Comparative Advantage and Quality with Heterogeneous Firms

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Abstract

This thesis is the first to explain the relationship between comparative advantage and heterogeneous firms' quality choices theoretically and empirically. It investigates how firms' quality varies across industries and firms' investment in quality.

Chapter 2 examines how comparative advantage can affect firms' quality. It extends a Heckscher-Ohlin model with heterogeneous firms where they are allowed to choose the quality of the product they offer. The theoretical results show that when a trade happens, more productive firms choose to export while serving the domestic market, less productive firms serve the domestic market only and the least productive firms exit the market. Meanwhile, trade liberalisation leads to an increase in product quality for exporters and a decrease in product quality for non-exporters. Furthermore, the model also reveals that exporters in a comparative advantage industry improve their quality by more than those in a comparative disadvantage industry, and non-exporters in a comparative advantage industry lower their quality by more than those in a comparative disadvantage industry.

One of the important stylised facts of the literature is that firms that offer higher-quality products charge higher prices. However, the framework developed in Chapter 2, featuring increasing returns and monopolistic competition, presents the opposite result. I decided to improve it in Chapter 3 by introducing different intermediate inputs so that the framework reproduces this stylised fact. Simultaneously, it still concludes that exporters in a comparative advantage industry improve their quality

more while non-exporters in a comparative advantage industry lower their quality by more. In addition, it also reveals a higher aggregate or average quality in a comparative advantage industry, which can potentially create additional welfare gains from trade.

Chapter 4 provides the empirical evidence for one of the main predictions in the theoretical models. It uses detailed Chinese firm-transaction-level data and firm-level production data and shows that Chinese exporters invest in product quality more in a comparative advantage industry than those in a comparative disadvantage industry conditional on productivity. It also suggests that China's comparative advantage stems from different factor endowments across countries, consistent with the theoretical models analysed in Chapter 2 and 3. In addition, it further explores the heterogeneity of this enhanced effect on export quality across the comparative advantage distribution and destinations and how it varies between firms with different export intensities and within firms for different varieties.

Declaration

I certify that the thesis I have presented for examination for the PhD degree of the University of Sheffield is solely my own work other than where I have clearly indicated that it is the work of others (in which case the extent of any work carried out jointly by me and any other person is clearly identified in it). The copyright of this thesis rests with the author. Quotation from it is permitted, provided that full acknowledgement is made. This thesis may not be reproduced without my prior written consent. I warrant that this authorisation does not, to the best of my belief, infringe the rights of any third party. I declare that my thesis consists of about 45,403 words.

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Chapter 1

Introduction

1.1 Motivation and Objectives

Understanding the role of product quality is one of the major challenges in international economics. As a key feature of products, quality is different across firms and is the key to understanding firms' performances (e.g. Kugler & Verhoogen, 2009; Amiti & Khandelwal, 2013; Manova & Yu, 2017). On the supply side, firms face decisions over product quality and may seek to increase it to attract consumers. On the demand side, the data supports that consumers value product quality, and there is a positive relationship between per capita income and aggregate demand for quality (e.g. Hallak, 2006). Product quality is a significant and promising research direction in international trade.

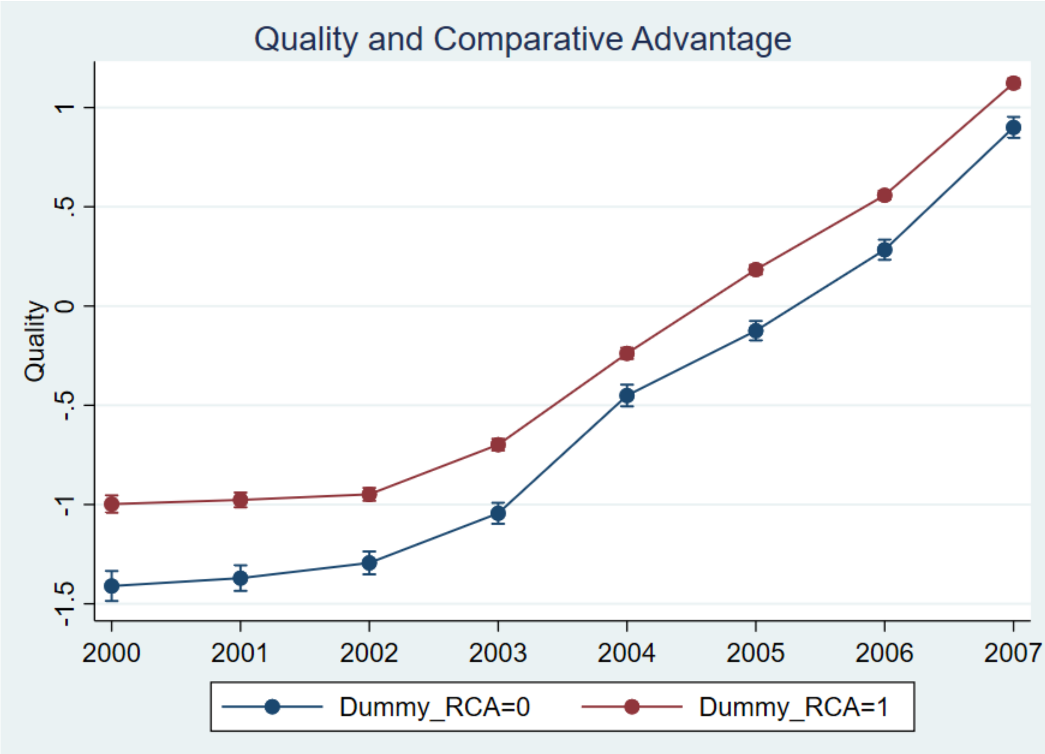
Product quality has been researched empirically at different levels, firm, industry, and country levels. Past work suggests large differences across countries regarding the quality of products they produce, export and even import. Schott (2004) finds a positive relationship between export unit values and a country's relative physical and human capital endowments. Hummels and Klenow (2005) show that richer countries exported more products with relatively high prices. Recent research also reveals the importance of the heterogeneous product quality of firms. More productive and larger firms produce higher-quality products (e.g. Kugler & Verhoogen, 2012; Manova & Zhang, 2012).

However, suppose the firm is altering product quality to respond to international trade. Does this response also differ across industries within one country? If so, what is the reason for the variation? The literature has not answered these questions and omits essential differences in product quality across industries due to international trade. Figure 1.1 shows the substantial variation in export product quality between industries in China from 2000 to 2007. The industries are classified into two categories, those in which the country reveals a comparative advantage and those in which the country does not reveal a comparative advantage. The comparative advantage is defined by using the Balassa index. Product quality is estimated using the method from A. K. Khandelwal, Schott, and Wei (2013). During the time period, the average quality in two kinds of industries both increased. However, it is unclear why this quality is higher in comparative advantage industries relative to comparative disadvantage industries.

