Monograph:
Zhang, D., Navas, A. and Gregory-Smith, I. (2023) Comparative advantage and the quality choice of heterogeneous firms. Working Paper. Sheffield Economic Research Paper Series, 2023022 (2023022). Department of Economics, University of Sheffield ISSN 1749-8368

The University Of Sheffield.

Department Of Economics

Comparative Advantage and the Quality Choice of Heterogeneous Firms

Dongzhe Zhang, Antonio Navas, and Ian Gregory-Smith

Sheffield Economic Research Paper Series

SERPS no. 2023022

ISSN 1749-8368

05 December 2023

Comparative Advantage and the Quality Choice of Heterogeneous Firms

Dongzhe Zhang*[1], Antonio Navas†[2], and Ian Gregory-Smith‡[3]

[1]Department of Economics, University of Sussex Business School, UK
[2]Department of Economics, University of Sheffield, UK
[3]Department of Economics, Newcastle University, UK

October 2023

Abstract

This paper examines how trade openness affects firms' product quality across industries based on a country's comparative advantage. We develop a Heckscher-Ohlin model with heterogeneous firms and endogenous quality upgrading. Trade openness affects a firm's product quality differently within an industry based on the firm's export status. In particular, trade openness increases exporters' product quality and reduces the quality from non-exporting firms. These effects are not homogeneous across industries; they are more pronounced in a country's comparative advantage industry. We test the main predictions of the model using transaction-level data of Chinese exports. Consistent with our theoretical predictions, we find that Chinese exporters export higher quality products in those industries in which China reveals a comparative advantage.

(JEL F11, F14)

Keywords: Heterogeneous Firms, Product Quality, Comparative Advantage,

*E-mail address: dz91@sussex.ac.uk
†Corresponding author. E-mail address: a.navas@sheffield.ac.uk
‡E-mail address: ian.gregory-smith@ncl.ac.uk

1 Introduction

A major challenge for contemporary research in international economics is to understand the role played by product quality. Macro-level studies suggest that product quality is likely to be an important determinant in trade. For example, a consistent observation is that richer countries consume and export higher-quality goods.[1] Micro-data on manufacturing plants has revealed significant heterogeneity in quality across firms: more productive firms produce higher quality goods and charge higher prices.[2] However, what determines the firm's product quality within a country and the role played by international trade in it has received little attention. In this paper, we show that fundamental determinants of a country's comparative advantage in an open economy environment are shaping a firm's product quality. In our theoretical framework, the difference in quality across industries within a country is explained by the intersection of trade openness and those fundamentals.

This paper embeds heterogeneous firms in a 2 country 2 industry Heckscher-Ohlin (H-O) model of comparative advantage based on Bernard et al. (2007). Our novel contribution to this framework is that firms endogenously determine the quality of the product they offer. While in an autarkic scenario, identical firms across industries do not exhibit any differences in quality, we will show that trade openness has an impact on a firm's product quality that is different across firms within an industry and across industries. In particular, trade openness induces exporters to upgrade their product quality. In contrast, non-exporters will respond to trade openness by lowering product quality. Trade openness creates new business opportunities for those firms that are able to export and the increase in market size causes quality upgrading to be more attractive. Thus, the trade openness increases the demand for production factors, raising production costs. The latter together with the increased access of foreign firms into the domestic market reduces market size, operating profits and the attractiveness of quality upgrading for non-exporting firms. Consequently, trade openness increases exporters' product quality and decreases non-exporters' product quality.

Unlike previous work, in our framework trade openness will induce different responses based on whether the country reveals a comparative advantage in the industry. In particular, a firm's reaction to trade openness in terms of quality upgrading will be more pronounced in the comparative advantage industry. This result arises because in the comparative advantage industry, the increase in market size enjoyed by exporters is larger and competition for the production factor used intensively in that industry is fiercer. This implies that in the comparative advantage industry, exporters will increase the quality of their product to a greater extent than if they were in a non-comparative advantage industry. Similarly, non-exporters will reduce their quality by more when they are in a comparative advantage industry. Thus, the impact of trade openness is amplified in the industry

[1] Hallak (2006) finds that richer countries import more from the countries that produce more high-quality goods. Hummels and Klenow (2005) and Schott (2004) provide supporting evidence that richer countries export higher-quality goods.

[2] Verhoogen (2008) and Baldwin and Harrigan (2011) establish models and provide evidence that more productive firms produce higher-quality goods. Kugler and Verhoogen (2012) and Manova and Zhang (2012) further confirm that more productive firms produce higher quality goods and charge higher prices for their goods.

with a comparative advantage.

A further important consideration is the impact of trade openness on the industry's aggregate (average) quality. We show that trade openness increases average quality in all industries but this effect will be stronger in the comparative advantage industry. As mentioned above, exporters improve their quality while non-exporters reduce their quality when the economy opens to trade. In addition, the least productive firms, with the lowest product quality, will exit the industry which contributes positively to the average quality. In aggregate, the increase in quality from exporters and the selection effect in quality more than compensate for the reduction in quality from the incumbent non-exporting firms.

Due to data limitations, we focus on a central testable prediction generated by our model: Exporters supply higher quality products in those industries in which a country reveals a comparative advantage. To test this prediction, we use firm-level transaction data obtained from Chinese Customs Trade Statistics. To control for firm characteristics, we merge this data with data obtained from the Chinese Annual Survey of Industrial Firms for the period 2000-2007. We follow Khandelwal et al. (2013) and our own theoretical model to infer product quality from unobserved attributes of a product variety that increase sales, conditional upon their price. To measure comparative advantage we follow the methodology proposed by Costinot et al. (2012) and expanded by Leromain and Orefice (2014) which avoids issues regarding stability and the endogeneity of the Balassa-Samuelson revealed comparative advantage index. The empirical evidence is consistent with the predictions of our model. We find that Chinese exporters produce higher-quality goods in its revealed comparative advantage industries conditional on firm productivity and other characteristics. This result is robust to alternative measures of quality, productivity, and comparative advantage, as well as potential endogeneity concerns.[3]

Our paper is the first one establishing a link between the quality of products firms, and therefore industries supply, and those deep determinants of comparative advantage. In this regard, our principal contribution is to the theoretical literature on international trade that links new models of trade with firm heterogeneity and neoclassical theories of trade. Other papers in the literature have explored how Heckscher-Ohlin determinants of comparative advantage have positively contributed to the evolution of average productivity across industries (Bernard et al., 2007), or firm's incentives to invest in cost-reducing innovations Navas (2018). Separate to considerations of comparative advantage, Baldwin and Harrigan (2011) investigate how quality may be behind the spatial variation in prices charged by exporters observed in the data. Kugler and Verhoogen (2012) and Fieler et al. (2018) develop models in which the quality of firm inputs is an important determinant of a firms' product quality and examines the impact of trade liberalisation on output quality. Our contribution is to bridge the gap in the trade literature between product quality and the deep determinants

[3]To obtain a measure of firm's quality in the domestic economy we should rely on unitary prices involved in domestic transactions. Our database does not include this and to the best of our knowledge, there are few databases that contain this type of information. For that reason, we only test predictions of the model that are associated with the exporting side of the economy.

of comparative advantage. In a relatively simple framework, we are able to explain the mapping between the quality of inputs and the quality of the final output.

Our paper also contributes to the empirical literature on exporting and product quality. Single-industry case studies have shown that quality can play an important role in exporting when a direct measure of observed product quality can be obtained.[4] When covering all exporting activity, as is the case here, product quality cannot be directly observed but instead, the literature has followed Khandelwal (2010) and Khandelwal et al. (2013) and estimated quality indirectly by exploiting detailed information on price and sales.[5] We contribute to this body of the evidence by providing empirical support for the notion that exporters export products of higher quality in industries that reveal a comparative advantage, a result that, to the best of our knowledge, it has not been tested before. In doing so, this paper is unique in linking product quality across firms and industries based on deep determinants of comparative advantage.

The rest of the paper is organised as follows. Section 2 develops the model and derives the relationships between comparative advantage, firms' productivity, and quality choice. Four theoretical propositions are presented, with proofs provided in the appendix. Section 3 presents the empirical work in the paper, covering the sample construction, empirical strategy, results and robustness checks. Section 4 concludes.

2 Model

This model considers a world of two countries, H and F, two industries 1 and 2, two factors, human capital, S and physical capital, K and a continuum of heterogeneous firms. As in the standard H-O model, we consider that countries are identical in preferences and technologies but differ in factor endowments. Factors of production can move between industries within countries but not across countries. We use H to index the relatively human-capital-abundant country (Home country) and F to index the relatively physical-capital-abundant country (Foreign country).

[4]For instance, Macchiavello (2010) and Crozet et al. (2012) obtain direct quality measures from wine guides; Bai (2018) measures the quality of watermelon from the biweekly quality checks using sweet meters; Bai et al. (2022) use the information of inspections to proxy the quality of Chinese dairy products.

[5]For example, Manova and Yu (2017) show that firms vary product quality by using inputs of different quality and find firms' core varieties are captured with the higher quality and Fan et al. (2018) show that China's tariff reductions encourage quality upgrading.

2.1 Autarky

2.1.1 Demand

Each country is populated by a continuum of citizens. They derive utility from the consumption of composite goods by two industries (denoted with C_j, $j = 1, 2$). Preferences over these two goods are described by the following Cobb-Douglas functional form:

$$U = (C_1)^{\mu}(C_2)^{1-\mu} \tag{1}$$

where μ and $1-\mu$ denote respectively the importance of composite good from industry 1 and 2 in the utility function.[6]

Varieties are aggregated following the Constant Elasticity of Substitution (CES) functional form,

$$C_j = \left[\int_{i\in\Omega} q_{ij}^{\frac{\gamma}{\sigma}} c_{ij}^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}} \tag{2}$$

where c_{ij} is consumption of the variety i in industry j and q_{ij} is its quality, σ is the elasticity of substitution across varieties ($\sigma > 1$), and γ ($\gamma > 0$) describes how much consumers care about product quality. To outline the importance of differences in factor endowments in determining quality, we set these two parameters equal across goods. The optimal consumption of each variety is given by the following expression:

$$x_{ij} = \frac{p_{ij}^{-\sigma} q_{ij}^{\gamma}}{P_j^{1-\sigma}} E_j \tag{3}$$

where E_j represents the aggregate expenditure on products of industry j (i.e., $E_1 = \mu R, E_2 = (1-\mu)R$, where R denotes total revenue of the economy) and P_j is the aggregate price index,

$$P_j = \left[\int_{i\in\Omega} p_{ij}^{1-\sigma} q_{ij}^{\gamma} di\right]^{\frac{1}{1-\sigma}} \tag{4}$$

2.1.2 Production

Each variety in the final good sector is produced by a unique firm in a monopolistically competitive environment. As standard in the literature (i.e., Melitz (2003) and Bernard et al. (2007)), the unit input requirements, a_{ij} varies across firms and they are uncertain at the moment of entry. In order

[6]From the solution of the utility maximisation problem, we also know that these represent the proportion of the income that the individual wants to spend on each good.

to enter, firms need to pay a fixed cost of entry F_E in terms of a generic intermediate input, y_j^g, which is common across all varieties within the same industry. This generic intermediate input is produced using a Cobb-Douglas technology that involves the use of human (S_j^g) and physical capital (K_j^g) in proportions β_j and $1-\beta_j$.[7] It takes the following functional form:

$$y_j^g = D_j (S_j^g)^{\beta_j} (K_j^g)^{1-\beta_j} \tag{5}$$

with $D_j = \beta_j{}^{-\beta_j}(1-\beta_j)^{-(1-\beta_j)}$ ($D_j > 0$). β_j measures the degree of human-capital intensity of intermediate inputs used in the industry j. Let us assume without loss of generality that $\beta_1 > \beta_2$, implying that industry 1 is human capital intensive.

Once the firm has made such an investment, the unit input requirements are an extract from a continuous random distribution function, $G(a)$, which is revealed to the firm. At this time, the firm can decide to stay and produce or to leave the market. If staying, the firm also incurs a fixed cost of production F_D in terms of the generic intermediate input. After that, the firm can decide their level of quality as explained in the following section. Then the decision about the price of final goods that the firm wants to charge (and indirectly the quantity produced) is taken.

To produce, firms use a technology that is linear in a unique intermediate input that depends on the quality of the final good product, with higher quality goods requiring firms in the intermediate input sector to devote more resources. Any firm in the intermediate input sector can produce this intermediate input using a technology similar to one of the generic intermediate inputs in a perfectly competitive environment. In particular,

$$y_{ij} = D_j S_{ij}^{\beta_j} K_{ij}^{1-\beta_j} T_{ij} \tag{6}$$

with $T_{ij} = q_{ij}^{-e}$ where $e > 0$. Somehow, this is equivalent to assuming that the production of high-quality final goods requires high-quality intermediate inputs, with high quality intermediate inputs requiring more resources. This relationship has been revealed by several empirical works like Verhoogen (2008), Kugler and Verhoogen (2009) and Manova and Zhang (2012).

Solving the firm's cost-minimisation problem and applying the fact that the price equals the marginal cost of production in intermediate sector, we obtain the price for each intermediate input,

$$p_{mij} = w^{\beta_j} r^{1-\beta_j} q_{ij}^e \tag{7}$$

$$p_{mj}^g = w^{\beta_j} r^{1-\beta_j} \tag{8}$$

where p_{mij} is the price of intermediate inputs used by firm i in the industry j, w is the wage of workers (human capital) and r indicates the rent of physical capital. p_{mj}^g, is the price of the generic intermediate input in each industry.

[7] We simply abstract the physical capital from capital accumulation, as standard in the literature.

2.1.3 Investment in Quality

As discussed above, firms are also allowed to choose quality endogenously in this setup. More precisely, let us assume that firms use the same intermediate input used in final production to produce the quality associated with that good. In particular, the technology to produce quality in the final good sector is described by the following cost function,

$$C(q_{ij}) = a_{ij}^{\alpha} q_{ij}^{1-e} p_{mij} \tag{9}$$

where α ($\alpha > 0$) describes how a firm's production ability can contribute to the production of quality. Substituting the price of intermediates, equation (7), the cost function can be expressed as $C(q_{ij}) = a_{ij}^{\alpha} q_{ij} w^{\beta_j} r^{1-\beta_j}$.

It is important to note here that more productive firms (lower a_{ij}) need fewer intermediate inputs to produce the same quality, with the parameter α governing this relationship. Therefore, more productive firms have an advantage in producing quality with respect to the less productive ones. It is also important to realise that this quality investment is a fixed cost in the sense that it does not depend directly on the volume produced by the firm.

2.1.4 Solution

The model is solved by backward induction. Conditional on quality, the firm's profit maximisation yields an optimal price per variety that is a constant mark-up over marginal cost:

$$p_{ij} = \frac{\sigma}{\sigma - 1} a_{ij} q_{ij}^{e} w^{\beta_j} r^{1-\beta_j} \tag{10}$$

Therefore, the operating profits of a firm with a final good of quality q_{ij} can be expressed as:

$$\pi_{ij} = a_{ij}^{(1-\sigma)} q_{ij}^{\gamma+e(1-\sigma)} (w^{\beta_j} r^{1-\beta_j})^{1-\sigma} B_j - a_{ij}^{\alpha} q_{ij} w^{\beta_j} r^{1-\beta_j} - F_D w^{\beta_j} r^{1-\beta_j} \tag{11}$$

where $B_j = \frac{(\frac{\sigma}{\sigma-1})^{1-\sigma}}{\sigma(P_j)^{1-\sigma}} E_j$, captures demand and supply features and is constant across all firms within the same industry.

The next step is to find the firm's quality optimal choice. Solving the operating profits maximisation problem yields an expression of the firm's optimal quality:

$$q_{ij} = \left[\frac{[\gamma + e(1-\sigma)] B_j}{a_{ij}^{\alpha+\sigma-1} (w^{\beta_j} r^{1-\beta_j})^{\sigma}} \right]^{\frac{1}{1-[\gamma+e(1-\sigma)]}} \tag{12}$$

To guarantee that the firm's quality is positive, let us assume that $\gamma + e(1-\sigma) > 0$ and to ensure that the solution satisfies the second order condition we must assume that $\gamma + e(1-\sigma) < 1$.

Inspecting Equation (12), we can observe that the firm's optimal quality increases with our variable that captures demand features, B_j (a larger market allows the firm to take advantage of the economies of scale associated with the production of quality) and decreases with the firm's unit input requirements (more productive firms invest more in quality).

For simplicity, let us denote $[\gamma + e(1-\sigma)] = m$ and a_{Dj}^{aut} the unit input threshold associated with the firm indifferent between staying or leaving the market, the marginal firm, in autarky. This firm satisfies $\pi_{ij} = F_D w^{\beta_j} r^{1-\beta_j}$. Substituting this into the expression for the quality we obtain,

$$q_{ij} = \frac{mF_D}{1-m} a_{ij}^{\frac{\alpha+\sigma-1}{m-1}} (a_{Dj}^{aut})^{\frac{\alpha m+\sigma-1}{1-m}} \tag{13}$$

This expression will be used in further sections for comparison between different scenarios. Note as well that a firm's optimal quality is positively associated with a_{Dij}^{aut}. In those industries in which there is a tougher selection (a lower a_{Dj}^{aut}), the quality of a firm is lower conditional on productivity due to more intense competition.

