|---------------------|----------------|-------------------|
| welfare change | (1) | (2) | (3) | (4) |
| | | $A(z)$ and $A(z)^*$ | τ and f | factor 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 2.8, assuming the death shock δ , lower bound of productivity θ and the relative fixed cost of entry \tilde{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 factor endowments, respectively.

³⁴As explained in Appendix 2.A.6, we assume the relative fixed entry cost \tilde{f} , death probability δ and the lower bound of the Pareto distribution θ are constant over time.

³⁵To put these numbers into perspective, the real GDP per capita grows at 12.5% for China and 4.9% for the RoW. But since we only capture the manufacturing sector, these numbers are not directly comparable.

³⁶In column (2), instead of replacing A , λ , we replace the estimated year 1999 sectoral productivity for China $A(z)$ and the RoW $A(z)^*$ by those estimated for 2007. If we only replace A , λ , only changes the relative productivity between China and the RoW would be captured. And we would miss out the productivity growth over time in China and the RoW.

Table 2.13: 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 2.8 is obtained by setting the Pareto shape $a = 3.43$. This table provides estimation results with a varying from 2.5 to 7.5.

2.6.5 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 2.13, 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 .

2.7 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 became more capital-intensive whereas exports did not during the period 1999-2007; export propensity increased in labour-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 favoured labour-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 factor endowments whereas changes in export propensity 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 factor endowments and trade liberalization.

Appendix

2.A Proofs and Additional Theoretical Results

2.A.1 Proof of Proposition 2.1

The proof is similar to the proof of Proposition 3 in Bernard, Redding, and Schott (2007). The complication is that we allow for specialization while they focus on cases within the diversification cone.³⁷ 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 (2.17), 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 (2.17), we find that:

$$\frac{r(\widehat{\varphi}_z)}{r(\widehat{\varphi}_z^*)} = \widetilde{p}_z^{1-\sigma} \frac{\left(\frac{P(z)}{P(z)^*}\right)^{\sigma-1} + \frac{R^*}{R} \tau^{1-\sigma} \chi_z \frac{a+1-\sigma}{a}}{\frac{R^*}{R} + \chi_z \frac{a+1-\sigma}{a} \tau^{1-\sigma} \left(\frac{P(z)}{P(z)^*}\right)^{\sigma-1}}, \quad (\text{E.2.1})$$

where $r(\widehat{\varphi}_z) = \frac{R_z}{M_z}$ is the average firm revenue, and $\widetilde{p}_z \equiv \frac{p_{zd}(\widehat{\varphi}_z)}{p_{zd}(\widehat{\varphi}_z^*)} = \frac{\widehat{\varphi}_z^* w}{\varepsilon(z) \widehat{\varphi}_z w^*} \left(\frac{r/w}{r^*/w^*}\right)^z$ 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 (2.9) and (2.10), and the fact that $\frac{r(\widehat{\varphi}_z)}{r(\widehat{\varphi}_z^*)} = \left(\frac{\widehat{\varphi}_z}{\widehat{\varphi}_z^*}\right)^{\sigma-1}$, we find $r(\widehat{\varphi}_z) = (f_z(\frac{\widehat{\varphi}_z}{\widehat{\varphi}_z^*})^{\sigma-1} + \chi_z f_{zx}(\frac{\widehat{\varphi}_z}{\widehat{\varphi}_z^*})^{\sigma-1}) \sigma r^z w^{1-z}$. Combined with the free entry condition, it can be shown that the average productivity between home and foreign country is $\frac{\widehat{\varphi}_z^*}{\widehat{\varphi}_z} = \left(\frac{1+f\chi_z^*}{1+f\chi_z}\right)^{\frac{1}{a}}$ while $f \equiv \frac{f_{zx}}{f_z}$. Using the Pareto

³⁷We will show how to determine the specialization pattern in proposition 2.

distribution assumption, we find that $\frac{\widehat{\varphi}_z}{\widehat{\varphi}_z} = \frac{\widehat{\varphi}_{zx}}{\widehat{\varphi}_{zx}} = \left(\frac{a}{a+1-\sigma}\right)^{\frac{1}{\sigma-1}}$, and $\chi_z = \frac{1-G(\widehat{\varphi}_{zx})}{1-G(\widehat{\varphi}_z)} = \Lambda_z^{-a}$, while Λ_z is the productivity cut-off ratio defined in Equation (2.11). Combining these results, it can be shown that:

$$\frac{r(\widehat{\varphi}_z)}{r(\widehat{\varphi}_z^*)} = \varepsilon \widetilde{p}_z \left(\frac{1 + f\chi_z}{1 + f\chi_z^*} \right)^{\frac{a+1}{a}}, \quad (\text{E.2.2})$$

Using the definition of \widetilde{p}_z and combining Equation (E.2.1) and (E.2.2), we have:

$$\chi_z = \frac{\widetilde{\tau}^{-a} f - \varepsilon^a h(z)}{\varepsilon^a f h(z) - \widetilde{\tau}^a}, \quad (\text{E.2.3})$$

where $h(z) = \left(\frac{w}{w^*} \left(\frac{r/w}{r^*/w^*}\right)^z\right)^{\frac{a\sigma}{1-\sigma}}$ and $\widetilde{\tau} = \tau f^{\frac{1}{\sigma-1}}$. From Equation (E.2.3), we find that χ_z is a function of the factor prices. From Equation (2.11) we have $\Lambda_z = \chi_z^{-1/a} = \frac{\tau P(z)}{P(z)^*} \left(\frac{fR}{R^*}\right)^{1/(\sigma-1)}$, then $\frac{P(z)}{P(z)^*} = \frac{\chi_z^{-1/a}}{\tau} \left(\frac{R^*}{fR}\right)^{1/(\sigma-1)}$, which is also function of the factor prices. Combined with Equations (2.17) and (2.18), the revenue for those industries that both countries produce are :

$$R_z = b(z) \left[\frac{R}{1 - \widetilde{\tau}^{-a} \varepsilon^a f h(z)} - \frac{fR^*}{\widetilde{\tau}^a \varepsilon^a h(z) - f} \right], \quad (\text{E.2.4})$$

$$R_z^* = b(z) \varepsilon^a h(z) \left[\frac{R^*}{\varepsilon^a h(z) - f \widetilde{\tau}^{-a}} - \frac{fR}{\widetilde{\tau}^a - \varepsilon^a f h(z)} \right]. \quad (\text{E.2.5})$$

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 $\frac{M_z}{M_z^*} = \widetilde{p}_z^{\sigma-1} \frac{\left(\frac{P(z)}{P(z)^*}\right)^{1-\sigma} - \chi_z^{-\frac{a+1-\sigma}{a}} \widetilde{\tau}^{-2(a+1-\sigma)} \tau^{1-\sigma}}{1 - \chi_z^{-\frac{a+1-\sigma}{a}} \tau^{1-\sigma} \left(\frac{P(z)}{P(z)^*}\right)^{1-\sigma}}$ ³⁸, 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 $\widehat{\varphi}_z$, and $\widehat{\varphi}_{zx}$. Once the cut-offs are known, average revenue for each industry is given by $r(\widehat{\varphi}_z) = (f_z \left(\frac{\widehat{\varphi}_z}{\widehat{\varphi}_z}\right)^{\sigma-1} + \chi_z f_{zx} \left(\frac{\widehat{\varphi}_{zx}}{\widehat{\varphi}_{zx}}\right)^{\sigma-1}) \sigma r^z w^{1-z}$. Then

³⁸This is derived from Equation (2.18) defining price index

we use the goods market clearing condition Equation (2.17) to determine the firm mass for each industry. The price index for each industry is also pinned down using Equation (2.18).

2.A.2 Proof of Proposition 2.2

Suppose $M_z^* \neq 0$, the relative firm mass between home and foreign can be extracted from Equation (2.18) as:

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

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

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

If $\chi_z = \frac{R^*}{fR} \left(\frac{f}{\tilde{\tau}^a}\right)^2$, 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 $\chi_z < \frac{R^*}{fR} \left(\frac{f}{\tilde{\tau}^a}\right)^2$, 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 $\frac{M_z}{M_z^*} \rightarrow +\infty$, or say $\frac{M_z^*}{M_z} \rightarrow 0$, 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:

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

where $\frac{f}{\tilde{\tau}^a} = \frac{f}{\tau^a f^{\frac{a}{\sigma-1}}} < \frac{f}{f^{\frac{a}{\sigma-1}}} < 1$. 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

$$\chi_z = \frac{\tilde{\tau}^{-a} f - \varepsilon^a h(z)}{\varepsilon^a f h(z) - \tilde{\tau}^a}, \quad (\text{E.2.6})$$

which is a continuous and monotonic between $[z, \bar{z}]$.³⁹ For the boundary industries \underline{z} and \bar{z} , since we have

$$\chi_{\underline{z}} = \frac{R^*}{fR} \text{ and } \chi_{\bar{z}} = \frac{R^*}{fR} \left(\frac{f}{\tilde{\tau}^a}\right)^2,$$

³⁹This is proved in proposition 4.

evaluating Equation (E.2.6) at \underline{z} and \bar{z} , we have:

$$\begin{aligned}\underline{z} &= \frac{\ln\left(\frac{\chi_{\underline{z}}\tilde{\tau}^a + f\tilde{\tau}^{-a}}{1+f\chi_{\underline{z}}}\right) - \frac{a\sigma}{1-\sigma}\ln\left(\frac{w}{w^*}\right) - a\ln(\lambda)}{\frac{a\sigma}{1-\sigma}\ln\left(\frac{r/w}{r^*/w^*}\right) + a\ln(A)}, \\ \bar{z} &= \frac{\ln\left(\frac{\chi_{\bar{z}}\tilde{\tau}^a + f\tilde{\tau}^{-a}}{1+f\chi_{\bar{z}}}\right) - \frac{a\sigma}{1-\sigma}\ln\left(\frac{w}{w^*}\right) - a\ln(\lambda)}{\frac{a\sigma}{1-\sigma}\ln\left(\frac{r/w}{r^*/w^*}\right) + a\ln(A)},\end{aligned}$$

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

2.A.3 Proof of Proposition 2.3

Let's focus on the home country. For any two industries z and z' , suppose $z < z'$, using the definition of Λ_z Equation (2.11), 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 labour 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 closed economy, no firms export and from Equation (2.18) we have $P(z) = M_z^{\frac{1}{1-\sigma}} p_{zd}(\hat{\varphi}_z)$. Firm mass for each industry is $M_z = \frac{b(z)R}{r(\hat{\varphi}_z)} = \frac{b(z)R}{r(\hat{\varphi}_z)} \left(\frac{\bar{\varphi}_z}{\hat{\varphi}_z}\right)^{\sigma-1}$. So $\frac{P(z)}{P(z')} = \left(\frac{w}{r}\right)^{(z'-z)/\rho} \left(\frac{b(z)}{b(z')}\right)^{\frac{1}{1-\sigma}} \frac{A(z')\bar{\varphi}_{z'}}{A(z)\bar{\varphi}_z}$. Using Equation (2.16) we have homogeneous cut-offs for all industries under autarky: $\bar{\varphi}_{z'} = \bar{\varphi}_z$. Then it can be verified that

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

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 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 $\frac{K}{L} < \frac{K^*}{L^*} \iff \frac{w}{r} < \frac{w^*}{r^*}$ 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 (2.16) 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 $g(\varphi) > 0$, $\bar{\varphi}_z \leq \varphi$ and $\bar{\varphi}_{zx} \leq \varphi$. 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.⁴⁰ So it must be the case that $\frac{\partial \bar{\varphi}_z}{\partial z} < 0$. Then the first term of Equation (2.16) 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: $P(z) = M_z^{\frac{1}{1-\sigma}} p_{zd}(\hat{\varphi}_z)$ and $P(z)^* = \chi_z^{\frac{1}{1-\sigma}} M_z^{\frac{1}{1-\sigma}} p_{zx}(\hat{\varphi}_{zx})$. So we have $\Lambda_z = \frac{\tau P(z)}{P(z)^*} \left(\frac{fR}{R^*}\right)^{\frac{1}{\sigma-1}} = \chi_z^{\frac{1}{\sigma-1}} \frac{\hat{\varphi}_{zx}}{\hat{\varphi}_z} \left(\frac{fR}{R^*}\right)^{\frac{1}{\sigma-1}}$. Using the definition of $\hat{\varphi}_z$ and $\hat{\varphi}_{zx}$, we

have $\Lambda_z = \left(\chi_z \frac{\int_{\bar{\varphi}_{zx}}^{\infty} \varphi^{\sigma-1} g(\varphi) d\varphi}{\int_{\bar{\varphi}_z}^{\infty} \varphi^{\sigma-1} g(\varphi) d\varphi}\right)^{\frac{1}{\sigma-1}} \left(\frac{fR}{R^*}\right)^{\frac{1}{\sigma-1}} = \left(\frac{\int_{\bar{\varphi}_{zx}}^{\infty} \varphi^{\sigma-1} g(\varphi) d\varphi}{\int_{\bar{\varphi}_z}^{\infty} \varphi^{\sigma-1} g(\varphi) d\varphi}\right)^{\frac{1}{\sigma-1}} \left(\frac{fR}{R^*}\right)^{\frac{1}{\sigma-1}}$ which is

an implicit function of Λ_z and $\bar{\varphi}_z$. Moreover, the free entry condition $\frac{f_z}{\delta} \int_{\bar{\varphi}_z}^{\infty} \left[\left(\frac{\varphi}{\bar{\varphi}_z}\right)^{\sigma-1} - 1\right] g(\varphi) d\varphi +$

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

2.A.4 Proof of Proposition 2.4

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

⁴⁰This 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 (2.16) will decrease with z . But the right hand side is a constant. Contradiction. Similar argument applies if $\frac{\partial \bar{\varphi}_z}{\partial z} = 0$.

$\Lambda_z = \frac{\widehat{\varphi}_{zx}}{\widehat{\varphi}_z} = \frac{\widehat{\varphi}_{zx}}{\widehat{\varphi}_z}$. Thus using the result that $\Lambda_z = \chi_z^{\frac{1}{\sigma-1}} \frac{\widehat{\varphi}_{zx}}{\widehat{\varphi}_z} \left(\frac{fR}{R^*}\right)^{\frac{1}{\sigma-1}}$ 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 $\chi_z = \frac{\tilde{\tau}^{-a} f - \varepsilon^a h(z)}{\varepsilon^a f h(z) - \tilde{\tau}^a}$ from the proof of Proposition 1. Using the chain rule, we have $\frac{\partial \chi_z}{\partial z} = \frac{(1 - \tilde{\tau}^{-2a} f^2) \varepsilon^a h(z) a (\ln(A) - \frac{\sigma}{\sigma-1} \ln(\frac{r/w}{r^*/w^*}))}{(\varepsilon^a f h(z) - \tilde{\tau}^a)^2}$. 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

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

whose sign depends only on $\ln(A)$ and $\frac{\sigma}{\sigma-1} \ln\left(\frac{r/w}{r^*/w^*}\right)$.⁴¹ For average export intensity for each sector is $\gamma_z \equiv \frac{\chi_z r(\widehat{\varphi}_{zx})}{r(\widehat{\varphi}_z) + \chi_z r(\widehat{\varphi}_{zx})} = \frac{\chi_z f_{zx} \left(\frac{\widehat{\varphi}_{zx}}{\widehat{\varphi}_z}\right)^{\sigma-1} \sigma r^z w^{1-z}}{(f_z \left(\frac{\widehat{\varphi}_z}{\widehat{\varphi}_z}\right)^{\sigma-1} + \chi_z f_{zx} \left(\frac{\widehat{\varphi}_{zx}}{\widehat{\varphi}_z}\right)^{\sigma-1}) \sigma r^z w^{1-z}} = \frac{f_{zx} \chi_z}{f_z + f_{zx} \chi_z} = \frac{f \chi_z}{1 + f \chi_z}$, 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 .

2.A.5 Proof of Proposition 2.5

From Equation (2.16) for free entry equation, we can calculate that the average of idiosyncratic firm productivity as

$$\widehat{\varphi}_z = \left(\frac{a}{a+1-\sigma}\right)^{\frac{1}{\sigma-1}} \widetilde{\varphi}_z = \left(\frac{a}{a+1-\sigma}\right)^{\frac{1}{\sigma-1}} \left[\frac{(\sigma-1)\theta^a}{(a+1-\sigma)\delta \widetilde{f}} (1 + f \chi_z) \right]^{\frac{1}{a}},$$

where $\widetilde{f} = \frac{f_{ez}}{f_z}$. Let $C = \left(\frac{a}{a+1-\sigma}\right)^{\frac{1}{\sigma-1}} \left[\frac{(\sigma-1)\theta^a}{(a+1-\sigma)\delta \widetilde{f}} \right]^{\frac{1}{a}}$, 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

$$\widehat{A}(z) = E_{\varphi} \{ A(z) \varphi | \varphi > \overline{\varphi}_z \} = A(z) \widetilde{\varphi}_z.$$

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

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

which is the second result of the proposition.

⁴¹ $B(z)$ is positive as $\tilde{\tau}^{-a} f < 1$.

2.A.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 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 (2.18). Plugging in the average price of domestic varieties and average F.O.B price of foreign varieties respectively: $P_z(\hat{\varphi}_z) = \frac{\sigma}{\sigma-1} \frac{r^z w^{1-z}}{A(z) \hat{\varphi}_z}$ and $P_z(\hat{\varphi}_{zx}^*) = \frac{\sigma}{\sigma-1} \frac{r^{*z} w^{*1-z}}{A(z)^* \hat{\varphi}_{zx}^*}$, we have

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

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):

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

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: $E(A(z)\varphi|\varphi \geq \bar{\varphi}_z) = A(z)\hat{\varphi}_z$ while $\hat{\varphi}_z$ can be computed from Proposition 5 as $\hat{\varphi}_z = C(1 + f\chi_z)^{1/a}$.⁴² Then an estimator of $A(z)$ is:

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

⁴²The 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 \tilde{f} .

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

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

is the real consumption, and the welfare change as measured by real consumption is given by:⁴³

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

2.A.7 CES Preference

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

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

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

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

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

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

⁴³Since 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 the RoW.

The profits from domestic and foreign sales are

$$\begin{aligned}\pi_{zd}(\varphi) &= \frac{r_{zd}(\varphi)}{\sigma} - f_z r^z w^{1-z}, \\ \pi_{zx}(\varphi) &= \frac{r_{zx}(\varphi)}{\sigma} - f_{zx} r^z w^{1-z}.\end{aligned}$$

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

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

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

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

2.A.8 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: $\underline{z} = \frac{\ln(\frac{\chi_{\underline{z}} \tilde{\tau}^a + f \tilde{\tau}^{-a}}{1 + f \chi_{\underline{z}}}) - \frac{a\sigma}{1-\sigma} \ln(\frac{w}{w^*}) - a \ln(\lambda)}{\frac{a\sigma}{1-\sigma} \ln(\frac{r/w}{r^*/w^*}) + a \ln(A)}$ and $\bar{z} = \frac{\ln(\frac{\chi_{\bar{z}} \tilde{\tau}^a + f \tilde{\tau}^{-a}}{1 + f \chi_{\bar{z}}}) - \frac{a\sigma}{1-\sigma} \ln(\frac{w}{w^*}) - a \ln(\lambda)}{\frac{a\sigma}{1-\sigma} \ln(\frac{r/w}{r^*/w^*}) + a \ln(A)}$, where $\chi_{\underline{z}} = \frac{R^*}{fR}$ and $\chi_{\bar{z}} = \frac{R^*}{fR} \left(\frac{f}{\tilde{\tau}^a} \right)^2$. The factor market clearing conditions for home country are

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

where R_z is given by Equation (E.2.4). 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 2.A.9.

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.

2.A.9 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

$$\begin{aligned} L_s &= \int_0^{\bar{z}} l(z) dz = \frac{R + R^*}{w} \int_0^{\bar{z}} (1 - z) b(z) dz = \frac{R + R^*}{w} N, \\ K_s &= \int_0^{\bar{z}} k(z) dz = \frac{R + R^*}{r} \int_0^{\bar{z}} z b(z) dz = \frac{R + R^*}{r} B, \\ L_s^* &= \int_{\bar{z}}^1 l^*(z) dz = \frac{R + R^*}{w^*} \int_{\bar{z}}^1 (1 - z) b(z) dz = \frac{R + R^*}{w^*} C, \\ K_s^* &= \int_{\bar{z}}^1 k^*(z) dz = \frac{R + R^*}{r^*} \int_{\bar{z}}^1 z b(z) dz = \frac{R + R^*}{r^*} D, \end{aligned}$$

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

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

$$\begin{aligned} L_{int} &= \frac{1}{w} \int_{\bar{z}}^{\bar{z}} b(z) (1 - z) \left[\frac{R}{1 - \tilde{\tau}^{-a} \varepsilon^a f h(z)} - \frac{f R^*}{\tilde{\tau}^a \varepsilon^a h(z) - f} \right] dz = \frac{R}{w} E - \frac{R^*}{w} F, \\ K_{int} &= \frac{1}{r} \int_{\bar{z}}^{\bar{z}} b(z) z \left[\frac{R}{1 - \tilde{\tau}^{-a} \varepsilon^a f h(z)} - \frac{f R^*}{\tilde{\tau}^a \varepsilon^a h(z) - f} \right] dz = \frac{R}{r} G - \frac{R^*}{r} H, \\ L_{int}^* &= \frac{1}{w^*} \int_{\bar{z}}^{\bar{z}} b(z) (1 - z) \varepsilon^a h(z) \left[\frac{R^*}{\varepsilon^a h(z) - f \tilde{\tau}^{-a}} - \frac{f R}{\tilde{\tau}^a - \varepsilon^a f h(z)} \right] dz = \frac{R^*}{w^*} I - \frac{R}{w^*} J, \\ K_{int}^* &= \frac{1}{r^*} \int_{\bar{z}}^{\bar{z}} b(z) z \varepsilon^a h(z) \left[\frac{R^*}{\varepsilon^a h(z) - f \tilde{\tau}^{-a}} - \frac{f R}{\tilde{\tau}^a - \varepsilon^a f h(z)} \right] dz = \frac{R^*}{r^*} X - \frac{R}{r^*} Y, \end{aligned}$$

where $E \equiv \int_{\bar{z}}^{\bar{z}} \frac{b(z)(1-z)}{1 - \tilde{\tau}^{-a} \varepsilon^a f h(z)} dz$, $F \equiv \int_{\bar{z}}^{\bar{z}} \frac{f b(z)(1-z)}{\tilde{\tau}^a \varepsilon^a h(z) - f} dz$, $G \equiv \int_{\bar{z}}^{\bar{z}} \frac{b(z)z}{1 - \tilde{\tau}^{-a} \varepsilon^a f h(z)} dz$, $H \equiv \int_{\bar{z}}^{\bar{z}} \frac{f b(z)z}{\tilde{\tau}^a \varepsilon^a h(z) - f} dz$, $I \equiv$

$$\int_{\underline{z}}^{\bar{z}} \frac{b(z)(1-z)\varepsilon^a h(z)}{\varepsilon^a h(z) - f\tilde{\tau}^{-a}} dz, J \equiv \int_{\underline{z}}^{\bar{z}} \frac{fb(z)(1-z)\varepsilon^a h(z)}{\tilde{\tau}^a - \varepsilon^a fh(z)} dz, X \equiv \int_{\underline{z}}^{\bar{z}} \frac{b(z)z\varepsilon^a h(z)}{\varepsilon^a h(z) - f\tilde{\tau}^{-a}} dz \text{ and } Y \equiv \int_{\underline{z}}^{\bar{z}} \frac{fb(z)z\varepsilon^a h(z)}{\tilde{\tau}^a - \varepsilon^a fh(z)} dz.$$

Using factor market clearing condition,

$$\begin{aligned} L_s + L_{int} &= L, K_s + K_{int} = K, \\ L_s^* + L_{int}^* &= L^*, K_s^* + K_{int}^* = K^*, \end{aligned}$$

we have

$$\begin{aligned} L &= \frac{R}{w}(N + E) + \frac{R^*}{w}(N - F), K = \frac{R}{r}(B + G) + \frac{R^*}{r}(B - H), \\ L^* &= \frac{R}{w^*}(C - J) + \frac{R^*}{w^*}(C + I), K^* = \frac{R}{r^*}(D - Y) + \frac{R^*}{r^*}(D + X). \end{aligned}$$

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, \dots, I, J, X and Y only depend on $\{r^*, \frac{w^*}{w}, A, \lambda, a, f, \tau, \sigma\}$ ⁴⁴, according to the equation above, $\frac{R^*}{R}$ also depends on $\{r^*, \frac{w^*}{w}, A, \lambda, a, f, \tau, \sigma\}$ only.