Including the quality variation between industries will be important for understanding a country's trade pattern, which is important for trade liberalisation policies and a country's trade pattern. The policymakers would know better about their countries' advantages in providing higher-quality products in certain industries and could encourage more firms to enter and compete with foreign firms. This will also have implications for welfare.

This thesis's first and most significant objective is to construct a tractable theoretical model to understand how firms' responses to trade liberalisation over product quality differ across the export status and industries. Based on the framework of Bernard, Redding, and Schott (2007), I introduced endogenous firm quality choice

Figure 1.1: The variation in the quality between industries



This figure shows the variation in the exporting product quality between industries from 2000-2007. The industries are classified into two categories by using the Balassa index. Product quality is estimated by using the method from A. K. Khandelwal et al. (2013), given the value of the elasticity of substitution σ equals 5.

into the Heckscher-Ohlin model (henceforth, the H-O model). The model follows the H-O model, therefore, outlines the importance of factor-driven comparative advantage in shaping a firm's decisions regarding product quality. Firms then alter their product quality to respond to international trade according to their export status and the industries they produce. It is expected to obtain some novel predictions while confirming several predictions from previous works. First, the model shows that only the most productive firms can export, consistent with Melitz (2003). As in Bernard, Redding, and Schott (2007), it also presents differences in the production unit-input threshold (with it, firms observe zero profit in production) and the exporting unit-input threshold (with it, exporters find no difference between exporting and serving the domestic market only) across industries. The production threshold is lower, and the exporting threshold is higher in a country's comparative advantage. Furthermore, several novel and interesting propositions are developed. The model shows that exporters (more productive firms) improve product quality in a comparative advantage industry by more, and non-exporters (less productive firms) produce lower-quality products from autarky to costly trade conditional on productivity. Additionally, these different responses over product quality finally contribute to a higher aggregate or average quality level in a country's comparative advantage industries.

The second objective of this thesis is to test main and novel predictions from the theoretical model. To do this, I apply the framework to Chinese firms. China is a particularly useful setting for this. First, it provides much information about firms' transactions and production. This is necessary to conduct the following empirical tests, including quality estimations and construction of control variables. Second, China's WTO accession in 2001 provides a good example of trade liberalisation. We can see that the exporting product quality has increased since 2002, as shown in Figure 1.1. Lastly, China was famous for its cheap labour at the beginning of this century, attracting many foreign firms to come and set up factories (Zou, Shen, Zhang, & Lee, 2022). Compared to other production factors, labour was more abundant in China, and the industries using labour intensively would have a comparative advantage in my model's setting. This way, it can provide evidence for propositions from the model by comparing product quality across industries.

With detailed Chinese transaction-level and firm-level data, the empirical analysis tends to treat the world consisting of China and the rest of the world. However, given the data, the thesis can test one of the main predictions of the model, exporters produce and export higher-quality products in a country's comparative advantage industry than those in a comparative disadvantage industry. The results highlight that Chinese exporters provide higher-quality products in a comparative advantage industry. Furthermore, the data also shows that a country's relative factor endowment is related to its comparative advantage.

1.2 Overview of the Thesis

The thesis is structured as follows. Chapter 2 presents the extended H-O model where heterogeneous firms can choose their endogenous product quality. It derives a set of theoretical predictions that help us understand the effects of comparative advantage on firms' quality choices. Based on the model in Chapter 2, Chapter 3 further improves it by allowing more productive firms to produce higher-quality products using more expensive (suggesting higher-quality) intermediate inputs and charging a higher price, consistent with facts found in the existing studies. It also obtains all the predictions in Chapter 2 and proposes a higher aggregate or average quality level in a country's comparative advantage industry. Then Chapter 4 utilises an empirical framework to test how Chinese exporters' product quality varies across industries.

The models in Chapters 2 and 3 are based on the H-O model, which is applied in many works. As it includes more than one production factor and industry, existing literature shows large differences across industries in international trade. This thesis follows the same idea to detect how firms' quality choice differs across industries.

Chapter 4 uses the combined panel data covering export transactions from Chinese Customs Trade Statistics and firm-level information from the National Bureau of Statistics of China from 2000 to 2007. In addition, this chapter uses Ordinary Least Squares (OLS) estimation with fixed effects to examine how the comparative advantage affects exporters' quality. It also uses a Two-Stage Least Squares (2SLS) estimator to reveal that the comparative advantage is related to the relative factor endowment and overcome the endogeneity problem.

The rest of this section provides an overview of each chapter in the thesis.

1.2.1 Chapter 2 Overview

This chapter derives a new theoretical model based on the frameworks of Bernard, Redding, and Schott (2007) and Ferguson (2010). Based on the differences in relative factor endowment across countries and relative factor intensity across industries (H-O model assumptions), this chapter shows some findings consistent with the existing literature. Also, it presents some new findings to show the differences in product quality of firms across industries, which is the main contribution to the literature.

In terms of the model set-up, by extending the model developed by Bernard, Redding, and Schott (2007), the chapter analyses a case in which heterogeneous firms can invest in product quality. The chapter reveals that exporters (more productive firms) will raise product quality, while non-exporters will lower product quality in all industries, from autarky to costly trade. Moreover, these responses will differ across industries; exporters invest in product quality more, and non-exporters decrease their investment in product quality by more in a comparative advantage industry.

1.2.2 Chapter 3 Overview

This chapter investigates the same question theoretically as Chapter 2 does. However, as Melitz (2003), the model in Chapter 2 features that more productive firms can produce at a lower production cost. Thus, it shows that more productive firms can charge lower prices but provide higher-quality goods, which conflicts with the fact that firms providing high-quality products always charge higher prices revealed in many empirical works (e.g. e.g. Kugler & Verhoogen, 2012; Manova & Zhang, 2012). Therefore, I tended to improve the model in terms of this point in Chapter

3, and the new model is expected to obtain all predictions proposed in Chapter 2. Also, it arrives at a situation where more productive firms produce higher-quality products using higher-quality intermediate inputs and thus charge a higher price. Additionally, it also reveals that the aggregate quality of the industry would be improved from autarky to trade, and this improvement would be more pronounced in a comparative advantage industry.