Substituting this into the firm's optimal price we obtain,

$$p_{ij} = \frac{\sigma}{\sigma-1} \left(\frac{mF_D}{1-m}\right)^e a_{ij}^{\frac{e\alpha+\gamma-1}{m-1}} (a_{Dj}^{aut})^{\frac{e(\alpha m+\sigma-1)}{1-m}} w^{\beta_j} r^{1-\beta_j} \tag{14}$$

This expression shows the trade-off that more productive firms face regarding the price they charge: on the one hand, more productive firms are able to charge lower prices, as their marginal costs of production are lower ceteris paribus. However, more productive firms will invest more in quality which requires intermediate inputs that are more expensive. If we assume that $e\alpha + \gamma > 1$, then there is an inverse relationship between the price charged by the firm and its unit requirements, since $m < 1$. Consequently, more productive firms charge higher prices as documented in Manova and Zhang (2012). Intuitively the parameter γ measures the importance of quality for consumers while α shapes the advantage that more productive firms have in the production of quality. The larger is α, or γ, the larger will be the investment in quality by more productive firms and this will increase the costs of production, increasing their price.

2.1.5 Firm Entry

Every period, a firm faces a natural death rate δ and exits the market.[8] Firms decide to enter the market by comparing their expected flow of profits with their entry cost. Substituting Equation (13)

[8] The assumption that the probability of death is independent of firm characteristics follows Melitz (2003) and Bernard et al. (2007).

into the expression for profits (i.e., Equation (11)) and rearranging terms we find,

$$\pi_{ij} = (1-m)m^{\frac{m}{1-m}} a_{ij}^{\frac{1-\sigma-\alpha m}{1-m}} B_j^{\frac{1}{1-m}} (w^{\beta_j} r^{1-\beta_j})^{\frac{1-m-\sigma}{1-m}} - F_D w^{\beta_j} r^{1-\beta_j} \tag{15}$$

Note that profits decrease with a_{ij}, (i.e., more productive firms obtain larger operating profits) as $\sigma > 1$. In equilibrium free entry ensures that firms will enter the market until the expected flow of profits is equal to the fixed entry cost,

$$EV(\frac{\pi_{ij}}{\delta}) = F_E w^{\beta_j} r^{1-\beta_j} \tag{16}$$

where $EV(\frac{\pi_{ij}}{\delta})$ is the expected discounted flow of profits of a prospective entrant.

To obtain a closed solution for the unit-input threshold, we follow the literature and assume that the random variable a_{ij} follows a Pareto distribution with cumulative distribution function $G(a) = \left(\frac{a}{a_M}\right)^k$ where k is the shape parameter. Thus, we can express the threshold as:

$$(a_{Dj}^{aut})^k = \frac{\delta F_E}{F_D} \frac{1-\sigma-\alpha m + k(1-m)}{\alpha m + \sigma - 1} (a_M)^k \tag{17}$$

The minimum value that the shape parameter of the density function, k, can take is $\frac{\alpha m+\sigma-1}{1-m}$ to obtain a positive value of the production unit-input threshold. Otherwise, there would not be any firms producing goods in the industry j. From the expression of a_{Dj}^{aut}, we can find that in autarky, the production threshold does not depend on industry variables, provided that the parameters are the same across industries. This result implies that in autarky, differences in factor endowments across countries and factor intensities across industries would not have any impact either on the survival unit input threshold or on the quality that every firm invests. This result resembles those found in Bernard et al. (2007) and Navas (2018).

2.2 Costly Trade

In this section, we analyse what happens when the two economies H and F open up to trade with each other. In the appendix we show that if trade is frictionless (i.e., no variable or fixed costs are involved), opening up to trade does not have any impact either on the unit input thresholds or on the quality invested per firm in each sector. What we show in this section is that this last result changes when we allow for trade with frictions with both variable trade costs and fixed trade costs put in place, which is both the most interesting and realistic case. The empirical relevance of fixed costs of exporting has been well documented in Roberts and Tybout (1997) and Bernard and Jensen (2004).

In order to serve the foreign market firms bear both, a fixed cost of exporting, F_X in terms of the generic intermediate good and a variable cost of the iceberg type as in Bernard et al. (2007). The existence of fixed and variable trade costs induce self-selection into the exporting market based on productivity and this self-selection will induce both differences in investment in quality across industries and differences in aggregate productivity across industries.

Firms decide whether to serve the foreign market and the optimal level of quality simultaneously.[9] After the firm decides which markets to serve the firm decides the pricing policy. We solve the model by backward induction.

2.2.1 Demand and Production

As the domestic and the foreign market are segmented, the firm's profit maximisation implies that the firm will pass through the entire variable trade cost onto consumers and therefore the pricing behaviour will be given by the following rule,

$$p_{idj} = p_{ij} \qquad p_{ixj} = \tau p_{idj} = \tau p_{ij} \tag{18}$$

Firms will endogenously decide the level of quality which is common to both the foreign and the domestic market by maximising profits:

$$\begin{aligned}\pi_{ij}^{l} = a_{ij}^{1-\sigma} q_{ij}^{l} B_j^l (1+\lambda\tau^{1-\sigma}A_j^l)((w^l)^{\beta_j}(r^l)^{1-\beta_j})^{1-\sigma} - a_{ij}^{\alpha} q_{ij}^{l}(w^l)^{\beta_j}(r^l)^{1-\beta_j} \\ -F_D(w^l)^{\beta_j}(r^l)^{1-\beta_j} - \lambda F_X (w^l)^{\beta_j}(r^l)^{1-\beta_j}\end{aligned} \tag{19}$$

where $B_j^l = \frac{(\frac{\sigma}{\sigma-1})^{1-\sigma}}{\sigma(P_j^H)^{1-\sigma}} E_j^l$, λ takes the value of 1 if firms export and 0 otherwise and q_{ij}^l denotes the quality choice of a firm from country l in free trade. Note that we denote with superscript l the variables associated with the country of origin either H or F and with superscript n the variables associated with the destination country either H or F. The variable A_j^l ($A_j^l = \frac{E_j^n}{E_j^l}(\frac{P_j^l}{P_j^n})^{1-\sigma}$) describes the profitability of serving the exporting market relative to the domestic market and it will play an important role in our results. This variable clearly varies across industries, depending on the country's comparative advantage.

From the firm's first order condition, we obtain an expression for the optimal quality in trade openness:

$$q_{ij}^l = \left[\frac{mB_j^l(1+\lambda\tau^{1-\sigma}A_j^l)}{a_{ij}^{\alpha+\sigma-1}((w^l)^{\beta_j}(r^l)^{1-\beta_j})^{\sigma}}\right]^{\frac{1}{1-m}} \tag{20}$$

Equation (20) shows that ceteris paribus exporters will invest more in quality compared to non-

[9] If instead, it is done sequentially, with firms deciding quality before deciding whether to serve the foreign market the results will be unaltered.

exporters conditional on productivity. The key to seeing this result lies in the numerator of expression (20). When the firm exports (i.e., $\lambda = 1$) the whole parenthesis is larger than one while the parenthesis takes the value of 1 when the firm does not export (i.e., $\lambda = 0$). The larger numerator in the case of exporters translates into more quality. The economic reason behind this is a pure market effect: compared to non-exporters, exporters are facing both the domestic and the foreign market. This larger market makes investment in quality more profitable due to the economies of scale in quality discussed above.

Results are less clear-cut when we try to compare the level of investment of the same firm in autarky and in costly trade and the level of investment in costly trade across both industries. To make comparisons easier, we are going to look for an expression for the shared endogenous variable (i.e., B_j^l) as a function of the variables associated with the marginal firm. Since we focus on an equilibrium with self-selection into the exporting market we know that the marginal firm should satisfy the following condition $\pi_{idj}^l(a_{Dj}^l) = F_D(w^l)^{\beta_j}(r^l)^{1-\beta_j}$. Using this, we obtain an expression for the quality of non-exporting and exporting firms:

$$q_{idj}^l = \frac{mF_D}{1-m} a_{ij}^{\frac{\alpha+\sigma-1}{m-1}} (a_{Dj}^l)^{\frac{\alpha m+\sigma-1}{1-m}} \tag{21}$$

$$q_{ixj}^l = q_{idj}^l (1 + \lambda \tau^{1-\sigma} A_j^l) \tag{22}$$

The expression (21) reveals that conditional on productivity, differences in firm quality across industries for the case of non-exporting firms can only come through changes in the unit input cut-off. Note that in those industries where selection is tougher (lower a_{Dj}^l) quality of non-exporting firms is lower. As we will discuss below both are the result of a tougher competition. Tougher selection will come through a reduction in operating profits. This reduction in operating profits reduces the profits from quality investment.

In contrast, expression (22) reveals that the difference in quality among exporters across industries, which is a combination of both the relative input unit cut-offs and the element in brackets that measures the extent of the global market relative to the domestic market in each industry. As we will see below this will benefit the comparative advantage industry, where the increase in the global market will be larger than in the comparative disadvantage industry.

Firms will export in each industry until the benefits of being an exporter are identical to those of remaining a domestic firm.

$$\pi_{idj}^l(a_{Xj}^l) = \pi_{ixj}^l(a_{Xj}^l) \tag{23}$$

where a_{Xj}^l denotes the unit-input cut-off of the marginal exporting firm. Using equations (20) and

(23), and rearranging terms we obtain,

$$\frac{a^l_{Xj}}{a^l_{Dj}} = \{\frac{F_D}{F_X}[(1 + A^l_j \tau^{1-\sigma})^{\frac{1}{1-m}} - 1]\}^{\frac{1-m}{\alpha m+\sigma-1}} \tag{24}$$

The exporting unit-input threshold is lower relative to the production unit-input threshold (i.e., there is self-selection into exporting) when $\frac{F_D}{F_X}[(1 + A^l_j \tau^{1-\sigma})^{\frac{1}{1-m}} - 1] < 1$. Since empirical evidence strongly supports selection into export markets, we will focus on this equilibrium.[10]

Using the equation above we can express the quality of exporting firms as,

$$q^l_{ixj} = \frac{mF_X}{1-m} a_{ij}^{\frac{\alpha+\sigma-1}{m-1}} (a^l_{Xj})^{\frac{\alpha m+\sigma-1}{1-m}} \{[(1 + A^l_j \tau^{1-\sigma})^{\frac{1}{1-m}} - 1]^{-1} + 1\} \tag{25}$$

To obtain the value for the production and exporting unit cut-off we need to combine the equations above with the free entry condition for each sector. These are given by the following expressions:

$$(a^l_{Dj})^k = \frac{\delta F_E}{F_D} \frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1} \{1 + (\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1} [(1 + A^l_j \tau^{1-\sigma})^{\frac{1}{1-m}} - 1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}\}^{-1} (a_M)^k \tag{26}$$

$$(a^l_{Xj})^k = \frac{\delta F_E}{F_X} \frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1} \{1 + (\frac{F_X}{F_D})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1} [(1 + A^l_j \tau^{1-\sigma})^{\frac{1}{1-m}} - 1]^{\frac{k(m-1)}{\sigma-1+\alpha m}}\}^{-1} (a_M)^k \tag{27}$$

In the equilibrium, the two thresholds and thus firms' quality choice depend on the profitability of serving the exporting market relative to the domestic market for each economy, A^l_j, which is related to the comparative advantage as considered further below.

A quick inspection of Equation (26), reveals that the unit input threshold in free trade is larger than in autarky. This result, shown in detail in the appendix, is common with Bernard et al. (2007) and it is a consequence of the fact that the asymmetric access to the foreign market with the existence of export fixed costs, increases the competition for productive resources reducing the operating profits of non-exporting firms. This toughens selection making survival more difficult.

As in Bernard et al. (2007), the profitability of serving the foreign market relative to the domestic market is larger in the comparative advantage industry ($A^H_1 > A^H_2$ and $A^F_1 < A^F_2$). This, also shown in the appendix, is crucial to derive several common results with Bernard et al. (2007) in-

[10]Many papers like Roberts and Tybout (1997) and Bernard and Jensen (2004) document the empirical evidence on selection into export markets.

cluding $a^H_{D1} < a^H_{D2}$ and $a^H_{X1} > a^H_{X2}$. That is, as the benchmark model without quality investment, the selection is tougher in the comparative advantage industry, and in the comparative advantage industry, more firms are devoted to exporting. It is also worth noticing that the inclusion of investment in quality reinforces selection and increases the relative profits of exporting in the comparative advantage industries.

2.3 Propositions

Specific to this paper, is how the comparative advantage affects the firm's investment in quality. This is described in the following three propositions.

Proposition 1. $q^l_{idj}(a_i) < q_{ij}(a_i)$ and $q^l_{ixj}(a_i) > q_{ij}(a_i)$ (i.e., Non-exporters lower their quality while exporters improve their quality from autarky to costly trade.)

Proof: See Appendix

As investment in quality is a fixed cost, the benefits of investing in quality are proportional to the firm's market size. Trade openness expands the business opportunities of those firms which can afford to export. As the exporter's market size becomes larger, so does the investment in quality. Trade openness also increases competition in each market and for the case of non-exporting firms, their market has shrunk and so does the firm's incentives to invest in quality. As a consequence, the investment in quality for non-exporting firms is reduced.

Proposition 2. $q^H_{ix1}(a_i) > q^H_{ix2}(a_i)$ and $q^F_{ix1}(a_i) < q^F_{ix2}(a_i)$ (i.e., Exporters will improve their quality by more in the comparative advantage industries.)

Proof: See Appendix

In the comparative advantage industry, firms are more competitive with respect to their relatives in the destination country and consequently, they increase their market size more when the country opens up to trade. As the market size is further increased for those firms their incentives to invest in quality upgrading also increase. Consequently, exporters in the comparative advantage industry invest more in quality compared to their relatives in the comparative disadvantage industry.

Proposition 3. $q^H_{id1}(a_i) < q^H_{id2}(a_i)$ and $q^F_{id1}(a_i) > q^F_{id2}(a_i)$ (i.e., Non-exporters will lower their quality by more in the comparative advantage industries.)

Proof: See Appendix

As exporters in the comparative advantage industry invest more in quality and they produce more, the demand for production factors increases. The Stolper-Samuelson theorem, which is verified in this context, implies that the costs of production factors increase more in the comparative advantage industry as a consequence of trade openness. This reduces the incentives for quality upgrading in the comparative advantage industry by more than in the comparative disadvantage industry.

An important question to address is what happens with the average quality across industries after trade openness. The following section discusses this in detail.

2.3.1 Aggregation

In the previous section, we discussed the differences in quality investment between exporters and non-exporters in the comparative advantage and the comparative disadvantage industry. In the comparative advantage industry the effects are more intense in the sense that exporters increase their quality more but non-exporters reduce their quality more. A good question to address is what happens with the overall quality at the industry level. To evaluate what is the effect on aggregate quality let us, first, define the average quality of both exporters, $\overline{q^l_{jx}}$, and non-exporters in each industry, $\overline{q^l_{jd}}$,

$$\overline{q^l_{jd}} = \frac{1}{G(a^l_{Dj}) - G(a^l_{Xj})} \int_{a^l_{Xj}}^{a^l_{Dj}} q^l_{ijd}(a_{ij})g(a)da \tag{28}$$

$$\overline{q^l_{jx}} = \frac{1}{G(a^l_{Xj})} \int_{0}^{a^l_{Xj}} q^l_{ijx}(a_{ij})g(a)da \tag{29}$$

Then the overall aggregate quality is given by the following expression,

$$\overline{q^l_j} = \frac{G(a^l_{Dj}) - G(a^l_{Xj})}{G(a^l_{Dj})}\overline{q^l_{id}} + \frac{G(a^l_{Xj})}{G(a^l_{Dj})}\overline{q^l_{ix}} \tag{30}$$

Developing the previous expression we obtained,

$$\overline{q^l_j} = (\frac{1}{a^l_{Dj}})^{\alpha} \frac{mkF_D}{1-\alpha-\sigma+k(1-m)}[1+(\frac{F_X}{F_D})^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}}(M^l_j)^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}}] \tag{31}$$

where $M^l_j = [(1+A^l_j\tau^{1-\sigma})^{\frac{1}{1-m}} - 1]^{-1}$.

A look at the equations (31) and (A.3) allows us to obtain the following proposition.

Proposition 4. $\overline{q^l_j} > \overline{q^{aut}_j}$ (i.e., The aggregate quality of an industry is improved when the economy opens to trade.); $\overline{q_1^H} > \overline{q_2^H}$ and $\overline{q_1^F} < \overline{q_2^F}$ (i.e., The aggregate quality of a comparative advantage industry is higher than that of a comparative disadvantage industry.)

Proof: See Appendix

Opening up to international trade affects the aggregate quality through different forces. On top of the effects for exporters and non-exporters commented above that contribute positively and negatively respectively to aggregate quality, we must also consider that trade also affects quality through the selection effect. This selection effect that removes the least productive firms and distributes market shares across the most productive ones, contributes positively to quality. All of these forces are stronger in the comparative advantage industry. This proposition shows that the first and the third forces dominate the reduction in quality experienced by the less productive non-exporting firms having an overall increase in the aggregate quality after trade openness. Interestingly, this effect is more pronounced in the comparative advantage industry.