Moreover,

$$\begin{aligned} \frac{L^*}{L} &= \frac{w}{w^*} \frac{C - J + (C + I)\frac{R^*}{R}}{N + E + (N - F)\frac{R^*}{R}}, \\ \frac{K^*}{K} &= \frac{r}{r^*} \frac{(D - Y) + (D + X)\frac{R^*}{R}}{B + G + (B - H)\frac{R^*}{R}}, \end{aligned}$$

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

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

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

For industries that home country specializes

$$\begin{aligned} b(z)(R + R^*) &= M_z r(\tilde{\varphi}_z) \\ &= M_z \frac{a\sigma f_z r^z w^{1-z}(1 + f\chi_z)}{a + 1 - \sigma}, \end{aligned}$$

⁴⁴Given $b(z)$, N, B, C, \dots, I, J, X and Y are integrals of function of $\varepsilon^a h(z)$ defined over a intersection given by $0, \underline{z}, \bar{z}$ and 1 . $\varepsilon^a h(z)$, \underline{z} and \bar{z} are functions of $\{r^*, \frac{w^*}{w}, \Psi, \lambda, a, f, \tau, \sigma\}$ only.

therefore,

$$\begin{aligned} M_z \left(\frac{r}{w}\right)^z &= \frac{b(z)(R + R^*)}{\frac{a\sigma f_z w}{a+1-\sigma}(1 + f\chi_z)} \\ &= b(z)L \frac{(1 + \frac{rK}{wL})(1 + \frac{R^*}{R})}{\frac{a\sigma f_z}{a+1-\sigma}(1 + f\chi_z)}. \end{aligned}$$

Similarly, for industries that both countries produces:

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

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

$$\begin{aligned} m_z &= \frac{M_z}{\int_0^{\bar{z}} M_z dz} \\ &= \frac{b(z)L \frac{(1 + \frac{rK}{wL})(1 + \frac{R^*}{R})}{\frac{a\sigma f_z}{a+1-\sigma}(\frac{r}{w})^z(1 + f\chi_z)}}{\int_0^{\bar{z}} b(z)L \frac{(1 + \frac{rK}{wL})(1 + \frac{R^*}{R})}{\frac{a\sigma f_z}{a+1-\sigma}(1 + f\chi_z)(\frac{r}{w})^z} dz + \int_{\bar{z}}^{\infty} \frac{b(z)L(1 + \frac{rK}{wL})(1 + \frac{R^*}{R})}{\frac{a\sigma f_z}{a+1-\sigma}(1 + f\chi_z)(1 + \frac{M_z^* r(\frac{r}{w})}{M_z r(\frac{r}{w})})(\frac{r}{w})^z} dz} \\ &= b(z) \frac{(\frac{r}{w})^{-z}(1 + f\chi_z)^{-1}}{\int_0^{\bar{z}} b(z)(\frac{r}{w})^{-z}(1 + f\chi_z)^{-1} dz + \int_{\bar{z}}^{\infty} \frac{b(z)(\frac{r}{w})^{-z}}{(1 + \frac{M_z^* r(\frac{r}{w})}{M_z r(\frac{r}{w})})(1 + f\chi_z)} dz} \end{aligned}$$

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

$$\begin{aligned} m_z &= \frac{M_z}{\int_0^{\bar{z}} M_z dz} \\ &= b(z) \frac{\frac{(\frac{r}{w})^{-z}}{(1 + \frac{M_z^* r(\frac{r}{w})}{M_z r(\frac{r}{w})})(1 + f\chi_z)}}{\int_0^{\bar{z}} b(z)(\frac{r}{w})^{-z}(1 + f\chi_z)^{-1} dz + \int_{\bar{z}}^{\infty} \frac{b(z)(\frac{r}{w})^{-z}}{(1 + \frac{M_z^* r(\frac{r}{w})}{M_z r(\frac{r}{w})})(1 + f\chi_z)} dz}. \end{aligned}$$

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

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

Therefore, $\frac{r}{w}$ 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 .

2.B Complementary Figures

2.B.1 Robustness of the Motivating Evidence

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

First, two alternative measures of productivity are used: labour productivity, and TFP estimated by the Olley and Pakes (1996) method. The results are presented in Figure B1. Again, productivity growth is relatively faster in labour intensive industries.



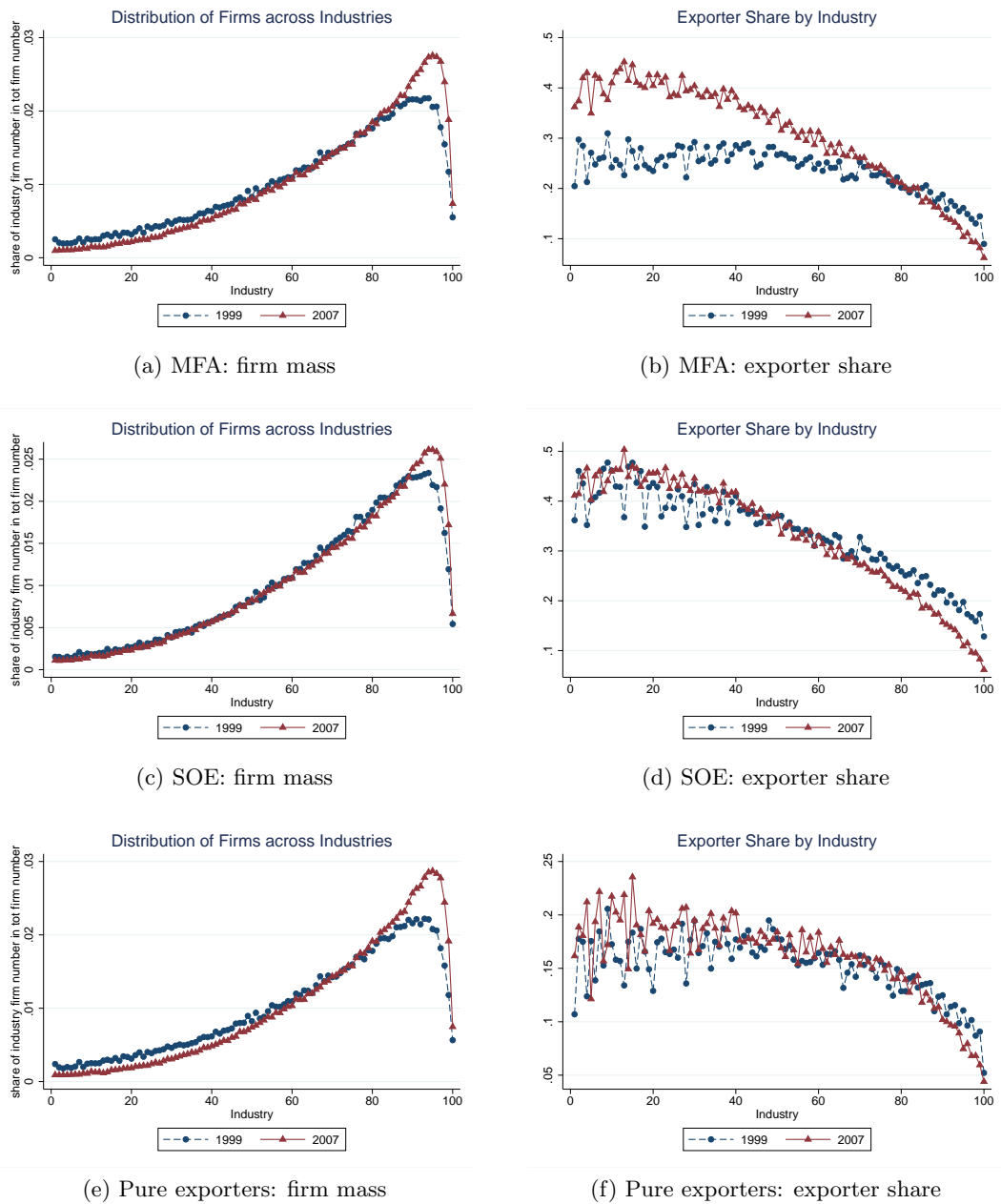
Notes: labour productivity is measured as real valued added per worker. TFP is estimated as in Olley-Pakes (1996).

Figure B1: Robustness of evidence on productivity growth

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 B2. 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 aggregates”, we use the four-digit Chinese Industry Classification (CIC) to see whether our evidence still hold. The results are presented Figure B3. The results are consistent with our evidence using HO aggregates as industries classification.

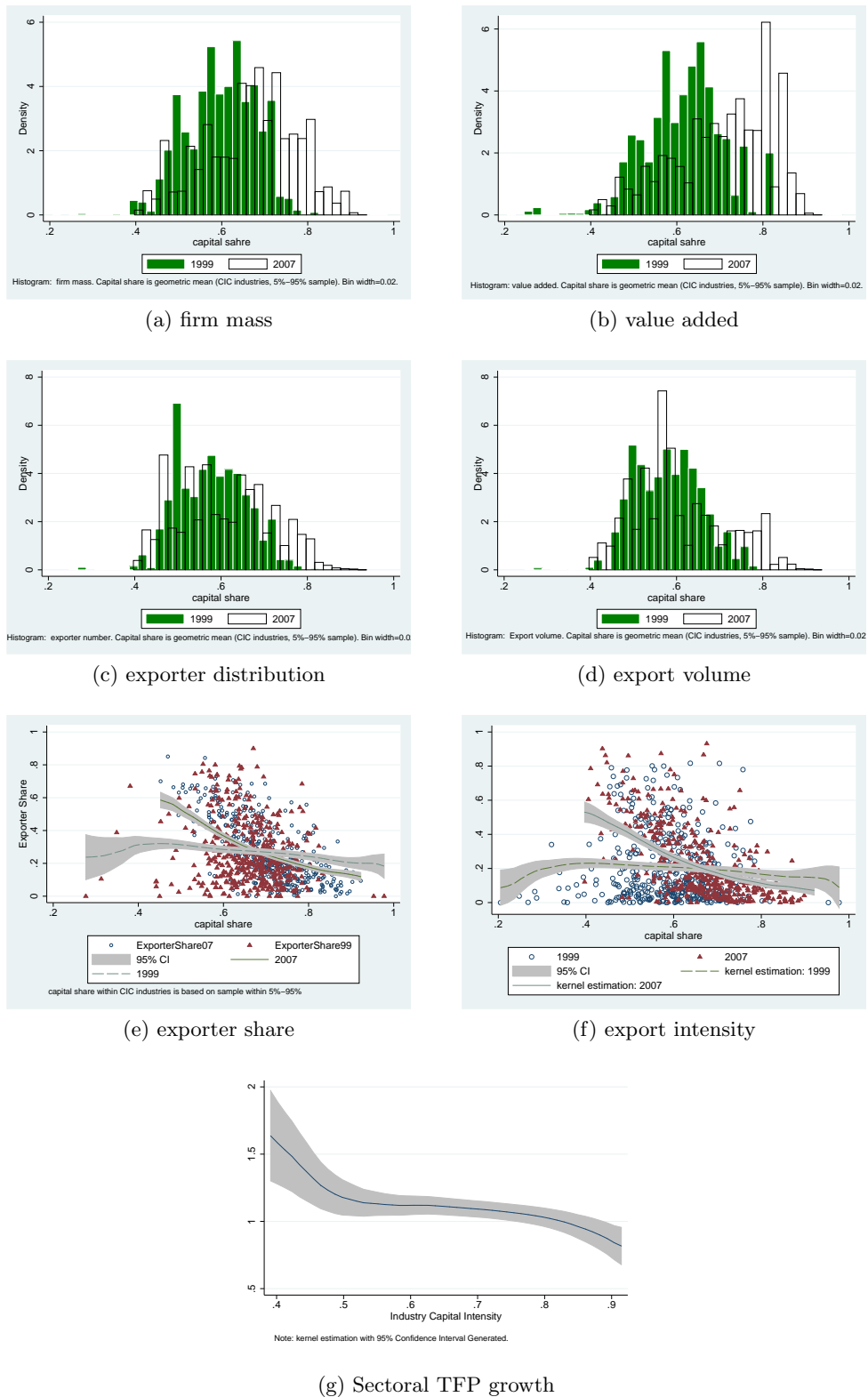
2.B.2 Additional Figures on Parametrization

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 B4 (a). The expenditure share $b(z)$ is computed as the



Notes: (a) The industry classification used is “HO aggregates” 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. (c) The charts on SOE are by excluding state owned firms. (d) The charts on Pure exporters are by excluding pure exporters, i.e., firms which export more than 70% of the outputs.

Figure B2: Robustness of motivating facts by sub-samples



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 B3: Motivating evidence using CIC industry classification

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 B4 (b).

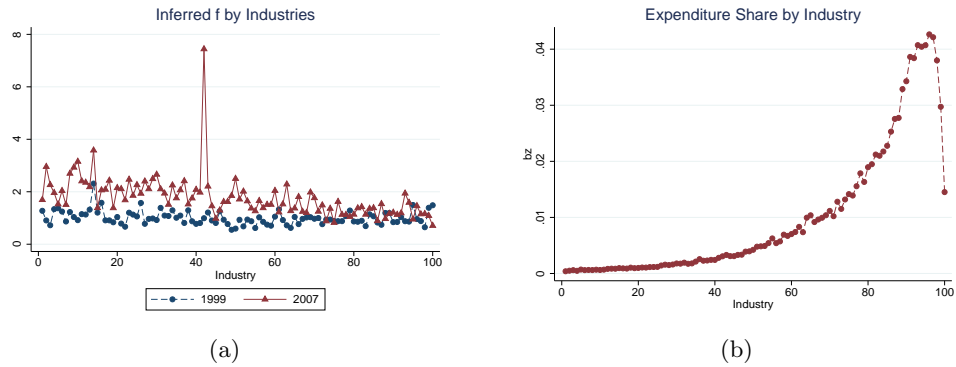


Figure B4: Relative fixed cost of exports and expenditure function

To infer export propensity for the 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 year 2007 are estimated above; $\tau = 2.38$ for year 1999 and $\tau = 1.76$ for year 2007 from the structural estimation. The results are plotted in Figure B5.

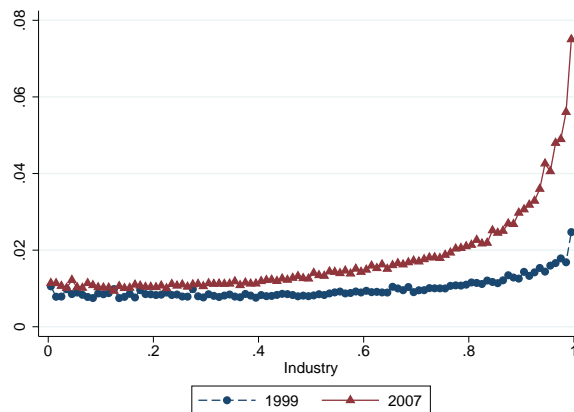


Figure B5: Inferred export propensity for the RoW

2.C Complementary Tables

2.C.1 Basic Summary Statistics of the Data

Table B1: 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.

Table B2: 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 firm data for year 2007.

Chapter 3

Comparative Advantage, Competition, and Firm Heterogeneity

3.1 Introduction

Comparative advantage which was first articulated by David Ricardo in 1817, has been one of the corner stones of international trade theory in the last 200 years. In the past two decades, firm heterogeneity has taken the centre stage in this research area. Despite the growing interest on its macro implications on productivity and welfare (see, e.g. Melitz, 2003; Arkolakis et al., 2012; Melitz and Redding, 2015; Arkolakis et al., forthcoming), we know relatively little about its impact on comparative advantage. Bernard, Redding, and Schott (2007) famously demonstrate that firm heterogeneity amplifies comparative advantage which increases the welfare gains from trade. In this paper, we show that in an environment with variable mark-ups where the pro-competitive effect is essential, there is another channel through which firm heterogeneity *dampens* comparative advantage. We find this new mechanism to be quantitatively more important than the amplifying mechanism in shaping comparative advantage in a calibrated Chinese economy.

We motivate our theory by four stylized facts about intra- and inter-firm reallocations generated from matched customs and firm-level data from China. First, compared with labour intensive firms, capital intensive Chinese firms are less likely to export. Second, capital intensive exporters export fewer products on average than labour intensive

exporters. Third, exports of capital intensive exporters are more skewed toward better performing products than labour intensive exporters. Finally, the skewness of domestic sales across labour intensive firms is higher than across capital intensive firms. The first two facts, which concern the extensive margin of reallocation within and across firms, can be rationalized by extending models such as Arkolakis and Muendler (2010), or Bernard, Redding, and Schott (2011) to multiple industries. However, their assumptions of CES demand and a continuum of firms impose an exogenously fixed mark-up across destinations and industries. The different market conditions therefore have no effect on the export product mix (the relative distribution of exports across products) or the variation of skewness of domestic sales across firms. The third and fourth stylized facts, which concern reallocations along the intensive margin, thus cannot be reconciled with models of this type.

Our theory explains all these facts simultaneously. We extend the analysis of Mayer, Melitz, and Ottaviano (2014) to a continuum of industries by embedding it in Dornbusch, Fischer, and Samuelson (1977). The model features heterogeneous firms and variable mark-ups as in Melitz and Ottaviano (2008). Each firm possesses a “core competency” and has access to a multi-product technology. The marginal cost of producing a product increases as it moves away from the firm’s core competency. There are two countries. In industries of comparative advantage, firms are assumed to be more likely to have lower marginal costs than firms from the other country. Exporters in comparative disadvantage industries face tougher competition in the export market, which shifts the whole distribution of mark-ups downwards. The tougher the competition is, the more exporters have to cut the scope of their export product and skew exports toward the better performing products. The relative ease of competition at home in comparative disadvantage industries also induces firms to sell more at home rather than export, thereby reducing their propensity to export. However, competition is tougher in comparative advantage industries in the domestic market, which induces reallocations of domestic sales toward the better performing firms.

Our theory generates new predictions about the effect of firm heterogeneity on comparative advantage. Melitz (2003) predicts that opening up to trade reallocates resources toward more productive firms. In a Heckscher-Ohlin model with heterogeneous firms, Bernard et al. (2007) find that the reallocation effect differs systematically across industries. Due to higher expected profits, an industry with comparative advantage has more entry and stronger selection. This generates endogenous Ricardian comparative advantage, which amplifies the *ex ante* comparative advantage. In our model, there is a new mechanism working on the top of this. In industries of comparative disadvantage, tougher

competition in the foreign market will induce more export sales toward the high productivity firms and the better performing products after the country has been opened up to trade. The more competitive the foreign market is, the more exporters have to toughen up. Such endogenous response reduces the relative productivity differences between the two countries and dampens comparative advantage. We also use the model to theoretically decompose Ricardian comparative advantage and find that the productivity measure matters for the decomposition. Industry productivity measures, which only capture selections along the extensive margin, fail to capture the dampening component. Productivity measures which take into account selections along both the extensive and intensive margins capture both the amplifying and the dampening components.

To test the mechanism of the model, we first extend the empirical analysis of Mayer et al. (2014) to incorporate the competition due to comparative advantage. They examine how French exporters vary their export product mix across markets with different sizes. We construct new variables which measure the competition faced by firms in each market due to comparative advantage. The idea is that capital intensive exporters face tougher competition when exporting to capital abundant markets; labour intensive exporters face tougher competition when exporting to labour abundant markets. Regressions using the matched customs and firm-level data confirm the model's predictions. Exporters export fewer products and skew exports more toward better performing products in markets where they face tougher competition due to comparative advantage, conditioning on the effect of market size.

We then employ a sufficient statistic approach to quantify the different components of comparative advantage. Comparative advantage is not directly observable. We show that, given the trade elasticity, iceberg trade costs, and domestic export participation (export intensities, and export propensities measured by the percent of firms that export), we can infer the home country's comparative advantage against the rest of the world (RoW). The intuition is that, conditional on trade costs and trade elasticity, firms' export participation reveals their relative competitiveness. The higher the fraction of firms that export and the more that exporters export, the stronger the country's comparative advantage. This echoes Balassa's idea of "*Revealed Comparative Advantage*" (RCA).¹ Our sufficient statistics result also allows us to decompose comparative advantage and evaluate the importance of individual components. Using this identification result, we estimate our two-country model for the case of China vs. RoW. We find that the dampening component appears to

¹While Balassa (1965) measured the underlying pattern of comparative advantage by relative exports across industries, we use data on firms' export participations together with estimated trade costs and trade elasticity. As noted by Costinot et al. (2012) and French (2017), the RCA index would not necessarily coincide with the underlying ranking of relative productivities. In contrast, our measure is theoretically consistent.

dominate the amplifying component. Ignoring the dampening component would lead to overestimations of comparative advantage.

Finally, we parametrize our model and conduct simulations on the effect of trade liberalization. We find that bilateral trade liberalization tends to strengthen the endogenous comparative advantage. Taken together, however, whether trade liberalization strengthens the overall comparative advantage or not depends on what kind of productivity measure is used, and which of the endogenous components dominates. It tends to strengthen comparative advantage if the productivity measure captures only the extensive margin. However, if the productivity measure also incorporates the intensive margin and the dampening component is more pronounced, bilateral trade liberalization weakens comparative advantage. As regards welfare, our simulated model with variable mark-ups and firm heterogeneity (Melitz and Ottaviano, 2008) generates higher welfare gains from trade than a simulated model with variable mark-ups but without firm heterogeneity (e.g., Ottaviano, Tabuchi, and Thisse, 2002).

Our paper contributes to the following strands in the literature. Our work is closely related to that of recent authors who study the macro implication of firm heterogeneity. We show that there is a new channel through which firm heterogeneity shapes comparative advantage, namely that tougher competition in the export market induces reallocations such that *ex ante* comparative advantage is dampened. This contrasts with the amplifying mechanism found in Bernard et al. (2007).² Arkolakis et al. (2012) find that for a group of models which satisfy certain restrictions, the formula for the welfare gains from trade is the same.³ Melitz and Redding (2015) show that the Melitz model with firm heterogeneity implies higher welfare gains from trade than the Krugman model with homogeneous firms. Compared with their results, our model features variable mark-ups. However, we also find trade yields higher welfare gains in the *simulated* heterogeneous firm model than it does in the homogeneous model.

We also contribute to the literature on the measurement of comparative advantage. Comparative advantage is the basis of classic trade theory. However, it has remained challenging to measure. Balassa's RCA index has in the last few decades been the key tool in measuring comparative advantage. There has been a renaissance in quantifying Ricardian comparative advantage since the seminal contribution by Eaton and Kortum (2002), which

²Recent contributions include Lu (2010), Huang et al. (2017), and Burstein and Vogel (2017). Gaubert and Itskhoki (2016) also study a multi-sector Ricardian model with heterogeneous firms but their focus is on the effect of the granularity force on comparative advantage. Ma et al. (2014) build on Bernard et al. (2011) and study within-firm specialization across products with different factor proportions.

³The restrictions include CES preferences and a constant trade elasticity. Arkolakis et al. (forthcoming) depart from these two restrictions and study welfare gains from trade in models with variable mark-ups.

provides a tractable multi-country Ricardian model.⁴ We provide sufficient statistic results, which identify comparative advantage directly and decompose it into exogenous and endogenous components. The sufficient statistic approach, as argued in Arkolakis et al. (2012), saves us from solving all the endogenous variables but still provides estimates for the object of interest. As far as we know, this paper is the first to provide sufficient statistics for comparative advantage.⁵ We also show that, in measuring comparative advantage, the exact productivity measures matter. Measures that capture only the extensive margin miss an important determinant of comparative advantage and bias our estimations.

Finally, the literature both theoretical and empirical on multi-product firm has been booming.⁶ Our analysis highlights how comparative advantage affects resource reallocation along the intra-firm extensive and intensive margins for multi-product firms, and how it feeds back to comparative advantage. The mechanism is similar to that in Mayer et al. (2014). Their focus is on the competition due to market size while the present paper concentrates on comparative advantage. Our model therefore provides a finer characterization of multi-product exports in a world with many industries.

The remainder of the paper is arranged as follows. Section 2 presents four stylized facts which motivate our theory. Section 3 presents the model and provides predictions on comparative advantage. Section 4 contains two sets of empirical analyses. Section 5 conducts numerical simulations on the effect of trade liberalization. Section 6 concludes.

3.2 Motivating Evidence

3.2.1 Data

In this section, we present a few stylized facts on the way in which export participation, exporters' product scope and product mix, and firm mix vary with capital intensity. These facts are generated using matched customs and firm-level data from China for the period 2000-2006. The first dataset that we use is the Chinese Annual Industrial Survey (CAIS)

⁴Costinot *et al.* (2012) estimate the importance of Ricardian comparative advantage on trade patterns and welfare using an extended Eaton-Kortum model. Relatedly, Levchenko and Zhang (2016) use the gravity equation to infer comparative advantage from trade flows and its evolution over time. Costinot et al. (2016) focus on the agriculture sector for which the parcel-level productivity of lands can be precisely estimated for different crops. Gaubert and Itskhoki (2016), Huang et al. (2017) instead use the two-country DFS framework to work out comparative advantage by structural estimation.

⁵The sufficient statistic approach has gained popularity in the field of public finance (Chetty, 2009). Arkolakis *et al.* (2012) shows that within a set of trade models which satisfy certain conditions, trade elasticity and the share of expenditure on domestic goods are sufficient statistics for welfare gains from trade.