It explains that firms have opportunities to export when countries are simultaneously open to trade. Exporting opportunities raise the ex-ante expected value of entering an industry, promoting greater firm entry, demanding more production factors, driving up the prices of production factors, increasing marginal costs of quality upgrading, and therefore forcing non-exporters to produce lower-quality products. Meantime, exporters with access to expanding markets find the increasing marginal returns of quality upgrading. As the effect of increasing marginal returns outweighs the effect of increasing marginal costs, exporters find it profitable to improve the quality and decide to improve their product quality. These responses are more pronounced in comparative advantage industries, for firms in a comparative advantage industry can benefit from producing goods at a lower cost compared to foreign competitors; however, at the same time, the comparative advantage gives a higher expected profit of entry, leading to more entrants and the thus higher relative price of the factor that is intensively used in the comparative advantage industry. Therefore, non-exporters suffer more from it, while exporters benefit more from exporting opportunities in comparative advantage industries. Furthermore, higher aggregate quality suggests the effect of improved quality of exporters and exit of the least productive firms outweighs the effect of lowered quality of non-exporters. Compared to comparative disadvantage industries, this improvement is larger in a country's comparative advantage industries.

1.2.3 Chapter 4 Overview

Chapter 4 tests one of the novel propositions derived from theoretical models: exporters improve product quality more in a comparative advantage industry. The contribution of this chapter is to provide evidence from China and shows that the comparative advantage is linked to the relative factor endowment, which echoes the theoretical model.

The unit values of products have been used as a coarse proxy for product qualities in literature. This chapter follows A. K. Khandelwal et al. (2013) in estimating quality and defining quality as unobserved attributes of a variety that make consumers willing to purchase relatively large quantities, holding prices across varieties constant. It also uses the Balassa Index of revealed comparative advantage, a standard measure used in trade literature to proxy those industries where a country reveals a comparative advantage, to measure the industry difference in one country. Using the panel transaction-level and firm-level data from China, this chapter reveals that China's comparative advantage is related to the relative factor endowment and emphasises that Chinese exporters raise product quality more in the comparative advantage industry, confirming the proposition drawn from the theoretical model.

In addition, this chapter explores the heterogeneity of the effects across the comparative advantage distribution and different destinations. It also compares the effects between firms with high and low export intensity and exploits within-firm variation in the quality of products with and without a comparative advantage. Furthermore, this chapter also applies different estimations of the total factor productivity (TFP), quality, revealed comparative advantage index and different samples to prove the results robust.

Chapter 2

Comparative Advantage and Quality Choice of Heterogeneous Firms

2.1 Introduction

Quality is a key feature of products and varies across firms within the same industry (e.g. Mussa & Rosen, 1978; Hallak, 2006). A substantial amount of academic work indicates that quality plays an important role in international trade. Linder (1961) first noted the role of quality as a determinant of the direction of trade and observed that rich countries produce and consume a higher share of high-quality goods. Empirically, the variation in product quality across countries and time-varying product quality have been linked to quantitative import restrictions (e.g. Aw & Roberts, 1986; Feenstra, 1998), trade patterns (e.g. Schott, 2004; Hallak, 2006), countries' growth (e.g. Hummels & Klenow, 2005), firms' export success (e.g. Brooks, 2006; E. A. Verhoogen, 2008), and countries' skill premia (e.g. E. A. Verhoogen, 2008). Amiti and Khandelwal (2013) find that lower tariffs affect firms' quality upgrading differently. Regarding firms initially close to the world technology frontier, lower tariffs promote the quality upgrading of products. In contrast, they discourage the quality upgrading of products that are distant from the world frontier. Bas and Strauss-Kahn (2014) reveal that the trade liberalisation related to restrictions on imports making more inputs available for domestic firms increases the number of products produced and exported, which inspires quality upgrading. Fieler, Eslava, and Xu (2018) show that the most productive firms self-select into providing higher-quality products. All of the above agree that product quality plays an important role in trade. This chapter focuses on how the country, industry, and firm characteristics interact in general equilibrium to determine a nation's responses regarding the quality choice to trade openness.

Although firm heterogeneity exists in the real world, recent studies have paid more attention to it only after revealing that most firms do not trade at all and that after trade liberalisation, there is a substantial reallocation of resources that happens within the industry. The increasing availability of micro-data on manufacturing plants also has fuelled a growing literature on heterogeneity at the firm level. Melitz (2003) introduces firm heterogeneity to build a new theoretical model and uses the new feature to explain the change in the distribution of active firms and productivity growth caused by trade. Bernard, Eaton, Jensen, and Kortum (2003) capture the productivity differential of firms by using U.S. plant-level data and illustrate that this differential leads to different market power.

Considering firm heterogeneity, more studies have realised the importance of quality in the trade and explored how product quality varies across firms. E. A. Verhoogen (2008) analyses Mexican manufacturing data and reports that more productive plants produced higher-quality goods than less productive plants. Kugler and Verhoogen (2012) suggest that larger firms produce higher quality goods and charge a relatively high price. Baldwin and Harrigan (2011) propose a modification of the model of Melitz (2003) and show that the firms with the lowest quality-adjusted price charge the highest market prices. Then Manova and Zhang (2012) obtain several facts from Chinese data and suggest that more productive firms produced high-quality products using high-quality inputs. Antoniades (2015) shows that the most productive firms raise product quality and prices while less productive firms behave oppositely or exit the market. Fan, Li, and Yeaple (2018) find that China's tariff reductions allow firms' quality upgrading, which was concentrated in the least productive Chinese exporters. All of the above emphasising the importance of the product quality of heterogeneous firms motivate me to think about this chapter.

On the other hand, many papers highlight the role played by the differences between industries and countries regarding the impact of trade openness. Krugman (1980) reports that countries traded more the more similar they were (regarding the number of labour within one country). However, Schott (2004) suggests that with products, high-wage countries used their endowment advantage (capital and skill abundance) to add features or quality to their varieties which were not present among the varieties produced in low-wage countries. Hummels and Klenow (2005) show that richer countries exported more products with relatively high prices. Hallak (2006) points out that rich countries tended to import relatively more from countries that produced high-quality goods. Bernard, Redding, and Schott (2007) build the basic H-O model incorporating firm heterogeneity in productivity to examine how the effects caused by trade openness vary across industries. It shows an improvement in average productivity in all industries, which is more pronounced in the comparative advantage industry. It also suggests a new reallocation of factor endowments from the comparative disadvantage industry towards the comparative advantage industries generating additional welfare gains from the trade.