This theoretical model has shown that, unlike autarky, trade openness does not only increase the aggregate quality in each industry but also it is a source for quality divergence across industries based on a H-O comparative advantage. In the next section, we provide empirical evidence that supports some of the propositions that we have just discussed.

3 Empirical Evidence

Section 2.4 presented four propositions. The propositions referring to non-exporters are difficult to test as currently we cannot retrieve data on quality for non-exporting firms.[11] Therefore, we will focus our empirical analysis on proposition 2. This proposition focuses upon the asymmetric quality response of exporters across industries, according to their comparative advantage. This proposition is central to the main mechanism in our theoretical model that sets it apart from the existing literature; namely, that competitive forces trigger a different quality response across industries. Following the literature and our theoretical model, we define quality as unobserved attributes of a variety that make consumers willing to purchase relatively large quantities of the variety despite relatively high prices charged for the variety. Such attributes could be intangible, for example, brand image. This section describes the data and the econometric model that we use and how we estimate the key variables of interest.

[11] In order to construct the measure of product quality we require transaction-level data which is only recorded when the firm exports.

3.1 Data

This paper uses two data sources. First, Chinese firm-level data comes from the Chinese Annual Survey of Industrial Firms, carried out by the National Bureau of Statistics of China (NBS). Second, international trade transaction-level data that comes from Chinese Customs Trade Statistics (CCTS) provide exporters' transaction-level data. Several recent papers have merged data from these sources because together they inform on international transactions as well as being able to control for firm heterogeneity (e.g. Defever et al. (2020); Fan et al. (2018); Manova and Yu (2016)). We also merge these sources and use a sample period of 2000 to 2007.[12]

3.1.1 Firm-level Survey Data

The NBS data includes all state-owned industrial enterprises and non-state-owned industrial enterprises with annual sales of greater than 5 million Chinese Yuan (RMB). For each firm-year observation, the data record information on output, sales, fixed assets, intermediate inputs, number of employees, location and industry (National Standard Classification).[13] The main variables of interest are firm characteristics, such as total factor productivity (TFP), employment, capital intensity and average wage bill per worker, as controls. We follow Cai and Liu (2009) and use General Accepted Accounting Principles to clean the data.[14] Following Brandt et al. (2012), we first link firms from each year of the data using firm registration identification numbers.

3.1.2 Transaction-level Trade Data

The transaction-level trade data covers the universe of all Chinese exports over the 2000-2007 period at the 8-digit Harmonized System (HS) level. For each trade transaction, there is detailed information including export values, quantities, products, company name, and the customs regime (i.e., whether it is for 'Processing and Assembling' or 'Ordinary Trade'). We only select transactions under the ordinary trade regime. We aggregate transactions from the 8-digit product level to the 6-digit product level on an annual basis because most firms do not sell the same product every month.[15] For each HS 6-digit product, we use export values and quantities to compute the unit value (i.e.,

[12] The data after 2007 in the Chinese Annual Survey of Industrial Firms do not include important variables such as total intermediate inputs.

[13] Consistent with Manova and Yu (2016), we remove firms in non-manufacturing industries (2-digit GB/T industry code > 43 or < 13) and tobacco (GB/T code 16).

[14] We use the following rules to construct our sample: (i) the total assets must be higher than the liquid assets; (ii) the total assets must be larger than the total fixed assets; (iii) the total assets must be larger than the net value of the fixed assets; (iv) a firm must have a unique identification number; and (v) the established time must be valid (for some observations, it is recorded incorrectly like a date before the year 1000 or after the year 2007).

[15] China changed HS 8-digit codes in 2002 and 2007. To ensure the consistency of the product categorisation over time (2000-2007), we have to convert the HS 2002 and the HS 2007 codes into the HS 1996 codes. However, concordance between the HS 8-digit codes before and after 2002 is not available. So, we can only choose to adopt HS 6-digit codes maintained by the World Customs Organization (WCO).

the price) by each firm. Furthermore, we drop export-import enterprises that serve exclusively as intermediaries.[16]

3.1.3 Data Matching

Our empirical analysis combines data from both sources. Firms use different registration numbers in each dataset and Chinese authorities have not released a unique firm identifier. Therefore, we use company names recorded in Chinese characters as the primary matching variable. We adopt the matching method used in Manova and Yu (2016) that uses all the different names ever used by a firm to match firms in the datasets.[17]

Table 1 summarises our sample. We obtain a matched firm-transaction dataset of 73,611 unique exporters and 1,270,097 firm-product observations over the period running from 2000 through 2007. The two datasets do not merge perfectly. First, a large number of non-trade firms do not appear in the Customs database but are included in the NBS database. Second, some firms in the NBS database trade through trading agents. Their transactions are recorded under the name of trading agents in the Customs database. Third, the Customs database records all trade transactions made by small firms and firms in non-manufacturing sectors, whereas the NBS database only includes larger firms in the manufacturing sectors. Overall, our matched sample covers 53% of the total export value reported by the Customs Database.[18]

Table 1: Matching results

Year	Number of exporters	Number of transactions
2000	13,462	66,390
2001	16,709	82,430
2002	20,007	107,891
2003	24,049	133,129
2004	26,669	147,033
2005	36,430	214,186
2006	43,681	248,291
2007	47,117	270,747
Total	73,611	1,270,097

Notes: This table summarises the matching results of two datasets in the period 2000-2007.

[16] Since the data do not directly flag trade intermediaries, we follow standard practice and use keywords in firm names to identify them (e.g. Ahn et al. (2011)).

[17] Matching on the firm name is a sensible strategy in this setting. By law, no firm can have the same name in the same administrative region, and the vast majority of all firms contain their local region name as part of their firm names. Details of the matching method are described in the Appendix.

[18] This ratio is consistent with other papers in the literature. Manova and Yu (2016) cover nearly 50% of China's total exports in 2005. The merged sample in Fan et al. (2018) covers 52.4% of total export value in 2001-2006 reported by the Customs Database.

3.2 Methodology

We aim to estimate the effect of comparative advantage on the product quality choice by Chinese exporters. The theory outlined in section 2.3.2 describes how exporting product quality relates to comparative advantage and firm productivity (see Equation (20)). Consequently, the baseline econometric model we wish to estimate is as follows:

$$\ln(q_{fht}) = \beta_0 + \beta_1 RCA_{ht} + \beta_2 \ln(Z_{ft}) + \varphi_h + \varphi_f + \varphi_t + \varphi_{hf} + \varepsilon_{fht} \tag{32}$$

where $ln(q_{fht})$ denotes the estimated quality of good h produced by firm f in year t and RCA_{ht} is a dummy variable indicating if China has a comparative advantage in the production of a variety h.[19] $ln(Z_{ft})$ is set of control variables that might impact quality including total factor productivity (TFP) and other firm-level variables used in the literature (e.g. Fan et al. (2018)), such as capital intensity. In addition, we also control the HS 6-digit level product fixed effects, firm fixed effects, year fixed effects and product-firm fixed effects. After controlling for this set of fixed effects together with time varying firm-level productivity and capital intensity, we argue that RCA_{ht} is a good approximation to the causal effect. We consider threats to this interpretation of RCA_{ht} and implement a number of robustness checks below.

3.3 Key Variables

Product quality is the dependent variable, and revealed comparative advantage (RCA) is the explanatory variable of central interest. We control for TFP alongside other firm-level variables. As alluded to above, some of these variables are not directly observable in the data. Below, we introduce and construct these variables.

3.3.1 Estimated Quality

To measure product quality, we follow Khandelwal et al. (2013) and Fan et al. (2018) in estimating quality based on the unit values and the market share rather than using the unit value as a coarse proxy for quality. According to the demand equation in our model ($x_{ij} = \frac{p_{ij}^{-\sigma} q_{ij}^{\gamma}}{P_j^{1-\sigma}} E_j$), we can estimate the quality of exported product h produced by firm f in year t, using an OLS regression:

$$\ln(x_{fhjt}) + \sigma \ln(p_{fhjt}) = \eta_h + \varphi_{jt} + \varepsilon_{fhjt} \tag{33}$$

[19] We can explain RCA_{ht} as an industry-level variable as there are more than one firm producing one variety. The portion of more than one firm for each product-year category is 99.7% in the data.

where x_{fhjt} denotes the demand of exported product h of sector j produced by firm f in year t;[20] p_{fhjt} is the unit value; σ is the elasticity of substitution across products; the product fixed effect η_h captures the difference in prices and quantities across product categories due to the inherent characteristics of products; the industry-year fixed effect φ_{jt} collects both sector price index and expenditure. Given the value of the elasticity of substitution, we can estimate quality from the above equation. The estimated quality is $ln(\hat{q}_{fhjt}) = \hat{\varepsilon}_{fhjt}$.[21] The intuition behind this is that conditional on price, a variety with a higher quantity demanded is assigned higher quality.

The literature adopts different values of σ when estimating Equation (33). Manova and Yu (2017) use the value at $\sigma = 5$. Fan et al. (2015) use values at $\sigma = 5$ and $\sigma = 10$, and also allow the elasticity of substitution to vary across industries using the estimates of Broda and Weinstein (2006). Likewise, we will present results setting sigma at $\sigma = 5$ and $\sigma = 10$, and use the estimates of Broda and Weinstein (2006).[22] As a robustness check, we also estimate values of σ from our dataset.

3.3.2 Total Factor Productivity

A traditional approach to estimating TFP is to estimate a Cobb-Douglas production function with data on input, output, and capital. OLS estimation assumes independence between a firm's inputs and the efficiency of that firm. It is well known that this is a strong assumption because firms' input choices are likely determined simultaneously by unobserved productivity shocks. Approaches that allow for the evolution of firms' productivity and input choices over time, such as Olley and Pakes (1992) and Levinsohn and Petrin (2003), control for endogeneity between inputs and unobserved productivity. In this paper, we use the Levinsohn-Petrin (LP) method to estimate firms' productivity [23]. As a robustness check, we also estimate TFP using the method from Wooldridge (2009).

To estimate TFP, we deflate firms' capital (measured by total fixed assets in the data), intermediate inputs (total expenditures on intermediate goods) and output (nominal value of gross production) using a capital price deflator, an intermediate input deflator and an output price deflator from Brandt et al. (2012). Furthermore, since firms in different sectors may have different factor inputs, we estimate the production function for each HS 2-digit sector separately rather than estimating the entire manufacturing sector.

[20] In quality estimation, we separate product at HS 6-digit level and separate sector categories at HS 2-digit level to control sector fixed effects.

[21] Here $\hat{q}_{fhjt} \equiv q^{\gamma}_{fhjt}$. In other words, the estimated quality $\hat{q}$ corresponds to q^{γ} in our model.

[22] Both Khandelwal et al. (2013) ; Fan et al. (2018) estimate values of sigma. Broda and Weinstein (2006) estimate the elasticity of substitution for disaggregated product categories which we merge into our sample.

[23] We lack information on firms' investment to implement Olley-Pakes.

3.3.3 Revealed Comparative Advantage

The literature has traditionally used the Balassa index (Balassa, 1965) to estimate a country's comparative advantage in a given industry. This is a measured of 'revealed' comparative advantage because it is calculated after observing export flows, not the determinants of them. However, our theoretical model proposes that the comparative advantage stems from a country's factor endowment and an industry's factor intensity which are predetermined before the country opens to trade. Therefore, we adopt the relatively new index of revealed comparative advantage index developed by Leromain and Orefice (2014) based on Costinot et al. (2012) which addresses these concerns.

Costinot et al. (2012) builds a multi-sector Ricardian trade model from which it derives an index of comparative advantage that can be estimated with the use of exporter-industry fixed effects in trade flows. The key observation in this model is that the fundamentals determining a comparative advantage are common to all exporter-destinations within the same industry. It is important to note that these fixed effects capture not only just Ricardian type exporter-industry productivity differences but also any fixed attribute that makes the cost of production smaller in a given industry. For example, this index will capture an advantage stemming from cheaper factor prices, which is both consistent with our theoretical model and also likely the case in our empirical setting of China. Costinot et al. (2012) compute their RCA index for a sample of 21 OECD countries in 1997 for 13 ISIC industries. Leromain and Orefice (2014) extend the calculations to HS 4-digit level product classification for the period from 1995 to 2010. We follow their method to calculate China's comparative advantage index at HS 4- and 6-digit levels for the period from 2000 to 2007. The method begins with the demand equation:

$$ln(x_{ikj}) = \varphi_{ik} + \varphi_{kj} + \theta ln(z_{ij}) + \varepsilon_{ikj} \tag{34}$$

where i, k and j indicate exporter, importer and industry respectively, φ_{ik} represents country-pair fixed effects and φ_{kj} represents importer-industry fixed effects. The term $\theta ln(z_{ij})$ denotes the productivity level of a country i in sector j. Technological differences are exporter-industry specific and depend on the productivity variation across a country-industry pair (z_{ij}), and differences in the technological know-how across varieties within the industry (θ). The value of θ is assumed to be identical across countries and industries.[24]

The measure of technological differences is captured from the exporter-industry fixed effects after the OLS estimation of:

$$ln(x_{ikj}) = \varphi_{ik} + \varphi_{kj} + \varphi_{ij} + \varepsilon_{ikj} \tag{35}$$

[24] See Leromain and Orefice (2014) for further discussion on the value of θ.

Note that the exporter-industry fixed effects capture all fixed determinants of trade flows within the exporter-industry pairs. To the extent they are fixed over time, this includes factor endowments and an industry's factor intensity. This allows the index to be extended to a more general interpretation of differences across the exporter-industry pairs (i.e., factor prices). Further taking that $\theta = 6.53$ used in Costinot et al. (2012) and Leromain and Orefice (2014) enables us to derive z_{ij} as follows:

$$z_{ij} = e^{\frac{\varphi_{ij}}{\theta}} \tag{36}$$

z_{ij} captures the comparative advantage that emerged in the trade flows that is caused solely by the exporter-industry differences. We then follow Leromain and Orefice (2014) to normalise z_{ij} with respect to 20 exporting countries, mainly G20 countries and leaders in manufacturing exporters.[25] We compute a weighted index by taking all the above exporting countries as a benchmark group as follows:

$$CLO\ RCA_{ij} = \frac{z_{ij}/z_{i.}}{z_{.j}/z_{..}} \tag{37}$$

where $z_{..}$ is the average of all z_{ij} across all industries and countries, $z_{i.}$ is the average of all z_{ij} across all industries for country i and $z_{.j}$ is the the average of all z_{ij} across all countries for industry j. The CLO index of RCA of one industry is expressed as the share of the total country's exports normalised for the share of the world's total exports. If it is bigger than 1, it means that the country has a comparative advantage in this industry compared to the world. We estimated the CLO RCA at HS 4- and 6-digit levels for China from 2000 to 2007.[26]

We consider China as the home country and measure China's comparative advantage in each industry compared to the rest of the world. In our sample, there are 39,925 observations of $CLO\ RCA$, with mean of 0.906 (st. dev. 0.221). If $CLO\ RCA_{ij}$ is greater than 1, we consider China to have a comparative advantage in the industry of producing product h in year t. In this case, when we use a dummy variable to capture RCA, it would take the value of 1 and zero otherwise.

[25] The 20 exporting countries include Argentina, Australia, Brazil, Canada, China, France, Germany, Indonesia, Italy, Japan, South Korea, Mexico, the Netherlands, Russia, India, South Africa, Spain, Turkey, United Kingdom and the United States.

[26] As mentioned in Leromain and Orefice (2014), we cannot directly run Equation (36) defining j as HS 4- or 6-digit level. We employed the method from their work to reduce the number of exporter-industry fixed effects. We assume j stands for HS 4- or 6-digit level industries. z_{ij} can be decomposed into two parts: (i) a sector-specific factor, z_{iJ}, which is common to all industries in the same sector J and (ii) an industry-specific factor, $z_{ij|J}$, capturing the differences for industry j from other industries of the same sector J. We estimate z_{iJ} first and then $z_{ij|J}$. Finally, we obtain z_{ij} using $z_{ij} = z_{iJ} * z_{ij|J}$.

3.3.4 Relative Factor Endowment

Our theoretical model implies that comparative advantage stems from a country's relative factor endowments. We are able to present evidence consistent with this idea. We follow Hall and Jones (1999) to use average educational attainment for the population aged 25 and over as human capital per worker and physical capital stocks over labour as the physical capital per worker to measure two factors. The data used, including capital stock at current PPPs, human capital index, and persons engaged, is from the Penn World Table (PWT).[27]

We denote human and physical capital for China with H and K respectively, and for the rest of the world with H^* and K^*. We expect $H/K > H^*/K^*$ such that China was relatively abundant in human capital compared to the rest of the world from 2000 to 2007. This implies $H/H^* > K/K^*$, so that the ratio of China's human capital is greater than its ratio of physical capital. This is shown in the left-hand side of figure 1 for the sample period. The left-hand side of figure 1 also shows that China's relative endowment of human capital has been stable while its ratio of physical capital rose steadily from 2000 to 2007. China has been catching up the rest of the world in terms of physical capital.