⁶Feenstra and Ma (2009), and Eckel and Neary (2010) examine the effect of competition on the distribution of sales and the cannibalization effect for multi-product firms. Arkolakis and Muendler (2010), and Bernard et al. (2011) emphasize selection along the extensive margin, while Mayer et al. (2014) focus on selection along the intensive margin. Manova and Yu (2017) instead appraise quality differentiation and study product selection along the quality margin. Bernard et al. (2010), Iacovone and Javorcik (2010), and Mayer et al. (2016) investigate product churning over time in response to changes in market conditions.

which covers all State Owned Firms (SOE) and non-SOEs with sales above 5 million Chinese Yuan. These data provide rich information on firms' financial statements, and forms of identification, such as name, address, ownership, and numbers of employees. The other dataset that we employ is Chinese Customs data, which cover all China's import and export transactions. For each transaction, we know the Chinese importer/exporter, the product (at HS-8 level), value, origin, destination, etc. There is no common firm identifier between the two datasets. We match the two datasets on the basis of firm's name, address, telephone number, and zip code.⁷ The sample of matched exports represents about 37% of all Chinese exports reported in the customs data for 2000 and 52% for 2006.

We focus on the Chinese manufacturers and exclude firms from the mining and utility sectors in CAIS, and wholesalers or intermediaries in the customs data. We use capital intensity to capture comparative advantage: given the abundance of labour endowment in China, we expect the country to have comparative advantage relative to the RoW in labour intensive industries and comparative disadvantage in capital intensive industries. We follow Schott (2004) and Huang et al. (2017) to define industries as "Heckscher-Ohlin aggregates" and group Chinese firms into 100 bins according to their capital intensity. Schott (2004) argues that traditional industry classification, which defines industries according to the final use of goods, aggregates goods that are produced using different factor proportions. Similarly, Huang et al. (2017) show that such industry classification also aggregates firms which use different technologies. Capital intensity is defined as $1 - \frac{\text{Labour Costs}}{\text{Value Added}}$ for each firm. For example, firms with capital intensity between 0 and 0.1 are defined as industry 1.⁸ Under this classification, which we use for the rest of the paper, the following stylized facts are found using data for the year 2003.

3.2.2 Stylized Facts

Stylized fact 1: *Export propensity and export intensity decline with capital intensity.*

This is captured in Figure 3.1. The left panel plots the export propensity of each industry, where export propensity is defined as the total number of exporters divided by the total number firms. The right panel plots the export intensity, where export intensity is defined as total exports divided by the total sales for each industry. As the figures indicate,

⁷Such matching method has been used by a few number of papers, including Ma et al. (2014), Yu (2015), and Manova and Yu (2016).

⁸We follow the traditional two-factor Heckscher-Ohlin paradigm to consider labour vs. capital. Here "capital" includes all non-labour factors, such as energies. Labour costs include payable wages, labour and employment insurance fees, and the total of employee benefits payable. We exclude firms with capital intensities which are negative or greater than 1. Their presence is very likely to be due to misreporting or errors. We also exclude firms with negative value added, employment or assets. Firms with fewer than 8 employees are also excluded since they are under different legal regime. The results using data for other years are qualitatively the same.

both measures decline with capital intensity. This is consistent with our expectation that China has comparative advantage in labour intensive industries and labour intensive firms are more likely to export.

Stylized fact 2: *Exporters' export product scope declines with capital intensity.*

A firm's export product scope is defined as the number of products it exports. We measure each exporter's export product scope by counting the number of distinctive HS-8 products exported to all destinations in the customs data. The left panel of Figure 3.2 plots the export product scope averaged across exporters for each industry. As we can see, it falls with capital intensity. The right panel of the figure plots the share of single-product exporters, which are firms exporting one HS-8 product only. It is obvious that single-product exporters are more prevalent in the capital intensive industries in China.

Stylized fact 3: *The export product mix is more skewed in capital intensive industries.*

This is captured by Figure 3.3. The left panel plots the average of the log-ratios between the exports of the core product to the second best product. The core product is defined as the product that makes up the greatest part of the total exports for each firm. As we can see, this measure tends to be higher in capital intensive industries. Exports are therefore more concentrated on the better performing products in capital intensive industries. However, this measure captures only the skewness of exports across a few products. To show the presence of such a relationship across all exported products, we use a measure which captures the skewness of the whole distribution of exports. The right panel plots the average Theil index of firm exports across products. Again, the skewness of exports across products tends to increase with capital intensity.

Stylized fact 4: *The skewness of domestic sales decreases with capital intensity.*

In the left panel of Figure 3.4, we plot the log-ratios of domestic sales between the 75th-percentile firm and the 25th-percentile firm. We measure a firm's domestic sales by deducting exports from its total sales. As is obvious from the figure, the skewness tends to be higher in labour intensive industries. We also use the Theil index to capture the skewness of the whole distribution of domestic sales across firms. This is shown in the right panel. Still, the skewness tends to decline with capital intensity.

3.2.3 Discussion

So far, our results are graphical evidence alone.⁹ In Appendix 3.A, we provide further regression evidence on the robustness of the stylized facts. In Appendix Table C1, we

⁹In Appendix 3.C, we provide figures for the years 2000 and 2006, and other measures to capture the skewness of distributions.

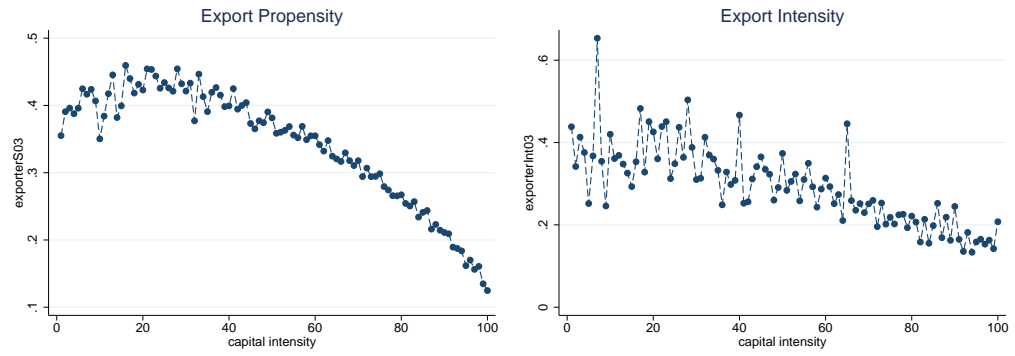


Figure 3.1: Export propensity and export intensity

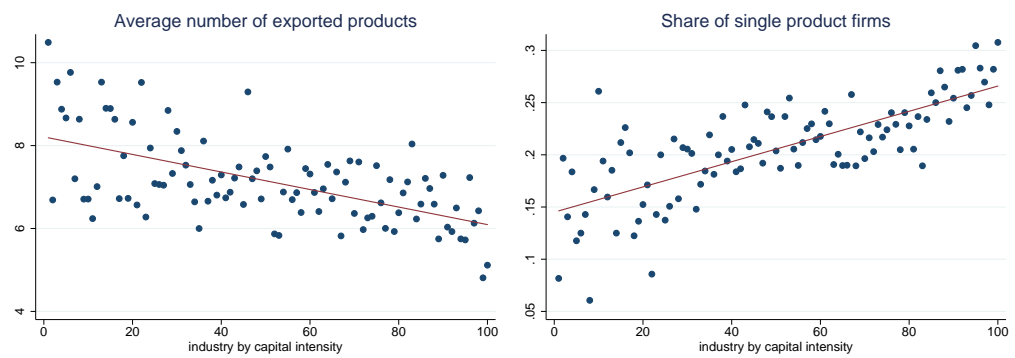


Figure 3.2: Number of products exported

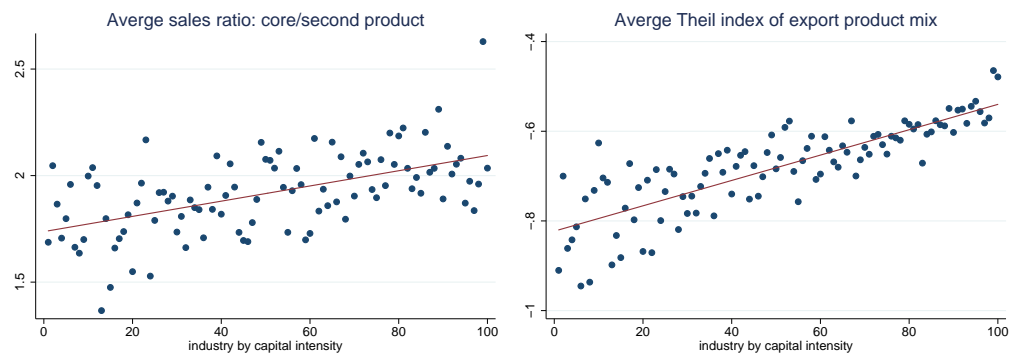


Figure 3.3: Skewness of export product mix

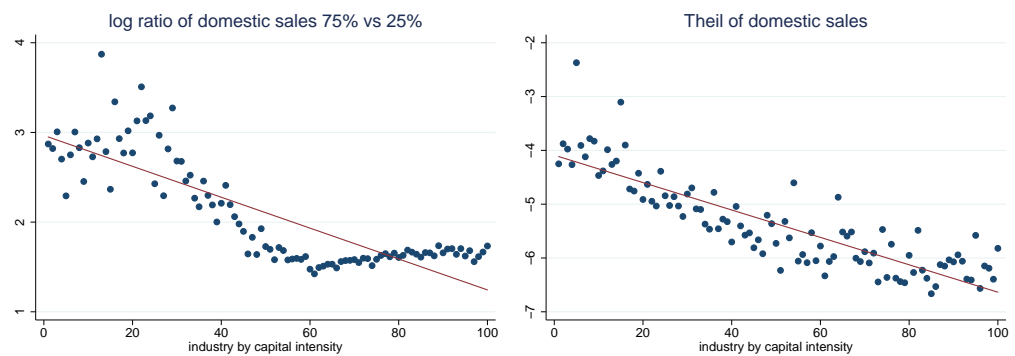


Figure 3.4: Skewness of domestic sales across firms

confirm fact 1, that export propensity and export intensity decline strongly with capital intensity, using data from 2000-2006. To deal with concerns that many Chinese exporters were processing traders, and China went through a period of state-owned-enterprise (SOE) reform which might have affected firms' exports, we examine whether fact 1 is true or not for non-processing traders and none-SOEs by excluding them from our sample. Still, fact 1 remains highly robust. Similarly, we examine the robustness of fact 2 on export product scope in Appendix Table C2, and find that it holds for the full sample and sub-sample of exporters. In Appendix Table C3-C5, we examine the robustness of fact 3 on the product mix of exporters and use alternative measures of skewness such as the Herfindahl index. Again, fact 3 is robust to alternative measures and data samples. Similarly, we examine the robustness of fact 4 on the skewness of domestic sales in Appendix Table C6-C8. It is still the case the skewness of domestic sales is higher in labour intensive industries.

Overall, these stylized facts reveal how comparative advantage shapes firm sales within and across firms at home and abroad. The first two stylized facts focus on the extensive margin, the third and fourth on the intensive margin. The first two facts can be easily explained by existing models, such as that of Bernard, Redding, and Schott (2007, 2011), by introducing multiple industries and multi-product firms.¹⁰ However, the third and fourth stylized facts are not consistent with these models which impose the CES demand and a continuum of firms assumptions. These two assumptions imply a fixed mark-up across markets and industries. There is therefore no variation in the intra-firm product mix or relative sale across firms in different markets or industries.¹¹ Mayer, Melitz, and Ottaviano (2014) provide a multi-product model built on Melitz and Ottaviano (2008), which features variable mark-ups. Their model explains how French exporters vary their sales across markets of different sizes. They find firms which export to larger markets skew their exports toward their better selling products. Such a mechanism should work at the industry level as well, and in principle can explain the third and fourth stylized facts. This motivates our theory in the following section.

3.3 Theory

We build a model which simultaneously explains the stylized facts discovered in the previous section. Our model extends Mayer, Melitz, and Ottaviano (2014) to a continuum of industries by embedding it in Dornbusch, Fischer, and Samuelson (1977). The model

¹⁰For example, Huang *et al.* (2007) provide a multi-sector extension of Bernard *et al.* (2007). Bernard *et al.* (2011) discuss an extension of their benchmark multi-product model to multiple industries in the appendix.

¹¹The relative sale of different products only depends on the relative firm or product productivity in these type of models.

makes novel predictions on the effect of firm heterogeneity on comparative advantage.

3.3.1 Closed Economy

We first consider the closed economy. Suppose there are two countries, Home and Foreign. The consumers in each country have identical preference given by

$$U = q_0^c + \int_0^1 [\alpha \int_{i \in \Omega(z)} q_i^c(z) di - \frac{\gamma}{2} \int_{i \in \Omega(z)} (q_i^c(z))^2 di - \frac{\eta}{2} (\int_{i \in \Omega(z)} q_i^c(z) di)^2] dz,$$

where q_0^c denotes the consumption of the numeraire good and $q_i^c(z)$ the consumption of the differentiated variety i in industry z . z indexes the continuum of industries and has a support of $[0, 1]$. $\Omega(z)$ is the set of differentiated varieties in industry z . The parameters capturing the substitution pattern between the differentiated varieties and numeraire good are α and η . As is obvious in the demand function below, a higher α or smaller η will lead to a higher demand for the differentiated varieties relative to the numeraire good. The parameter capturing the substitution pattern of the differentiated varieties within each industry is given by γ . The degree of differentiation increases with γ . In the extreme case that $\gamma = 0$, the differentiated varieties become perfect substitutes.

We normalized the price of the numeraire good to be 1. The budget constraint faced by consumers is given by

$$q_0^c + \int_0^1 \int_{i \in \Omega(z)} p_i^c(z) q_i^c(z) di dz = y_0^c + I,$$

where y_0^c is the endowment of the numeraire good and I the labour income. Assuming that consumers have positive demand for the numeraire good, solving the consumers' problem delivers the following demand for the differentiated varieties

$$p_i(z) = \alpha - \gamma q_i^c(z) - \eta Q^c(z).$$

Then the corresponding market demand is

$$q_i(z) = L q_i^c(z) = \frac{L}{\gamma} (p_{\max}^z - p_i(z)),$$

where L is the number of consumers in the home country and p_{\max}^z is the choke price of industry z . Then a firm with marginal cost c operating in industry z faces the following problem

$$\max_{p(z)} (p(z, c) - c) q(z).$$

Solving the firm's problem, we have

$$\begin{aligned} p(z, c) &= \frac{1}{2}(p_{\max}^z + c), \\ \mu(z, c) &= \frac{1}{2}(p_{\max}^z - c), \\ q(z, c) &= \frac{L}{2\gamma}(p_{\max}^z - c), \\ \pi(z, c) &= \frac{L}{4\gamma}(p_{\max}^z - c)^2, \end{aligned}$$

where $p(z, c)$, $\mu(z, c)$, $q(z, c)$, and $\pi(z, c)$ are the price, mark-up, output, and profit, respectively.

Each industry has a pool of potential entrants. Firms pay a fixed cost of f_E , and draw their marginal costs from a common distribution $G(z, c)$ defined on the support of $[0, C_M(z)]$ for industry z . Firms with marginal costs higher than the threshold $C_D(z) = p_{\max}^z$ will exit from the market. Free entry implies that

$$\int_0^{C_D(z)} \pi(z, c) dG(z, c) = f_E.$$

Under the Pareto distribution assumption that

$$G(z, c) = \left(\frac{c}{C_M(z)}\right)^k, \quad c \in [0, C_M(z)],$$

the cut-off marginal cost under autarky is given by

$$C_D(z)^A = \left[\frac{2(k+1)(k+2)\gamma C_M(z)^k f_E}{L}\right]^{1/(k+2)}. \quad (3.1)$$

Similarly, for the foreign country, we have¹²

$$C_D(z)^{*A} = \left[\frac{2(k+1)(k+2)\gamma C_M(z)^{*k} f_E}{L^*}\right]^{1/(k+2)}. \quad (3.2)$$

3.3.2 Open Economy with Single-product Firms

We now consider the open economy case without multi-product firms. The key purpose is to study how competition varies across industries when countries start trading with each other. To export to the foreign country, we assume that domestic firms need to pay an iceberg trade cost of τ . Foreign firms face the iceberg trade cost of τ^* .

Free entry implies that the sum of expected profits from both markets equals the fixed

¹²Variables with asterisk are for the foreign country.

entry cost. The free entry condition therefore becomes

$$\int_0^{C_D(z)} \pi_d(z, c) dG(z, c) + \int_0^{C_X(z)} \pi_x(z, c) dG(z, c) = f_E,$$

where $C_X(z) = C_D^*/\tau$ is the marginal cost cut-off for exporters. Thanks to the Pareto distribution assumption, this can be simplified as

$$LC_D(z)^{k+2} + \rho L^* C_D^*(z)^{k+2} = \beta C_M(z)^k, \quad (3.3)$$

where $\rho = \tau^{-k} \in [0, 1]$ is the freeness of trade and $\beta = 2\gamma(k+1)(k+2)f_E$ is a constant.

Similarly, for the foreign country, we have

$$L^* C_D^*(z)^{k+2} + \rho^* LC_D(z)^{k+2} = \beta C_M^*(z)^k, \quad (3.4)$$

where $\rho^* = \tau^{*-k}$. Combining the two equations above, we have¹³

$$C_D(z)^{k+2} = \frac{\beta[C_M(z)^k - \rho C_M^*(z)^k]}{L(1 - \rho\rho^*)}, \quad (3.5)$$

$$C_D^*(z)^{k+2} = \frac{\beta[C_M^*(z)^k - \rho^* C_M(z)^k]}{L^*(1 - \rho\rho^*)}. \quad (3.6)$$

Following Dornbusch et al. (1977), we rank the industries such that $\frac{\partial C_M(z)}{\partial z} > 0$ and $\frac{\partial C_M^*(z)}{\partial z} < 0$. That is, domestic firms in industries with higher z draw their marginal costs from a wider support, while the converse is true for the foreign firms. Under such assumptions, the home country will have comparative advantage in industries with lower z . There are different ways that these assumptions can be micro-founded. For example, they can be generated by the Heckscher-Ohlin force. Suppose that firms use a Cobb-Douglas production technology with z indexing the capital intensity, and $C_M(z) = w^{1-z}r^z$ and $C_M^*(z) = w^{*1-z}r^{*z}$. Then $\frac{\partial C_M(z)}{\partial z} = C_M(z) \ln \frac{r}{w}$ and $\frac{\partial C_M^*(z)}{\partial z} = C_M^*(z) \ln \frac{r^*}{w^*}$. If the home country is labour abundant relative to the foreign such that $\frac{r^*}{w^*} < 1 < \frac{r}{w}$, then we have $\frac{\partial C_M(z)}{\partial z} > 0$ and $\frac{\partial C_M^*(z)}{\partial z} < 0$. Under this interpretation, the home country has comparative advantage in labour intensive industries while the foreign country has comparative advantages in capital intensive industries.

Given the assumption that $\frac{\partial C_M(z)}{\partial z} > 0$ and $\frac{\partial C_M^*(z)}{\partial z} < 0$, it is easy to verify that

$$\frac{\partial C_D(z)}{\partial z} > 0, \text{ and } \frac{\partial C_D^*(z)}{\partial z} < 0.$$

So the cut-offs are lower in industries of comparative advantage. Exporters therefore face

¹³To ensure that the equations have real solutions, we assume that $\rho \leq \frac{C_M(z)^k}{C_M^*(z)^k} \leq \frac{1}{\rho^*}$ for all z .

tougher competition to sell in the foreign market in industries where the foreign country has comparative advantage. Immediately, we have the following proposition.

Proposition 3.1. *Export propensity $\chi(z) \equiv \left(\frac{C_X(z)}{C_D(z)}\right)^k$ and export intensity $\lambda(z) \equiv \frac{\text{Exports}(z)}{\text{Total Sales}(z)}$ increase with comparative advantage.*

Proof. See Appendix 3.D.1. □

This proposition implies that firms are more likely to export in industries of comparative advantage. This is consistent with Stylized fact 1 if we believe that China has comparative advantage in labour intensive industries.

According to Melitz and Ottaviano (2008), the number of entrants in each industry is given by

$$\begin{aligned} N_E(z) &= \frac{2C_M(z)^k(k+1)\gamma}{\eta(1-\rho\rho^*)} \left(\frac{\alpha - C_D(z)}{C_D(z)^{k+1}} - \rho^* \frac{\alpha - C_D^*(z)}{C_D^*(z)^{k+1}} \right), \\ N_E^*(z) &= \frac{2C_M^*(z)^k(k+1)\gamma}{\eta(1-\rho\rho^*)} \left(\frac{\alpha - C_D^*(z)}{C_D^*(z)^{k+1}} - \rho \frac{\alpha - C_D(z)}{C_D(z)^{k+1}} \right). \end{aligned}$$

If $\frac{\alpha - C_D^*(z)}{C_D^*(z)^{k+1}} \leq \rho \frac{\alpha - C_D(z)}{C_D(z)^{k+1}}$, we have $N_E^*(z) \leq 0$ so that there is no foreign firm in such industries. In this case, the home country specializes in these industries. This is more likely to happen if the freeness of trade ρ is sufficiently high, or $C_D^*(z)$ is greater than $C_D(z)$. Intuitively, in such cases, foreign firms face tough competition and get eliminated from the market. Similarly, the foreign country will specialize in industries where $\frac{\alpha - C_D(z)}{C_D(z)^{k+1}} \leq \rho^* \frac{\alpha - C_D^*(z)}{C_D^*(z)^{k+1}}$ is satisfied.¹⁴

3.3.3 Open Economy with Multi-product Firms

Now we extend the model to allow firms producing multiple products by following Mayer et al. (2014). Each firm's marginal cost of producing the core competency is given by c . Varieties are ranked in increasing order of distance from the core competency and indexed by m . The marginal cost of producing variety m is given by $v(m, c) = \varpi^{-m}c$, and $\varpi \in (0, 1)$. So the marginal cost increases as we move away from the core competency.¹⁵ Firms will keep adding products until the marginal cost is higher than the choke price. Therefore, the number of varieties produced by each firm is given by

$$M_d(z, c) = \begin{cases} 0, & \text{if } c > C_D(z), \\ \max\{m | v(m, c) \leq C_D(z)\} + 1, & \text{if } c \leq C_D(z). \end{cases}$$

¹⁴Given that China imports and exports in every industry, we assume for the rest of the paper that the no-specialization conditions are always satisfied.

¹⁵Eckel and Neary (2010) provide an alternative way to model the asymmetries between products on the cost side. Eckel et al. (2015) further allow firms to invest in quality.

The number of varieties exported to the foreign country by domestic firms is given by

$$M_x(z, c) = \begin{cases} 0, & \text{if } c > C_X(z), \\ \max\{m | v(m, c) \leq C_X(z) = \frac{C_D^*(z)}{\tau}\} + 1, & \text{if } c \leq C_X(z). \end{cases}$$

The free entry condition now becomes

$$\int_0^{C_D(z)} \Pi_d(z, v(m, c)) dG(z, c) + \int_0^{C_X(z)} \Pi_x(z, v(m, c)) dG(z, c) = f_E, \quad (3.7)$$

where firm profits from Home $\Pi_d(z, c)$, and Foreign $\Pi_x(z, v(m, c))$, are the sum of the profits made from each product sold in the respective market:

$$\begin{aligned} \Pi_d(z, c) &= \sum_{m=0}^{M_d(z, c)-1} \pi_d(z, v(m, c)), \\ \Pi_x(z, v(m, c)) &= \sum_{m=0}^{M_x(z, c)-1} \pi_x(z, v(m, c)). \end{aligned}$$

According to Mayer et al. (2014), the free entry condition Equation (3.7) can be simplified as

$$LC_D(z)^{k+2} + \rho L^* C_D^*(z)^{k+2} = \frac{\beta C_M(z)^k}{\Psi}, \quad (3.8)$$

where $\Psi = (1 - \varpi^k)^{-1}$ is an index of multi-product flexibility. Similarly, for the foreign country, we have

$$L^* C_D^*(z)^{k+2} + \rho^* LC_D(z)^{k+2} = \frac{\beta C_M^*(z)^k}{\Psi}.$$

We can solve the two equations above for the choke prices:

$$C_D(z)^{k+2} = \frac{\beta [C_M(z)^k - \rho C_M^*(z)^k]}{\Psi L (1 - \rho \rho^*)}, \quad (3.9)$$

$$C_D^*(z)^{k+2} = \frac{\beta [C_M^*(z)^k - \rho^* C_M(z)^k]}{\Psi L^* (1 - \rho \rho^*)}. \quad (3.10)$$

It is easy to see that we still have $\frac{\partial C_D(z)}{\partial z} > 0$ and $\frac{\partial C_D^*(z)}{\partial z} < 0$ under the assumptions that $\frac{\partial C_M(z)}{\partial z} > 0$ and $\frac{\partial C_M^*(z)}{\partial z} < 0$. Therefore, Propositions 3.1 still holds in an environment with multi-product firms. The following two propositions focus on the variations in the product scope and product mix across industries, which the single-product model cannot explain.