Despite extensive literature documenting large heterogeneity in trade across industries and product quality following a trade liberalisation episode, few papers have examined how firms adjust product quality in response to trade liberalisation and how this varies across industries. A. Khandelwal (2010) uses U.S. product-level import data to show that quality ladders vary across industries leading to different relationships between prices and the related qualities for industries. Navas (2018) establishes a theoretical model incorporating both innovation and heterogeneous firms to illustrate that an increase in innovation can be caused by trade openness. The increase is more in the comparative advantage industry. However, innovation in his paper contributes to firms' productivity rather than quality improvements, and assumptions in his paper restrict the possibility for every firm to make the innovation. His paper inspired me to relax these assumptions and create a new model where I treat quality improvement as the result of product innovation. With a focus on product quality, this chapter aims to build a tractable theoretical model allowing all firms to choose their endogenous qualities to illustrate how firms' potential responses over product quality to international trade can differ across industries.

Schott (2004), Hummels and Klenow (2005) and Hallak (2006) conclude that the imports from the capital- and skill-abundant countries are generally charged at a higher price than imports from labour-abundant countries. This price differential suggests a vertical differential of products. The relationship between export prices and the relative endowment of exporters seems to echo a key implication of Neoclassical trade theory (it explains the main reason countries trade as they are different). As a substantial amount of studies use export price as a proxy of quality, all these findings support the idea that countries produce relatively high-quality varieties generated from their endowment advantage to compete with firms in other countries in international trade.

Following this, I build a two-country, two-industry and two-factor model (the standard H-O model) with heterogeneous firms allowing them to choose endogenous qualities for products. Once the upgrading cost is made, product quality affects consumers symmetrically in both countries. Countries feature different factor endowments used to produce goods in both industries, but industries vary in relative factor intensity used in production. Each firm produces a single differentiated variety with a certain quality they can rely on to maximise their profits. To enter an industry, firms have to pay a sunk fixed cost. Their marginal production costs are noticed only after the sunk cost is paid. To enter exporting market in a costly trade model, they also need to pay another fixed cost and variable costs (the "iceberg" form). Then the model shows that exporters raise their product quality while non-exporters decrease their product quality to respond to trade liberalisation. Moreover, these responses are more pronounced in a country's comparative advantage industry.

The rest of the chapter is organised as follows. Section 2 reviews the related literature. Section 3 describes the autarky model to show how firms produce goods and choose the quality of goods. Section 4 presents the situation when there is a costless trade. Section 5 illustrates how firms adjust their product quality when the trade is costly. Section 6 summarises the propositions from the model. The last section concludes. The proofs are included in the appendix.

2.2 Literature Review

Melitz (2003) as the most important trade model recently introduces firm heterogeneity into the model of Krugman (1980), and many recent models are construed based on it. The model assumes that firms can only observe their productivity that remains fixed in their lifetime after paying a sunk market entry cost from a fixed distribution. The least effective firms cannot earn enough profits to cover that cost. In other words, there is a selection of firms (i.e. the industry selection effect). In terms of all surviving firms, they also have to face a constant probability of an exogenous shock that makes them quit the market in each period. Firms enter the market until the expected payoff equals the entry cost. When countries move towards open economies, the exposure to trade gives firms access to more markets, which motivates them to export. However, this model assumes that firms must pay another fixed cost for exporting. As they already know their productivity, they must consider whether the profits gained from foreign markets can also cover the exporting cost. This novel feature indicates that only those with relatively high productivity of all active firms would export, and the rest would not (i.e. the export selection effect). The implication behind these two selections is the inter-firm reallocations of production factor (in this model, labour is the only factor) and market share towards the most efficient firms. As a result, the least productive firms exit and industry productivity growth can be observed. This growth can contribute to extra welfare gains. In addition, a steady-state mass of firms active in the industry induces the mass of new entrants who draw productivity exceeding the production productivity cut-off equals the mass of dead firms in each period.

This model also illustrates how the change in trade costs can impact firms. It shows that the reductions in trade costs make more firms find exporting profitable. Hence, firms with higher productivity who used to be non-exporters start exporting. This change causes a higher demand for production factors (labour in this model) and thus bids up the rewards of factors. As a result, all firms pay more for production factors. Firms that used to be marginal (i.e. the firms with the least productivity) in each industry cannot cover the costs anymore and exit the markets, which induces market share and production factors are both reallocated towards the most productive firms. As a final result, aggregate productivity is higher.

This model shows the interaction between international trade and firm heterogeneity. It explains the fact about firm heterogeneity in trade recorded in many papers. Roberts and Tybout (1997) find that entry into the export market asks firms to pay a sunk cost, which leads to only the most productive firms finding it profitable to export. This finding induces that firms are heterogeneous in productivity, and not all firms can participate in export markets. Bernard et al. (2003) find that productivity differs dramatically across firms within one industry, and this differential generates firms' different market power. More studies observe that an increase in aggregate productivity happens following trade openness. This increase is due to the successful entry into exporting markets of high-productivity firms and the exit of low-productivity firms. Pavcnik (2002) suggests that Chile's trade liberalisation caused a relatively great survival and growth of productive firms, which can be seen as the main reason for the aggregate productivity growth. Trefler (2004) finds that a greater increase in aggregate productivity following Canadian tariff reductions is due to resource and market share reallocating from the least productive firms to the most productive firms. Furthermore, it also provides a tractable trade model for a substantial number of further studies to extend.

The rest of this chapter will then be divided into two subsections as this chapter unites two strands of the international trade literature, the models incorporating product quality of firms and the models emphasising differences between countries' factor endowments.

2.2.1 Models Incorporating quality

Ferguson (2010) adds endogenous quality choice for all firms and relative upgrading costs. Under his model, producers can choose quality, and consumers feel better off when they derive utility from consuming high-quality products. Thus, according to the CES utility function, higher quality can contribute to higher demand in all markets firms serve but does not affect prices. The model assumes a positive relationship between product quality and related upgrading costs. It predicts that firms tend to choose different product qualities to maximise profits (quality choice increases with a firm's productivity). When the economy opens to trade, only the most productive firms choose export (i.e. the export selection effect), and marginal firms who used to produce and sell goods cannot survive anymore (i.e. the industry selection effect).

Moreover, those firms respond to quality choice, assuming that a firm's product quality affects consumers symmetrically in all counties. More specifically, the most productive firms, exporters, tend to raise their product quality, while less efficient firms serving only the domestic markets lower their product quality. It explains the different upgrading decisions by two countervailing channels. First, trade openness reduces the price index, which leads to lower demand for all firms in one country. However, being open to trade gives extra markets to exporters. Overall, the positive effect outweighs the negative price index effect, so exporters decide to improve the quality. However, non-exporters can only be affected negatively by the price index and lower their quality. The model also predicts that industries, where upgrading is more important, respond less elastically to trade liberalisation.