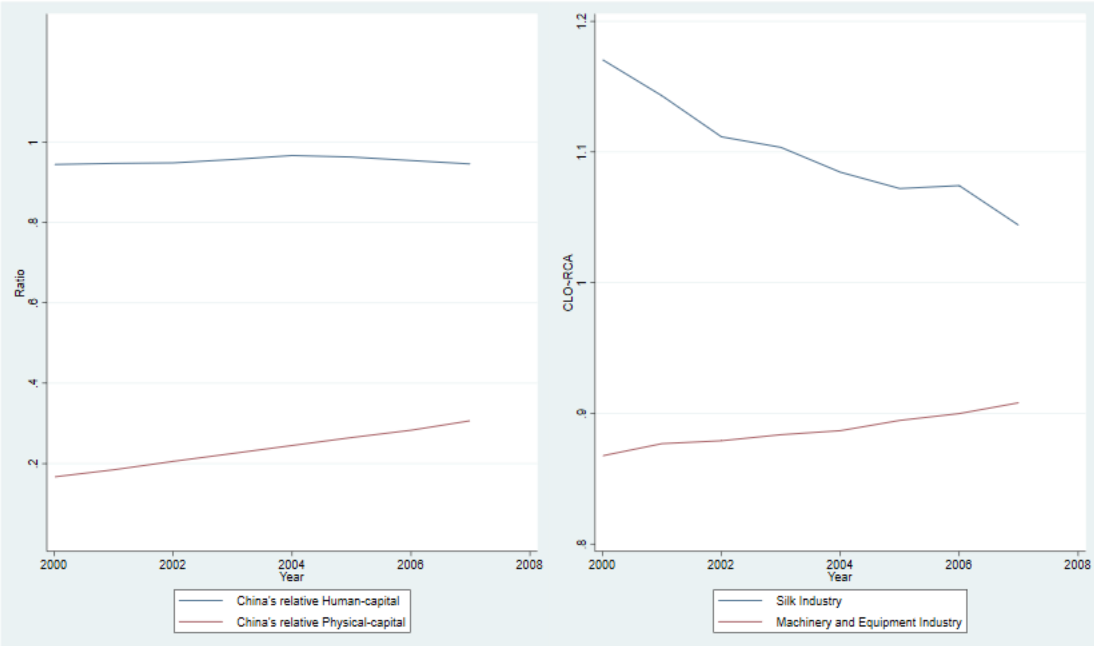
As we will be estimating a fixed effects model, identification of the impact of $CLO\ RCA$ on product quality will come through *changes* in $CLO\ RCA$. The right hand side of figure 1 shows how RCA has moved over time for a capital intensive industry (Machinery and Equipment) compared to a typically labour intensive industry (Silk). While China experiences a comparative advantage in the labour intensive industry, the trend overtime is that the capital intensive industry is catching up. This is not an isolated case: Table A.1 shows several labour intensive and capital intensive industries experience the same dynamic over our sample period. The assumption that there is a close connection between between comparative advantage and relative factor endowments appears to be descriptively well founded.

3.4 Empirical Results

This section presents our main results using a sample of Chinese manufacturing exporters. We begin by looking at some summary statistics. Given our interest in comparative advantage, we group firms into exporters within comparative advantage industries and exporters within non-comparative advantage industries. Table 2 provides a comparison of the characteristics of firms. The majority of Chinese exporters (71.69%) come from comparative advantage industries. Each estimate of product quality shows that exporters in comparative advantage industries outperform exporters in non-

[27] We first calculated the average years of schooling for the population aged 25 and over for each country, based on the constructing method of the human capital index in the PWT. To compute the human capital of the rest of the world, we use the weighted average human capital, where the persons engaged in each country over persons engaged in the rest of the world are used as the weight.

Figure 1: China's relative endowments and the RCA of Chinese industries



Notes: The left panel describes how the relative endowment (human capital and physical capital) of China compared to the rest of the world changed during the period 2000-2007. Human capital and physical capital are measured per worker. The right panel displays how the CLO RCA changed for the Machinery and Equipment (capital-intensive) industry and the Silk (labour-intensive) industry from 2000 to 2007 in China.

comparative industries in terms of product quality.

3.4.1 RCA and Product Quality

Table 3 estimates (32) describing the relationship between RCA and product quality. Each column corresponds to different values of the elasticity of substitution used in the estimation of quality. The first row considers the dummy variable $CLO\ RCA_D$, that takes the value of one when China has a comparative advantage in that industry and zero otherwise. The second row considers instead, our RCA index as a continuous variable, $CLO\ RCA$. In both cases, RCA is positively associated with quality, albeit the estimated coefficient in column 3 (where $\sigma = 10$) falls short of statistical significance. The estimates in column 1 imply that if China has a comparative advantage in an industry, exporters within this industry, on average, produce goods with $(e^{\beta} - 1) * 100 = 10.96\%$ more quality. This rises to 11.62% (shown in column 5) if the estimates of the elasticity from Broda and Weinstein (2006) are used in the estimation of quality. These results are consistent with Proposition 6, that exporters in a comparative advantage industry raise their product quality because these exporters find it more profitable to upgrade quality in international markets.

Columns 2, 4 and 6 treat RCA as a continuous variable. While the dummy variable captures the

Table 2: Summary statistics of key variables

Variable	All exporters	Exporters within CA industries	Exporters within Non-CA industries	Mean difference
$ln(Quality\_5)$	0.000	0.005	-0.014	0.019
	(5.794)	(5.199)	(7.081)	(0.091)
$ln(Quality\_10)$	0.000	0.004	-0.009	0.013
	(11.725)	(10.373)	(14.599)	(0.576)
$ln(Quality\_\sigma)$	0.000	0.007	-0.018	0.025
	(4.926)	(4.711)	(5.431)	(0.010)
$ln(TFP)$	2.438	2.430	2.458	-0.028
	(0.641)	(0.624)	(0.683)	(0.000)
$ln(CapitalIntensity)$	10.555	10.344	11.089	-0.745
	(1.316)	(1.282)	(1.247)	(0.000)
$ln(Employment)$	5.557	5.541	5.599	-0.058
	(1.207)	(1.150)	(1.337)	(0.000)
$ln(WagePerWorker)$	9.612	9.552	9.764	-0.213
	(0.655)	(0.630)	(0.691)	(0.000)
Observations	1,270,076	910,523	359,553	550,970
(% of total)	(100%)	(71.69%)	(28.31%)	(43.38%)

Notes: This table summarizes the variation in product quality (measured using different values of elasticity of substitution, σ), total factor productivity (TFP), capital intensity (the ratio of capital and labour), total employment and wage bill per worker across industries with comparative advantage and industries with comparative disadvantage. Reported are the means of the variables in natural logarithm with standard deviations in parentheses in the first three columns. Mean differences are reported with P-values of the t-test in parentheses in the last column.

Table 3: Effects of RCA on product quality

Dependent variable	ln(quality)					
	$\sigma = 5$		$\sigma = 10$		$\sigma = \sigma_i$	
	(1)	(2)	(3)	(4)	(5)	(6)
$CLO\ RCA\_D$	0.104***		0.008		0.110***	
	(0.028)		(0.055)		(0.024)	
$CLO\ RCA$		1.407***		0.626**		1.545***
		(0.117)		(0.221)		(0.159)
$ln(TFP)$	0.222***	0.220***	0.287***	0.286***	0.185***	0.182***
	(0.017)	(0.017)	(0.033)	(0.033)	(0.013)	(0.013)
$ln(Capital/Labour)$	0.076***	0.077***	0.069***	0.070***	0.087***	0.088***
	(0.009)	(0.009)	(0.018)	(0.018)	(0.008)	(0.008)
$ln(Employment)$	0.372***	0.367***	0.392***	0.389***	0.369***	0.363***
	(0.015)	(0.015)	(0.029)	(0.029)	(0.013)	(0.013)
$ln(WagePerWorker)$	0.145***	0.144***	0.164***	0.163***	0.147***	0.145***
	(0.012)	(0.012)	(0.022)	(0.022)	(0.010)	(0.010)
Product fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Product & Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	848,916	848,916	848,916	848,916	847,200	847,200
R-squared	0.790	0.790	0.808	0.808	0.831	0.831

Notes: This table examines the relationship between export quality and the RCA. For each firm-product-year triplet, the dependent variable is the estimated quality, given the value of the elasticity of substitution σ, 5, 10, and the estimates of Broda and Weinstein (2006). $CLO\ RCA\_D$ is a dummy variable, and it equals 1 when China does have a comparative advantage in the industry of producing product h in year t; otherwise, it takes a value of 0. $CLO\ RCA$ is calculated using the method developed by Leromain and Orefice (2014). Firm-level control variables contain total factor productivity (TFP), capital intensity (the ratio of capital and labour), total employment and average wage, all in log. All regressions include a constant term, product-fixed effects, firm-fixed effects, year-fixed effects and product-firm fixed effects. Significant at ***1%, **5%, and *10%. Robust standard errors are corrected for clustering at the firm-product level in parentheses.

binary conceptualisation of comparative advantage, it is also informative to consider how marginal changes in the RCA index impact exporters' quality decisions. The results remain consistent with Proposition 6. Exporters increase average quality by 13.8% (column 4) to 34.2% (column 6) following a one standard deviation increase in the $CLO\ RCA$ index.

Each of the control variables behaves as expected. More productive exporters produce higher-quality goods, larger exporters produce higher-quality goods, and exporters that use capital more intensively produce high-quality goods, as do firms in which the average wage per worker is higher. These findings are robust across each of the values of sigma utilised in the estimation of quality.

Taken together, these results show that exporters in a comparative advantage industry provide goods at a higher quality level on average. This is consistent with the notion that firms in a comparative advantage industry are able to produce goods at a lower cost and find upgrading quality more profitable than foreign competitors. The exposure to trade brought firms in these industries access to a larger market which increased their marginal benefit from upgrading product quality.

3.5 Robustness Checks

We conduct several exercises to test the robustness of our results. First, we use an alternative method to measure RCA; the Balassa index. Second, we estimate TFP using the Wooldridge (2009) method, instead of Levinsohn and Petrin (2003). Third, in the measurement of quality we use values of σ (the elasticity of substitution) estimated from our sample. Finally, we use an instrument for product quality to address possible endogeneity concerns with RCA. Fifth, we estimate the results using a balanced sample i.e., dropping firms that entry or exit during the sample period.

3.5.1 Alternative Measure of the RCA

We can compare our empirical results to those generated by using the Revealed Comparative Advantage created by Balassa (1965). The Balassa RCA is calculated as:

$$B\ RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_{wt}} \tag{38}$$

where E_{ht} and E_{wht} respectively denote the export value in the industry of producing product h in year t of one country and its trading partner, TE is the total export value. This index captures the relative ability of a firm in a home industry to produce a good compared to a firm in the same industry of a foreign trading partner. We follow Navas (2018) and use data from the BACI trade database that provides disaggregated data (at HS 6-digit level) on bilateral trade flows for more than 200 countries during 2000-2007 and measure RCA at HS 6-digit level.

The results are shown in Table A.2. In each case, $B\ RCA$ is positively associated with quality and the estimates are larger in magnitude than under $CLO\ RCA$. The estimates in column 1 imply that if China has a comparative advantage in an industry, exporters within this industry, on average, produce goods with $e^{\beta} * 100 = 20.7\%$ more quality. This rises to 26.7% (column 5) if the estimates of the elasticity from Broda and Weinstein (2006) are used in the estimation of quality.

3.5.2 Alternative Estimation of TFP

In section 3.4 above, we applied the LP method to estimate a firm's TFP. Using the LP method creates the largest sample size in our setting. However, we now use the method from Wooldridge (2009) and report the results in Table A.3. The estimates of RCA_D and RCA are unchanged from our main set of results. There are only marginal differences in the estimated impact of TFP on product quality. Overall, our results continue to show that firms in the comparative advantage industries produce and export higher-quality products, conditional on firm-level productivity.

3.5.3 Alternative Estimation of Quality

In this sub-section, we provide two alternative estimations of quality based on different values of σ. We first employ the estimations of trade elasticities at the HS-6 product category from Fontagné et al. (2022). Thus far, we have parameterised σ based on the values given in the existing literature. Yet we can also estimate σ from our own sample using an IV approach found in Fan et al. (2015). We first estimate σ_j for each sector at HS 2-digit level using our sample. Equation (33) changes to:

$$\ln(x_{fhjt}) = -\sigma_j \ln(p_{fhjt}) + \eta_h + \varphi_{jt} + \varepsilon_{fhjt} \tag{39}$$

where σ refers to the sector j where product h is located. We estimate σ by regressing export quantity on price, product fixed effects, and sector-year fixed effects for each sector j. Since the error term is potentially correlated with the product price, we use local average wages as an instrument for prices to correct the parameters, as shown in Fan et al. (2015). We compute the local wage as the average wage per worker across all firms in the same province in China, capturing common cost shocks on the supply side. The local wages affect product prices by changing firms' production costs. A potential concern could be that local wages may be correlated with product quality (workers with higher wages produce higher-quality products). However, the exclusion restriction remains valid as long as average wages do not affect deviations from average quality. In other words, if a Chinese exporter chooses to produce and export higher-quality varieties because of the shocks of local wages, the instruments remain valid as long as shocks do not affect deviations from the firm's average quality choice.[28] We obtained estimates for 95 industries after dropping three industries with less than ten

[28] Here, we are consistent with the spirit of Khandelwal (2010) in terms of the validity of our instruments.

observations.

The second step is to infer product quality using the estimate of the residual $\hat{\varepsilon}_{fhjt}$ from Equation (33). This is the same procedure as described in 3.3.1 above. Table A.4 presents the results. The first column shows the result of using the estimations of trade elasticities from Fontagné et al. (2022) to compute the quality and the second column refers to the quality using the IV estimation. Consistent with our main results, there is a positive and statistically significant coefficient on $CLO\ RCA$. Both columns support the proposition that exporters in the comparative advantage industries produce higher-quality goods.

3.5.4 Endogeneity

We argue that the comparative advantage at the level of industry is plausibly exogenous to the product quality decisions made by an individual firm, conditional firm-level fixed effects, product-level fixed effects and time varying productivity (TFP). Nevertheless, it is possible that firms change product quality for reasons unobserved to us but correlated with an industry acquiring a comparative advantage. As such, the identification of a causal effect running from RCA to product quality remains an empirical challenge. One potential source of exogenous variation in comparative advantage in our setting can be measured by using the $CLO\ RCA$ index at a more aggregated (HS 4-digit) level, like the relevant spill-over in knowledge with a HS 4-digit group.

The RCA index at a more aggregated level will almost certainly be correlated with the RCA index at a more dis-aggregated level. Therefore, we expect the RCA index at the HS 4-digit industry level to be significant in the first-stage of an IV estimation of the HS 6-digit RCA. The exclusion restriction that needs to hold is that firm level quality choices on a product measured at the HS 6-digit level are exogenous to the industry comparative advantage at the HS 4-digit level. In other words, the only route that comparative advantage at the 4-digit level impacts firm's decision over product quality is through its correlation with comparative advantage at the 6-digit level. We argue this is plausible. We expect firms to decide on their product quality choices when observing the product-specific RCA index with reference to their competitors in their industry at that 6-digit level. However, it is difficult to imagine the 4-digit industry driving firm level product quality choices, other than through its relation to RCA at the 6-digit level.[29]

The results are shown in Table A.5. We find the coefficients on $B\ RCA$ index and the $CLO\ RCA$ are positive and significant in all specifications. We checked for instances in our sample where there is only one HS 6-digit product within one HS 4-digit level industry. This led to dropping 2,620 HS 6-digit industry-year pairs from 33,617. In each specification, we conduct a Kleibergen and Paap (2006) rk statistic test (where the null hypothesis that the model is underidentified is rejected) and

[29]We considered other potential sources of exogenous variation in comparative advantage such as the China's adoption into the WTO. However, there is evidence in Fan et al. (2018) to suggest that WTO adoption violates the exclusion restriction because WTO adoption had a direct impact on product quality in China.

a Kleibergen and Paap (2006) Wald statistic test (where the null hypothesis that the first stage is weakly identified). The tests suggest the instruments provide a good fit in the first stage and perform as valid instruments. Overall, these results suggest our main results are not driven by outstanding endogeneity between RCA and product quality choices.

3.5.5 Balanced Sample

The sample generated above includes all exporters who enter and exit during the sample period. However, these firms may be different in unobserved ways from firms that export over the entire sample period. If these differences interact with decisions over product quality it may be prudent to restrict the sample to only those firms observed over the entire sample period. Dropping firms who enter and or exit generates a balanced panel of exporters. The balanced sample comprises 343,639 product-firm-year observations.

The results are shown in Table A.7 and are consistent with the main set of results in Table A.2. The notion that the main results are driven by movers with unobserved differences is not supported. These results are also consistent with the spirit of the theoretical model. Recall, the proposition that exporters will improve their quality by more in the comparative advantage industries is an equilibrium prediction. As such, we expect it should hold for the firms that survive the dynamics of entry and exit, and indeed it does.

4 Conclusion

This paper examines the choices made by firms over product quality across industries in international trade. We establish and describe a tractable model featuring countries with different endowments, industries with different factor intensities and heterogeneous firms with an endogenous quality choice. Based on the notion of comparative advantage, this paper delivers a set of predictions that reveal how efficiency and industry characteristics interact to contribute to product quality in international trade. Additionally, we provide evidence for the key cross-industry prediction regarding exporters' product quality.