Proposition 3.2. *The export product scope increases weakly with comparative advantage.*

Proof. See Appendix 3.D.2. □

Proposition 3.2 implies that the export product scope tends to be lower in the industries of comparative disadvantage. For firms with the same marginal cost, those exporting in

the industries of comparative disadvantage are more likely to be single-product exporters. This is consistent with Stylized Fact 2.

Proposition 3.3. *Exports are skewed toward better products in the industries of comparative disadvantage.*

Proof. See Appendix 3.D.3. □

In industries of comparative disadvantage, the export market is more competitive. The tougher competition induces exporters to reallocate more sales to the better selling products. If we agree that capital intensive industries are the industries of comparative disadvantage for China, we should expect capital intensive exporters to have a more skewed export product mix. This is consistent with Stylized Fact 3.

Proposition 3.4. *Domestic sales tend to skew toward more productive firms in comparative advantage industries.*

Proof. See Appendix 3.D.4. □

In comparative advantage industries, the domestic market is more competitive. Such tougher competition would induce reallocations of sales more toward products that are produced with lower marginal costs. Since such products are more likely to be produced by firms with higher core efficiencies, outputs are reallocated toward these firms. In the end, domestic sales are skewed toward these firms and Stylized fact 4 is also rationalized.

3.3.4 Comparative Advantage

Our model has new implications for comparative advantage. Bernard et al. (2007) show that the different degree of selection across industries generates endogenous Ricardian comparative advantage which amplifies ex ante comparative advantage. In this subsection, we show that variable mark-ups allow for selections along the intensive margin, which generate endogenous Ricardian comparative advantage that dampens ex ante comparative advantage. We also find that the measure of sectoral productivity matters for the estimate of comparative advantage. Comparative advantage is usually measured by relative productivity (Costinot et al., 2012). If the productivity measure captures only selections along the extensive margin, we miss the dampening effect of intensive margin selections and overestimate comparative advantage.

Relative average marginal cost

Comparative advantage is defined as the relative productivity between home and foreign for each industry. We can measure productivity as the inverse of the simple average

marginal cost across firms within each industry. The average marginal cost of industry z in the home country is given by

$$\bar{c}(z) = \int_0^{C_D(z)} cdG(z, c) = \frac{k}{k+1} C_D(z).$$

For the foreign country, it is $\bar{c}(z)^* = \frac{k}{k+1} C_D(z)^*$. Then using Equations (3.1) and (3.2), the relative average marginal cost under autarky is given by:

$$\frac{\bar{c}(z)}{\bar{c}(z)^*} = \frac{C_D(z)^A}{C_D(z)^*A} = \left(\frac{L^* C_M(z)^k}{L C_M^*(z)^k} \right)^{1/(k+2)}. \quad (3.11)$$

If we denote the cost cut-offs in the open economy as $C_D(z)^T$ and $C_D(z)^*T$, according to Equations (3.9) and (3.10) the relative marginal cost between home and foreign is¹⁶

$$\begin{aligned} \frac{\bar{c}(z)}{\bar{c}(z)^*} &= \frac{C_D(z)^T}{C_D(z)^*T} \\ &= \left(\frac{L^* C_M(z)^k - \rho C_M^*(z)^k}{L C_M^*(z)^k - \rho^* C_M(z)^k} \right)^{1/(k+2)}. \end{aligned}$$

Proposition 3.5. *Comparative advantage as measured by the relative simple average of margin costs between home and foreign $\frac{\bar{c}(z)}{\bar{c}(z)^*}$ is amplified after opening up to trade as*

$$\frac{C_D(z)^T}{C_D(z)^*T} = \underbrace{\frac{C_D(z)^A}{C_D(z)^*A}}_{\text{ex ante}} \underbrace{\left[\frac{1 - \rho \frac{C_M^*(z)^k}{C_M(z)^k}}{1 - \rho^* \frac{C_M(z)^k}{C_M^*(z)^k}} \right]^{\frac{1}{k+2}}}_{\text{amplifying}}. \quad (3.12)$$

Proof. See Appendix 3.D.5. □

As noted above, the amplifying mechanism in Bernard et al. (2007) is also present in our model. This proposition shows not only that it exists but also how to tease it out by decomposition. However, the productivity measure varies only with the cost cut-off, or the productivity of the marginal survival firm, which misses the details of allocations across the inframarginal firms which form the majority in each industry. We next show that a different result arises if the inframarginal firms also matter for the productivity measure.

Relative TFPQ

Now we consider a quantity-based TFP (TFPQ) from Mayer et al. (2014). It measures industry output per worker and captures both the intensive and the extensive margins by incorporating the fact that firms have different amounts of inputs and outputs, and only

¹⁶The single-product economy gives the same result. Equations (3.5) and (3.6) differ only by a constant as compared with Equations (3.9) and (3.10).

a subset of firms export. In the closed economy, the TFPQ of industry z is

$$\bar{\Phi}(z)^A = \frac{\int_0^{C_D(z)^A} Q(z, c) dG(z, c)}{\int_0^{C_D(z)^A} C(z, c) dG(z, c)} = \frac{k+2}{k} \frac{1}{C_D(z)},$$

where $Q(z, c) = \sum_{m=0}^{M_d(z, c)-1} q(z, v(m, c))$ and $C(z, c) = \sum_{m=0}^{M_d(z, c)-1} v(m, c)q(z, v(m, c))$ are firm outputs and inputs, respectively. The relative TFPQ under autarky is given by

$$\frac{\bar{\Phi}(z)^A}{\bar{\Phi}(z)^{*A}} = \frac{C_D(z)^{A*}}{C_D(z)^A} = \left(\frac{L}{L^*} \frac{C_M^*(z)^k}{C_M(z)^k} \right)^{1/(k+2)}.$$

which is the *ex ante* comparative advantage before countries open to trade. It coincides with Equation (3.11) which measures the relative average marginal cost under autarky. In the open economy, we need to account for exports. The TFPQ is then given by

$$\bar{\Phi}(z)^T = \frac{\int_0^{C_D(z)} Q_d(z, c) dG(z, c) + \int_0^{C_X(z)} Q_x(z, c) dG(z, c)}{\int_0^{C_D(z)} C_d(z, c) dG(z, c) + \int_0^{C_X(z)} C_x(z, c) dG(z, c)}.$$

It can be shown that the total industry outputs and inputs for each market are

$$\begin{aligned} \int_0^{C_D(z)} Q_d(z, c) dG(z, c) &= \frac{LC_D(z)^{k+1}}{2\gamma C_M^k (k+1)} \frac{1}{1-\varpi^k}, \\ \int_0^{C_X(z)} Q_x(z, c) dG(z, c) &= \frac{\rho L^* C_D^*(z)^{k+1}}{2\gamma C_M^k (k+1)} \frac{1}{1-\varpi^k}, \\ \int_0^{C_D(z)} C_d(z, c) dG(z, c) &= \frac{kLC_D(z)^{k+2}}{2\gamma C_M^k (k+1)(k+2)} \frac{1}{1-\varpi^k}, \\ \int_0^{C_X(z)} C_x(z, c) dG(z, c) &= \frac{\rho k L^* C_D^*(z)^{k+2}}{2\gamma C_M^k (k+1)(k+2)} \frac{1}{1-\varpi^k}. \end{aligned}$$

substituting these results into the definition of the TFPQ, we have

$$\bar{\Phi}(z)^T = \frac{k+2}{k} \left[\frac{LC_D(z)^{k+2}}{LC_D(z)^{k+2} + \rho L^* C_D^*(z)^{k+2}} \frac{1}{C_D(z)} + \frac{\rho L^* C_D^*(z)^{k+2}}{LC_D(z)^{k+2} + \rho L^* C_D^*(z)^{k+2}} \frac{1}{C_D^*(z)} \right],$$

which is a weighted average of the competitiveness of each market. The weights are given by the total costs for the goods sold in each market. If $\rho = 0$, we go back to the closed economy case. Using the free entry condition (3.8), it can be further simplified as

$$\bar{\Phi}(z)^T = \frac{(k+2)\Psi}{k\beta C_M(z)^k} (LC_D(z)^{k+1} + \rho L^* C_D^*(z)^{k+1}).$$

There is a similar equation for the foreign country. The relative TFPQ between home and foreign for each industry is therefore given by

$$\frac{\bar{\Phi}(z)^T}{\bar{\Phi}^*(z)^T} = \frac{C_M^*(z)^k LC_D(z)^{k+1} + \rho L^* C_D^*(z)^{k+1}}{C_M(z)^k L^* C_D^*(z)^{k+1} + \rho^* LC_D(z)^{k+1}}.$$

Proposition 3.6. *Comparative advantage as measured by the relative quantity-based TFP between home and foreign $\frac{\bar{\Phi}(z)}{\bar{\Phi}^*(z)}$ after opening up to trade can be decomposed into three components: an ex ante component, an amplifying component, and a dampening component as:*

$$\frac{\bar{\Phi}(z)^T}{\bar{\Phi}^*(z)^T} = \underbrace{\frac{\bar{\Phi}(z)^A}{\bar{\Phi}(z)^{*A}}}_{\text{ex ante}} \underbrace{\left(\frac{\bar{\Phi}(z)^A}{\bar{\Phi}(z)^{*A}}\right)^{k+1}}_{\text{amplifying}} \underbrace{\frac{L^* \frac{L}{L^*} \left(\frac{C_D(z)}{C_D^*(z)}\right)^{k+1} + \rho}{L \left(1 + \rho^* \frac{L}{L^*} \left(\frac{C_D(z)}{C_D^*(z)}\right)^{k+1}\right)}}_{\text{dampening}}. \quad (3.13)$$

Proof. See Appendix 3.D.6. □

As pointed out by Bernard et al. (2007), given the higher expected profits of exporting, there will be more entrants and more intense selection in the comparative advantage industries. This tends to enlarge the relative productivity differences across industries and amplify comparative advantage. Such a channel is preserved in this measure and given by the term $\left(\frac{\bar{\Phi}(z)^A}{\bar{\Phi}(z)^{*A}}\right)^{k+1}$ which is positively correlated with the ex ante component $\frac{\bar{\Phi}(z)^A}{\bar{\Phi}(z)^{*A}}$.¹⁷

However, their assumptions of CES demand and a continuum of firms impose a constant exogenous mark-up. This implies that the relative revenue in each market between firms depends only on relative productivity and has nothing to do with market conditions. So selections along the intensive margin are constant across markets and industries. Our model with variable mark-ups has different implications. Tougher competition would induce reallocations of resources toward more productive firms and better performing products, as evident from Propositions 3.3 and 3.4. In other words, in tougher markets or industries, firms toughen up. This channel tends to dampen their comparative disadvantage.

If we follow Mayer et al. (2014) to define revenue-based TFP (TFPR) as

$$\bar{P}(z) = \frac{\int_0^{C_D(z)} R_d(z, c) dG(z, c) + \int_0^{C_X(z)} R_x(z, c) dG(z, c)}{\int_0^{C_D(z)} Q_d(z, c) dG(z, c) + \int_0^{C_X(z)} Q_x(z, c) dG(z, c)},$$

where $R_d(z, c)$ and $R_x(z, c)$ are firms' domestic and foreign revenues, respectively, we get

¹⁷In Appendix 3.E.1 we extend the model by Bernard et al. (2007) to multiple industries. To simplify the analysis, we use a quasi-CES preference and decompose comparative advantage in similar manners.

the same result since

$$\begin{aligned}\bar{\Phi}_R(z) &= \frac{(\int_0^{C_D(z)} R_d(z, c) dG(z, c) + \int_0^{C_X(z)} R_x(z, c) dG(z, c)) / \bar{P}(z)}{\int_0^{C_D(z)} C_d(z, c) dG(z, c) + \int_0^{C_X(z)} C_x(z, c) dG(z, c)} \\ &= \bar{\Phi}(z).\end{aligned}$$

3.4 Empirical Analysis

in this section, we provide two empirical tests on our theory. The first one is a reduced form analysis, which shows that exporters skew more of their exports toward the better selling products in markets where they face tougher competition due to comparative advantage. This is followed by a more structural analysis, in which we calibrate our model to the Chinese economy and quantify the different components of comparative advantage via a sufficient statistic approach.

3.4.1 Comparative Advantage and Export Product Mix

Exporters face different levels of competition across different markets. For example, they face tougher competition in larger markets (Mayer et al., 2014). Our theory emphasizes competition induced by comparative advantage. Capital intensive firms face tougher competition in capital abundant markets while labour intensive firms face tougher competition in labour abundant markets. To capture this channel, we need to first measure the competition faced by firms due to comparative advantage in each market. We propose the following two measures. The first is given by

$$CA1_{ij} = (z_i - \bar{z}) \left(\frac{K_j}{L_j} - \frac{\bar{K}}{L} \right),$$

where z_i is the capital intensity of firm i and \bar{z} is the average capital intensity of all Chinese manufacturing firms, $\frac{K_j}{L_j}$ is the capital to labour ratio of market j and $\frac{\bar{K}}{L}$ is the average capital to labour ratio of all markets (other than China). The larger that $CA1_{ij}$ is, the tougher the competition that exporter i will face in market j . The reason is that $CA1_{ij}$ would be higher if z_i is high above \bar{z} and $\frac{K_j}{L_j}$ is also high above $\frac{\bar{K}}{L}$, or if z_i is far below \bar{z} and $\frac{K_j}{L_j}$ is also far below $\frac{\bar{K}}{L}$. In both cases, firm i faces tough competition in market j since the market is abundant in the factor that firm i uses intensively. Alternatively, we can use firms' capital to labour ratio instead of the capital intensity and have the following measure

$$CA2_{ij} = \left(\frac{k_i}{l_i} - \frac{\bar{k}}{\bar{l}} \right) \left(\frac{K_j}{L_j} - \frac{\bar{K}}{L} \right),$$

where $\frac{k_i}{l_i}$ is the capital to labour ratio of firm i and $\bar{\frac{k}{l}}$ is the average capital to labour ratio of all Chinese firms.

To construct these measures, we need to estimate the capital to labour ratio for each destination market. We use the Penn World Table 9.0, which provides estimates of capital stock (at constant prices) and employment.¹⁸ The capital to labour ratio of each country is then computed as the ratio of capital stock to employment. The world average capital to labour ratio $\bar{\frac{K}{L}}$ is computed as the average of the capital to labour ratio across all countries except China.¹⁹ For the firm level measures, capital intensity is the same measure that we used in constructing motivating evidence. To measure the capital to labour ratio of each firm, following Brandt et al. (2012), we first estimate the capital stock for each firm using the perpetual inventory method. Labour is measured as the total number of employees. The average capital intensity \bar{z} and capital to labour ratio $\bar{\frac{k}{l}}$ are computed as the simple average across all Chinese firms.

To compare our results with Mayer et al. (2014), we also use data for the year 2003. Table 3.1 shows our first result, which extends their basic empirical analysis on the exporters' product mix by including our new competition measures. The dependent variable is the logarithm of the ratio of exports between the core product and the second best product in each market for each firm.²⁰ We include the GDP of each market to capture the competition due to the effect of market size. Following Mayer et al. (2014), we also include the supply potential to capture the competition due to geography.²¹ As we can see, the market size effect highlighted in their paper remains highly significant. The supply potential is positive but not precisely estimated. Our new competition measures are positive and significant. That is to say, in markets where firms face tougher competition due to comparative advantage, exports are more skewed toward the core product.

Table 3.2 looks at the skewness across all products that firms export to a market. The skewness is measured by the Herfindhal or the Theil index. Here, we control for the market fixed effect and firm fixed effect. The market fixed effect will capture the size and geography of the destination market. As we can see, the skewness measures tend to be higher in markets where firms have comparative disadvantage. That is to say, exports are more skewed in foreign markets where exporters face tougher competition due to comparative advantage.

Table 3.3 examines the effect on product scope, that is, the number of products ex-

¹⁸The data are available at <http://www.rug.nl/ggdc/>

¹⁹We exclude China from the sample to make the measure more exogenous, but in fact adding China makes little difference.

²⁰The product rank is the rank at the local market.

²¹Markets which are closer to other markets have more potential competitors. The supply potential variable is constructed as the predicted aggregate exports to a market based on a gravity regression with the usual gravity variables and fixed effects.

Table 3.1: Comparative advantage and sales ratio between the core and second best product: 2003

| | (1) | (2) | (3) | (4) |
|---------------------|------------------------|------------------------|------------------------|------------------------|
| ln GDP | 0.0157*** (0.00381) | 0.0138*** (0.00390) | 0.0147*** (0.00399) | 0.0146*** (0.00402) |
| ln supply potential | | 0.0127 (0.00823) | 0.0128 (0.00863) | 0.0136 (0.00871) |
| CA1 | | | 0.0695*** (0.0244) | |
| CA2 | | | | 0.00744* (0.00383) |
| Constant | -0.000603 (0.00808) | -0.000367 (0.00815) | 0.000748 (0.00868) | -0.000163 (0.00849) |
| Within R^2 | 0.000113 | 0.000124 | 0.000229 | 0.000165 |
| No. of observations | 92904 | 92904 | 85293 | 92637 |

Notes: The dependent variable is the logarithm of the ratio of exports between the core product ($m=0$) and second best product ($m=1$) in each market for each firm. CA1 and CA2 measure competition due to comparative advantage (higher value is associated with tougher competition). CA1 is an interaction term between firms' capital intensity (relative to all other firms) and the destination market's capital-labour ratio (relative to the world average). CA2 is another measure, which is an interaction term between firms' capital-labour ratio (relative to all other firms) and the destination market's capital to labour ratio (relative to the world average). We apply country-specific random effects on firm-demeaned data. Standard errors are reported in parentheses. The number of observations is significantly less than the following two tables since the dependent variable can be constructed only if the firms export at least two products at the destination. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01 respectively.

Table 3.2: Comparative advantage and the skewness of export sales: 2003

| | (1) | (2) | (3) | (4) |
|----------------------|------------------------|--------------------------|------------------------|-------------------------|
| | Herfindahl | Herfindahl | Theil | Theil |
| CA1 | 0.0141*** (0.00271) | | 0.0261*** (0.00536) | |
| CA2 | | 0.00208*** (0.000488) | | 0.00381*** (0.00108) |
| country fixed effect | Y | Y | Y | Y |
| firm fixed effect | Y | Y | Y | Y |
| No. of observations | 187693 | 202779 | 187693 | 202779 |

Notes: CA1 and CA2 measure competition due to comparative advantage (higher value is associated with tougher competition). CA1 is an interaction term between firms' capital intensity (relative to all other firms) and the destination market's capital-labour ratio (relative to the world average). CA2 is another measure, which is an interaction term between firms' capital-labour ratio (relative to all other firms) and the destination market's capital to labour ratio (relative to the world average). Standard errors are clustered at firm level. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01 respectively.

Table 3.3: Comparative advantage and firms' export product scope: 2003

| | (1) | (2) | (3) | (4) | (5) | (6) |
|----------------------|-------------------------|-------------------------|-----------------------|-------------------------|------------------------|-------------------------|
| | ln product # | ln product # | product # | product # | product # | product # |
| CA1 | -0.0340*** (0.00866) | | -0.146*** (0.0226) | | -0.113*** (0.00919) | |
| CA2 | | -0.00358** (0.00167) | | -0.0340*** (0.00674) | | -0.0277*** (0.00151) |
| Constant | | | | | 1.547*** (0.00763) | 1.543*** (0.00734) |
| country fixed effect | Y | Y | Y | Y | Y | Y |
| firm fixed effect | Y | Y | Y | Y | Y | Y |
| R^2 | 0.451 | 0.454 | | | | |
| No. of observations | 187693 | 202779 | 187694 | 202779 | 187694 | 202779 |

Notes: Columns (1) and (2) use OLS method and $\ln(\text{product count})$ as the dependent variable. Columns (3) to (6) use product count as the dependent variable. Columns (3) and (4) use Poisson method while columns (5) and (6) use negative binomial method. CA1 and CA2 measure competition due to comparative advantage (higher value is associated with tougher competition). CA1 is an interaction term between firms' capital intensity (relative to all other firms) and the destination market's capital-labour ratio (relative to the world average). CA2 is another measure, which is an interaction term between firms' capital-labour ratio (relative to all other firms) and the destination market's capital to labour ratio (relative to the world average). Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01 respectively.

ported by firms to each market. Again, we control for the market fixed effect and firm fixed effect. We use $\ln(\text{product count})$ as the dependent variable in columns (1) and (2), and product count from column (3) to (6). In all cases, firms tend to export fewer products in markets where they face tougher competition due to comparative advantage.

To sum up, the evidence is consistent with Propositions 3.2 and 3.3 that firms facing tougher competition due to comparative advantage have narrower export product scope and more skewed export product mix.

3.4.2 Quantification of Comparative Advantage

We have shown that different measures of comparative advantage capture different margins of reallocations in action. Measures capturing only the extensive margin miss the dampening force. Does such a distinction quantitatively make a difference? How important are the different components of comparative advantage? To answer these questions, we need to quantify and decompose comparative advantage using these different measures. However, there are a few challenges in doing so. First, we do not observe the *ex ante* comparative advantage, which depends on the relative productivity differences across industries between the home country and the RoW under autarky. We observe only the open economies.²² Second, even for the open economies which we can observe, measuring the relative productivities between the home country and the RoW remains difficult. One practical obstacle is that we do not have the firm-level data for the RoW. Even if we had

²²Most modern economies are far from economic autarky. Historically, economic autarky is less unusual but only a few cases have been studied by economists. Bernhofen and Brown (2004) investigate the sudden opening-up of Japan in the 1860s to test the theory of comparative advantage. Irwin (2005) studies the welfare cost of the Jeffersonian Trade Embargo from 1807 to 1809. Kung and Ma (2014) exploit the severe trade suppression during 1550-1567 in Ming China to study the relationship between autarky and piracy.

the data, selection into exports would posit a significant challenge in estimating the underlying productivities (Costinot et al., 2012).²³ Finally, it is challenging to measure the endogenous components directly. They depend either on the relative cost upper-bound of the Pareto distribution or on the relative cost cut-off between the two economies, which do not have clear empirical counterparts.

Given these challenges, we provide an identification result which shows that only the export propensity $\chi(z)$ and export intensity $\lambda(z)$ for the *home country*, trade elasticity k , and trade freeness ρ and ρ^* are needed to measure and decompose comparative advantage. In other words, $\chi(z)$, $\lambda(z)$, k , ρ , and ρ^* are *sufficient statistics* for comparative advantage and its subcomponents.

Proposition 3.7. *We can write comparative advantage (as defined in Propositions 3.5 or 3.6) and its different subcomponents as functions of the trade elasticity k , the trade freeness ρ and ρ^* , the export propensity $\chi(z)$, and export intensity $\lambda(z)$.*

Proof. See Appendix 3.D.7. □

To quantify comparative advantage using this result, we calibrate the model to the Chinese economy. We set the Pareto shape parameter $k = 3.43$, which is the estimated median trade elasticity by Broda et al. (2006) for China.²⁴ ρ and ρ^* , the freeness of trade, are estimated using the Head-Ries Index (Head and Ries, 2001) and the World Input Output Database. The details of the estimation are in Appendix 3.B. The results are presented in Appendix Table C10. As we can see, the freeness of trade between China and the RoW has been increasing over time. The average freeness was 0.043 in 2000 and rose to 0.058 in 2003 and 0.071 in 2006. Given the trade elasticity $k = 3.43$, the implied average iceberg trade costs dropped from 2.50 in 2000 to 2.16 in 2006. Finally, we measure the export propensity $\chi(z)$ by the percentage of firms that export, and the export intensity $\lambda(z)$ by the percent of sales exported, which are the data underlining Figure 3.1.

Validating the calibration

Before getting the result, we validate the estimation by evaluating the model prediction on moments that have not been used in the estimation. Our sufficient statics rely only on information about exports. We can evaluate the model prediction on imports. According

²³Costinot et al. (2012) argue that relative producer prices are good measures of relative productivity. However, we do not have the relative producer prices between China and the RoW.

²⁴As proved by Melitz and Ottaviano (2008) and synthesized in Head and Mayer(2014), under our current model, the Pareto shape parameter corresponds to the trade elasticity. For robustness, we have also checked the results using the median trade elasticity of 5.03 from the literature (Head and Mayer, 2014) and experimented with relative low and high elasticities of 2.5 and 7.5. The results are qualitatively the same.

to the model, the volume of exports from China to the RoW in industry z is given by $EXP(z) = \frac{1}{2\gamma(k+2)C_M(z)^k} N_E(z) C_D^*(z)^{k+2} L^* \rho$, and the volume of imports from the RoW to China is $IMP(z) = \frac{1}{2\gamma(k+2)C_M^*(z)^k} N_E^*(z) C_D(z)^{k+2} L \rho^*$. Therefore, the ratio of imports to exports is

$$\frac{IMP(z)}{EXP(z)} = \frac{L}{L^*} \frac{\rho^*}{\rho} \frac{N_E^*(z)}{N_E(z)} \frac{C_M(z)^k}{C_M^*(z)^k} \frac{C_D(z)^{k+2}}{C_D^*(z)^{k+2}},$$

which depends on the relative market size $\frac{L}{L^*}$, relative trade freeness $\frac{\rho^*}{\rho}$, the relative number of entrants $\frac{N_E^*(z)}{N_E(z)}$, and comparative advantage captured by $\frac{C_M(z)^k}{C_M^*(z)^k} \frac{C_D(z)^{k+2}}{C_D^*(z)^{k+2}}$. We can estimate $\frac{C_D(z)^{k+2}}{C_D^*(z)^{k+2}} \frac{C_M(z)^k}{C_M^*(z)^k}$ directly using the sufficient statistics results from Proposition 3.7. How well does this explain the variation of $\frac{IMP(z)}{EXP(z)}$ in the data? Answering this question helps to validate the calibrated model.