To explain spatial variation in prices, Baldwin and Harrigan (2011) mortify the model of Melitz (2003) by introducing product quality. However, given the interest of the authors is not to explore how firms choose quality, firms are not assumed to choose product quality endogenously. Higher quality is assumed to come with higher marginal costs. A similar positive relationship is common in the literature, including E. A. Verhoogen (2008), Ferguson (2010) and Antoniades (2015). They draw the proposition from the model that the firms with the lowest quality-adjusted price charge the highest market prices. This proposition can then be used to explain the fact they found in the data that there is a positive relationship between the average export unit value and distance.

Kugler and Verhoogen (2012) made an extension of the model of Melitz (2003) by incorporating an endogenous choice of input and output quality, which is the closest to my model. They propose two variants of the model. In the first one, firm capability and input quality are complements in producing output quality. In the second one, producing high-quality outputs requires high-quality inputs, and there is a fixed cost of producing quality. Both two variants of the model can be used to explain the observed facts from the data. The larger firms charge more for their outputs and pay more for their inputs. Thus, they suggest that producing high-quality outputs requires high-quality inputs and emphasise the important role played by the quality differences of both outputs and inputs in trade. They also used the measure of the scope of quality differential from Sutton (2001) to show the different relationships between prices and plant sizes across industries. However, they do not provide direct evidence for differences in product quality across industries. Furthermore, compared to their model, my model in this thesis considers more than one production factor, which is more suitable for exploring the research question of how product quality varies across industries.

Antoniades (2015) incorporates quality choice into the model of Melitz and Ottaviano (2008), and thus firms have to pay an endogenous sunk cost. Compared to the model of Melitz (2003), Melitz and Ottaviano (2008) uses the utility function featuring different preferences among varieties rather than the CES utility function. One feature of this utility function is that the linear market demand for each variety can be yielded, resulting in the mark-up responding to the toughness of competition in a market rather than a constant mark-up to firms' productivity (featured in Melitz (2003)).

In Antoniades (2015), product quality as a new component is added to the utility function. At the same time, a parameter that captures country-specific differences in the ability to innovate or in the innovation technology comes into the total cost of firms. This paper reveals that the competition caused by trade lowers the cost cut-off and expands the quality differential, similar to my model in this chapter. However, He not only proposes that the most productive firms raise their product quality and price to respond to the competition and the least productive firms respond in the opposite way or exit but also shows the same response of firms to the markup. As a whole, it predicts that average price and markup exhibit a U-shape response to the competition. In addition, this model also shows how the differences between trading partners can affect firms' performance. Compared to developing countries, trading with developed countries implies higher average quality, price, and markup due to a higher scope for quality differentiation of all firms serving the domestic market. Although this work presents a highly tractable model to investigate how firms respond to trade openness over quality choice, it omits the difference between industries which is the focus of this chapter.

Fieler et al. (2018) also develop a theoretical model incorporating the quality of inputs and outputs. With the focus on input quality, they find that tariff reductions on inputs allow firms to increase their output quality. This improvement also requires a higher quality of other inputs, contributing to quality improvement for final-output suppliers. However, compared to my model, they emphasise the role played by the input in firms' quality decisions for their outputs and omit the differences in quality across industries.

2.2.2 Models Incorporating Factor Endowments

Neoclassical trade theory outlines the importance of comparative advantage in determining trade patterns across countries. These theories emphasise inter-industry trade: countries will export the goods in which the economy has a comparative advantage and import others. As one of the theories, the Ricardian model reveals that comparative advantage comes from technological differences. In contrast, the H-O model states that it is due to the endowment differences in countries and the different factor intensity across industries. The H-O model features more than one country, factor endowment and industry. Relative endowment varies across countries, and production requires different relative factor intensities in different industries. For simplicity, I will focus on the condition with two factors, two industries and two countries where the production requires a combination of two factors. Factors can only move across industries within one country. At the equilibrium, Factor Price Equalisation (FPE) prevails when the economies do not experience factor intensity reversals, and factor endowments in both countries are similar. Countries produce and export goods that use the abundant factor more intensively and import goods that use the scarce factor more intensively. This specialisation increases the relative demand for the abundant factor, which bids up the relative rewards of this factor within one country. Finally, the model draws that only people who own the relatively abundant factor in the economy can be benefited from international trade.

Helpman and Krugman (1987) incorporate increasing returns to scale into the Neoclassical, which features endowment-based comparative advantage and shows the same pattern of inter-industry trade as the H-O model. Bernard, Jensen, Redding, and Schott (2007) use U.S. manufacturing data to show that a difference in factor intensity between exporters and non-exporters cannot be neglected. It shows that the U.S. exporters focused more on capital- and skill-intensive products. Bernard, Jensen, and Schott (2006) highlight that if factor intensity used for production can feature their products, the U.S. firms are connected with products with U.S. comparative advantage. Although the results obtained by many empirical studies conflict with the Neoclassical trade theory, these findings revive its implications to some degree.

Bernard, Redding, and Schott (2007) incorporate an additional industry and production factor into the model of Melitz (2003), inducing that factor endowment differs across countries, and factor intensities vary across industries (the standard H-O model). They also reveal that the transition from autarky to costly trade can lead to the industry selection effect and the export selection effect. Aggregate productivity and firm output in both industries are higher than before. However, these are more pronounced in the comparative advantage industry (one industry where the production asks the more abundant factor in this country more intensively). They argue that this is since the expansion in expected profits caused by trade openness is relatively larger in this industry, as domestic firms can offer their products at a lower price than foreign counterparts. Furthermore, this inspires more firms to export in the comparative advantage industry, and bids up the relative reward of abundant factors within one country, which results in more firms cannot find production profitable and exiting; net job creation would be caused within the comparative advantage industry, and net job destruction would be resulted in within the comparative disadvantage industry. Hence, they emphasise within-industry reallocations and across-industry reallocations (towards the comparative advantage industry), contributing to a productivity differential in different industries. This difference in average productivity can magnify the ex-ante comparative advantage of countries. This magnified comparative advantage can provide an additional source of welfare gains from trade. This model reveals some novel findings of the change of relative reward of two factors. The conclusion that the real reward of abundant factors increases and the real reward of scarce factors decreases (the Stolper-Samuelson theorem) holds in the H-O model. Compared to this conclusion, in this model, increases in aggregate productivity derived from trade liberalisation drive down the prices of varieties and thus benefit both factors. The real reward of the abundant factor is improved more, and the productivity gains dampen the decline of the real reward of the scarce factor relative to its decline in the H-O model. The real scarce factor reward can be positively affected if productivity growth is strong enough. This potential means that everyone in the economy might be benefited from international trade in this model.