We find that firms respond endogenously over the choice of product quality to trade openness based on their export status. Exporters find quality upgrading more profitable and decide to improve their product quality as they have access to expanding markets, while non-exporters lower their product quality to survive the intensifying competition. In aggregate, quality across industries increases after trade openness. The increase in quality by exporters together with the exit of low productivity, low quality, firms outweighs the reduction in quality experienced by non-exporting surviving firms. Linking these responses to the industry's comparative advantage, we further find that exporters improve their product quality more in the comparative advantage industries than those in other industries, conditional on firm-level productivity. Our model also predicts that a comparative advantage industry captures greater improvement in aggregate quality. We present robust empirical evidence that exporters in the comparative advantage industries improve their product quality more than those in other industries. We also highlight that this comparative advantage stems from countries' different factor endowments.

A limitation pertaining to our empirical analysis is the inability to observe the product quality decisions for domestic producers who do not export. Unfortunately, we are not aware of any dataset that is available at the required level of disaggregation with respect to non-exporters. When such a data set is made available, future empirical work could investigate the interplay of comparative advantage and product quality specifically for non-exporters. An interesting theoretical extension could be to incorporate firms' ability to produce multiple goods within industries to show potential resource redistribution within multi-product firms in terms of product quality. More generally, investigating how comparative advantage impacts different types of firms together with the endogenous decisions over product quality remains an exciting opportunity for research in international trade.

Acknowledgements

We want to thank MingHai Zhou who kindly shared the Chinese data, and Enrico Vanino, Giordano Mion, Jen-Chung Mei, L Alan Winters CB and Wanyu Chung who provided us with many valuable comments and suggestions.

References

JaeBin Ahn, Amit K Khandelwal, and Shang-Jin Wei. The role of intermediaries in facilitating trade. *Journal of International Economics*, 84(1):73–85, 2011.

Jie Bai. Melons as lemons: Asymmetric information, consumer learning and quality provision. *Wp, July*, 2018.

Jie Bai, Ludovica Gazze, and Yukun Wang. Collective reputation in trade: Evidence from the chinese dairy industry. *Review of Economics and Statistics*, 104(6):1121–1137, 2022.

Bela Balassa. Trade liberalisation and "revealed" comparative advantage 1. *The manchester school*, 33(2):99–123, 1965.

Richard Baldwin and James Harrigan. Zeros, quality, and space: Trade theory and trade evidence. *American Economic Journal: Microeconomics*, 3(2):60–88, 2011.

Andrew B Bernard and J Bradford Jensen. Why some firms export. *Review of economics and Statistics*, 86(2):561–569, 2004.

Andrew B Bernard, Stephen J Redding, and Peter K Schott. Comparative advantage and heterogeneous firms. *The Review of Economic Studies*, 74(1):31–66, 2007.

Loren Brandt, Johannes Van Biesebroeck, and Yifan Zhang. Creative accounting or creative destruction? firm-level productivity growth in chinese manufacturing. *Journal of development economics*, 97(2):339–351, 2012.

Christian Broda and David E Weinstein. Globalization and the gains from variety. *The Quarterly journal of economics*, 121(2):541–585, 2006.

Hongbin Cai and Qiao Liu. Competition and corporate tax avoidance: Evidence from chinese industrial firms. *The Economic Journal*, 119(537):764–795, 2009.

Arnaud Costinot, Dave Donaldson, and Ivana Komunjer. What goods do countries trade? a quantitative exploration of ricardo's ideas. *The Review of economic studies*, 79(2):581–608, 2012.

Matthieu Crozet, Keith Head, and Thierry Mayer. Quality sorting and trade: Firm-level evidence for french wine. *The Review of Economic Studies*, 79(2):609–644, 2012.

Fabrice Defever, Michele Imbruno, and Richard Kneller. Trade liberalization, input intermediaries and firm productivity: Evidence from china. *Journal of International Economics*, 126:103329, 2020.

Haichao Fan, Yao Amber Li, and Stephen R Yeaple. Trade liberalization, quality, and export prices. *Review of Economics and Statistics*, 97(5):1033–1051, 2015.

Haichao Fan, Yao Amber Li, and Stephen R Yeaple. On the relationship between quality and productivity: Evidence from china's accession to the wto. *Journal of International Economics*, 110:28–49, 2018.

Ana Cecília Fieler, Marcela Eslava, and Daniel Yi Xu. Trade, quality upgrading, and input linkages: Theory and evidence from colombia. *American Economic Review*, 108(1):109–46, 2018.

Lionel Fontagné, Houssein Guimbard, and Gianluca Orefice. Tariff-based product-level trade elasticities. *Journal of International Economics*, 137:103593, 2022.

Robert E Hall and Charles I Jones. Why do some countries produce so much more output per worker than others? *The quarterly journal of economics*, 114(1):83–116, 1999.

Juan Carlos Hallak. Product quality and the direction of trade. *Journal of international Economics*, 68(1):238–265, 2006.

David Hummels and Peter J Klenow. The variety and quality of a nation's exports. *American economic review*, 95(3):704–723, 2005.

Amit Khandelwal. The long and short (of) quality ladders. *The Review of Economic Studies*, 77(4): 1450–1476, 2010.

Amit K Khandelwal, Peter K Schott, and Shang-Jin Wei. Trade liberalization and embedded institutional reform: evidence from chinese exporters. *American Economic Review*, 103(6):2169–95, 2013.

Frank Kleibergen and Richard Paap. Generalized reduced rank tests using the singular value decomposition. *Journal of econometrics*, 133(1):97–126, 2006.

Maurice Kugler and Eric Verhoogen. Plants and imported inputs: New facts and an interpretation. *American Economic Review*, 99(2):501–07, 2009.

Maurice Kugler and Eric Verhoogen. Prices, plant size, and product quality. *The Review of Economic Studies*, 79(1):307–339, 2012.

Elsa Leromain and Gianluca Orefice. New revealed comparative advantage index: Dataset and empirical distribution. *International Economics*, 139:48–70, 2014.

James Levinsohn and Amil Petrin. Estimating production functions using inputs to control for unobservables. *The review of economic studies*, 70(2):317–341, 2003.

Rocco Macchiavello. Development uncorked: Reputation acquisition in the new market for chilean wines in the uk. 2010.

Kalina Manova and Zhihong Yu. How firms export: Processing vs. ordinary trade with financial frictions. *Journal of International Economics*, 100:120–137, 2016.

Kalina Manova and Zhihong Yu. Multi-product firms and product quality. *Journal of International Economics*, 109:116–137, 2017.

Kalina Manova and Zhiwei Zhang. Export prices across firms and destinations. *The Quarterly Journal of Economics*, 127(1):379–436, 2012.

Marc J Melitz. The impact of trade on intra-industry reallocations and aggregate industry productivity. *econometrica*, 71(6):1695–1725, 2003.

Antonio Navas. Technology and the dynamics of comparative advantage. *Review of International Economics*, 26(1):140–164, 2018.

Steven Olley and Ariel Pakes. The dynamics of productivity in the telecommunications equipment industry, 1992.

Mark J Roberts and James R Tybout. The decision to export in colombia: An empirical model of entry with sunk costs. *The american economic review*, pages 545–564, 1997.

Peter K Schott. Across-product versus within-product specialization in international trade. *The Quarterly Journal of Economics*, 119(2):647–678, 2004.

Eric A Verhoogen. Trade, quality upgrading, and wage inequality in the mexican manufacturing sector. *The Quarterly Journal of Economics*, 123(2):489–530, 2008.

Jeffrey M Wooldridge. On estimating firm-level production functions using proxy variables to control for unobservables. *Economics letters*, 104(3):112–114, 2009.

5 Appendix

5.1 Autarky

5.1.1 Quality choice expression

Given $[\gamma + e(1-\sigma)] = m$, we rewrite Equation (12) in the main text to obtain a relationship between B_j, q_{ij} and a_{ij}:

$$B_j = \frac{1}{m} q_{ij}^{1-m} a_{ij}^{\alpha+\sigma-1} (w^{\beta_j} r^{1-\beta_j})^{\sigma}$$

This needs to be held for all a_{ij}. Let consider the case of $a_{ij} = a_{Dj}^{aut}$, it becomes:

$$B_j(a_{Dj}^{aut}) = \frac{1}{m} q_{ij}(a_{Dj}^{aut})^{1-m} (a_{Dj}^{aut})^{\alpha+\sigma-1} (w^{\beta_j} r^{1-\beta_j})^{\sigma}$$

Substituting the previous expression in the zero-profit condition yields:

$$(a_{Dj}^{aut})^{1-\sigma} q_{ij}(a_{Dj}^{aut})^{m} (w^{\beta_j} r^{1-\beta_j})^{1-\sigma} \frac{1}{m} q_{ij}(a_{Dj}^{aut})^{1-m} (a_{Dj}^{aut})^{\alpha+\sigma-1} (w^{\beta_j} r^{1-\beta_j})^{\sigma} - (a_{Dj}^{aut})^{\alpha} q_{ij}(a_{Dj}^{aut}) w^{\beta_j} r^{1-\beta_j} = F_D w^{\beta_j} r^{1-\beta_j}$$

$$q_{ij}(a_{Dj}^{aut}) = \frac{m}{1-m} F_D (a_{Dj}^{aut})^{-\alpha}$$

Finally, note that we can obtain the relative quality between firms with a_{ij} and firms with a_{Dj}^{aut} based on Equation (12) in the main text:

$$\frac{q_{ij}}{q_{ij}(a_{Dj}^{aut})} = [\frac{a_{ij}^{\alpha+\sigma-1}}{(a_{Dj}^{aut})^{\alpha+\sigma-1}}]^{\frac{1}{m-1}}$$

After simplifying this equation and then substituting the equation for the zero-profit condition, we can obtain the quality choice equation as Equation (13):

$$q_{ij} = \frac{mF_D}{1-m} a_{ij}^{\frac{\alpha+\sigma-1}{m-1}} (a_{Dj}^{aut})^{\frac{\alpha m+\sigma-1}{1-m}}$$

5.2 Costless Trade

In this section, we analyse the case where the economies are open to international trade but the latter is costless. As in the case of costly trade we denote with superscript l the variables related to the country of origin and with superscript n the variables referred to the destination country.

5.2.1 Demand and Production

Since there are no trade costs and firms face the same elasticity of demand in both the domestic and export markets, profit maximisation implies the same equilibrium price that a Home firm will charge in the two markets.[30] The price charged in both markets are the same, which can be expressed as:

$$p_{ij}^l = p_{ijd}^l = p_{ijx}^l = \frac{\sigma}{\sigma-1} a_{ij}(q_{ij}^l)^e (w^l)^{\beta_j} (r^l)^{1-\beta_j}$$

Firms sell products and gain profits in the two markets, while they only pay for the quality improvement once. Thus, the profit function can be expressed as:

$$\pi_{ij}^l = a_{ij}^{1-\sigma}(q_{ij}^l)^m (B_j^l + B_j^n)[(w^l)^{\beta_j}(r^l)^{1-\beta_j}]^{1-\sigma} - a_{ij}^{\alpha} q_{ij} (w^l)^{\beta_j}(r^l)^{1-\beta_j} - F_D (w^l)^{\beta_j}(r^l)^{1-\beta_j}$$

where $B_j^l = \frac{(\frac{\sigma}{\sigma-1})^{1-\sigma}}{\sigma(P_j^l)^{1-\sigma}} E_j^l$ and $B_j^n = \frac{(\frac{\sigma}{\sigma-1})^{1-\sigma}}{\sigma(P_j^n)^{1-\sigma}} E_j^n$.

5.2.2 Investment in Quality

Given the profit function, firms tend to choose the optimal level of quality, q_{ij}, to maximise profits. Therefore, we can express the quality function as:

$$q_{ij}^l = \left[\frac{m(B_j^l + B_j^n)}{a_{ij}^{\alpha+\sigma-1}[(w^l)^{\beta_j}(r^l)^{1-\beta_j}]^{\sigma}}\right]^{\frac{1}{1-m}}$$

We can see that quality increases with $(B_j^l + B_j^n)$ (i.e., higher total demand from both markets is related to a higher quality for goods). Thus, again, we want to find another expression of quality where we replace B_j^l and B_j^n by a_{Dj}^{CL}, which will give a better idea of how quality changes from autarky to costless trade. However, the above quality function will still be used for the following model setup.

[30] In the following analysis of the costless trade condition, we write out expressions for Home only; those for Foreign are analogous.

Based on the zero-profit condition where $\pi^l_{ij}(a^{CL}_{Dj}) = F_D(w^l)^{\beta_j}(r^l)^{1-\beta_j}$, the quality can also be expressed as:

$$q^l_{ij} = \frac{mF_D}{1-m} a_{ij}^{\frac{\alpha+\sigma-1}{m-1}} (a^{CL}_{Dj})^{\frac{\alpha m+\sigma-1}{1-m}}$$

5.2.3 Firm Entry

New entrants will enter the industry until the expected profit equals the entry fixed costs. Given the free entry condition and zero-profit condition, we can obtain the threshold in the costless trade as:

$$(a^{CL}_{Dj})^k = \frac{\delta F_E}{F_D} \frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1} (a_M)^k$$

From this result, we can see that firms that used to produce in autarky can still produce and export now, and firms that failed to produce in autarky are still forced to exit. Furthermore, all active firms keep producing the products with the same quality as in autarky.

With no transportation costs or trade barriers, all firms, irrespective of their unit-input requirement, experience increased demand for their products in export markets and reduced demand in domestic markets due to import competition. Indeed, this integration does not affect either the zero-profit condition or the free-entry condition (the average industry variables). Therefore, the production threshold is proved unchanged from autarky to costless trade, which leads to firms' quality choice staying the same as before (which can be seen from the second expression of quality).

5.3 Costly trade

5.3.1 Profitability of serving the foreign market

In the costly trade condition, we first prove the profitability of serving the foreign market relative to the domestic market is larger in the comparative advantage industry (i.e., $A^H_1 > A^H_2$ and $A^F_1 < A^F_2$).

As mentioned before, $A^l_j = \frac{E^n_j}{E^l_j}(\frac{P^l_j}{P^n_j})^{1-\sigma}$. Assume that both countries share the same ratio of expenditure spent in one industry to the total expenditure. Hence, we can obtain the ratio of A^l_1 and A^l_2.

$$\begin{aligned}\frac{A^l_1}{A^l_2} &= (\frac{P^l_1}{P^l_2})^{1-\sigma}(\frac{P^n_2}{P^n_1})^{1-\sigma}\frac{\mu R^n}{\mu R^l}\frac{(1-\mu)R^l}{(1-\mu)R^n} \\ &= (\frac{P^l_1}{P^l_2})^{1-\sigma}(\frac{P^n_2}{P^n_1})^{1-\sigma}\end{aligned}$$

Through this equation, the value of the ratio depends on the relative industry price levels in the two countries. In costly trade, the relative industry price level in Home can be expressed as:

$$(\frac{P_1^l}{P_2^l})^{1-\sigma} = \frac{N_{D1}^l(p_1^l(\overline{a_{D1}^l}))^{1-\sigma} q_{1d}^l(\overline{a_{D1}^l})^{\gamma} + N_{X1}^l(p_1^l(\overline{a_{X1}^l}))^{1-\sigma} q_{1x}^l(\overline{a_{X1}^l})^{\gamma} + N_{X1}^n(\tau p_1^n(\overline{a_{X1}^n}))^{1-\sigma} q_{1x}^n(\overline{a_{X1}^n})^{\gamma}}{N_{D2}^l(p_2^l(\overline{a_{D2}^l}))^{1-\sigma} q_{2d}^l(\overline{a_{D1}^l})^{\gamma} + N_{X2}^l(p_2^l(\overline{a_{X2}^l}))^{1-\sigma} q_{2x}^l(\overline{a_{X2}^l})^{\gamma} + N_{X2}^n(\tau p_2^n(\overline{a_{X2}^n}))^{1-\sigma} q_{2x}^n(\overline{a_{X2}^n})^{\gamma}}$$

This equation shows that the price level is determined by three types of firms (domestic firms, domestic exporters and foreign exporters) within one industry.

First, we have to notice one extreme situation when $\tau \to \infty$ and $F_X \to \infty$, foreign exporters have to sell their goods at a very high price in the domestic market that no consumer can afford. As a result, there will not be any exporters. The whole economy goes back to the autarky situation. Thus, the relative industry price index converges its autarky value.