Our matched firm and customs data contain imports for importers. We assume that the imports of industry z from the RoW are the total imports of importers from industry z in China.²⁵ Under this assumption, we find $\frac{IMP(z)}{EXP(z)}$ tends to increase with capital intensity z , as shown in Figure 3.5. For the most capital intensive industries, China ran trade deficits since $\frac{IMP(z)}{EXP(z)} > 1$.

On Figure 3.6, we plot $\ln(\frac{IMP(z)}{EXP(z)})$ against $\ln(\frac{C_M(z)^k}{C_M^*(z)^k} \frac{C_D(z)^{k+2}}{C_D^*(z)^{k+2}})$. As can be seen, there is a very strong positive correlation. China tends to run trade deficits in industries of comparative disadvantage. We confirm this by regressing $\ln(\frac{IMP(z)}{EXP(z)})$ on $\ln(\frac{C_M(z)^k}{C_M^*(z)^k} \frac{C_D(z)^{k+2}}{C_D^*(z)^{k+2}})$.²⁶ The results are shown in Appendix Table C9. The coefficients for $\ln(\frac{C_M(z)^k}{C_M^*(z)^k} \frac{C_D(z)^{k+2}}{C_D^*(z)^{k+2}})$ are positive and highly significant. Comparative advantage explains around half of the variation in $\ln(\frac{IMP(z)}{EXP(z)})$ and remains robust after controlling for capital intensity.

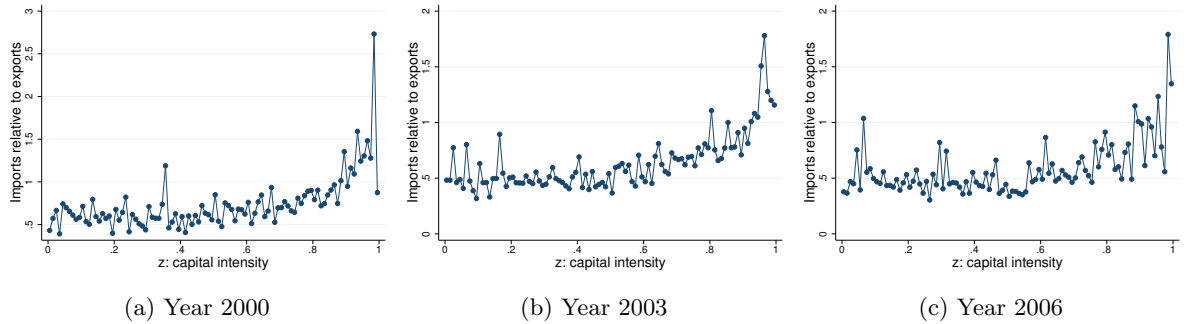
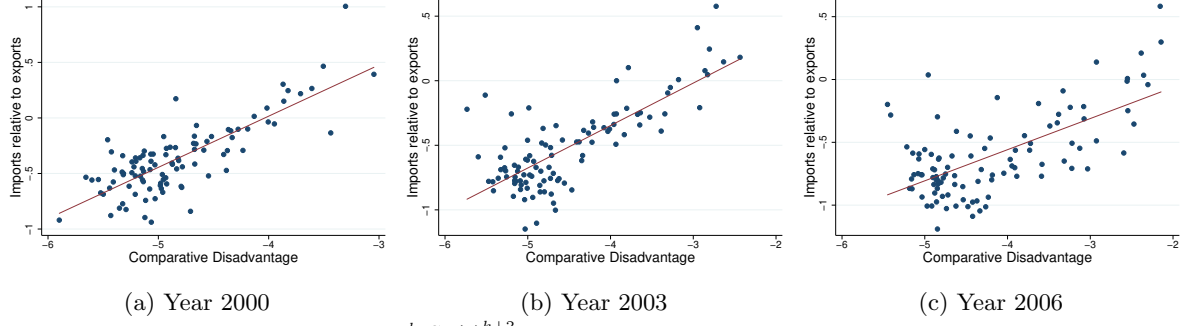


Figure 3.5: Chinese imports relative to exports by industries

²⁵Ideally, we would like the firm-level data for the RoW to get exports to China by capital intensity.

²⁶Ideally, we would like to run this regression: $\ln(\frac{IMP(z)}{EXP(z)}) = a_0 + a_1 \ln(\frac{C_M(z)^k}{C_M^*(z)^k} \frac{C_D(z)^{k+2}}{C_D^*(z)^{k+2}}) + a_2 \ln(\frac{N_E^*(z)}{N_E(z)}) + \varepsilon_z$.

Our theory predicts that $a_0 = \frac{L}{L^*} \frac{\rho^*}{\rho}$, $a_1 = a_2 = 1$. However, $\frac{N_E^*(z)}{N_E(z)}$ is not observable.



Notes: The horizontal axis is $\ln\left(\frac{C_M(z)^k}{C_M^*(z)^k} \frac{C_D(z)^{k+2}}{C_D^*(z)^{k+2}}\right)$. Higher values indicate greater comparative disadvantage of China relative to the RoW. The vertical axis plots the logarithm of Chinese imports from the RoW relative to exports to the RoW.

Figure 3.6: Imports relative to exports and comparative disadvantage

Results

Armed with the calibrated parameters and the data, we quantify and decompose the comparative advantage of China relative to the RoW in 2000, 2003, and 2006, using Proposition 3.7. First, the *ex ante* component is the same for the two measures of comparative advantage as shown in the proof of Proposition 3.7 (we invert relative cost so that it is comparable with relative TFPQ). This is plotted in Figure 3.7. To filter out the noise in the data, we use local polynomials to fit the data, with confidence intervals indicated. According to the result, China had *ex ante* comparative advantage in the labour intensive industries. Over time, the *ex ante* component appears to favour the labour intensive industries.²⁷

To single out the endogenous components of comparative advantage, we divide the overall comparative advantage by the *ex ante* component and get

$$\frac{C_D(z)^T / C_D(z)^A}{C_D(z)^{*T} / C_D(z)^{*A}} = \left[\frac{1 - \rho C_M^*(z)^k / C_M(z)^k}{1 - \rho^* C_M(z)^k / C_M^*(z)^k} \right]^{\frac{1}{k+2}}, \quad (3.14)$$

$$\frac{\bar{\Phi}(z)^T / \bar{\Phi}(z)^A}{\bar{\Phi}^*(z)^T / \bar{\Phi}^*(z)^A} = \left(\frac{\bar{\Phi}(z)^A}{\bar{\Phi}^*(z)^A} \right)^{k+1} \frac{L^*}{L} \frac{\frac{L}{L^*} \left(\frac{C_D(z)}{C_D^*(z)} \right)^{k+1} + \rho}{1 + \rho^* \frac{L}{L^*} \left(\frac{C_D(z)}{C_D^*(z)} \right)^{k+1}}. \quad (3.15)$$

The right hand side of the equations above are left with the endogenous components. They are plotted in Figures 3.8 and 3.9. As can be seen from Figure 3.8, the endogenous component of relative cost cut-off tends to favour labour intensive industries (relative cost is inverted to be comparable with relative TFPQ. Here, it is the RoW relative to China). This is not surprising given that the theory predicts that it is positively correlated with

²⁷Huang et al. (2017) also find that the exogenous Ricardian comparative advantage increasingly favoured labour intensive industries in China during the period 1999-2007.

the *ex ante* component which favours the labour intensive industries.

However, as is evident from Figure 3.9, the endogenous component of relative TFPQ tends to favour capital intensive industries. Given that our theory predicts that the dampening component is negatively correlated with the *ex ante* component, the dampening component would favour the capital intensive industries. This implies that the dampening component must have dominated the amplifying component such that it determines how the endogenous component will vary with capital intensity.

To examine the effect of the endogenous components on comparative advantage, we plot the inferred overall comparative advantage in Figures 3.10 and 3.11. Figure 3.10 plots the overall comparative advantage which captures only the extensive margin, i.e., $\frac{C_D(z)^{*T}}{C_D(z)^T}$. Figure 3.11 plots the overall comparative advantage which captures both the extensive and intensive margins, i.e., $\frac{\bar{\Phi}(z)^T}{\bar{\Phi}^*(z)^T}$. Both measures tend to favour the labour intensive industries. Given that the endogenous component of the measure capturing only the extensive margin amplifies the *ex ante* component as we saw in Figure 3.8, it is more variant than the *ex ante* component since all the lines are steeper in Figure 3.10 than in Figure 3.7. However, due to the dampening effect of the endogenous component, the measure that captures both margins is less variant than the *ex ante* component since all the lines in Figure 3.11 are flatter than in Figure 3.7.

Table 3.4 confirms a similar message. Column (1) reports the regression coefficients of capital intensity out of an OLS regression which regresses the *ex ante* comparative advantage on capital intensity. Indeed, given the negative coefficients, the home country tends to be less productive in the capital intensive industries *ex ante*. These coefficients become even more negative in Column (2) when we replace the dependent variable by the measure of comparative advantage which captures only the extensive margin. This shows the effect of the amplifying endogenous component. However, the coefficients become less negative in Column (3) when we replace the dependent variable by relative TFPQ which captures both margins. This again shows that the dampening component dominates the amplifying component.

3.5 Numerical Simulations

In this section, we parametrize and simulate the single-product model.²⁸ We are particularly interested in the way that trade liberalization (lower variable trade costs) affects comparative advantage. We are also interested in comparing the associated welfare change with the homogeneous firm model.

²⁸The purpose of the simulations is to demonstrate the model channel and provide numerical comparative statics. For future work, we will structurally estimate a multi-product model.

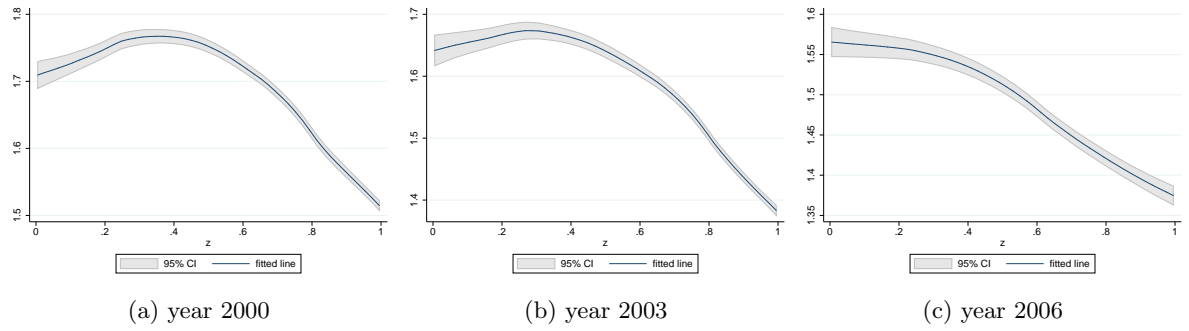


Figure 3.7: The ex ante component of comparative advantage

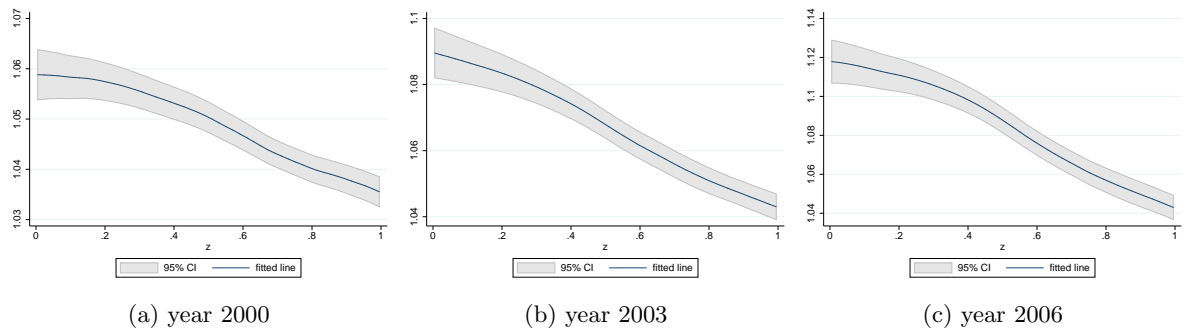


Figure 3.8: The endogenous component of relative marginal cost cut-off

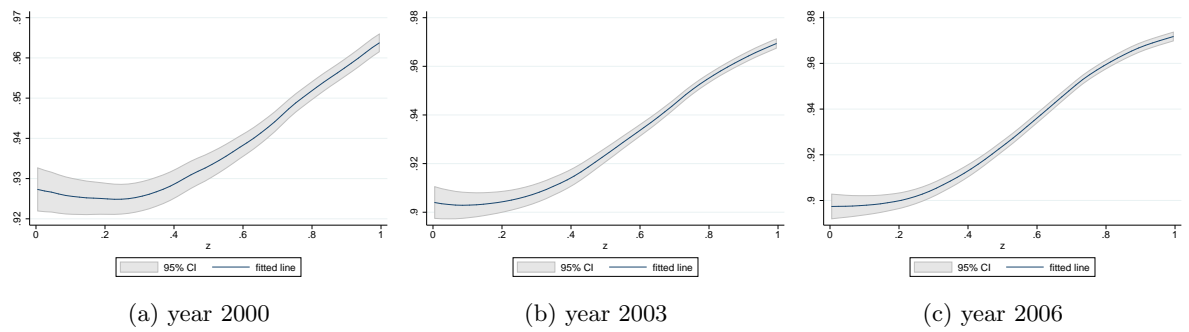


Figure 3.9: The endogenous component of relative TFPQ

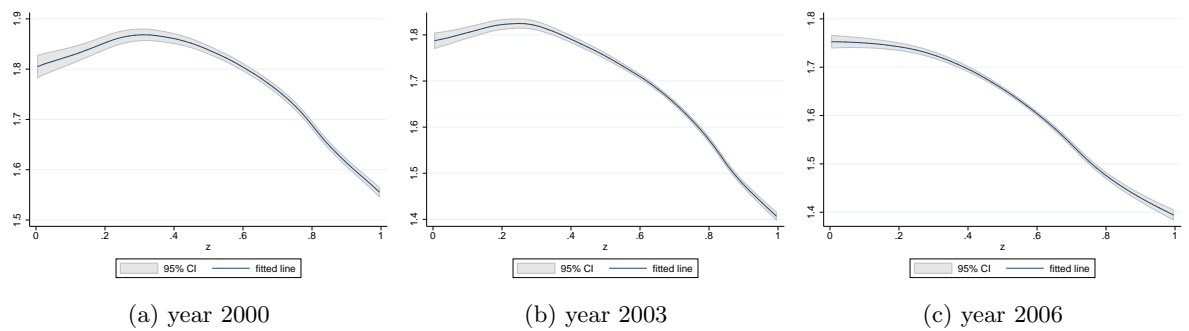


Figure 3.10: Comparative advantage measured by relative marginal cost cut-off

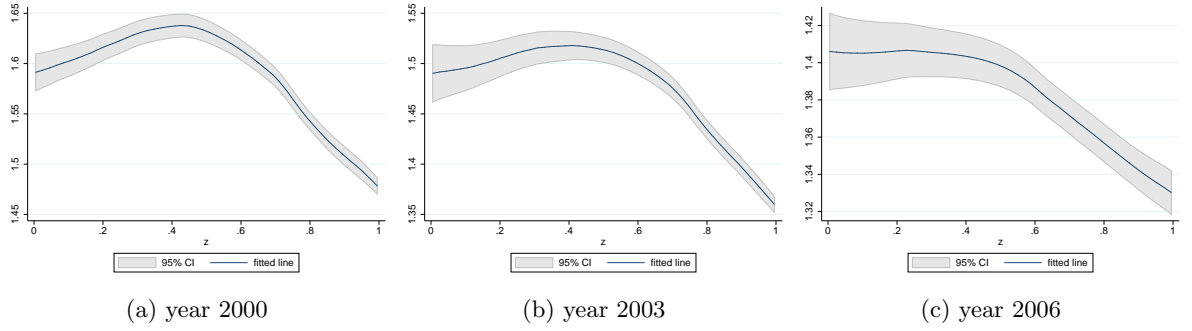


Figure 3.11: Comparative advantage measured by relative TFPQ

Table 3.4: Comparing different measures of comparative advantage

| Regressor | Dependent variables | | |
|-------------------|--------------------------------------|-----------------------|---------------|
| | (1) | (2) | (3) |
| capital intensity | | | |
| year | <i>ex ante</i> comparative advantage | relative cost cut-off | relative TFPQ |
| 2000 | -0.223 | -0.285 | -0.135 |
| 2003 | -0.292 | -0.428 | -0.142 |
| 2006 | -0.267 | -0.451 | -0.106 |

Notes: The table reports the coefficients of capital intensity out of regressions which regress the different measures of comparative advantage on capital intensity. The dependent variable of column (1) is the *ex ante* comparative advantage implied by the sufficient statistics. For column (2), it is the relative cost cut-off estimated using the sufficient statistics. For column (3), it is the relative TFPQ estimated from the sufficient statistics. All coefficients are significant at the 0.1% level.

3.5.1 Parameters

We assume that $C_M(z)$ and $C_M(z)^*$, the cost upper bounds for the home country and the RoW, which determine the *ex ante* comparative advantage, can be parametrized as

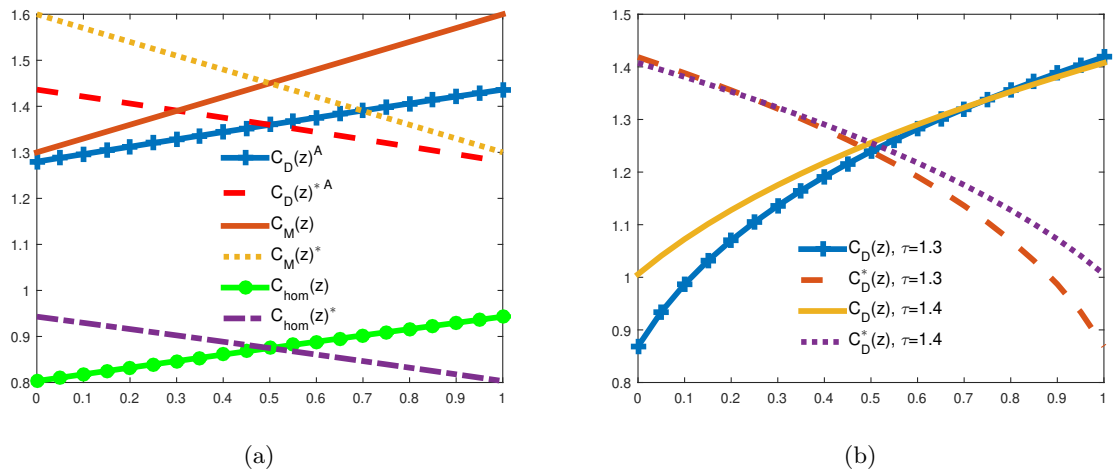
$$\begin{aligned} C_M(z) &= az + b, \\ C_M(z)^* &= a^*z + b^*. \end{aligned}$$

We also assume that $a > 0$ and $a^* < 0$. Therefore, the home country has comparative advantage in low z industries and the RoW has comparative advantage in high z industries. The key parameters of the model are given by Table 3.5. We assume that $C_M(z) = 1.3 + 0.3z$, and $C_M(z)^* = 1.6 - 0.3z$. As can be seen in panel (a) of Figure 3.12, the cost upper bounds are symmetric around $z = 0.5$ for the two economies.

Moreover, we set the size of the two economies to be the same $L = L^* = 10$. This is to neutralize the market size effect. Consumers' endowments of the homogeneous good and incomes are set to be $y_0^c = y_0^{c^*} = 50$ and $I = I^* = 50$, respectively. These values are high enough to ensure that the demand for the homogeneous good is positive.

Table 3.5: Model parameters

| Parameter | Definition | Value |
|------------|---|------------|
| a | the slope of $C_M(z)$ | 0.3 |
| b | the intercept of $C_M(z)$ | 1.3 |
| a^* | the slope of $C_M(z)^*$ | -0.3 |
| b^* | the intercept of $C_M(z)^*$ | 1.6 |
| f_E | fixed cost of firm entry | 0.5 |
| k | Pareto Shape | 2.5 |
| α | consumer preference | 5 |
| γ | consumer preference | 1 |
| η | consumer preference | 0.5 |
| τ | iceberg trade cost, home to foreign | [1.3, 1.4] |
| τ^* | iceberg trade cost, foreign to home | [1.3, 1.4] |
| L | number of consumers in the home country | 10 |
| L^* | number of consumers in the foreign country | 10 |
| y_0^c | home country consumers' endowments of homogeneous good | 50 |
| y_0^{c*} | foreign country consumers' endowments of homogeneous good | 50 |
| I | home country consumers' labour income | 50 |
| I^* | foreign country consumers' labour income | 50 |



Notes: The solid lines indicate the home country while the dashed or dotted lines indicate the RoW. $C_{hom}(z)$ and $C_{hom}(z)^*$ are the marginal costs inferred for the homogeneous firm model such that it has the same welfare level as the heterogeneous firm model under autarky (see Appendix 3.E.2 for more details).

Figure 3.12: Cost upper bounds and cut-off costs

3.5.2 Simulation Results

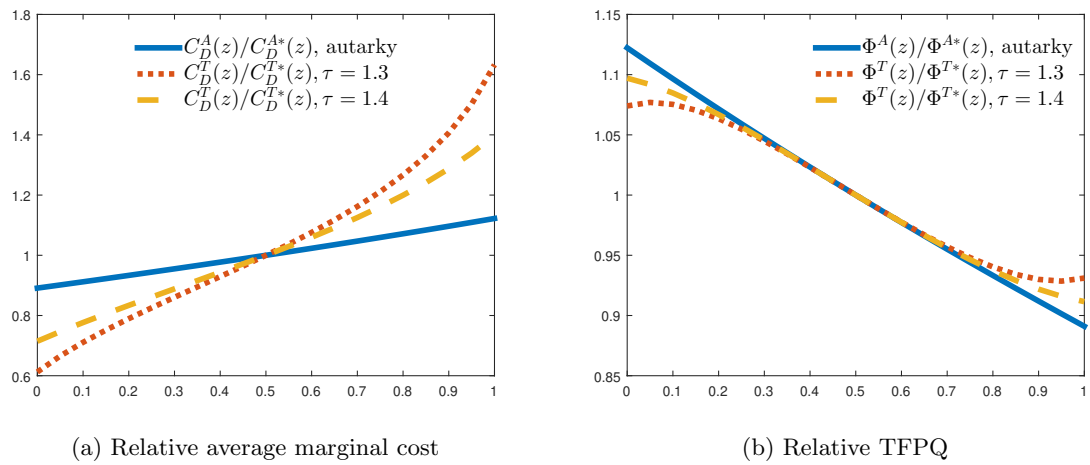
Given that the two economies have the same size, we expect the cost cut-offs under autarky $C_D(z)^A$ and $C_D(z)^{A*}$ to be symmetric around $z = 0.5$ as well. This is indeed the case in Figure 3.12 (a).²⁹ Since we are interested in comparing the welfare change with the homogeneous firm model, we follow Melitz and Redding (2015) to find marginal cost profiles $C_{hom}(z)$ and $C_{hom}(z)^*$ for the homogeneous firm model such that it has the same welfare level as the heterogeneous firm model under autarky. The detailed procedure in finding $C_{hom}(z)$ and $C_{hom}(z)^*$ are in Appendix 3.E.2. For the model that we have parametrized, the associated $C_{hom}(z)$ and $C_{hom}(z)^*$ are plotted on Figure 3.12 (a) as well. They turn out to follow a pattern similar to $C_M(z)$ and $C_M(z)^*$ as well and are symmetric around $z = 0.5$.