The relationship between export prices and the relative endowment of exporters that the imports from the capital- and skill-abundant countries are generally charged at a higher price than imports from labour-abundant countries documented in several works (i.e. Schott, 2004; Hummels & Klenow, 2005; and Hallak, 2006) seems to echo a key implication of the H-O framework. The relationship between export prices and the relative endowment of exporters seems to echo a key implication of the H-O framework. Hence, when I try to establish a model to explore how firms' quality choices differ across industries facing trade openness, combining the models of Bernard, Redding, and Schott (2007) and Ferguson (2010) seems quite promising. In other words, I add firms' endogenous quality choice for products and related upgrading costs into the model of Bernard, Redding, and Schott (2007). Consistent with their propositions, firms' export opportunities increase when countries simultaneously transition to costly trade. These opportunities raise the ex-ante expected value of entry, thus promoting greater entry and driving down the ex-post profits of firms. As a result, the maximum level of unit-input requirement of one unit output that firms need to survive is pushed down. As the production unit-input threshold decreases, the average unit input of firms in both industries decreases, thereby inducing aggregate (i.e. the industry level) productivity growth. I also obtain that the production unit-input threshold is lower and the exporting unit-input threshold is higher in a comparative advantage industry. Thus, a higher exporting firm ratio can be found in a comparative advantage industry.

This chapter mainly contributes to the different quality choices of firms across industries. Consistent with Ferguson (2010), I find different responses from firms over quality choice; more precisely, exporting firms decide to raise their quality and firms producing only for domestic markets tend to lower their quality choice to respond to trade openness. Considering the asymmetric export opportunities afforded by the comparative advantage, this model further provides more interesting and novel propositions for firms' product quality. Firstly, exporting firms in the comparative advantage industry improve their product quality more. This conclusion is because the comparative advantage allows firms in the comparative advantage industry to produce at relatively low costs compared to foreign competitors. Therefore, exporters can benefit more from expanding markets by improving product quality. Secondly, non-exporters in the comparative advantage industry lower their product quality by more. More expanding markets indicate more potential profits, which drives more entrants in the comparative advantage industry. More product factors are required to satisfy the expansion of markets, driving up the relative price of the abundant factor. Therefore, increasing production costs and limited market size enforce non-exporters to lower product quality for survival.

2.3 The Autarky Model

Consider a world with two countries (Home country and Foreign country), two industries, two production factors (human capital and physical capital) and a continuum of firms with a heterogeneous unit-input requirement within both industries. The standard H-O assumption is assumed that consumer preferences and production technologies are homogeneous across countries, but factor endowment differs across countries and factor intensities used for production vary across industries. Factors of production can move freely between industries within countries but not across countries. H is used to index the Home country where the human capital is relatively abundant, and F denotes the Foreign country where the physical capital is relatively abundant. The above assumptions are the same as the model of Bernard, Redding, and Schott (2007). The section analyses the case where two countries do not trade with each other (i.e. autarky condition).

2.3.1 Set-up

Consider one country consisting of a continuum of consumers. Their utility comes from the consumption of the output of two industries denoted with $C_j, j = 1, 2$. The utility function is specified as the Cobb-Douglas function form:

$$U = (C_1)^{\mu}(C_2)^{1-\mu} \qquad 0 < \mu < 1 \tag{2.1}$$

where μ is the ratio of how much consumers in this country would like to spend on the output of industry 1 (in equilibrium, μ is also the proportion of total expenditure devoted to the goods of industry 1).

Each industry contains a continuum of differentiated varieties i with potentially differentiated qualities. Compared to Bernard, Redding, and Schott (2007), C_j is a consumption index defined over consumption of individual varieties, c_{ij} and its quality, q_{ij}, assumed to be observable to all. Varieties are aggregated according to the standard Constant Elasticity of Substitution across varieties (CES) functional form, with price index P_j in industry j, defined over prices of varieties, p_{ij} and its quality:

$$C_j = \left[\int_{i \in \Omega} q_{ij}^{\frac{\gamma}{\sigma}} c_{ij}^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}} \tag{2.2}$$

where σ ($\sigma > 1$) is the elasticity of substitution across varieties and γ ($\gamma > 1$) describes how much consumers care about product quality. For simplicity, I assume that the elasticity is the same in the two industries.

Consumers purchase goods in each industry, and thus the budget constraint for industry j can be expressed as:

$$E_j = \int_{i \in \Omega} p_{ij} c_{ij} di \tag{2.3}$$

Subject to the budget constraint, consumers choose the consumption bundles that maximise their utility. The optimal consumption of each variety i is the demand x_{ij} in the market, which can be solved as:

$$x_{ij} = \frac{p_{ij}^{-\sigma} q_{ij}^{\gamma}}{P_j^{1-\sigma}} E_j \tag{2.4}$$

where E_j represents the aggregate expenditure on output of the industry j (i.e. $E_1 = \mu R$, $E_2 = (1-\mu)R$, where R denotes total revenue of the economy). The price index, P_j, in industry j can be expressed as:

$$P_j = \left[\int_{i \in \Omega} p_{ij}^{1-\sigma} q_{ij}^{\gamma} di \right]^{\frac{1}{1-\sigma}} \tag{2.5}$$

To introduce differences in factor intensity across industries, I assume that firms use an intermediate input (y_j) for production and quality investment in industry j. This intermediate input is assumed homogeneous for all varieties within one industry but varies across industries. It is produced by using both human capital (S_j) and physical capital (K_j) according to the following Cobb-Douglas technology under perfect competition:

$$y_j = H_j S_j^{\beta_j} K_j^{1-\beta_j} \tag{2.6}$$

with $H_j = \beta_j^{-\beta_j}(1-\beta_j)^{\beta_j - 1}$ and β_j $(0 < \beta_j < 1)$ measuring the degree of the human capital intensity of intermediate inputs used in industry j. Assume that $\beta_1 > \beta_2$, implying that industry 1 is human capital used intensively. Perfect competition in the intermediate input implies:

$$p_{mj} = W_S^{\beta_j} W_K^{1-\beta_j} \tag{2.7}$$

where p_{mj} is the price of intermediate input used in industry j, W_S and W_K are prices of human capital and physical capital respectively.