Combining $B_j = \frac{(\frac{\sigma}{\sigma-1})^{1-\sigma}}{\sigma(P_j)^{1-\sigma}} E_j$ and the zero-profit condition in autarky $((1-m)m^{\frac{m}{1-m}}(a_{Dj}^{aut})^{\frac{1-\sigma-\alpha m}{1-m}} B_j^{\frac{1}{1-m}}(w^{\beta_j} r^{1-\beta_j})^{\frac{1-m-\sigma}{1-m}} - F_D w^{\beta_j} r^{1-\beta_j} = 0)$ contributes to the relative industry price index which can be expressed as $(\frac{P_1^l}{P_2^l})^{1-\sigma} = \frac{\mu}{1-\mu}[(\frac{w^l}{r^l})^{\beta_1-\beta_2}]^{-\sigma}$, since the production cut-off is indifferent across industries. Hence, the value of the ratio of A_1^l and A_2^l can be found as:

$$\begin{aligned} \frac{A_1^l}{A_2^l} &= \frac{\mu}{1-\mu}[(\frac{w^l}{r^l})^{\beta_1-\beta_2}]^{-\sigma} \frac{1-\mu}{\mu}[(\frac{w^n}{r^n})^{\beta_1-\beta_2}]^{\sigma} \\ &= [(\frac{w^l/r^l}{w^n/r^n})^{\beta_1-\beta_2}]^{-\sigma} \end{aligned}$$

where the production of industry 1 uses skilled labour more intensively inducing that $\beta_1 > \beta_2$. For example, in the Home country skilled labour is relatively abundant, $\frac{w^H}{r^H} < \frac{w^F}{r^F}$ and, thus $A_1^H > A_2^H$. Likewise, we know that $A_1^F < A_2^F$.

Another extreme situation that we have to mention is when $\tau \to 1$, and $F_X \to 0$. All active firms can export (the whole economy comes back to the costless trade situation). In this case, the number of active firms within one industry is the same across countries (the sum of all active firms in two countries). Hence, the relative price is equalised across countries, inducing $A_1^l = A_2^l$.

For intermediate fixed and variable costs where costly trade occurs, the value of the ratio should lie between these two values, the autarky and the costless trade value (i.e., $A_1^H > A_2^H$ and $A_1^F < A_2^F$).

5.3.2 Survival cutoffs

To identify the relationship between the survival cutoffs in different industries, we get the ratio of a_{D1}^l and a_{D2}^l from the expression of a_{Dj}^l.

$$\frac{a^l_{D1}}{a^l_{D2}} = [\frac{\frac{\delta F_E}{F_D}^{\frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}}\{1+(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A^l_1\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}\}^{-1}a_M}{\frac{\delta F_E}{F_D}^{\frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}}\{1+(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A^l_2\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}\}^{-1}a_M}]^{\frac{1}{k}}$$

Simplify it,

$$\frac{a^l_{D1}}{a^l_{D2}} = [\frac{1+(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A^l_2\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}}{1+(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A^l_1\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}}]^{\frac{1}{k}}$$

As $\frac{k(1-m)}{\sigma-1+\alpha m} > 1$ and $A^H_1 > A^H_2$ ($A^F_1 < A^F_2$), this ratio is smaller (larger) than 1. Therefore, we can prove that $a^H_{D1} < a^H_{D2}$ ($a^F_{D1} < a^F_{D2}$).

5.3.3 Exporting cutoffs

Then we turn to get the ratio of a^H_{X1} and a^H_{X2} from the expression of a^l_{Xj}.

$$\frac{a^l_{X1}}{a^l_{X2}} = [\frac{\frac{\delta F_E}{F_X}^{\frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}}\{1+(\frac{F_X}{F_D})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A^l_1\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(m-1)}{\sigma-1+\alpha m}}\}^{-1}a_M}{\frac{\delta F_E}{F_X}^{\frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}}\{1+(\frac{F_X}{F_D})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A^l_2\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(m-1)}{\sigma-1+\alpha m}}\}^{-1}a_M}]^{\frac{1}{k}}$$

Simplify it,

$$\frac{a^l_{X1}}{a^l_{X2}} = [\frac{1+(\frac{F_X}{F_D})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A^l_2\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(m-1)}{\sigma-1+\alpha m}}}{1+(\frac{F_X}{F_D})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A^l_1\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(m-1)}{\sigma-1+\alpha m}}}]^{\frac{1}{k}}$$

As $\frac{k(m-1)}{\sigma-1+\alpha m} < -1$ and $A^H_1 > A^H_2$ ($A^F_1 < A^F_2$), this ratio is greater (smaller) than 1. Therefore, we can prove that $a^H_{X1} > a^H_{X2}$ ($a^F_{X1} < a^F_{X2}$).

5.4 Proof of Propositions

5.4.1 Proof for Proposition 1

To compare qualities, we will use the second expression of quality. Get the ratio of qualities of a non-exporter first in costly trade and autarky.

$$\frac{q^l_{idj}}{q_{ij}} = \frac{\frac{mF_D}{1-m}a_{ij}^{\frac{\alpha+\sigma-1}{m-1}}(a^l_{Dj})^{\frac{\alpha m+\sigma-1}{1-m}}}{\frac{mF_D}{1-m}a_{ij}^{\frac{\alpha+\sigma-1}{m-1}}(a^{aut}_{Dj})^{\frac{\alpha m+\sigma-1}{1-m}}}$$

Simplify it,

$$\frac{q^l_{idj}}{q_{ij}} = (\frac{a^l_{Dj}}{a^{aut}_{Dj}})^{\frac{\alpha m+\sigma-1}{1-m}}$$

Then we substitute the closed solutions for a^l_{Dj} and a^{aut}_{Dj}.

$$\frac{q^l_{idj}}{q_{ij}} = (\frac{\frac{\delta F_E}{F_D}\frac{1-\sigma-\alpha m+k(1-m)}{\sigma-1+\alpha m}(a_M)^k}{\frac{\delta F_E}{F_D}\frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}\{1+(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A^l_j\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}\}^{-1}(a_M)^k})^{\frac{\alpha m+\sigma-1}{k(m-1)}}$$

Simplify it,

$$\frac{q^l_{idj}}{q_{ij}} = \{1+(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A^l_j\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}\}^{\frac{\alpha m+\sigma-1}{k(m-1)}}$$

where $(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A^l_j\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}$ is positive and $\frac{\alpha m+\sigma-1}{k(m-1)}$ is negative, so we find the above equation lower than one. It means that firms servicing only the domestic market will choose to lower their quality from autarky to costly trade.

Then we turn to get the ratio of qualities of an exporter in costly trade and autarky.

$$\frac{q^l_{ixj}}{q_{ij}} = \frac{\frac{mF_X}{1-m}a_{ij}^{\frac{\alpha+\sigma-1}{m-1}}(a^l_{Xj})^{\frac{\alpha m+\sigma-1}{1-m}}\{[(1+A^l_j\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}+1\}}{\frac{mF_D}{1-m}a_{ij}^{\frac{\alpha+\sigma-1}{m-1}}(a^{aut}_{Dj})^{\frac{\alpha m+\sigma-1}{1-m}}}$$

Simplify it,

$$\frac{q^l_{ixj}}{q_{ij}} = \frac{F_X}{F_D}(\frac{a^l_{Xj}}{a^{aut}_{Dj}})^{\frac{\alpha m+\sigma-1}{1-m}}\{1+[(1+A^l_j\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}\}$$

Substitute the closed solutions for a^l_{Xj} and a^{aut}_{Dj}, and assume that $[(1+A^l_j\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1} = M^l_j$.

Simplify it,

$$\frac{q^l_{ixj}}{q_{ij}} = (\frac{F_X}{F_D})^{\frac{1-\sigma-\alpha m+k(1-m)}{k(1-m)}}[1+(\frac{F_X}{F_D}M^l_j)^{\frac{k(m-1)}{1-\sigma-\alpha m}}\frac{F_D}{F_X}]^{\frac{1-\sigma-\alpha m}{k(1-m)}}(1+M^l_j)$$

Extract the common factor $\frac{F_D}{F_X}$ in the bracket.

$$\frac{q^l_{ixj}}{q_{ij}}=(\frac{F_X}{F_D})^{\frac{1-\sigma-\alpha m+k(1-m)}{k(1-m)}}\{\frac{F_D}{F_X}[\frac{F_X}{F_D}+(\frac{F_X}{F_D}M^l_j)^{\frac{k(m-1)}{1-\sigma-\alpha m}}]\}^{\frac{1-\sigma-\alpha m}{k(1-m)}}(1+M^l_j)$$

We can propose Equation (A.1) which is smaller than the relative quality equation:

$$(\frac{F_X}{F_D})^{\frac{1-\sigma-\alpha m+k(1-m)}{k(1-m)}}\{\frac{F_D}{F_X}[\frac{F_X}{F_D}+(\frac{F_X}{F_D}M^l_j)]^{\frac{k(m-1)}{1-\sigma-\alpha m}}\}^{\frac{1-\sigma-\alpha m}{k(1-m)}}(1+M^l_j) \tag{A.1}$$

We know that $-1<\frac{1-\sigma-\alpha m}{k(1-m)}<0$ and $[\frac{F_X}{F_D}+(\frac{F_X}{F_D}M^l_j)]^{\frac{k(m-1)}{1-\sigma-\alpha m}}>\frac{F_X}{F_D}+(\frac{F_X}{F_D}M^l_j)^{\frac{k(m-1)}{1-\sigma-\alpha m}}$. However, to prove the latter one, we have to explore the monotonicity of the function $y(z)=(\frac{F_X}{F_D}+x)^z-(\frac{F_X}{F_D}+x^z)$. The first order condition of it is $\ln(\frac{F_X}{F_D}+x)(\frac{F_X}{F_D}+x)^z-\ln x(x^z)$.

Now, it turns to prove that $\ln(\frac{F_X}{F_D}+x)(\frac{F_X}{F_D}+x)^z>\ln x(x^z)$. As the functions $f(t)=lnt$ and $f(t)=t^z$ are increasing in t with $t>1$ and $z>1$, we know that $ln(\frac{F_X}{F_D}+x)>lnx$ and $(\frac{F_X}{F_D}+x)^z>x^z$ with $\frac{F_X}{F_D}>1$, $x>1$ and $z>1$. Thus, we know that $\ln(\frac{F_X}{F_D}+x)(\frac{F_X}{F_D}+x)^z-\ln x(x^z)>0$ for $z>1$.

Then we can find that $y(1)=0$, and thus $y(z)$ is always bigger than 0. So we can obtain that $[\frac{F_X}{F_D}+(\frac{F_X}{F_D}M^l_j)]^{\frac{k(m-1)}{1-\sigma-\alpha m}}>\frac{F_X}{F_D}+(\frac{F_X}{F_D}M^l_j)^{\frac{k(m-1)}{1-\sigma-\alpha m}}$ given that $\frac{F_X}{F_D}>1$, $\frac{F_X}{F_D}M^l_j>1$ and $\frac{k(m-1)}{1-\sigma-\alpha m}>1$.

Simplify Equation (A.1),

$$(\frac{F_X}{F_D})^{\frac{1-\sigma-\alpha m+k(1-m)}{k(1-m)}}(\frac{F_D}{F_X})^{\frac{1-\sigma-\alpha m}{k(1-m)}}[\frac{F_X}{F_D}+(\frac{F_X}{F_D}M^l_j)]^{-1}(1+M^l_j)$$

$$(\frac{F_X}{F_D})^{\frac{1-\sigma-\alpha m+k(1-m)}{k(1-m)}}(\frac{F_D}{F_X})^{\frac{1-\sigma-\alpha m}{k(1-m)}}\frac{F_D}{F_X}(1+M^l_j)^{-1}(1+M^l_j)$$

$$(\frac{F_X}{F_D})^{\frac{1-\sigma-\alpha m+k(1-m)}{k(1-m)}}(\frac{F_D}{F_X})^{\frac{1-\sigma-\alpha m+k(1-m)}{k(1-m)}}\frac{1+M^l_j}{1+M^l_j}=1$$

As Equation (A.1) is smaller than the original equation, we can say the original equation is greater than 1 and then we can prove that $q^l_{ixj}>q_{ij}$, inducing that exporters improve the quality from autarky to costly trade.

5.4.2 Proof for Proposition 2

Now, we are proving that exporters will improve their quality by more in the comparative advantage industries. We first get the ratio of qualities of exporters with the same productivity in two industries.

$$\frac{q^l_{ix1}}{q^l_{ix2}}=\frac{\frac{mF_X}{1-m}a_{ij}^{\frac{\alpha+\sigma-1}{m-1}}(a^l_{X1})^{\frac{\alpha m+\sigma-1}{1-m}}}{\frac{mF_X}{1-m}a_{ij}^{\frac{\alpha+\sigma-1}{m-1}}(a^l_{X2})^{\frac{\alpha m+\sigma-1}{1-m}}}\frac{1+[(1+A^l_1\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}}{1+[(1+A^l_2\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}}$$

Then simplify it,

$$\frac{q^l_{ix1}}{q^l_{ix2}} = (\frac{a^l_{X1}}{a^l_{X2}})^{\frac{\alpha m+\sigma-1}{1-m}} \frac{1+[(1+A^l_1\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}}{1+[(1+A^l_2\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}}$$

Substitute the closed solutions for a^l_{X1} and a^l_{X2}.

$$\frac{q^l_{ix1}}{q^l_{ix2}} = [\frac{1+(\frac{F_X}{F_D})^{\frac{k(1-m)}{\alpha m+\sigma-1}-1}[(1+A^l_1\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(m-1)}{\alpha m+\sigma-1}}a_M}{1+(\frac{F_X}{F_D})^{\frac{k(1-m)}{\alpha m+\sigma-1}-1}[(1+A^l_2\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(m-1)}{\alpha m+\sigma-1}}a_M}]^{\frac{\alpha m+\sigma-1}{k(m-1)}} \frac{1+[(1+A^l_1\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}}{1+[(1+A^l_2\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}}$$

Here, for simplicity, with the assumption that $[(1+A^l_1\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1} = M^l_1$ and $[(1+A^l_2\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1} = M^l_2$, this ratio can be expressed as:

$$\frac{q^l_{ix1}}{q^l_{ix2}} = [\frac{1+(\frac{F_X}{F_D}M^l_1)^{\frac{k(1-m)}{\alpha m+\sigma-1}}\frac{F_D}{F_X}}{1+(\frac{F_X}{F_D}M^l_2)^{\frac{k(1-m)}{\alpha m+\sigma-1}}\frac{F_D}{F_X}}]^{\frac{\alpha m+\sigma-1}{k(m-1)}} \frac{1+M^l_1}{1+M^l_2}$$

Extract the common factor $\frac{F_D}{F_X}$ from the numerator and denominator in the bracket.

$$\frac{q^l_{ix1}}{q^l_{ix2}} = [\frac{\frac{F_X}{F_D}+(\frac{F_X}{F_D}M^l_1)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}{\frac{F_X}{F_D}+(\frac{F_X}{F_D}M^l_2)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}]^{\frac{\alpha m+\sigma-1}{k(m-1)}} \frac{1+M^l_1}{1+M^l_2}$$

We know that $M^H_1 < M^H_2$ $(M^F_1 > M^F_2)$ from $A^H_1 > A^H_2$ $(A^F_1 < A^F_2)$ and $0 < m < 1$. Taking the Home country as an example, we are able to propose Equation (A.2) is smaller than the above equation for the Home country.

$$[\frac{(\frac{F_X}{F_D} + \frac{F_X}{F_D}M^H_1)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}{(\frac{F_X}{F_D} + \frac{F_X}{F_D}M^H_2)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}]^{\frac{\alpha m+\sigma-1}{k(m-1)}} \frac{1+M^H_1}{1+M^H_2} \tag{A.2}$$

Here, we add an additional proof of proposing Equation (A.2) which is smaller than the original equation. Given $-1 < \frac{\alpha m+\sigma-1}{k(m-1)} < 0$, we have to prove that $\frac{(\frac{F_X}{F_D}+\frac{F_X}{F_D}M^H_1)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}{(\frac{F_X}{F_D}+\frac{F_X}{F_D}M^H_2)^{\frac{k(1-m)}{\alpha m+\sigma-1}}} > \frac{\frac{F_X}{F_D}+(\frac{F_X}{F_D}M^H_1)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}{\frac{F_X}{F_D}+(\frac{F_X}{F_D}M^H_2)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}$ which is equal to $\frac{\frac{F_X}{F_D}+(\frac{F_X}{F_D}M^H_2)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}{(\frac{F_X}{F_D}+\frac{F_X}{F_D}M^H_2)^{\frac{k(1-m)}{\alpha m+\sigma-1}}} > \frac{\frac{F_X}{F_D}+(\frac{F_X}{F_D}M^H_1)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}{(\frac{F_X}{F_D}+\frac{F_X}{F_D}M^H_1)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}$. In order to do that, we are exploring the monotonicity of the function $y = \frac{\frac{F_X}{F_D}+x^z}{(\frac{F_X}{F_D}+x)^z}$. Since $M^H_2 > M^H_1$, we just have to derive that the function is monotonically increasing for x in the valid interval.

The first-order condition of the function subject to x can be expressed as:

$$\frac{dy}{dx} = \frac{zx^{z-1}(\frac{F_X}{F_D}+x)^z - z(\frac{F_X}{F_D}+x)^{z-1}(\frac{F_X}{F_D}+X^z)}{(\frac{F_X}{F_D}+x)^{2z}}$$

Simplify it,

$$\frac{dy}{dx} = \frac{z}{(\frac{F_X}{F_D}+x)^{z+1}}[\frac{F_X}{F_D}(x^{z-1}-1)]$$

Since $\frac{F_X}{F_D}M_1^H > 1$, $\frac{F_X}{F_D}M_2^H > 1$ (which means that $x > 1$) and $\frac{k(1-m)}{\alpha m+\sigma-1} > 1$ (which means that $z > 1$), the first order condition is positive all the time. This is because the function x^{z-1} is monotonically increasing for $z > 1$ and $x > 1$, and the function equals 1 when $x = 1$. Equation (A.2) is smaller than the original equation.