Figure 3.12 (b) plots the equilibrium cost cut-offs in the open economy $C_D(z)$ and $C_D(z)^*$ for two scenarios, one in which the iceberg trade costs are $\tau = \tau^* = 1.4$, and the other with bilateral trade liberalization such that the iceberg trade costs are reduced to $\tau = \tau^* = 1.3$. Two observations result from comparing these two scenarios. First, bilateral trade liberalization appears to widen the gap between $C_D(z)$ and $C_D(z)^*$. Both $C_D(z)$ and $C_D(z)^*$ become steeper in the case with lower trade costs. It suggests that if we use industry productivity measures which capture only the extensive margin, we will find comparative advantage strengthened by bilateral trade liberalization. Second, bilateral trade liberalization can change the cut-offs of different industries in different directions. In Figure 3.12 (b), when trade costs are reduced, the home country cost cut-offs of industries closer to $z = 1$ rise, while those closer to $z = 0$ fall. This result can be explained as follows. In industries where the home country has comparative advantage, trade liberalization reduces the cut-offs by increasing the accessibility of the foreign market. Furthermore, there will be more entrants in these industries, given the rising profits of exporting. This drives the cut-offs further down. Trade liberalization also increases market accessibility for the industries where the home country has comparative disadvantage. However, it also makes the very efficient foreign competitors even more efficient in serving the home country, which deters home entrants and lessens competition in the home country. If the entry channel is more pronounced, the cut-offs will rise after trade liberalization.³⁰

We now examine how bilateral trade liberalization affects comparative advantage. As

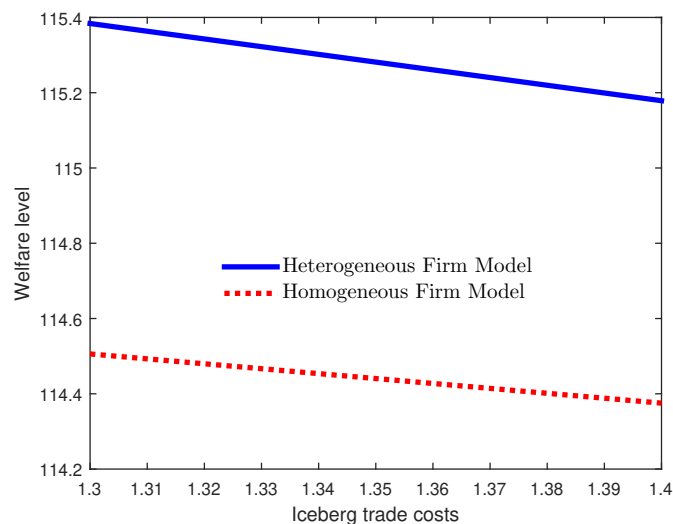
²⁹Our choice of parameters guarantees that $C_D(z)^A < C_M(z)$ and $C_D(z)^{A*} < C_M(z)^*$ to ensure that there is export selection. The conditions are $C_M(z) > \sqrt{2(k+1)(k+2)\gamma/L}$ and $C_M(z)^* > \sqrt{2(k+1)(k+2)\gamma/L^*}$.

³⁰The mechanism is similar to the discussion of preferential trade liberalization in Melitz and Ottaviano (2008). In our case, formally, we have $\frac{\partial C_D(z)^{A*}}{\partial \rho} = \frac{\beta}{L^2} \frac{2\rho C_M(z)^k - (1+\rho^2)C_M^*(z)^k}{(1-\rho^2)^2}$. Therefore, the effect of bilateral trade liberalization on cost cut-offs is positive if $2\rho C_M(z)^k \geq (1+\rho^2)C_M^*(z)^k$ is satisfied. This is more likely to be the case for high z industries in the home country.



Notes: Panel (a) plots the relative average firm marginal cost between the home country and the foreign country under autarky and open economy, which are simply the relative cost cut-off. Panel (b) plots the relative quantity-based TFP (TFPQ) between the home country and the foreign under economic autarky and open economy.

Figure 3.13: Bilateral trade liberalization and comparative advantage



Notes: This figure plots the welfare level of the homogeneous firm and heterogeneous firm model with respect to iceberg trade costs. The model parameters are chosen such that the two models have the same welfare level under autarky.

Figure 3.14: Trade liberalization and welfare

suggested above, if the industry productivity measure incorporates only the extensive margin, we expect comparative advantage to be strengthened. This is indeed the case in Figure 3.13 (a). As trade costs go down, the relative cost cut-off get steeper. In contrast, if we use TFPQ to measure industry productivity, the relative TFPQ becomes flatter when we reduce trade costs. Therefore, comparative advantage is weakened by bilateral trade liberalization. This suggests that the endogenous dampening force becomes stronger and dominates when trade costs fall.

Finally, we compare the welfare level of our heterogeneous firm model with a homogeneous model which has the same welfare level under autarky. The details on the welfare formula are given in Appendix 3.E.2. Melitz and Redding (2015) show that the Melitz model with heterogeneous firms predicts higher welfare gains from trade than the Krugman model with homogeneous firms. While the mark-up is constant in the models that they consider, it is variable in the models that we examine. As Figure 3.14 indicates, at least in the parameter space that we specify, the heterogeneous firm model still predicts higher welfare gains from trade than the homogeneous firm model.

3.6 Conclusion

We uncover new stylized facts on the way in which comparative advantage shapes intra- and inter-firm reallocations. Not all of the facts can be reconciled with existing models with constant mark-ups. We construct a model which interacts firm heterogeneity with comparative advantage, featuring variable mark-ups. The model simultaneously explains the facts and generates novel insights on the way in which firm heterogeneity affects comparative advantage. We find that exporters face tougher competition in comparative disadvantage industries. Such an effect from competition induces exporters to cut their product scope and skew their product mix in the comparative disadvantage industries. We also find that export selections along the intensive margin generate endogenous Ricardian comparative advantage, which is *negatively* correlated with the *ex ante* comparative advantage. This contrasts with the amplifying mechanism found by Bernard et al. (2007). In both our calibrated Chinese economy and the simulated model, we find that the dampening force can dominate the amplifying force.

To conclude, while comparative advantage has important implications for the micro behaviour of individual firms, the micro level responses from firms have profound macro implications. Some of the macro implications, such as welfare gains from trade, appear robust to the model specification. Other macro implications, such as comparative advantage, appear to depend on whether we allow for variable mark-ups or not.

Appendix

3.A Complementary Tables

Table C1: Export propensity and intensity: 2000-2006

| Regressand: | Export Propensity | | | Export Intensity | | |
|-------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|------------------------|
| | All Exporters | Non-SOEs | Non-Processing Firms | All Exporters | Non-SOEs | Non-Processing Firms |
| capital intensity | -0.247*** (0.0140) | -0.314*** (0.0126) | -0.169*** (0.0146) | -0.247*** (0.0103) | -0.334*** (0.0121) | -0.150*** (0.00905) |
| year FE | Y | Y | Y | Y | Y | Y |
| R^2 | 0.793 | 0.880 | 0.654 | 0.648 | 0.708 | 0.608 |
| Observations | 700 | 700 | 700 | 700 | 700 | 700 |

Notes: Export propensity is the percent of firms that are exporters. Export intensity is defined as the share of goods exported. Each observation is a year-industry while industry is defined as “HO aggregates”. Year fixed effect is included in each regression. OLS is used. Standard errors clustered at each industries are reported in parentheses. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01 respectively.

Table C2: Export product scope: all exporters 2000-2006

| Regressand: | Mean Product Scope | | | Share of Single Product Firms | | |
|-------------------|----------------------|----------------------|----------------------|-------------------------------|------------------------|------------------------|
| | All Exporters | Non-SOEs | Non-Processing Firms | All Exporters | Non-SOEs | Non-Processing Firms |
| capital intensity | -1.921*** (0.174) | -1.989*** (0.162) | -0.719*** (0.166) | 0.0950*** (0.00594) | 0.0988*** (0.00608) | 0.0564*** (0.00912) |
| year FE | Y | Y | Y | Y | Y | Y |
| R^2 | 0.236 | 0.293 | 0.133 | 0.495 | 0.497 | 0.292 |
| Observations | 700 | 700 | 700 | 700 | 700 | 700 |

Notes: Mean product scope is the average number of products exported within each industry. Industry is defined as “HO aggregates”. Year fixed effect is included in each regression. OLS is used. Standard errors clustered at each industries are reported in parentheses. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01 respectively.

Table C3: Export product mix: all exporters 2000-2006

| | (1) | (2) | (3) | (4) | (5) |
|-------------------|------------------------|----------------------|----------------------|------------------------|-----------------------|
| | core product share | m0/m1 | m0/m2 | mean Herfindhal | mean Theil |
| capital intensity | 0.0742*** (0.00373) | 0.311*** (0.0271) | 0.452*** (0.0318) | 0.0920*** (0.00432) | 0.238*** (0.00987) |
| year FE | Y | Y | Y | Y | Y |
| R^2 | 0.553 | 0.260 | 0.307 | 0.581 | 0.613 |
| Observations | 700 | 700 | 700 | 700 | 700 |

Notes: The table contains results using the full sample of exporters. Industry is defined as “HO aggregates”. The regressand of column (1) is the average sales share of the core product across firms within each industry, and the log sales ratio of the core product to the second best product in column (2), and the log sales ratio of the core product to the third best product in column (3). Column (4) and (5) regress the average Herfindhal index and Theil Index of exports on capital intensity. Standard errors clustered at each industries are reported in parentheses. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01 respectively.

Table C4: Export product mix: all non-SOE exporters 2000-2006

| | (1) | (2) | (3) | (4) | (5) |
|-------------------|------------------------|----------------------|----------------------|------------------------|-----------------------|
| | core product share | m0/m1 | m0/m2 | mean Herfindhal | mean Theil |
| capital intensity | 0.0760*** (0.00369) | 0.311*** (0.0264) | 0.456*** (0.0303) | 0.0944*** (0.00433) | 0.243*** (0.00976) |
| year FE | Y | Y | Y | Y | Y |
| R^2 | 0.558 | 0.262 | 0.312 | 0.586 | 0.619 |
| Observations | 700 | 700 | 700 | 700 | 700 |

Notes: The table contains results using the sample of none-state-owned-enterprises (SOE) exporters. Industry is defined as “HO aggregates”. The regressand of column (1) is the average sales share of the core product across firms within each industry, and the log sales ratio of the core product to the second best product in column (2), and the log sales ratio of the core product to the third best product in column (3). Column (4) and (5) regress the average Herfindhal index and Theil Index of exports on capital intensity. Standard errors clustered at each industries are reported in parentheses. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01 respectively.

Table C5: Export product mix: all non-processing exporters 2000-2006

| | (1) | (2) | (3) | (4) | (5) |
|-------------------|------------------------|----------------------|--------------------|------------------------|----------------------|
| | core product share | m0/m1 | m0/m2 | mean Herfindhal | mean Theil |
| capital intensity | 0.0314*** (0.00494) | 0.123*** (0.0414) | 0.114* (0.0684) | 0.0401*** (0.00559) | 0.100*** (0.0120) |
| year FE | Y | Y | Y | Y | Y |
| R^2 | 0.178 | 0.0283 | 0.0146 | 0.210 | 0.225 |
| Observations | 700 | 700 | 700 | 700 | 700 |

Notes: The table contains results using the sample of non-processing exporters. Industry is defined as “HO aggregates”. The regressand of column (1) is the average sales share of the core product across firms within each industry, and the log sales ratio of the core product to the second best product in column (2), and the log sales ratio of the core product to the third best product in column (3). Column (4) and (5) regress the average Herfindhal index and Theil Index of exports on capital intensity. Standard errors clustered at each industries are reported in parentheses. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01 respectively.

Table C6: Skewness of domestic sales within industry 2000-2006: all firms

| | (1) | (2) | (3) |
|-------------------|-------------------------|-----------------------|-----------------------------------|
| | Herfindahl index | Theil Index | Inter quartile range of log sales |
| capital intensity | -0.0358*** (0.00621) | -2.270*** (0.0958) | -1.633*** (0.0997) |
| year FE | Y | Y | Y |
| R^2 | 0.0905 | 0.712 | 0.601 |
| Observations | 700 | 700 | 700 |

Notes: The skewness of sales is measured across all firms within each industry, while industry is defined as “HO aggregates”. Robust standard errors clustered at industry level are reported in parentheses. The constants are absorbed by the year fixed effects. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01 respectively.

Table C7: Skewness of domestic sales within industry 2000-2006: all non-SOEs

| | (1) | (2) | (3) |
|-------------------|-------------------------|----------------------|-----------------------------------|
| | Herfindahl index | Theil Index | Inter quartile range of log sales |
| capital intensity | -0.0413*** (0.00684) | -2.529*** (0.128) | -2.357*** (0.174) |
| year FE | Y | Y | Y |
| R^2 | 0.0943 | 0.734 | 0.504 |
| Observations | 700 | 700 | 695 |

Notes: The skewness of sales is measured across all none-state-owned-firms within each industry, while industry is defined as “HO aggregates”. Column (3) has less observations because the 25th percentile of non-SOE firm has zero domestic sales in certain industries. Robust standard errors clustered at industry level are reported in parentheses. The constants are absorbed by the year fixed effects. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01 respectively.

Table C8: Skewness of domestic sales within industry 2000-2006: all non-processing firms

| | (1) | (2) | (3) |
|-------------------|-------------------------|-----------------------|-----------------------------------|
| | Herfindahl index | Theil Index | Inter quartile range of log sales |
| capital intensity | -0.0269*** (0.00414) | -2.269*** (0.0826) | -0.468*** (0.0506) |
| year FE | Y | Y | Y |
| R^2 | 0.0680 | 0.716 | 0.388 |
| Observations | 700 | 700 | 700 |

Notes: The skewness of sales is measured across all none-processing firms (firms not engaged in processing exports) within each industry, while industry is defined as “HO aggregates”. Robust standard errors clustered at industry level are reported in parentheses. The constants are absorbed by the year fixed effects. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01 respectively.

Table C9: Imports relative to exports and comparative advantage

| dependent variable: imports relative to exports $\ln\left(\frac{IMP(z)}{EXP(z)}\right)$ | year 2000 | | year 2003 | | year 2006 | |
|--|---------------------|--------------------|---------------------|--------------------|-------------------|--------------------|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| $\ln\left(\frac{C_M(z)^k C_D(z)^{k+2}}{C_M^*(z)^k C_D^*(z)^{k+2}}\right)$ | 0.461*** (.0460) | 0.404*** (.071) | 0.329*** (.0322) | 0.257*** (.032) | .247*** (.037) | 0.317*** (.087) |
| capital intensity z | | 0.143 (.115) | | .214 (.168) | | -.228 (.245) |
| constant | 1.86*** (.227) | 1.51*** (.396) | 0.968*** (.141) | .540 (.372) | .432*** (.156) | 0.837* (.485) |
| Adjusted R^2 | 0.635 | 0.641 | 0.589 | 0.596 | 0.413 | 0.420 |
| N | 100 | 100 | 100 | 100 | 100 | 100 |

Notes: The dependent variable is log total Chinese imports relative to exports within each industry. Robust standard errors are in parentheses. Significance levels are indicated by *, **, *** at 0.1, 0.05 and 0.01 respectively.

3.B The Head-Ries Index

We estimate the trade freeness between China and the Rest of World using the Head-Reis Index (Head and Ries, 2001). If we assume symmetric trade costs $\rho_{ij} = \rho_{ji}$ and zero domestic trade costs, then

$$\rho_{ij} = \sqrt{\frac{X_{ij}X_{ji}}{X_{ii}X_{jj}}},$$

where X_{ij} is the aggregate exports from region i to region j which follows the gravity equation.³¹ So if let $i = China$ and $j = RoW$, we can infer the trade freeness between China and the RoW. However, to implement this equation, we need data on local absorption X_{ii} and X_{jj} . These are not available from our firm survey or customs data but available from the World Input Output Database (WIOD).³² Local absorption is computed as the total outputs minus total exports. We estimate trade freeness using the formula above for each sector. The summary statistics for the manufacturing sectors are displayed in Table C10.³³ The estimated average trade freeness between China and the RoW increased from 0.043 in 2000 to 0.071 in 2006. If the trade elasticity is $k = 3.43$, which is the median trade elasticity estimated for China by Broda et al. (2006), then the implied iceberg trade costs $\tau = \rho^{-\frac{1}{k}}$ dropped from around 2.50 in 2000 to 2.16 in 2006. If we use the median trade elasticity 5.03 from the literature (Head and Mayer, 2014), the implied iceberg trade costs are lower.

Table C10: Trade costs between China and the RoW: the Head-Ries index

| year | trade freeness ρ | | | implied iceberg trade costs τ | |
|------|-----------------------|-------|-------|------------------------------------|--------|
| | average | min | max | k=3.43 | k=5.03 |
| 2000 | 0.043 | 0.012 | 0.116 | 2.50 | 1.87 |
| 2001 | 0.045 | 0.012 | 0.129 | 2.47 | 1.85 |
| 2002 | 0.051 | 0.012 | 0.165 | 2.38 | 1.81 |
| 2003 | 0.058 | 0.013 | 0.218 | 2.29 | 1.76 |
| 2004 | 0.070 | 0.015 | 0.282 | 2.17 | 1.70 |
| 2005 | 0.073 | 0.015 | 0.323 | 2.15 | 1.68 |
| 2006 | 0.071 | 0.015 | 0.313 | 2.16 | 1.69 |

Notes: Trade freeness ρ is estimated using the Head and Ries (2001) method and the World Input Output Data for manufacturing industries. The columns titled “average”, “min”, and “max” are the average, minimum and maximum of the Head-Ries Index across 13 manufacturing sectors. The iceberg trade costs τ are inferred using the average trade freeness according to $\rho = \tau^{-k}$ where k is the trade elasticity.

³¹Our model generates gravity equation for the sectoral trade flow which satisfies the general gravity equations classified by Head and Mayer (2014) even if firms produce multiple products.

³²We use the 2013 release at <http://www.wiod.org/database/wiots13>. The details of the data can be found in Timmer, Dietzenbacher, Los and Vries (2015).

³³There are 15 sectors of goods and 20 sectors of services. Manufacturing sectors include all the 15 goods sector except the sector of “Agriculture, hunting, forestry and fishing” and the sector of “Mining and quarrying”. For brevity, we do not report the trade freeness for the service sectors. The trade freeness for services between China and the RoW is lower but increases over time.

3.C Complementary Figures

Our benchmark results only use data from year 2003. Now we include results using data for 2000 and 2006. Our stylized fact 3 states that export product mix is more skewed in capital intensive industries. Other than the measures of skewness used in the main text, we present results using other measures. Figure C5 plots the average sales share of the core product. The core product is defined as the product that makes up most of the total exports. As evident from the figures, the average share of sales from the core product is higher for the capital intensive industries. Figure C7 plots the average of the log-ratios between the sales of the core product to the third best product. Figure C8 plots the average Herfindhal Index of exporters for each industry. Similarly, we also include additional evidence for stylized fact 4 using alternative measures, including Figure C10 which plots the Herfindahl Index of domestic sales across firms.