Compared to Bernard, Redding, and Schott (2007), the total cost of firms' production (TC_{ij}) in the final good sector involves three parts, the fixed cost, the variable cost and the quality upgrading cost in each period, as firms can make the quality decision and thus pay for it. All costs are expressed in terms of the intermediate input. To produce a variety, all firms are asked for the same fixed cost, F_D, that is indifferent across industries and countries (an investment like the fees of maintenance of the basic machine or providing regular training classes for staff), but the variable cost and the upgrading cost f_{ij} vary with the firm's heterogeneous unit-input requirement $a \in (0, \infty)$. Since the total cost can be expressed as:

$$TC_{ij} = [x_{ij} a_i + f_{ij}(a_i) + F_D] p_{mj} \tag{2.8}$$

Following Melitz (2003), each firm is assumed to produce only one variety and they are the unique producers for their varieties. However, they now provide their varieties with endogenous qualities. Hence, to maximise the profit, they charge a standard monopoly price:

$$p_{ij} = \frac{\sigma}{\sigma - 1} a_i p_{mj} \tag{2.9}$$

2.3.2 Zero-profit condition

With the pricing rule, a firm's post-entry profit can be expressed as:

$$\pi_{ij} = \frac{p_{ij} x_{ij}}{\sigma} - [f_{ij}(a_i) + F_D] p_{mj} \tag{2.10}$$

Substitute the price function and demand function, and the profit function can then be simplified as:

$$\pi_{ij} = [q_{ij}^{\gamma} a_i^{1-\sigma} B_j - f_{ij}(a_i) - F_D] p_{mj} \tag{2.11}$$

where $B_j = \frac{(\frac{\sigma}{\sigma-1})^{1-\sigma}}{\sigma P_j^{1-\sigma}} E_j (p_{mj})^{-\sigma}$.

After entry, firms draw their unit-input requirement, a_i, from a distribution, $g(a)$, which is assumed to be common across industries and countries. Producing firms face a fixed probability of death caused by an exogenous shock in each period, δ. A firm drawing the unit-input requirement, a_i, produces within one industry j. To survive, its revenue at least has to cover its total production costs (i.e. $\pi_{ij} \geq 0$). This defines the zero-profit condition within industry j in autarky, such that:

$$\pi_{ij}(a_{Dj}^{aut}) = q_{ij}(a_{Dj}^{aut})^{\gamma} (a_{Dj}^{aut})^{1-\sigma} B_j p_{mj} - [f_{ij}(a_{Dj}^{aut}) + F_D] p_{mj} = 0 \tag{2.12}$$

where a_{Dj}^{aut} is the production unit-input threshold (with it, a firm can make zero profit from its production) of industry j in autarky.

Firms drawing their unit-input requirements below a_{Dj}^{aut} can engage in profitable production, while those with higher unit-input requirements exit the market immediately. The fixed production cost ensures this production selection in both industries.

2.3.3 Upgrading costs

To provide products of a certain quality, firms pay endogenous upgrading costs, f_{ij}. Thus, firms choose their optimal product quality and related costs by equalling the marginal benefit of increasing quality to its related marginal cost. The optimal choice of quality is the solution for profit maximisation and can then be defined by the first-order condition of Equation (2.11):

$$\frac{\partial \pi_{ij}}{\partial q_{ij}} = \gamma q_{ij}^{\gamma-1} a_i^{1-\alpha} B_j - \frac{\partial f_{ij}(q_{ij})}{\partial q_{ij}} = 0 \tag{2.13}$$

For simplicity, let us consider the following increasing and convex functional form for the upgrading costs from Ferguson (2010),

$$f_{ij}(q_{ij}) = q_{ij}^{\frac{1}{\theta}} \qquad \theta \in [0, 1] \tag{2.14}$$

where θ is a parameter common to all firms that determines the convexity of the cost to improve the quality. The larger is θ, the easier it is for firms to affect consumers' demand by investing in quality upgrading (i.e. the industry features a higher intensity of upgrading competition).

The assumed function of upgrading cost is then used to simplify Equation (2.14),

$$\gamma q_{ij}^{\gamma-1} a_i^{1-\alpha} B_j = \frac{1}{\theta} q_{ij}^{\frac{1-\theta}{\theta}} \tag{2.15}$$

Equation (2.15) describes the relationship between a firm's unit-input requirement and product quality further. When it is considered for the marginal firms (i.e. firms with the production unit-input threshold), it can be further substituted into the zero-profit condition, Equation (2.12) after replacing the upgrading costs,

$f_{ij}(a_{Dj}^{aut})$ with Equation (2.14):

$$q_{ij}(a_{Dj}^{aut})^{\frac{1}{\theta}} = \frac{1-\theta\gamma}{\theta\gamma}F_D \tag{2.16}$$

which represents the quality choice for the marginal firms.

2.3.4 Optimal quality choice

To derive firms' optimal quality choice, firstly, the relationship between the relative quality of firms with a_i compared to marginal firms and the relative unit-input requirements can be obtained from Equation (2.15). The function of marginal firms' product quality is then substituted into it to obtain a firm's optimal quality as:

$$q_{ij}(a_i) = (\frac{\theta\gamma}{1-\theta\gamma}F_D)^{\theta}(\frac{a_i}{a_{Dj}^{aut}})^{\frac{\theta}{1-\theta\gamma}(1-\sigma)} \tag{2.17}$$

According to Equation (2.14), the function of a firm's upgrading costs can be expressed as:

$$f_{ij}(a_i) = \frac{\theta\gamma}{1-\theta\gamma}F_D(\frac{a_i}{a_{Dj}^{aut}})^{\frac{1-\sigma}{1-\theta\gamma}} \tag{2.18}$$

where Equations (2.17) and (2.18) reveal that a firm's quality choice and associated upgrading cost are decreasing in its unit-input requirement, a_i, given $\sigma > 1$ and $\theta\gamma < 1$. Although firms with a lower unit-input requirement (i.e. more productive firms) have to face a higher marginal cost, they experience a higher marginal revenue. This higher marginal revenue more than compensate for the higher marginal cost. Additionally, quality choice and upgrading cost are both increasing in the production unit-input threshold of industry, a_{Dj}^{aut}. A lower production unit-input threshold induces more intensive competition, leading to a higher demand for the production factors, which drives up the prices of factors. Thus, firms have to survive the increased production costs and choose to lower their product quality.

These two expressions also reveal that the quality choice and upgrading cost for the marginal firm ($a_i = a_{Dj}^{aut}$) are independent of their unit-input requirement. This means that the lowest product quality is homogeneous across industries. But the different price of intermediate input captures that the associated cost differs across industries. Furthermore, $\partial q_{ij}/\partial\theta > 0$, $\partial q_{ij}/\partial\gamma > 0$, $\partial f_{ij}/\partial\theta > 0$ and $\partial f_{ij}/\partial\gamma > 0$ can be easily drawn from these two equations which mean that more intense quality upgrading (larger θ) or more attention consumers pay for product quality (larger γ) can encourage firms to invest more in quality upgrading and provide their varieties with higher quality.