Then we simplify Equation (A.2),

$$\frac{1+M_2^H}{1+M_1^H}\frac{1+M_1^H}{1+M_2^H} = 1$$

Since Equation (A.2) equalling 1 is smaller than the original equation, we are able to obtain $q_{ix1}^H(a_{ij}) > q_{ix2}^H(a_{ij})$. In the same, we could also prove that $q_{ix1}^F(a_i) < q_{ix2}^F(a_i)$.

5.4.3 Proof for Proposition 3

Get the ratio of $q_{id1}^l(a_i)$ and $q_{id2}^l(a_i)$ from the expression of q_{idj}^l.

$$\frac{q_{id1}^l(a_{ij})}{q_{id2}^l(a_{ij})} = \frac{\frac{mF_D}{1-m}a_{ij}^{\frac{\alpha+\sigma-1}{m-1}}(a_{D1}^l)^{\frac{\alpha m+\sigma-1}{1-m}}}{\frac{mF_D}{1-m}a_{ij}^{\frac{\alpha+\sigma-1}{m-1}}(a_{D2}^l)^{\frac{\alpha m+\sigma-1}{1-m}}}$$

As $\frac{\alpha m+\sigma-1}{1-m} > 0$ and $a_{D1}^H < a_{D2}^H$ ($a_{D1}^F > a_{D2}^F$), this ratio is smaller than 1. Therefore, $q_{id1}^H(a_i) < q_{id2}^H(a_i)$ ($q_{id1}^F(a_i) > q_{id2}^F(a_i)$).

5.4.4 Proof for Proposition 4

First, we can derive the aggregate quality of industries when it is in autarky, which is given by,

$$\overline{q_j^{aut}} = \frac{1}{G(a_{Dj}^{aut})} \int_0^{a_{Dj}^{aut}} q_{ij} g(a) da$$

Then substitute the autarky quality function $q_{ij} = \frac{mF_D}{1-m} a_{ij}^{\frac{\alpha+\sigma-1}{m-1}} (a_{Dj}^{aut})^{\frac{\alpha m+\sigma-1}{1-m}}$, $G(a) = (\frac{a}{a_M})^k$ and $g(a) = ka^{k-1}(a_M)^{-k}$ into the above the equation and simplify it as:

$$\overline{q_j^{aut}} = (\frac{1}{a_{Dj}^{aut}})^{\alpha} \frac{mkF_D}{1-\alpha-\sigma+k(1-m)} \tag{A.3}$$

In costly trade, first of all, we can derive the aggregate quality of non-exporters, which is given by,

$$\overline{q_{jd}^l} = \frac{1}{G(a_{Dj}^l)-G(a_{Xj}^l)} \int_{a_{Xj}^l}^{a_{Dj}^l} q_{ijd}^l(a_{ij}) g(a) da$$

$$= \frac{1}{G(a_{Dj}^l)-G(a_{Xj}^l)} \int_{a_{Xj}^l}^{a_{Dj}^l} \frac{mF_D}{1-m} a_{ij}^{\frac{\alpha+\sigma-1}{m-1}} (a_{Dj}^l)^{\frac{\alpha m+\sigma-1}{1-m}} ka^{k-1}(a_M)^{-k} da$$

$$= \frac{1}{G(a_{Dj}^l)-G(a_{Xj}^l)} \frac{mF_D k}{1-m} (a_{Dj}^l)^{\frac{\alpha m+\sigma-1}{1-m}} \frac{m-1}{\alpha+\sigma-1+k(m-1)} (a_M)^{-k}$$
$$[(a_{Dj}^l)^{\frac{\alpha+\sigma-1}{m-1}+k} - (a_{Xj}^l)^{\frac{\alpha+\sigma-1}{m-1}+k}]$$

$$= \frac{1}{G(a_{Dj}^l)-G(a_{Xj}^l)} \frac{mF_D k}{1-m} (a_{Dj}^l)^{\frac{\alpha m+\sigma-1}{1-m}} \frac{m-1}{\alpha+\sigma-1+k(m-1)} (a_M)^{-k}$$
$$(a_{Dj}^l)^{\frac{\alpha+\sigma-1}{m-1}+k} [1 - (\frac{a_{Xj}^l}{a_{Dj}^l})^{\frac{\alpha+\sigma-1}{m-1}+k}]$$

As we have obtained in our model, the relationship between two thresholds can be expressed as, $\frac{a_{Xj}^l}{a_{Dj}^l} = (\frac{F_X}{F_D} M_j^l)^{\frac{m-1}{\alpha m+\sigma-1}}$ where $M_j^l = [(1+A_j^l \tau^{1-\sigma})^{\frac{1}{1-m}} - 1]^{-1}$. We can further simplify the aggregate quality of non-exporters as follows:

$$\overline{q_{jd}^l} = \frac{1}{G(a_{Dj}^l)-G(a_{Xj}^l)} \frac{mkF_D}{1-\alpha-\sigma+k(1-m)} [1 - (\frac{F_X}{F_D} M_j^l)^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}}] (a_{Dj}^l)^{k-\alpha} (a_M)^{-k} \tag{A.4}$$

Then the aggregate quality of exporters can be given by,

$$\overline{q_{jx}^l} = \frac{1}{G(a_{Xj}^l)} \int_0^{a_{Xj}^l} q_{ijx}^l(a_{ij}) g(a) da$$

$$= \frac{1}{G(a_{Xj}^l)} \int_0^{a_{Xj}^l} \frac{mF_X}{1-m} a_{ij}^{\frac{\alpha+\sigma-1}{m-1}} (a_{Xj}^l)^{\frac{\alpha m+\sigma-1}{1-m}} \{[(1+A_j^l \tau^{1-\sigma})^{\frac{1}{1-m}} - 1]^{-1} + 1\} ka_{ij}^{k-1} (a_M)^{-k}$$

$$= \frac{1}{G(a_{Xj}^l)} \frac{mF_X k}{1-m} (a_{Xj}^l)^{\frac{\alpha+\sigma-1}{m-1}+k} (a_{Xj}^l)^{\frac{\alpha m+\sigma-1}{1-m}} \{[(1+A_j^l \tau^{1-\sigma})^{\frac{1}{1-m}} - 1]^{-1} + 1\} \frac{m-1}{\alpha+\sigma-1+k(m-1)} (a_M)^{-k}$$

We can further simplify the quality equation of exporters as,

$$\overline{q_{jx}^{l}} = \frac{1}{G(a_{Xj}^{l})}\frac{mkF_X}{1-\alpha-\sigma+k(1-m)}(1+M_j^l)(a_{Xj}^{l})^{k-\alpha}(a_M)^{-k} \tag{A.5}$$

Finally, we calculate the average quality of one industry within one country using the average quality of non-exporters and exporters (Equations (A.4) and (A.5)) with their weights respectively.

$$\overline{q_j^l} = \frac{G(a_{Dj}^l)-G(a_{Xj}^l)}{G(a_{Dj}^l)}\overline{q_{id}^l} + \frac{G(a_{Xj}^l)}{G(a_{Dj}^l)}\overline{q_{ix}^l}$$

$$\begin{aligned}
&= \tfrac{G(a_{Dj}^l)-G(a_{Xj}^l)}{G(a_{Dj}^l)}\tfrac{1}{G(a_{Dj}^l)-G(a_{Xj}^l)}\tfrac{mkF_D}{1-\alpha-\sigma+k(1-m)}[1-(\tfrac{F_X}{F_D}M_j^l)^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}}](a_{Dj}^l)^{k-\alpha}(a_M)^{-k} \\
&\quad + \tfrac{G(a_{Xj}^l)}{G(a_{Dj}^l)}\tfrac{1}{G(a_{Xj}^l)}\tfrac{mkF_X}{1-\alpha-\sigma+k(1-m)}(1+M_j^l)(a_{Xj}^l)^{k-\alpha}(a_M)^{-k}
\end{aligned}$$

$$\begin{aligned}
&= \tfrac{1}{G(a_{Dj}^l)}\tfrac{mkF_D}{1-\alpha-\sigma+k(1-m)}[1-(\tfrac{F_X}{F_D}M_j^l)^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}}](a_{Dj}^l)^{k-\alpha}(a_M)^{-k} \\
&\quad + \tfrac{1}{G(a_{Dj}^l)}\tfrac{mkF_X}{1-\alpha-\sigma+k(1-m)}(1+M_j^l)(a_{Xj}^l)^{k-\alpha}(a_M)^{-k}
\end{aligned}$$

We substitute $G(a) = (\frac{a}{a_M})^k$ and $\frac{a_{Xj}^l}{a_{Dj}^l} = (\frac{F_X}{F_D}M_j^l)^{\frac{m-1}{\alpha m+\sigma-1}}$ into the above equation to simplify it,

$$\begin{aligned}
\overline{q_j^l} &= \tfrac{1}{(a_{Dj}^l)^k}\tfrac{mkF_D}{1-\alpha-\sigma+k(1-m)}[1-(\tfrac{F_X}{F_D}M_j^l)^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}}](a_{Dj}^l)^{k-\alpha} \\
&\quad + \tfrac{1}{(a_{Dj}^l)^k}\tfrac{mkF_X}{1-\alpha-\sigma+k(1-m)}(1+M_j^l)[(\tfrac{F_X}{F_D}M_j^l)^{\frac{m-1}{\alpha m+\sigma-1}}a_{Dj}^l]^{k-\alpha}
\end{aligned}$$

Combine a_{Dj}^l,

$$\begin{aligned}
&= \tfrac{1}{(a_{Dj}^l)^\alpha}\tfrac{mkF_D}{1-\alpha-\sigma+k(1-m)}[1-(\tfrac{F_X}{F_D}M_j^l)^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}}] \\
&\quad + \tfrac{1}{(a_{Dj}^l)^\alpha}\tfrac{mkF_X}{1-\alpha-\sigma+k(1-m)}(1+M_j^l)(\tfrac{F_X}{F_D}M_j^l)^{\frac{(k-\alpha)(m-1)}{\alpha m+\sigma-1}}
\end{aligned}$$

Extract the common factor.

$$\begin{aligned}
&= \tfrac{1}{(a_{Dj}^l)^\alpha}\tfrac{mk}{1-\alpha-\sigma+k(1-m)}[F_D - F_D(\tfrac{F_X}{F_D}M_j^l)^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}} \\
&\qquad + F_X(1+M_j^l)(\tfrac{F_X}{F_D}M_j^l)^{\frac{(k-\alpha)(m-1)}{\alpha m+\sigma-1}}]
\end{aligned}$$

Extract the common factor for the latter two items in the brace.

$$= \frac{1}{(a^l_{Dj})^\alpha} \frac{mk}{1-\alpha-\sigma+k(1-m)} \{F_D - (\frac{F_X}{F_D} M^l_j)^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}} [F_D - F_X(1+M^l_j)(\frac{F_X}{F_D} M^l_j)^{-1}]\}$$

Simplify it,

$$= \frac{1}{(a^l_{Dj})^\alpha} \frac{mk}{1-\alpha-\sigma+k(1-m)} [F_D - (\frac{F_X}{F_D} M^l_j)^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}} (F_D - F_D \frac{1+M^l_j}{M^l_j})]$$

Extract the common factor F_D and simplify it,

$$= \frac{1}{(a^l_{Dj})^\alpha} \frac{mkF_D}{1-\alpha-\sigma+k(1-m)} [1 + (\frac{F_X}{F_D} M^l_j)^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}} \frac{1}{M^l_j}]$$

$$= \frac{1}{(a^l_{Dj})^\alpha} \frac{mkF_D}{1-\alpha-\sigma+k(1-m)} [1 + (\frac{F_X}{F_D})^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}} (M^l_j)^{\frac{\alpha(1-m)+k(m-1)}{\alpha m+\sigma-1}}]$$

As the final result, the aggregate quality of industries in costly trade can be expressed as:

$$\overline{q^l_j} = (\frac{1}{a^l_{Dj}})^\alpha \frac{mkF_D}{1-\alpha-\sigma+k(1-m)} [1 + (\frac{F_X}{F_D})^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}} (M^l_j)^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}}] \tag{A.6}$$

As we have the aggregate quality equation for autarky, Equation (A.3) and that for costly trade, Equation (A.6), we can compare them by a ratio between them,

$$\overline{q^l_j}/\overline{q^{aut}_j} = (\frac{a^{aut}_{Dj}}{a^l_{Dj}})^\alpha [1 + (\frac{F_X}{F_D})^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}} (M^l_j)^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}}]$$

As we know that the threshold of input required for one unit final good is lower in costly trade ($a^l_{Dj} < a^{aut}_{Dj}$), α is positive ($\alpha > 0$), and the latter part of the above equation is bigger than one ($1 + (\frac{F_X}{F_D})^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}} (M^l_j)^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}} > 1$) in this equation, we know the result of it which is bigger than one meaning that the aggregate quality has been improved in all sectors from autarky to costly trade.

From here, let us take the Home country as an example. Given that in Home country $a^H_{D1} < a^H_{D2}$, $M^H_1 < M^H_2$ and $0 < m < 1$, we cannot arrive at a conclusion that $\overline{q^H_1} > \overline{q^H_2}$ (i.e., the average quality in the comparative advantage industries is relatively high) without the assumption that $\alpha < k$ (α describes how firms' productivity can effectively contribute to quality investment shown in Equation (9) in the main text and k is a shape parameter in the distribution function for ex-ante firm input-requirement).

For this, we can also prove that the same parameter assumption is needed by exploring the monotonicity of the above function after substituting the expression of a^H_{Dj} shown below. When $\alpha < k$, the average quality function is monotonically decreasing for $\frac{F_X}{F_D} M^H_j$.

After substituting the expression of a^l_{Dj}, the average quality can be expressed as,

$$\overline{q_j^H} = [\frac{\delta F_E}{F_X}\frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}]^{-\frac{\alpha}{k}}[1+(\frac{F_X}{F_D})^{\frac{k(m-1)}{\alpha m+\sigma-1}+1}(M_j^H)^{\frac{k(m-1)}{\alpha m+\sigma-1}}]^{\frac{\alpha}{k}}$$
$$\frac{mkF_D}{1-\alpha-\sigma+k(1-m)}[1+(\frac{F_X}{F_D})^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}}(M_j^H)^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}}]$$

$$= \frac{mkF_D}{1-\alpha-\sigma+k(1-m)}[\frac{\delta F_E}{F_X}\frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}]^{-\frac{\alpha}{k}}$$
$$[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j^H)^{\frac{k(m-1)}{\alpha m+\sigma-1}}]^{\frac{\alpha}{k}}[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j^H)^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}}]$$

Now, let us denote that $\frac{mkF_D}{1-\alpha-\sigma+k(1-m)}[\frac{\delta F_E}{F_X}\frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}]^{-\frac{\alpha}{k}}$ is N containing only parameters and express the equation as,

$$\overline{q_j^H} = N[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j^H)^{\frac{k(m-1)}{\alpha m+\sigma-1}}]^{\frac{\alpha}{k}}[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j^H)^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}}]$$

We explore the monotonicity of the expression above subject to $\frac{F_X}{F_D}M_j^H$.

$$\frac{d\overline{q_j^H}}{d(\frac{F_X}{F_D}M_j^H)} = N\{\frac{\alpha}{k}[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j^H)^{\frac{k(m-1)}{\alpha m+\sigma-1}}]^{\frac{\alpha}{k}-1}\frac{F_X}{F_D}\frac{k(m-1)}{\alpha m+\sigma-1}(\frac{F_X}{F_D}M_j^H)^{\frac{k(m-1)}{\alpha m+\sigma-1}-1}$$
$$[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j^H)^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}}]+\frac{F_X}{F_D}\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}(\frac{F_X}{F_D}M_j^H)^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}-1}$$
$$[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j^H)^{\frac{k(m-1)}{\alpha m+\sigma-1}}]^{\frac{\alpha}{k}}\}$$

$$= N\frac{F_X}{F_D}\frac{m-1}{\alpha m+\sigma-1}(\frac{F_X}{F_D}M_j^H)^{\frac{k(m-1)}{\alpha m+\sigma-1}-1}[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j^H)^{\frac{k(m-1)}{\alpha m+\sigma-1}}]^{\frac{\alpha}{k}}$$
$$\{\frac{\alpha}{k}k[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j^H)^{\frac{k(m-1)}{\alpha m+\sigma-1}}]^{-1}[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j^H)^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}}]$$
$$-(\alpha-k)(\frac{F_X}{F_D}M_j^H)^{\frac{\alpha(1-m)}{\alpha m+\sigma-1}}\}$$

As $0 < m < 1$, we rearrange the equation to keep the part outside the brace positive given $\frac{F_X}{F_D}M_j^H > 1$ as,

$$\frac{d\overline{q_j^H}}{d(\frac{F_X}{F_D}M_j^H)} = N\frac{F_X}{F_D}\frac{1-m}{\alpha m+\sigma-1}(\frac{F_X}{F_D}M_j^H)^{\frac{k(m-1)}{\alpha m+\sigma-1}-1}[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j^H)^{\frac{k(m-1)}{\alpha m+\sigma-1}}]^{\frac{\alpha}{k}}$$
$$[(\alpha-k)(\frac{F_X}{F_D}M_j^H)^{\frac{\alpha(1-m)}{\alpha m+\sigma-1}}-\alpha\frac{1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j^H)^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}}}{1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j^H)^{\frac{k(m-1)}{\alpha m+\sigma-1}}}]$$

From the final expression, we can see that when $\alpha < k$, the second row will be negative which causes the first-order condition to be negative too. In this condition, we are able to conclude that the average quality function is monotonically decreasing for $\frac{F_X}{F_D}M_j^H$ and we will find that the average quality of Industry 1 in the Home country (the comparative advantage industry) is higher given $M_1^H < M_2^H$. Likewise, we could also prove that the average quality of Industry 2 in the Foreign country is higher under this condition.