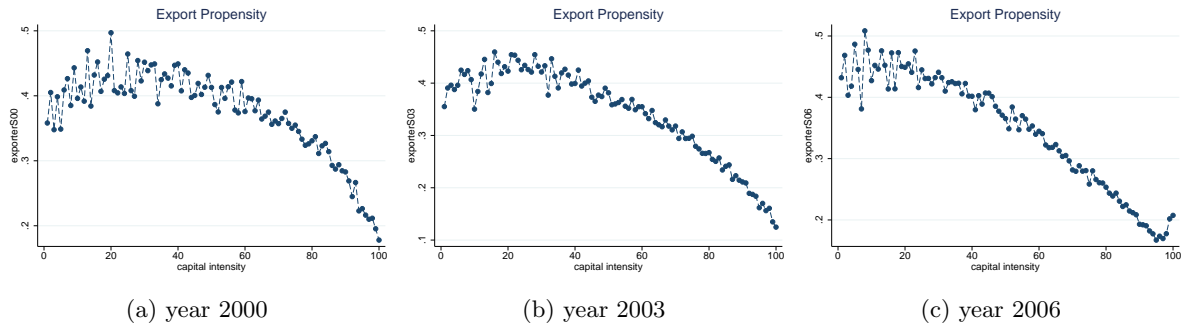


Figure C1: Export propensity by industry

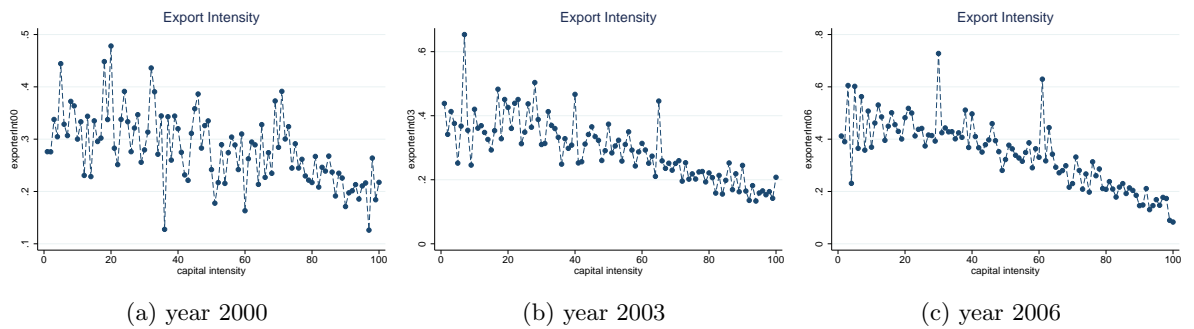


Figure C2: Export intensity by industry

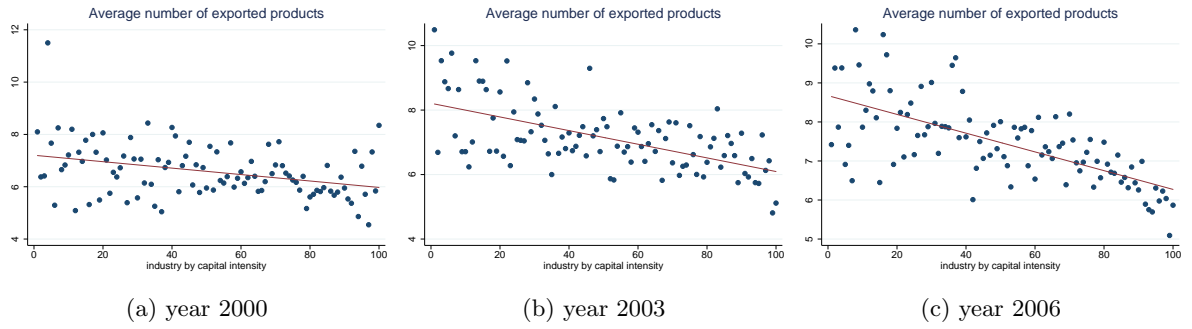


Figure C3: Number of products exported

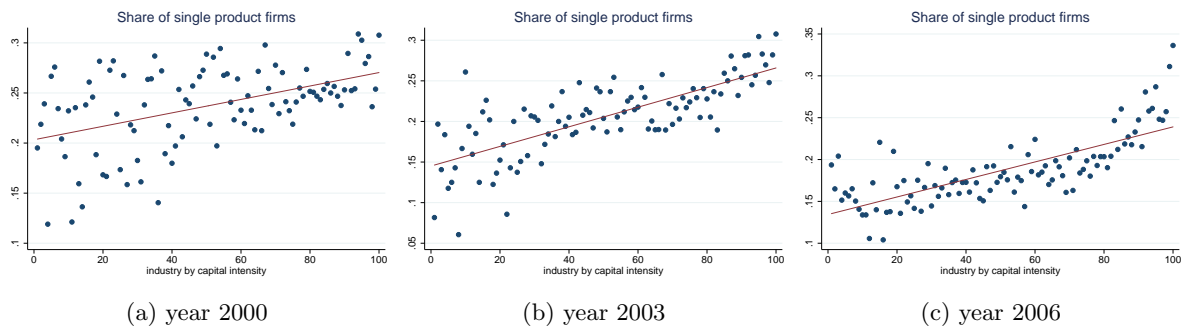


Figure C4: Share of single product exporters

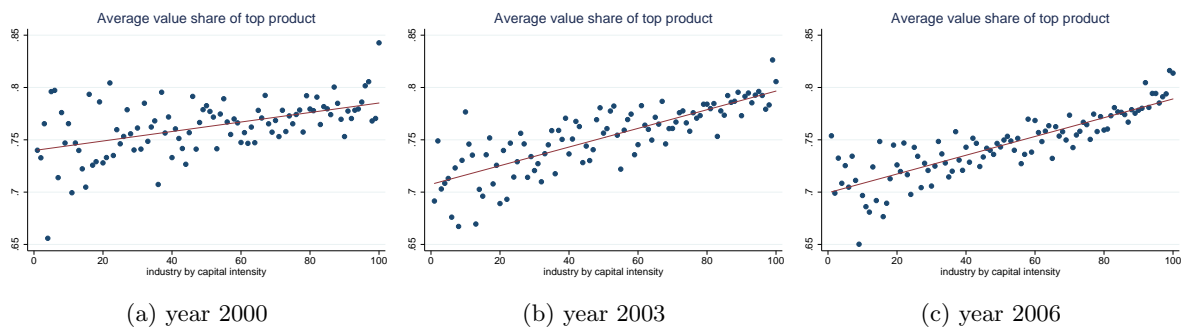


Figure C5: Average value share of the core product for exporters

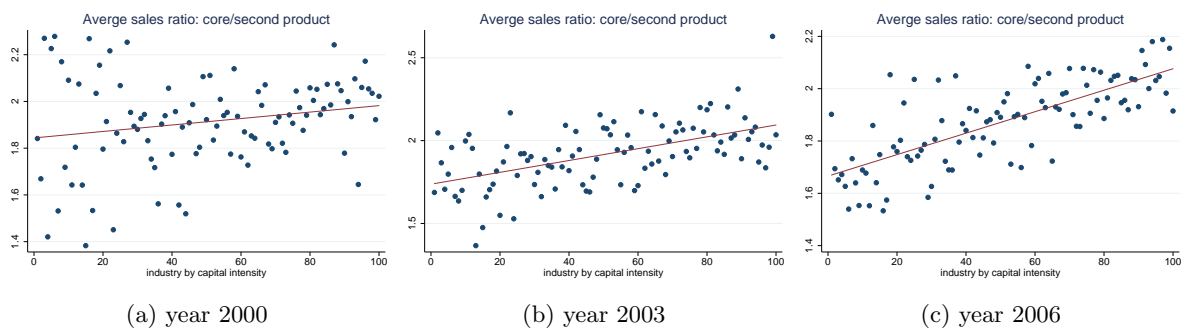


Figure C6: Exports of the core product relative to the second best product

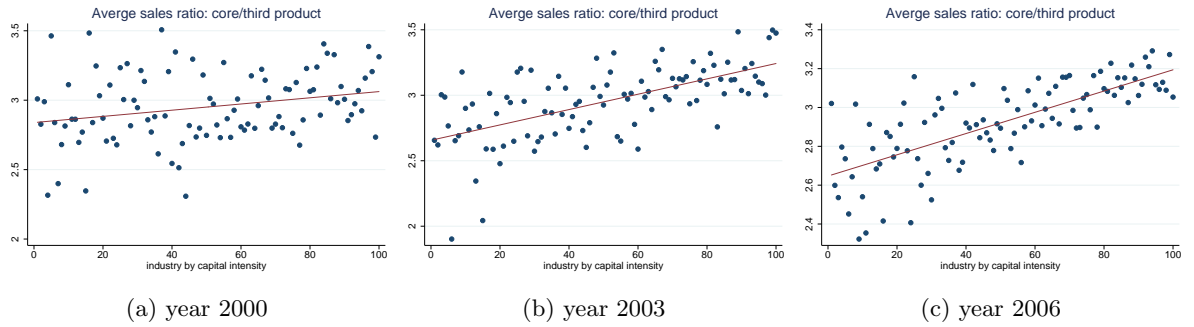


Figure C7: Exports of the core product relative to the third best product

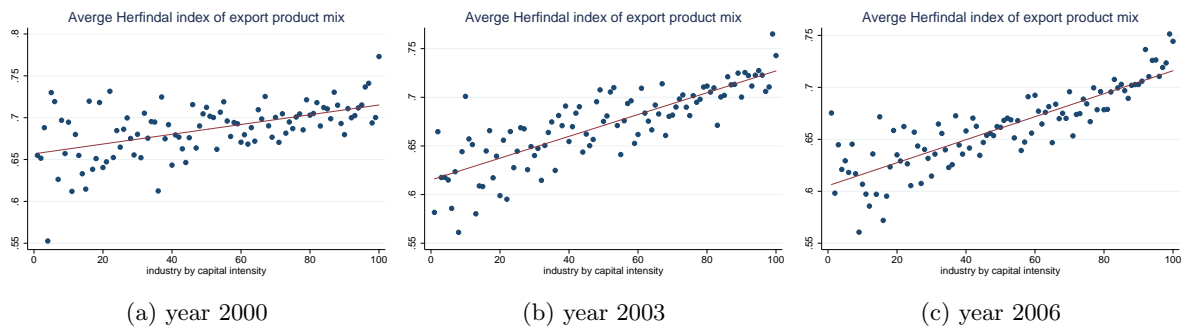


Figure C8: Average Herfindhal index of exports across products

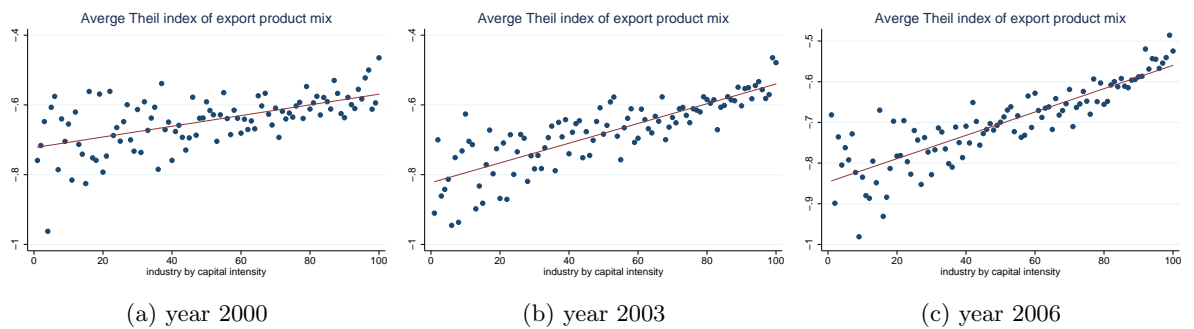


Figure C9: Average Theil index of exports across products

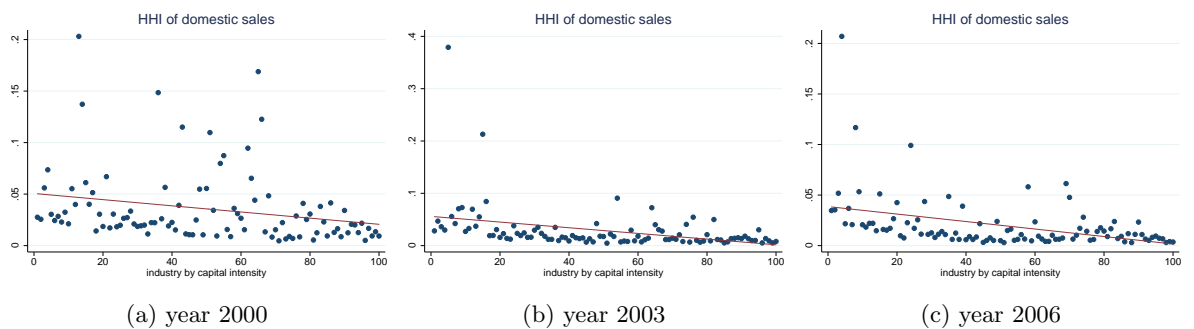


Figure C10: Herfidhal index of domestic sales across firms

3.D Proofs

3.D.1 Proof of Proposition 3.1

The export propensity from the home country to the foreign in industry z is

$$\chi(z) = \left(\frac{C_X(z)}{C_D(z)} \right)^k,$$

where $C_X(z)$ is the cut-off cost of export which satisfies $\tau C_X(z) = C_D^*(z)$. So we have

$$\chi(z) = \rho \left(\frac{C_D^*(z)}{C_D(z)} \right)^k.$$

Given that $\frac{\partial C_D(z)}{\partial z} > 0$ and $\frac{\partial C_D^*(z)}{\partial z} < 0$, it is easy to see that $\frac{\partial \chi(z)}{\partial z} < 0$. Similarly, we can prove that $\frac{\partial \chi^*(z)}{\partial z} > 0$.

The model predicts that exports from the home country to the foreign in industry z is

$$EXP(z) = \frac{1}{2\gamma(k+2)C_M(z)^k} N_E(z) C_D^*(z)^{k+2} L^* \rho.$$

On the other hand, the sales of industry z at home is

$$S(z) = \frac{1}{2\gamma(k+2)C_M(z)^k} N_E(z) C_D(z)^{k+2} L.$$

The export intensity of industry z is thus given by

$$\begin{aligned} \lambda(z) &\equiv \frac{EXP(z)}{EXP(z) + S(z)} \\ &= \frac{L^* \rho}{L^* \rho + L \left(\frac{C_D^*(z)}{C_D(z)} \right)^{k+2}} \\ &= \frac{L^* \rho}{L^* \rho + L \rho^{\frac{k+2}{k}} \chi(z)^{-\frac{k+2}{k}}}. \end{aligned}$$

Since we have $\frac{\partial \chi(z)}{\partial z} < 0$, it is easy to see that $\frac{\partial \lambda(z)}{\partial \chi(z)} > 0$, thus $\frac{\partial \lambda(z)}{\partial z} < 0$. Similar results hold for the foreign.

3.D.2 Proof of Proposition 3.2

The export product scope is given by $M_x(z, c)$ for a firm with core competency c in industry z . For firms that do export, i.e., the marginal cost of their core competency satisfies $c \leq C_X(z)$. Then $M_x(z, c) = \max\{m | v(m, c) \leq \frac{C_D^*(z)}{\tau}\} + 1$. Since $v(m, c) = \varpi^{-m} c$

and $\varpi \in (0, 1)$, we have

$$M_x(z, c) = \max\{m|\ln \tau + \ln c + m \ln(\frac{1}{\varpi}) \leq \ln C_D^*(z)\} + 1.$$

Since $\frac{\partial C_D^*(z)}{\partial z} < 0$, for two industries $z' > z$, we have $C_D^*(z') < C_D^*(z)$, we should have

$$M_x(z', c) \leq M_x(z, c).$$

That is the export product scope is non-increasing with comparative disadvantage.

3.D.3 Proof of Proposition 3.3

The sales ratio of product m and m' for an exporter to the foreign country in industry z can be written as

$$\frac{r(z, v(m, c))}{r(z, v(m', c))} = \frac{C_D^*(z)^2 - (\tau\varpi^{-m}c)^2}{C_D^*(z)^2 - (\tau\varpi^{-m'}c)^2}.$$

Suppose $m' > m$, so product m is closer to core: $\tau\varpi^{-m}c < \tau\varpi^{-m'}c$. Since $\frac{\partial C_D^*(z)}{\partial z} < 0$, it can be shown that

$$\frac{\partial \frac{r(z, v(m, c))}{r(z, v(m', c))}}{\partial z} > 0.$$

Export sales from the home country to the foreign country therefore become more skewed in the more comparative disadvantage industries.

3.D.4 Proof of Proposition 3.4

Consider two single-product firms in industry z such that $c_1 < c_2$, the ratio of their sales in the domestic market is given by

$$\frac{r_d(z, c_1)}{r_d(z, c_2)} = \frac{C_D^2(z) - c_1^2}{C_D^2(z) - c_2^2}.$$

Taking partial derivatives of the sales ratio with respect to $C_D(z)$, we have

$$\frac{\partial \frac{r_d(z, c_1)}{r_d(z, c_2)}}{\partial C_D(z)} = 2C_D(z) \frac{c_1^2 - c_2^2}{(C_D^2(z) - c_2^2)^2} < 0.$$

Tougher competition therefore skews more sales toward the better performing firm.

The multi-product firm case is less straightforward. Consider two firms with $c_1 < c_2$,

their sales ratio in the domestic market is given by

$$\begin{aligned} \frac{R_d(z, c_1)}{R_d(z, c_2)} &= \frac{\sum_{m=0}^{M_1-1} r_d(z, v(m, c_1))}{\sum_{m=0}^{M_2-1} r_d(z, v(m, c_2))} \\ &= \frac{C_D^2(z)M_1 - c_1^2 \frac{w^2}{w^{2M_1}} \frac{1-w^{2M_1}}{1-w^2}}{C_D^2(z)M_2 - c_2^2 \frac{w^2}{w^{2M_2}} \frac{1-w^{2M_2}}{1-w^2}}, \end{aligned}$$

where M_1 and M_2 are the product scope of the two firms, respectively. Since $c_1 < c_2$, we have $M_2 \leq M_1$. If $M_1 = M_2$, we have $\frac{\partial \frac{R_d(z, c_1)}{R_d(z, c_2)}}{\partial C_D(z)} = \frac{2C_D(z)M_1 w^2}{w^{2M_1}} \frac{1-w^{2M_1}}{1-w^2} \frac{c_1^2 - c_2^2}{(C_D^2(z) - c_2^2)^2} < 0$. If $M_1 > M_2$, we cannot sign the partial derivative. However, we claim that if the intra-firm reallocation is dominated by inter-firm reallocation, our result is still true. To see that, we first note that

$$\frac{R_d(z, c_1)}{R_d(z, c_2)} = \frac{r_0 + r_1 + r_2 + \dots + r_{M_1-1}}{R_d(z, c_2)},$$

where $r_0 = r_d(z, v(0, c_1))$, $r_1 = r_d(z, v(1, c_1))$, ..., $r_{M_1-1} = r_d(z, v(M_1 - 1, c_1))$. It can be further rearranged as

$$\frac{R_d(z, c_1)}{R_d(z, c_2)} = \frac{\sum_{i=0}^{M_2-1} r_i}{R_d(z, c_2)} + \frac{R_d(z, c_1) - \sum_{i=0}^{M_2-1} r_i}{R_d(z, c_1)} \frac{R_d(z, c_1)}{R_d(z, c_2)}.$$

If we move the second term of the right hand side to the left, we have

$$\left(1 - \frac{R_d(z, c_1) - \sum_{i=0}^{M_2-1} r_i}{R_d(z, c_1)}\right) \frac{R_d(z, c_1)}{R_d(z, c_2)} = \frac{\sum_{i=0}^{M_2-1} r_i}{R_d(z, c_2)},$$

or

$$\frac{R_d(z, c_1)}{R_d(z, c_2)} \frac{\sum_{i=0}^{M_2-1} r_i}{R_d(z, c_1)} = \frac{\sum_{i=0}^{M_2-1} r_i}{R_d(z, c_2)}. \quad (\text{E.3.1})$$

Now we make two claims. First, the term on the right hand side of Equation (E.3.1), which captures inter-firm reallocations, decreases with $C_D(z)$. This term looks at the ratio of total sales for the first M_2 products between the two firms, which is

$$\frac{\sum_{i=0}^{M_2-1} r_i}{R_d(z, c_2)} = \frac{C_D^2(z)M_2 - c_1^2 \frac{w^2}{w^{2M_2}} \frac{1-w^{2M_2}}{1-w^2}}{C_D^2(z)M_2 - c_2^2 \frac{w^2}{w^{2M_2}} \frac{1-w^{2M_2}}{1-w^2}}.$$

Therefore, we have

$$\frac{\partial \frac{\sum_{i=0}^{M_2-1} r_i}{R_d(z, c_2)}}{\partial C_D(z)} = 2C_D(z)M_2 \frac{w^2}{w^{2M_2}} \frac{1-w^{2M_2}}{1-w^2} \frac{c_1^2 - c_2^2}{(C_D^2(z)M_2 - c_2^2 \frac{w^2}{w^{2M_2}} \frac{1-w^{2M_2}}{1-w^2})^2} < 0.$$

Second, the intra-firm reallocation component $\frac{\sum_{i=0}^{M_2-1} r_i}{R_d(z, c_1)}$ decreases with $C_D(z)$. To show that is the case, first we note that for any product i , $0 \leq i \leq M_1 - 1$, its share in the firms' total sales in the home market is

$$\frac{r_i}{R_d(z, c_1)} = \frac{C_D^2(z) - (c_1 w^{-i})^2}{C_D^2(z)M_1 - c_1^2 \frac{w^2}{w^{2M_1}} \frac{1-w^{2M_1}}{1-w^2}}.$$

Therefore, we have

$$\frac{\partial \frac{r_i}{R_d(z, c_2)}}{\partial C_D(z)} = \frac{2C_D c_1^2 (M_1 w^{-2i} - \frac{w^2}{w^{2M_1}} \frac{1-w^{2M_1}}{1-w^2})}{(C_D^2(z)M_1 - c_1^2 \frac{w^2}{w^{2M_1}} \frac{1-w^{2M_1}}{1-w^2})^2}. \quad (\text{E.3.2})$$

For $i = 0$, we have $M_1 w^{-2i} = M_1 < \frac{w^2}{w^{2M_1}} \frac{1-w^{2M_1}}{1-w^2} = \sum_{i=0}^{M_1-1} w^{-2i}$ given that $0 < w < 1$. Therefore, $\frac{\partial \frac{r_0}{R_d(z, c_1)}}{\partial C_D(z)} < 0$, which means the share of the core product must always increase when competition intensifies. For $i = M_1 - 1$, we have $M_1 w^{-2i} = M_1 w^{-2(M_1-1)} > \frac{w^2}{w^{2M_1}} \frac{1-w^{2M_1}}{1-w^2}$ since it is equivalent to $M_1 > \frac{1-w^{2M_1}}{1-w^2} = \sum_{i=0}^{M_1-1} w^{2i}$. Thus we have $\frac{\partial \frac{r_{M_1-1}}{R_d(z, c_1)}}{\partial C_D(z)} > 0$, which means that the share of the worst product must always decline when competition intensifies. Since $M_1 w^{-2i}$ is decreasing with i , there exists a product m^* such that for $i \leq m^*$, we have $\frac{\partial \frac{r_i}{R_d(z, c_1)}}{\partial C_D(z)} \leq 0$, and for $i \geq m^*$, we have $\frac{\partial \frac{r_i}{R_d(z, c_1)}}{\partial C_D(z)} \geq 0$. Consequently, when $C_D(z)$ increases, the market becomes less competitive and the share of the total sales of the firm's first M_2 products declines.

Given these two claims, going back to Equation (E.3.1), if we let $f(C_D(z)) = \frac{R_d(z, c_1)}{R_d(z, c_2)}$,

$$h(C_D(z)) = \frac{\sum_{i=0}^{M_2-1} r_i}{R_d(z, c_1)}, \text{ and } g(C_D(z)) = \frac{\sum_{i=0}^{M_2-1} r_i}{R_d(z, c_2)}, \text{ we have}$$

$$f(C_D(z))h(C_D(z)) = g(C_D(z)).$$

If we take the partial derivatives with respect to $C_D(z)$ for the equation above, we have

$$\frac{f'}{f} = \frac{g'}{g} - \frac{h'}{h},$$

where $f' = \partial f(C_D)/\partial C_D$, $h' = \partial h(C_D)/\partial C_D$, and $g' = \partial g(C_D)/\partial C_D$. Given the two claims that we have made above, we have $g' < 0$ and $h' < 0$. The sign of f' is therefore undetermined. It is negative if $\frac{g'}{g} < \frac{h'}{h}$, which means that inter-firm reallocations (captured

by $\frac{g'}{g}$) dominates intra-firm reallocations (captured by $\frac{h'}{h}$). In the case of single-product firms, there is no intra-firm reallocation, therefore, this condition holds naturally.

3.D.5 Proof of Proposition 3.5

Comparing the relative average marginal costs between the home country and the foreign country under autarky and open economy, we have:

$$\frac{C_D(z)^T}{C_D(z)^{*T}} = \underbrace{\frac{C_D(z)^A}{C_D(z)^{*A}}}_{\text{ex ante}} \underbrace{\left[\frac{1 - \rho \frac{C_M^*(z)^k}{C_M(z)^k}}{1 - \rho^* \frac{C_M(z)^k}{C_M^*(z)^k}} \right]^{\frac{1}{k+2}}}_{\text{amplifying}}. \quad (\text{E.3.3})$$

where the first term is the *ex ante* comparative advantage and the second term is only present when countries open to trade. It is easy to verify that the second term increases with capital intensity z .

Depending on the relative size of $C_M(z)$ and $C_M(z)^*$ and the trade freeness, the relationship between $\frac{C_D(z)^T}{C_D(z)^{*T}}$ and $\frac{C_D(z)^A}{C_D(z)^{*A}}$ is illustrated by Figure C11. Panel (a) is when $\rho^* C_M(z)^{2k}$ is always larger than $\rho C_M^*(z)^{2k}$ so that $\frac{1 - \rho \frac{C_M^*(z)^k}{C_M(z)^k}}{1 - \rho^* \frac{C_M(z)^k}{C_M^*(z)^k}} > 1$, *vice versa* for panel (c). Panel (b) is when there exists an industry such that $\rho^* C_M(z)^{2k} = \rho C_M^*(z)^{2k}$. In all 3 cases, the differences in the relative average marginal costs across industries enlarge under the trade equilibrium. Hence comparative advantage is amplified by the second component.

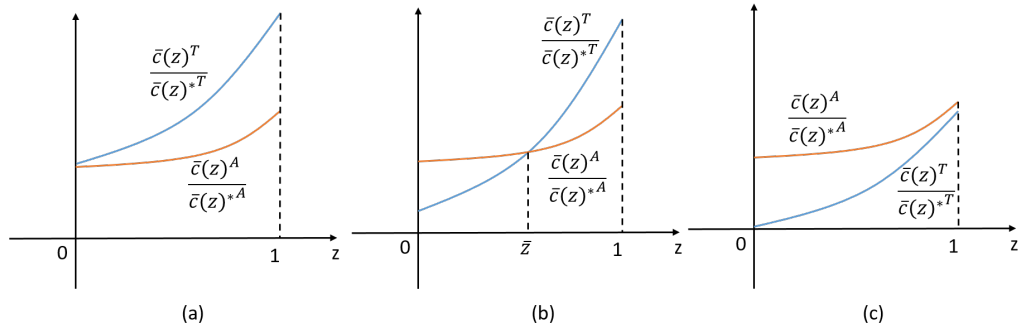


Figure C11: Relative average marginal costs: autarky vs. trade

3.D.6 Proof of Proposition 3.6

The relative quantity-based TFP between the home country and the foreign country under open economy can be rewritten as

$$\begin{aligned} \frac{\bar{\Phi}(z)^T}{\bar{\Phi}^*(z)^T} &= \left(\frac{L}{L^*} \frac{C_M^*(z)^k}{C_M(z)^k} \right)^{\frac{1}{k+2}} \left(\frac{L}{L^*} \frac{C_M^*(z)^k}{C_M(z)^k} \right)^{\frac{k+1}{k+2}} \frac{L^*}{L} \frac{\frac{L}{L^*} \left(\frac{C_D(z)}{C_D^*(z)} \right)^{k+1} + \rho}{1 + \rho^* \frac{L}{L^*} \left(\frac{C_D(z)}{C_D^*(z)} \right)^{k+1}} \\ &= \underbrace{\frac{\bar{\Phi}(z)^A}{\bar{\Phi}(z)^{*A}}}_{\text{ex ante}} \underbrace{\left(\frac{\bar{\Phi}(z)^A}{\bar{\Phi}(z)^{*A}} \right)^{k+1}}_{\text{amplifying}} \underbrace{\frac{L^*}{L} \frac{\frac{L}{L^*} \left(\frac{C_D(z)}{C_D^*(z)} \right)^{k+1} + \rho}{1 + \rho^* \frac{L}{L^*} \left(\frac{C_D(z)}{C_D^*(z)} \right)^{k+1}}}_{\text{dampening}}. \end{aligned} \quad (\text{E.3.4})$$

Given that $k > 0$, it is obvious that the second component is amplifying the effect of the first component, the ex ante comparative advantage measured by relative TFPQ under autarky. For the third component, if we define as $f(z) \equiv \frac{L^*}{L} \frac{\frac{L}{L^*} \left(\frac{C_D(z)}{C_D^*(z)} \right)^{k+1} + \rho}{1 + \rho^* \frac{L}{L^*} \left(\frac{C_D(z)}{C_D^*(z)} \right)^{k+1}}$, we have

$$\frac{\partial f(z)}{\partial z} = \frac{(1 - \rho\rho^*)(k+1) \left(\frac{C_D(z)}{C_D^*(z)} \right)^k \frac{\partial \left(\frac{C_D(z)}{C_D^*(z)} \right)}{\partial z}}{\left(1 + \rho^* \frac{L}{L^*} \left(\frac{C_D(z)}{C_D^*(z)} \right)^{k+1} \right)^2} > 0.$$

Given our assumptions that $\frac{\partial C_M(z)}{\partial z} > 0$ and $\frac{\partial C_M^*(z)}{\partial z} < 0$, we have $\frac{\partial \left(\frac{\bar{\Phi}(z)^A}{\bar{\Phi}(z)^{*A}} \right)}{\partial z} < 0$. That is to say the third component is negatively correlated with the first two components. Hence, it is dampening the ex ante comparative advantage.

3.D.7 Proof of Proposition 3.7

According to Proposition 1, the export intensity is

$$\begin{aligned} \lambda(z) &= \frac{L^* \rho}{L^* \rho + L \rho^{\frac{k+2}{k}} \chi(z)^{-\frac{k+2}{k}}} \\ &= \frac{1}{1 + \frac{L}{L^*} \rho^{\frac{2}{k}} \chi(z)^{-\frac{k+2}{k}}}. \end{aligned}$$

As a result, we can infer the relative market size $\frac{L}{L^*}$ as

$$\frac{L}{L^*} = \frac{1 - \lambda(z)}{\lambda(z)} \frac{\chi(z)^{\frac{k+2}{k}}}{\rho^{\frac{2}{k}}}. \quad (\text{E.3.5})$$

Again, according to Proposition 1, the export propensity in each industry is given by

$$\begin{aligned} \chi(z) &= \rho \left(\frac{C_D^*(z)}{C_D(z)} \right)^k \\ &= \rho \left(\frac{L}{L^*} \frac{C_M^*(z)^k - \rho^* C_M(z)^k}{C_M(z)^k - \rho C_M^*(z)^k} \right)^{\frac{k}{k+2}}. \end{aligned} \quad (\text{E.3.6})$$

Immediately, ratio of average costs between the home country and the foreign is given by

$$\frac{C_D^*(z)}{C_D(z)} = \left(\frac{\chi(z)}{\rho}\right)^{1/k}, \quad (\text{E.3.7})$$

which is the measure of comparative advantage. Moreover the relative cost upper bounds can be solved out of Equation (E.3.6) as

$$\frac{C_M^*(z)^k}{C_M(z)^k} = \frac{\rho^* + \frac{L^*}{L} \left(\frac{\chi(z)}{\rho}\right)^{\frac{k+2}{k}}}{1 + \frac{L^*}{L} \rho^{-\frac{2}{k}} \chi(z)^{\frac{k+2}{k}}}, \quad (\text{E.3.8})$$

substituting the relative size of $\frac{L}{L^*}$ using Equation (E.3.5), it can be written as a function of the observables. Then the endogenous component of the comparative advantage given by $\frac{1-\rho \frac{C_M^*{}^k}{C_M^k}}{1-\rho^* \frac{C_M^*{}^k}{C_M^k}}$ is also known. Finally, the *ex ante* comparative advantage $\frac{C_D(z)^{*A}}{C_D(z)^A} = \left(\frac{L}{L^*} \frac{C_M^*(z)^k}{C_M(z)^k}\right)^{1/(k+2)}$ can also be inferred.