5.5 Matching between the Firm-level and the Transaction-level Data

Our matching strategy is to link firms in CASIF to those in CCTS by matching their names. We follow Manova and Yu (2016) and construct a concordance matching the firm's identifiers across these two datasets. The matching procedure is as follows where we use "FIRMID" to refer to the firm identifier code in the CASIF and "FIRMCODE" to refer to those in the CCTS).

The basic idea of this matching method is that we use all the different names ever used by a firm to match firm identifiers in both datasets. More specifically, a NBS FIRMID will be matched to a CCTS FIRMCODE, as long as one of the names ever used by the FIRMID in the firm-level data can match with one of the names ever registered by the FIRMCODE in the CCTS data. Using this method, we can achieve the largest flexibility in variations of company names and minimise the possibility of failure to identify matched firms simply due to changes in their names.

After the above matching procedure, we conduct some checks to assess the quality of the matching. Firstly, we drop the duplicates. Secondly, we found 1,885 matches where within a given year more than one NBS FIRMID match with one CCTS FIRMCODE constituting a negligible proportion of the sample (accounting for less than 0.1% of export and import) and excluding them. Thirdly, we check if multiple CCTS FIRMCODEs match with one NBS FIRMID for the same year. There are 34,633 matches from the sample where multiple FIRMCODEs match with one FIRMID in the same year. After checking these in the original CCTS data, we found that this is due to that firms changing their CCTS code during the same year in different months while keeping their names unchanged. This indicates that the same firm does these transactions under multiple CCTS codes. Therefore, we keep these duplicates and aggregate them into the same FIRMID.

Following this procedure, we finally obtain a matched firm-transaction dataset including 83,391 unique firms and 2,735,247 observations over the 2000-2007 period.

5.6 Supplementary Tables

Table A.1: Chinese Comparative Advantage: Labour vs Capital intensive industries

HS Code	Product description	Chinese RCA in 2000	Trend in *CLO RCA 2000-2007*
Labour Intensive Industries			
64	Footwear, gaiters and the like; parts of such articles	Yes	Decreasing
36	Explosives; pyrotechnic products; matches; pyrophoric alloys; certain combustible preparations	Yes	Decreasing
67	Prepared feathers and down and articles made of feathers or of down; artificial flowers; articles of human hair	Yes	Decreasing
53	Other vegetable textile fibres; paper yarn and woven fabrics of paper yarn	Yes	Decreasing
18	Cocoa and cocoa preparations	Yes	Decreasing
62	Articles of apparel and clothing accessories, not knitted or crocheted	Yes	Decreasing
Capital Intensive Industries			
87	Vehicles other than railway or tramway rolling stock, and parts and accessories thereof	No	Increasing
40	Rubber and articles thereof	No	Increasing
48	Paper and paperboard; articles of paper pulp, of paper or of paperboard	No	Increasing
49	Printed books, newspapers, pictures and other products of the printing industry; manuscripts, typescripts and plans	No	Increasing
90	Optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments and apparatus	No	Increasing
39	Plastics and articles thereof	No	Increasing

Notes: This table shows that the changes in the CLO RCA index experienced by China over the sample period are strongly related to whether the industry is labour or capital intensive. All the listed labour-intensive industries feature the comparative advantage in China and a decreasing trend and the capital-intensive industries are without the comparative advantage but with an increasing trend.

Table A.2: Effects of Balassa RCA on product quality

Dependent variable	ln(quality)					
	$\sigma = 5$		$\sigma = 10$		$\sigma = \sigma_i$	
	(1)	(2)	(3)	(4)	(5)	(6)
$B\ RCA_D$	0.188***		0.099		0.237***	
	(0.035)		(0.069)		(0.029)	
$B\ RCA$		0.027***		0.016***		0.029***
		(0.003)		(0.005)		(0.002)
$ln(TFP)$	0.222***	0.223***	0.287***	0.288***	0.185***	0.186***
	(0.017)	(0.017)	(0.033)	(0.033)	(0.013)	(0.013)
$ln(Capital/Labour)$	0.076***	0.077***	0.069***	0.069***	0.088***	0.087***
	(0.009)	(0.009)	(0.018)	(0.018)	(0.008)	(0.008)
$ln(Employment)$	0.372***	0.371***	0.391***	0.391***	0.369***	0.368***
	(0.015)	(0.015)	(0.029)	(0.029)	(0.013)	(0.013)
$ln(WagePerWorker)$	0.145***	0.145***	0.164***	0.163***	0.147***	0.147***
	(0.012)	(0.012)	(0.022)	(0.022)	(0.010)	(0.010)
Product fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Product & Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	848,962	848,962	848,962	848,962	847,246	847,246
R-squared	0.790	0.790	0.808	0.808	0.831	0.831

Notes: This table examines the relationship between export quality and the RCA. For each firm-product-year triplet, the dependent variable is the estimated quality, given the value of the elasticity of substitution σ, 5, 10, and the estimates of Broda and Weinstein (2006). $B\ RCA_D$ is a dummy variable, and it equals 1 when China does have a comparative advantage in the industry of producing product h in year t; otherwise, it takes a value of 0. Balassa RCA is calculated according to the formula: $B\ RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_{wt}}$ where E_{ht} and E_{wht} respectively denote the export value in the industry of producing product h in year t of China and the rest of world, TE is the total export value. Firm-level control variables contain total factor productivity (TFP), capital intensity (the ratio of capital and labour), total employment and average wage, all in log. All regressions include a constant term, product-fixed effects, firm-fixed effects, year-fixed effects and product-firm fixed effects. Significant at ***1%, **5%, and *10%. Robust standard errors are corrected for clustering at the firm-product level in parentheses.

Table A.3: Effects of RCA on product quality with an alternative estimation of TFP

Dependent variable	ln(quality)					
	$\sigma = 5$		$\sigma = 10$		$\sigma = \sigma_i$	
	(1)	(2)	(3)	(4)	(5)	(6)
$CLO\ RCA_D$	0.103***		0.008		0.110***	
	(0.028)		(0.055)		(0.024)	
$CLO\ RCA$		1.409***		0.630**		1.547***
		(0.117)		(0.221)		(0.159)
$ln(TFP)$	0.207***	0.205***	0.259***	0.258***	0.178***	0.176***
	(0.016)	(0.016)	(0.031)	(0.031)	(0.012)	(0.012)
$ln(Capital/Labour)$	0.073***	0.074***	0.065***	0.065***	0.084***	0.085***
	(0.009)	(0.009)	(0.018)	(0.018)	(0.008)	(0.008)
$ln(Employment)$	0.366***	0.361***	0.384***	0.382***	0.363***	0.358***
	(0.015)	(0.015)	(0.029)	(0.029)	(0.013)	(0.013)
$ln(WagePerWorker)$	0.145***	0.143***	0.164***	0.163***	0.146***	0.145***
	(0.011)	(0.011)	(0.022)	(0.022)	(0.010)	(0.010)
Product fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Product & Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	848,916	848,916	848,916	848,916	847,200	847,200
R-squared	0.790	0.790	0.808	0.808	0.831	0.831

Notes: This table examines the relationship between export quality and the RCA. For each firm-product-year triplet, the dependent variable is the estimated quality, given the value of the elasticity of substitution σ, 5, 10, and the estimates of Broda and Weinstein (2006). $CLO\ RCA\_D$ is a dummy variable, and it equals 1 when China does have a comparative advantage in the industry of producing product h in year t; otherwise, it takes a value of 0. $CLO\ RCA$ is calculated using the method developed by Leromain and Orefice (2014). Firm-level control variables contain total factor productivity (TFP) estimated by the method from Wooldridge (2009), capital intensity (the ratio of capital and labour), total employment and average wage which are all in log. All regressions include a constant term, product fixed effects, firm fixed effects and year fixed effects. Significant at ***1%, **5%, and *10%. Robust standard errors are corrected for clustering at the firm-product level in parentheses.

Table A.4: Effects of RCA on product quality with alternative estimations of quality

Dependent variable	ln(quality)	
	(1)	(2)
CLO RCA	0.968***	2.267***
	(0.280)	(0.125)
$ln(TFP)$	0.270***	0.177***
	(0.037)	(0.014)
$ln(Capital/Labour)$	0.054***	0.068***
	(0.016)	(0.008)
$ln(Employment)$	0.332***	0.359***
	(0.029)	(0.013)
$ln(WagePerWorker)$	0.144***	0.137***
	(0.024)	(0.009)
Product fixed effect	Yes	Yes
Firm fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
Product & Firm fixed effect	Yes	Yes
Observations	760,435	848,916
R-squared	0.816	0.738

Notes: This table examines the relationship between export quality and the RCA where the quality is estimated either by using the estimations of trade elasticities or from Fontagné et al. (2022) from our data using an IV estimation. Column 1 refers to the quality using elasticities from Fontagné et al. (2022) and column 2 refers to the quality estimated by using the IV estimation. *CLO RCA* is calculated using the method developed by Leromain and Orefice (2014). Firm-level control variables contain total factor productivity (TFP), capital intensity (the ratio of capital and labour), total employment and average wage, all in log. All regressions include a constant term, product fixed effects, firm fixed effects and year fixed effects. Significant at ***1%, **5%, and *10%. Robust standard errors are corrected for clustering at the firm-product level in parentheses.

Table A.5: Results of using the CLO RCA at HS 4-digit level as an IV for RCA

Dependent variable	ln(quality)					
	$\sigma = 5$		$\sigma = 10$		$\sigma = \sigma_i$	
	(1)	(2)	(3)	(4)	(5)	(6)
$B\ RCA$	0.171***		0.133***		0.152***	
	(0.021)		(0.039)		(0.030)	
$CLO\ RCA$		1.685***		1.312***		1.504***
		(0.201)		(0.380)		(0.294)
$ln(TFP)$	0.231***	0.224***	0.298***	0.293***	0.188***	0.182***
	(0.018)	(0.018)	(0.034)	(0.034)	(0.013)	(0.013)
$ln(Capital/Labour)$	0.079***	0.077***	0.072***	0.070***	0.089***	0.087***
	(0.010)	(0.010)	(0.018)	(0.018)	(0.008)	(0.008)
$ln(Employment)$	0.358***	0.364***	0.377***	0.381***	0.359***	0.364***
	(0.016)	(0.015)	(0.029)	(0.029)	(0.013)	(0.013)
$ln(WagePerWorker)$	0.139***	0.142***	0.158***	0.161***	0.142***	0.145***
	(0.012)	(0.012)	(0.023)	(0.023)	(0.010)	(0.010)
Product fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
P & F fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
K-P rk LM χ^2 statistic	$4215.53^\dagger$	$25908.24^\dagger$	$4215.53^\dagger$	$25908.24^\dagger$	$4226.66^\dagger$	$25914.38^\dagger$
K-P rk Wald F statistic	$4603.51^\dagger$	$1.2e+05^\dagger$	$4603.51^\dagger$	$1.2e+05^\dagger$	$4616.10^\dagger$	$1.2e+05^\dagger$
Observations	814,077	814,077	814,077	814,077	812,384	812,384
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000

Notes: This table examines the relationship between export quality, the Balassa RCA index, and the CLO RCA index at HS 6-digit level by using the CLO RCA at HS 4-digit level as an instrument variable. The dependent variable is the estimated quality, given the value of the elasticity of substitution σ, 5, 10, and the estimates of Broda and Weinstein (2006). New RCA is calculated using the method developed by Leromain and Orefice (2014). Balassa RCA is calculated according to the formula: $B\ RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_{wt}}$ where E_{ht} and E_{wht} respectively denote the export value in the industry of producing product h in year t of China and the rest of world, TE is the total export value. Firm-level control variables contain total factor productivity (TFP), capital intensity (the ratio of capital and labour), total employment and average wage, all in log. All regressions include a constant term, product-fixed effects, firm-fixed effects and product-firm fixed effects. Significant at ***1%, **5%, and *10%. † indicates significance at the 0.01 per cent level (p-values< 0.00001). Robust standard errors are corrected for clustering at the firm-product level in parentheses.

Table A.6: Results of first stage regression of RCA using the CLO RCA at HS 4-digit level

Dependent variable	RCA					
	(1)	(2)	(3)	(4)	(5)	(6)
$CLO\ RCA_4$	9.789***	0.993***	9.789***	0.993***	9.814***	0.994***
	(0.142)	(0.003)	(0.142)	(0.003)	(0.143)	(0.003)
$ln(TFP)$	-0.038***	-0.0002	-0.038***	-0.0002	-0.039***	-0.0002
	(0.010)	(0.002)	(0.010)	(0.002)	(0.010)	(0.0002)
$ln(Capital/Labour)$	-0.016	-0.0004***	-0.016	-0.0004***	-0.016	-0.0004***
	(0.007)	(0.0001)	(0.007)	(0.0001)	(0.007)	(0.0001)
$ln(Employment)$	0.038**	0.001**	0.038**	0.001**	0.037**	0.0005*
	(0.012)	(0.0002)	(0.012)	(0.0002)	(0.012)	(0.0002)
$ln(WagePerWorker)$	0.025***	0.0004***	0.025***	0.0004***	0.024***	0.0004***
	(0.007)	(0.0001)	(0.007)	(0.0001)	(0.007)	(0.0001)
Observations	810,171	765,932	810,171	765,932	808,478	764,244
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000

Notes: This table shows the results of the first stage regression of the RCA measure by either the Balassa RCA index or the CLO RCA index at the HS 6-digit level when exploring the relationship between export quality and the RCA by using the CLO RCA at HS 4-digit level as an instrument variable. The numbers of the columns correspond to Table A.5. Columns 1, 3 and 5 are for the Balassa RCA index while columns 2, 4 and 6 are for CLO RCA. CLO RCA is calculated using the method developed by Leromain and Orefice (2014). RCA indicates China's relative ability to produce goods in one industry compared to the rest of the world. Firm-level control variables contain total factor productivity (TFP), capital intensity (the ratio of capital and labour), total employment and average wage, all in log. All regressions include a constant term, product-fixed effects, firm-fixed effects and product-firm fixed effects. Significant at ***1%, **5%, and *10%. Robust standard errors are corrected for clustering at the firm-product level in parentheses.

Table A.7: Results of balanced sample test

Dependent variable	ln(quality)					
	$\sigma = 5$		$\sigma = 10$		$\sigma = \sigma_i$	
	(1)	(2)	(3)	(4)	(5)	(6)
$CLO\ RCA_D$	0.141***		0.058		0.148***	
	(0.042)		(0.081)		(0.036)	
$CLO\ RCA$		1.605***		0.860*		1.516***
		(0.182)		(0.348)		(0.267)
$ln(TFP)$	0.125***	0.124***	0.182***	0.182***	0.087***	0.086***
	(0.021)	(0.021)	(0.040)	(0.040)	(0.016)	(0.016)
$ln(Capital/Labour)$	0.071***	0.072***	0.064	0.065	0.072***	0.074***
	(0.017)	(0.017)	(0.033)	(0.033)	(0.015)	(0.015)
$ln(Employment)$	0.403***	0.395***	0.461***	0.457***	0.381***	0.374***
	(0.026)	(0.026)	(0.049)	(0.049)	(0.022)	(0.022)
$ln(WagePerWorker)$	0.139***	0.137***	0.170***	0.169***	0.137***	0.135***
	(0.020)	(0.020)	(0.037)	(0.037)	(0.017)	(0.017)
Product fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Product & Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	343,639	343,639	343,639	343,639	343,639	343,639
R-squared	0.760	0.760	0.779	0.779	0.791	0.791

Notes: This table examines the relationship between export quality and the CLO RCA using the balanced sample (all firms were active during the sample period). For each firm-product-year triplet, the dependent variable is the estimated quality, given the value of the elasticity of substitution σ, 5, 10, and the estimates of Broda and Weinstein (2006). *CLO RCA_D* is a dummy variable, and it equals 1 when China does have a comparative advantage in the industry of producing product h in year t; otherwise, it takes a value of 0. *CLO RCA* is calculated using the method developed by Leromain and Orefice (2014). Firm-level control variables contain total factor productivity (TFP), capital intensity (the ratio of capital and labour), total employment and average wage, all in log. All regressions include a constant term, product fixed effects, firm fixed effects and year fixed effects. Significant at ***1%, **5%, and *10%. Robust standard errors are corrected for clustering at the firm-product level in parentheses.