The *ex ante* component of comparative advantage are the same for the two measures of comparative advantage since

$$\begin{aligned} \frac{\bar{\Phi}(z)^A}{\bar{\Phi}(z)^{*A}} &= \left(\frac{L}{L^*} \frac{C_M^*(z)^k}{C_M(z)^k}\right)^{1/(k+2)} \\ &= \frac{C_D(z)^{*A}}{C_D(z)^A}. \end{aligned} \quad (\text{E.3.9})$$

The way to quantify $\frac{\bar{\Phi}(z)^A}{\bar{\Phi}(z)^{*A}}$ therefore is the same as quantifying $\frac{C_D(z)^{*A}}{C_D(z)^A}$. Then the amplifying component $\left(\frac{\bar{\Phi}(z)^A}{\bar{\Phi}(z)^{*A}}\right)^{k+1}$ is also known. On the other hand, the dampening component is given by

$$\begin{aligned} \frac{L^*}{L} \frac{L}{L^*} \frac{(C_D(z))^{k+1} + \rho}{(C_D^*(z))^{k+1}} &= \frac{\left(\frac{\chi(z)}{\rho}\right)^{-\frac{k+1}{k}} + \rho^{1+\frac{2}{k}} \frac{\lambda(z)}{1-\lambda(z)} \chi(z)^{-\frac{k+2}{k}}}{1 + \rho^* \frac{1-\lambda(z)}{\lambda(z)} \frac{\chi(z)^{\frac{k+2}{k}}}{\rho^{\frac{2}{k}}} \left(\frac{\chi(z)}{\rho}\right)^{-\frac{k+1}{k}}} \\ &= \left(\frac{\chi(z)}{\rho}\right)^{-\frac{k+1}{k}} \frac{1 + \rho^{\frac{1}{k}} \frac{\lambda(z)}{1-\lambda(z)} \chi(z)^{-\frac{1}{k}}}{1 + \rho^* \frac{1-\lambda(z)}{\lambda(z)} \chi(z)^{\frac{1}{k}} \rho^{\frac{k-1}{k}}}, \end{aligned}$$

which can also be inferred as long as we know $\{\rho, \rho^*, k\}$ and observe $\{\chi(z), \lambda(z)\}$.

3.E Complementary Theoretical Results

3.E.1 A Model with Constant Mark-ups

This appendix section shows how to decompose comparative advantage in the constant mark-up heterogeneous firm model *à la* Bernard, Redding, and Schott (2007). Suppose

the demand is given by the following quasi-CES preference³⁴

$$U = q_0^c - \gamma \int_0^1 \ln Q(z) dz.$$

Under such a preference, solving the consumer's problem we have

$$q_i^c = -\gamma \frac{p_i^{-\sigma}}{P(z)^{1-\sigma}},$$

where $P(z) = (\int_{i \in \Omega(z)} p_i(z)^{1-\sigma} di)^{\frac{1}{1-\sigma}}$ is the price index, and $P(z)Q(z) = \int p_i(z)q_i^c(z)di = -\gamma$.

For the supply side, we follow the standard Melitz (2003) set up in the case of open economy: the entry cost is f_E and fixed cost of serving the domestic market and foreign market is f_d and f_x , respectively. On top of that, we assume that firms draw their marginal costs from the Pareto distribution $G(z, c) = (\frac{c}{C_M(z)})^k$, where $C_M(z)$ is the upper bound of the marginal cost at home. Given the market demand faced by firm at home and foreign and the iceberg cost assumption, we have

$$\begin{aligned} q_i(z) &= -\gamma L \frac{p_i^{-\sigma}}{P(z)^{1-\sigma}}, \\ q_i^*(z) &= -\gamma L^* \frac{p_i^{-\sigma}}{P^*(z)^{1-\sigma}}, \end{aligned}$$

and the optimal pricing for each market is given by

$$\begin{aligned} p_d(z, c) &= \frac{\sigma}{\sigma - 1} c, \\ p_x(z, c) &= \frac{\sigma}{\sigma - 1} \tau c. \end{aligned}$$

Then firm's profit functions for each market are given by

$$\begin{aligned} \pi_d(z, c) &= \frac{r_d(z, c)}{\sigma} - f_d = \frac{-\gamma L}{\sigma} \left(\frac{p_d(z, c)}{P(z)} \right)^{1-\sigma} - f_d, \\ \pi_x(z, c) &= \frac{r_x(z, c)}{\sigma} - f_x = \frac{-\gamma L^*}{\sigma} \left(\frac{p_x(z, c)}{P^*(z)} \right)^{1-\sigma} - f_x. \end{aligned}$$

The zero-profit conditions are

$$\begin{aligned} \frac{-\gamma L}{\sigma} \left(\frac{\frac{\sigma}{\sigma-1} c_D(z)}{P(z)} \right)^{1-\sigma} &= f_d, \\ \frac{-\gamma L^*}{\sigma} \left(\frac{\frac{\sigma}{\sigma-1} \tau c_X(z)}{P^*(z)} \right)^{1-\sigma} &= f_x, \end{aligned}$$

³⁴We get rid of the income effect to simplify the algebra. Huang et al. (2017) include the income effect and arrive at similar results.

where $c_D(z)$ and $c_X(z)$ are the cost cut-offs. Dividing the two equations above, we have

$$\frac{c_X(z)}{c_D(z)} = \frac{P^*(z)}{\tau P(z)} \left(\frac{f_d L^*}{f_x L} \right)^{\frac{1}{\sigma-1}}. \quad (\text{E.3.10})$$

To determine how $\frac{c_X(z)}{c_D(z)}$ varies across industries, we need to know how $\frac{P^*(z)}{P(z)}$ varies with z . To do that, we follow Bernard et al. (2007) to consider two extreme cases: free trade and autarky. Then the costly trade case would then fall between.

In the case of free trade, every surviving firm from every country exports. The number of varieties and the price charged by each firm in each market is the same. As a result, the price indexes satisfy $P(z) = (\int_{i \in \Omega(z)} p_i(z)^{1-\sigma} di)^{\frac{1}{1-\sigma}} = P(z)^* = (\int_{i \in \Omega^*(z)} p_i(z)^{1-\sigma} di)^{\frac{1}{1-\sigma}}$ under free trade. Moreover, the relative price index $\frac{P^*(z)}{P(z)}$ is constant.

Under autarky, $P(z) = (\int_{i \in \Omega(z)} p_i(z)^{1-\sigma} di)^{\frac{1}{1-\sigma}} = M_z^{\frac{1}{1-\sigma}} p_d(\hat{c}_d(z))$ where M_z is the domestic firm mass, and $\hat{c}_d(z)^{-1} = (\frac{1}{G(c_D(z))} \int_0^{c_D(z)} c^{1-\sigma} g(c) dc)^{\frac{1}{\sigma-1}}$ is the average marginal cost. Similarly, for the foreign country, we have $P(z)^* = M_z^{*\frac{1}{1-\sigma}} p_d^*(\hat{c}_d^*(z))$. For the firm mass, using the market clearing condition, we have $M_z = \frac{P(z)Q(z)}{r(\hat{c}_d(z))} = \frac{-\gamma}{r(\hat{c}_d(z))}$. Given the CES demand, we have $\frac{r(\hat{c}_d(z))}{r(c_D(z))} = (\frac{c_D(z)}{\hat{c}_d(z)})^{\sigma-1}$. Combining this result with the zero profit condition, we have $r(\hat{c}_d(z)) = r(c_D(z)) (\frac{c_D(z)}{\hat{c}_d(z)})^{\sigma-1} = \sigma f_d (\frac{c_D(z)}{\hat{c}_d(z)})^{\sigma-1}$, which implies that the firm mass is

$$M_z = \frac{-\gamma}{\sigma f_d} \left(\frac{\hat{c}_d(z)}{c_D(z)} \right)^{\sigma-1}.$$

So the autarky price index in home country is given by

$$P(z) = \left[\frac{-\gamma}{\sigma f_d} \left(\frac{\hat{c}_d(z)}{c_D(z)} \right)^{\sigma-1} \right]^{\frac{1}{1-\sigma}} \frac{\sigma}{\sigma-1} \hat{c}_d(z).$$

If we impose the Pareto distribution assumption, we have $\frac{\hat{c}_d(z)}{c_D(z)} = (\frac{k-\sigma+1}{k})^{\frac{1}{\sigma-1}}$. Then the price index is

$$P(z) = \left[\frac{-\gamma}{\sigma f_d} \frac{k-\sigma+1}{k} \right]^{\frac{1}{1-\sigma}} \frac{\sigma}{\sigma-1} \left(\frac{k-\sigma+1}{k} \right)^{\frac{1}{\sigma-1}} c_D(z),$$

which varies one-to-one with $c_D(z)$. To determine $c_D(z)$, we use the free entry condition under autarky which says the probability of survival times the expected profit equals to the fixed cost of entry:

$$G(c_D(z)) \pi(\hat{c}_d(z)) = f_e,$$

where $G(c_D(z)) = (\frac{c_D(z)}{C_M(z)})^k$. Since $\pi(\hat{c}_d(z)) = \frac{r(\hat{c}_d(z))}{\sigma} = \frac{r(c_D(z))}{\sigma} \left(\frac{c_D(z)}{\hat{c}_d(z)} \right)^{\sigma-1} = f_d \left(\frac{k}{k-\sigma+1} \right)^{\frac{1}{\sigma-1}}$, it is easy to find that

$$c_D(z) = \left(\frac{f_e}{f_d} \frac{k-\sigma+1}{k} \right)^{1/k} C_M(z),$$

which varies one-to-one with the cost upper bound. Therefore, under autarky, we have

$$\frac{P^*(z)}{P(z)} = \frac{C_M^*(z)}{C_M(z)},$$

which declines with z given the assumption that $\frac{\partial C_M(z)}{\partial z} > 0$ and $\frac{\partial C_M^*(z)}{\partial z} < 0$. That is to say, if we have $z' > z$, then we have

$$\begin{aligned} \frac{c_X(z)}{c_D(z)} &= \frac{P^*(z)}{\tau P(z)} \left(\frac{f_d L^*}{f_x L} \right)^{\frac{1}{\sigma-1}} \\ &= \frac{c_X(z')}{c_D(z')}, \end{aligned}$$

under free trade, and

$$\frac{c_X(z)}{c_D(z)} > \frac{c_X(z')}{c_D(z')},$$

under autarky. Given the continuity of trade costs, it must be the case that under costly trade, we have

$$\frac{\partial \chi(z)}{\partial z} < 0,$$

where $\chi(z) = \left(\frac{c_X(z)}{c_D(z)}\right)^k$ is the probability of export. Similarly, we can prove that $\frac{\partial \chi(z)^*}{\partial z} > 0$ holds for foreign.

Combining the zero profit condition and free entry condition under costly trade, we have

$$f_d \int_0^{C_D(z)} \left(\frac{\pi_x(z, c)}{\pi_x(z, C_D(z))} - 1 \right) dG(z, c) + f_x \int_0^{C_X(z)} \left(\frac{\pi_x(z, c)}{\pi_x(z, C_X(z))} - 1 \right) dG(z, c) = f_e,$$

for the home country. It can be simplified as

$$f_d C_D(z)^k + f_x C_X(z)^k = \frac{k - \sigma + 1}{\sigma - 1} f_e C_M(z)^k.$$

Similarly, for the foreign country, we have

$$f_d C_D^*(z)^k + f_x C_X^*(z)^k = \frac{k - \sigma + 1}{\sigma - 1} f_e C_M^*(z)^k.$$

These two equations imply

$$\frac{f_d C_D^*(z)^k + f_x C_X^*(z)^k}{f_d C_D(z)^k + f_x C_X(z)^k} = \frac{C_M^*(z)^k}{C_M(z)^k},$$

or

$$\left(\frac{C_D^*(z)}{C_D(z)}\right)^k = \underbrace{\frac{C_M^*(z)^k}{C_M(z)^k}}_{\text{exogenous}} \underbrace{\frac{1 + \frac{f_X}{f_D}\chi(z)}{1 + \frac{f_X}{f_D}\chi(z)^*}}_{\text{endogenous}},$$

where the exogenous and endogenous components are positively correlated.

3.E.2 Welfare in the Homogeneous and Heterogeneous Firm Models

Welfare in the Heterogeneous firm model

Substituting the demand function and consumers' budget constraint into the utility function, we have

$$U = y_0^c + I + \int_0^1 \left[\frac{\gamma}{2} \int_{i \in \Omega(z)} (q_i^c(z))^2 di + \frac{\eta}{2} Q^c(z)^2 \right] dz. \quad (\text{E.3.11})$$

If we define average price of industry z as $\bar{p}(z) = \frac{1}{N(z)} \int_{i \in \Omega(z)} p_i^c(z) di$, and the variance of price within each industry $\sigma_p^2(z) = \frac{1}{N(z)} \int_{i \in \Omega(z)} (p_i^c(z) - \bar{p}(z))^2 di$, we have

$$U = y_0^c + I + \frac{1}{2} \int_0^1 \left[\left(\eta + \frac{\gamma}{N(z)} \right)^{-1} (\alpha - \bar{p}(z))^2 + \frac{N(z)}{\gamma} \sigma_p^2(z) \right] dz.$$

If firm productivities are Pareto distributed, we have

$$U^{het} = y_0^c + I + \frac{1}{2\eta} \int_0^1 \left[(\alpha - C_D(z)) \left(\alpha - \frac{k+1}{k+2} C_D(z) \right) \right] dz. \quad (\text{E.3.12})$$

Welfare in the homogeneous firm model

If firms are homogeneous, their profits are all given by

$$\pi_i(z) = \frac{L}{4\gamma} (p_{\max}(z) - c(z))^2.$$

Due to free entry, firms earn zero profit, and we have

$$\frac{L}{4\gamma} (p_{\max}(z) - c(z))^2 - f_E = 0,$$

which implies that the choke price is given by

$$p_{\max}(z) = \sqrt{\frac{4\gamma f_E}{L}} + c(z).$$

Then immediately, we have

$$\begin{aligned} q(z) &= \frac{L}{2\gamma}(p_{\max}(z) - c(z)) \\ &= \sqrt{\frac{f_E L}{\gamma}}. \end{aligned}$$

Therefore, the demand by each consumer is $q^c(z) = \frac{q(z)}{L} = \sqrt{\frac{f_E}{\gamma L}}$. Given the demand function, the choke price can be rewritten as

$$\begin{aligned} p_{\max}(z) &= \alpha - \eta Q^c(z) \\ &= \alpha - \eta q^c(z) N(z), \end{aligned}$$

which implies that the number of varieties is given by

$$\begin{aligned} N(z) &= \frac{\alpha - p_{\max}(z)}{\eta q^c(z)} \\ &= \frac{(\alpha - c(z))\sqrt{\frac{\gamma L}{f_E}} - 2\gamma}{\eta}, \end{aligned}$$

and the overall consumption of the differentiated varieties is

$$\begin{aligned} Q^c(z) &= \frac{\alpha - p_{\max}(z)}{\eta} \\ &= \frac{\alpha - c(z) - \sqrt{\frac{4\gamma f_E}{L}}}{\eta}. \end{aligned}$$

Then using Equation (E.3.11), we know that the welfare:

$$\begin{aligned} U^{\text{hom}} &= y_0^c + I + \int_0^1 \left[\frac{\gamma}{2} \int_{i \in \Omega(z)} (q_i^c(z))^2 di + \frac{\eta}{2} Q^c(z)^2 \right] dz \\ &= y_0^c + I + \int_0^1 \left[\frac{N(z) f_E}{2L} + \frac{\eta}{2} \left(\frac{\alpha - c(z) - \sqrt{\frac{4\gamma f_E}{L}}}{\eta} \right)^2 \right] dz \\ &= y_0^c + I + \frac{1}{2\eta} \int_0^1 \left[((\alpha - c(z))\sqrt{\frac{\gamma f_E}{L}} - 2\frac{\gamma f_E}{L}) + (\alpha - c(z) - \sqrt{\frac{4\gamma f_E}{L}})^2 \right] dz. \end{aligned}$$

To ensure that the welfare are the same under autarky for the models of homogeneous and heterogeneous firms, i.e., $U^{\text{hom}} = U^{\text{het}}$, we can let

$$(\alpha - C_D(z)^A) \left(\alpha - \frac{k+1}{k+2} C_D(z)^A \right) = (\alpha - c(z)) \sqrt{\frac{\gamma f_E}{L}} - 2\frac{\gamma f_E}{L} + (\alpha - c(z) - \sqrt{\frac{4\gamma f_E}{L}})^2. \quad (\text{E.3.13})$$

This is a sufficient condition for $U^{\text{hom}} = U^{\text{het}}$. Let $\tilde{U}(z)^A = (\alpha - C_D(z)) \left(\alpha - \frac{k+1}{k+2} C_D(z) \right)$,

the equation above can be rewritten as

$$(\alpha - c(z))^2 - 3\sqrt{\frac{\gamma f_E}{L}}(\alpha - c(z)) + 3\left(\sqrt{\frac{\gamma f_E}{L}}\right)^2 - \tilde{U}(z)^A = 0.$$

It is, however, difficult to identify which of the two roots of this quadratic equation in $(\alpha - c(z))$ is the sensible solution. Alternatively, we can write the welfare for the homogeneous firm case as the function of varieties $N(z)$:

$$\begin{aligned} U^{\text{hom}} &= y_0^c + I + \int_0^1 \left[\frac{\gamma}{2} \int_{i \in \Omega(z)} (q_i^c(z))^2 di + \frac{\eta}{2} Q^c(z)^2 \right] dz \\ &= y_0^c + I + \int_0^1 \left[\frac{\gamma}{2} N(z) q^c(z)^2 + \frac{\eta}{2} (N(z) q^c(z))^2 \right] dz. \end{aligned}$$

Again, let $U^{\text{hom}} = U^{\text{het}}$, we have

$$\frac{\gamma}{2} N(z) (q^c(z))^2 + \frac{\eta}{2} (N(z) q^c(z))^2 = \frac{1}{2\eta} \tilde{U}(z)^A.$$

Since $q^c(z) = \sqrt{\frac{f_E}{\gamma L}}$, the left hand side can be rewritten as

$$\frac{\gamma}{2} N(z) (q^c(z))^2 + \frac{\eta}{2} (N(z) q^c(z))^2 = \frac{f_E}{2L} N(z) + \frac{\eta f_E}{2\gamma L} N(z)^2.$$

Then we have

$$\frac{f_E}{\gamma L} \eta^2 N(z)^2 + \frac{\eta f_E}{L} N(z) - \tilde{U}(z)^A = 0, \quad (\text{E.3.14})$$

which is a simple quadratic equation of $N(z)$. Given that $N(z) \geq 0$, the permissible solution is therefore given by

$$N(z)^A = \frac{\sqrt{\eta^2 f_E^2 / L^2 + 4 \frac{f_E}{\gamma L} \eta^2 \tilde{U}(z)^A} - \frac{\eta f_E}{L}}{2 \frac{f_E}{\gamma L} \eta^2}.$$

Then we also know the corresponding $C_{\text{hom}}(z)$ which satisfies $N(z)^A = \frac{(\alpha - C_{\text{hom}}(z)) \sqrt{\frac{\gamma f_E}{L}} - 2\gamma}{\eta}$.

Substituting the expression for $N^A(z)$ then gives

$$\begin{aligned} C_{\text{hom}}(z) &= \alpha - \left[2\gamma + \eta \frac{1}{2} \frac{\gamma}{\eta} \left(\sqrt{1 + 4 \frac{\tilde{U}(z)^A L}{\gamma f_E}} - 1 \right) \right] \sqrt{\frac{f_E}{\gamma L}} \quad (\text{E.3.15}) \\ &= \alpha - \frac{1}{2} \sqrt{\frac{\gamma f_E}{L}} \left(3 + \sqrt{1 + 4 \frac{\tilde{U}(z)^A L}{\gamma f_E}} \right) \\ &= \alpha - \frac{1}{2} \left(3 \sqrt{\frac{\gamma f_E}{L}} + \sqrt{\frac{\gamma f_E}{L} + 4 \tilde{U}(z)^A} \right). \end{aligned}$$

It is easy to verify that this is a solution to Equation (E.3.13). On the other hand, the other root of Equation (E.3.13) leads to $N(z)^A = \frac{-\sqrt{\frac{\gamma f_E}{L}(\tilde{U}(z)^A + 4\frac{\gamma f_E}{L}) - \frac{\gamma}{2}}}{\eta} < 0$.

In the open economy, the free entry condition is given by

$$\begin{aligned}\frac{L}{4\gamma}(p_{\max}(z) - c^A(z))^2 + \frac{L^*}{4\gamma}(p_{\max}(z)^* - \tau c^A(z))^2 &= f_E, \\ \frac{L^*}{4\gamma}(p_{\max}(z)^* - c^A(z)^*)^2 + \frac{L}{4\gamma}(p_{\max}(z) - \tau^* c^A(z)^*)^2 &= f_E.\end{aligned}$$

There are two equations and two unknowns $p_{\max}(z)$ and $p_{\max}(z)^*$. In principle, we can solve for $p_{\max}(z)$ and $p_{\max}(z)^*$ for given parameters. Once the choke prices are known, we can solve for $Q^c(z)$ and $Q(z)^{c^*}$ using:

$$\begin{aligned}p_{\max}(z) &= \alpha - \eta Q^c(z), \\ p_{\max}(z)^* &= \alpha - \eta Q(z)^{c^*}.\end{aligned}$$

Moreover, firm outputs are known given that

$$\begin{aligned}q^{HH}(z) &= \frac{L}{2}(p_{\max}(z) - c(z)), \\ q^{HF}(z) &= \frac{L^*}{2}(p_{\max}(z)^* - \tau c(z)), \\ q^{FF}(z) &= \frac{L^*}{2}(p_{\max}(z)^* - c(z)^*), \\ q^{FH}(z) &= \frac{L}{2}(p_{\max}(z) - \tau^* c(z)^*).\end{aligned}$$

Then we can solve for the number of varieties $\{n^H(z), n^F(z)\}$ using

$$\begin{aligned}Q^c(z)L &= n^H(z)q^{HH}(z) + n^F(z)q^{FH}(z), \\ Q(z)^{c^*}L^* &= n^F(z)q^{FF}(z) + n^H(z)q^{HF}(z).\end{aligned}$$

The solution is

$$\begin{aligned}n^H(z) &= \frac{Q(z)^{c^*}L^*q^{FH}(z) - Q^c(z)Lq^{FF}(z)}{q^{FH}(z)q^{HF}(z) - q^{FF}(z)q^{HH}(z)}, \\ n^F(z) &= \frac{Q^c(z)Lq^{HF}(z) - Q(z)^{c^*}L^*q^{HH}(z)}{q^{FH}(z)q^{HF}(z) - q^{FF}(z)q^{HH}(z)}.\end{aligned}$$

The welfare for the home country is then given by

$$\begin{aligned}
 U &= y_0^c + I + \int_0^1 \left[\frac{\gamma}{2} \int_{i \in \Omega(z)} (q_i^c(z))^2 di + \frac{\eta}{2} \left(\int_{i \in \Omega(z)} q_i^c(z) di \right)^2 \right] dz, \\
 &= y_0^c + I + \int_0^1 \left[\frac{\gamma}{2} (n^H(z) \left(\frac{q^{HH}(z)}{L} \right)^2 + n^F(z) \left(\frac{q^{FH}(z)}{L} \right)^2) + \frac{\eta}{2} Q^c(z)^2 \right] dz.
 \end{aligned}$$

For the foreign country, it is given by

$$U^* = y_0^c + I + \int_0^1 \left[\frac{\gamma}{2} (n^F(z) \left(\frac{q^{FF}(z)}{L^*} \right)^2 + n^H(z) \left(\frac{q^{HF}(z)}{L^*} \right)^2) + \frac{\eta}{2} Q(z)^{c*2} \right] dz.$$

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