2.3.5 Free entry condition

To enter an industry, firms must pay a fixed entry cost F_E units of intermediate input before finding out their unit-input requirement. Firms enter the market until the expected profit from entry discounted by the probability of natural death, δ, equals the sunk entry cost.[1] Thus, the free entry condition can be defined as:

$$E(\frac{\pi_{ij}}{\delta}) = F_E p_{mj} \tag{2.19}$$

which can be further expressed as:

$$\delta F_E p_{mj} = \int_0^{a_{Dj}^{aut}} [(q_{ij}^{\gamma} a_i^{1-\sigma} B_j - f_{ij}(q_{ij}) - F_D) p_{mj}] g(a) da \tag{2.20}$$

Substituting quality and related cost functions, assuming a Pareto distribution, $G(a) = a^k$, which is the cumulative distribution function for $g(a)$, where k is the shape parameter, and integrating over all surviving firms provide an analytical so-

[1] The assumption that the probability of death is exogenous, which is not related to firm characteristics, follows Melitz (2003) and Bernard, Redding, and Schott (2007).

lution for the production unit-input threshold in autarky:

$$(a_{Dj}^{aut})^k = \frac{\delta F_E}{F_D} \frac{k(1-\theta\gamma)+1-\sigma}{\sigma-1} \tag{2.21}$$

Let us assume that $\frac{k(1-\theta\gamma)}{\sigma-1} > 1$ to obtain a positive solution for the threshold. Otherwise, no firm finds the production profitable. Note in Equation (2.21) that $\partial a_{Dj}^{aut}/\partial\theta < 0$ and $\partial a_{Dj}^{aut}/\partial\gamma < 0$. This induces that more intense quality upgrading or more attention consumers pay for product quality can make the production unit-input threshold lower (i.e. a more competitive market). In addition, we can also find that there is no difference between the production unit-input thresholds in different industries in autarky.

2.4 The Costless Trade Model

This section focuses on firms' quality choice of a movement from autarky to free trade where firms are able to serve the foreign markets at no cost, meaning all producing firms would also export. The basic sets remain the same as under autarky. However, there are two new assumptions necessary. The first assumption is that the function of upgrading costs, f_{ij}, is not country-specific. This means that firms only have to pay for the quality upgrading once and can provide varieties with quality in both markets. This assumption is consistent with costs like $R\&D$ that are spent once, and then firms take advantage of it in all markets they serve. The second is that each firm's quality decision, q_{ij}, affects consumers symmetrically in both countries.

2.4.1 Zero-profit condition

Since firms face the same elasticity of demand in both the domestic and export markets, and trade is costless, profit maximisation implies the same equilibrium price in the two markets. With the pricing rule, the profit of each Home firm, it coming from both markets, can be expressed as:

$$\pi_{ij} = \frac{p_{ij} x_{ij}^H}{\sigma} + \frac{p_{ij} x_{ij}^F}{\sigma} - [f_{ij}(a_i) + F_D] p_{mj}^H \tag{2.22}$$

which can be further expressed as:

$$\pi_{ij} = [q_{ij}^{\gamma} a_i^{1-\sigma} B_j^H + q_{ij}^{\gamma} a_i^{1-\sigma} B_j^F - f_{ij}(a_i) - F_D] p_{mj}^H \tag{2.23}$$

where $B_j^H = \frac{(\frac{\sigma}{\sigma-1})^{1-\sigma}}{\sigma (P_j^H)^{1-\sigma}} E_j^H (p_{mj}^H)^{-\sigma}$ and $B_j^F = \frac{(\frac{\sigma}{\sigma-1})^{1-\sigma}}{\sigma (P_j^F)^{1-\sigma}} E_j^F (p_{mj}^F)^{-\sigma}$.

Notice, under free trade, all producing firms export, so the price level for one industry is the same across countries, inducing that $P_j^H = P_j^F$.

The production unit-input threshold within industry j in free trade, a_{Dj}^{ft}, denotes the unit-input requirement of the firms whose operating profits equal costs. Thus, the zero-profit condition is expressed as:

$$\pi_{ij}(a_{Dj}^{ft}) = q_{ij}(a_{Dj}^{ft})^{\gamma} (a_{Dj}^{ft})^{1-\sigma} (B_j^H + B_j^F) p_{mj}^H - [f_{ij}(a_{Dj}^{ft}) + F_D] p_{mj}^H = 0 \tag{2.24}$$

where $f_{ij}(a_{Dj}^{ft})$ is the specific upgrading cost of marginal firms.

2.4.2 Upgrading costs

Each firm tries to maximise its profit by choosing quality choices, and the first-order condition can define the optimal quality choice:

$$\frac{\partial f_{ij}(q_{ij})}{\partial q_{ij}} = \gamma q_{ij}^{\gamma-1} a_i^{1-\sigma} (B_j^H + B_j^F) = 0 \tag{2.25}$$

The same functional form for upgrading costs as in autarky is assumed:

$$f_{ij}(q_{ij}) = q_{ij}^{\frac{1}{\theta}} \tag{2.26}$$

2.4.3 Optimal quality choice

Similarly, each firm's optimal quality and its related cost can be solved as follows:

$$q_{ij}(a_i) = (\frac{\theta\gamma}{1-\theta\gamma}F_D)^{\theta}(\frac{a_i}{a_{Dj}^{ft}})^{\frac{\theta}{1-\theta\gamma}(1-\sigma)} \tag{2.27}$$

$$f_{ij}(a_i) = \frac{\theta\gamma}{1-\theta\gamma}F_D(\frac{a_i}{a_{Dj}^{ft}})^{\frac{1-\sigma}{1-\theta\gamma}} \tag{2.28}$$

As in autarky, both the quality function and the upgrading cost function found in the free trade induce that firm's quality choice is decreasing with their unit-input requirement, a_i and is increasing with the production unit-input threshold, (a_{Dj}^{ft}).

2.4.4 Free entry condition

Firms entering the market until the expected profit from entry equals costs implies the free entry condition:

$$E(\frac{\pi_{ij}}{\delta}) = F_E p_{mj}^H \tag{2.29}$$

which can be further expressed as:

$$\delta F_E P_{mj}^H = \int_0^{a_{Dj}^{ft}} [(q_{ij}^{\gamma} a_i^{1-\sigma}(B_j^H + B_j^F) - f_{ij}(q_{ij}) - F_D)p_{mj}^H]g(a)da \tag{2.30}$$

An analytical solution for the production unit-input threshold in the costless trade can be found:

$$(a_{Dj}^{ft})^k = \frac{\delta F_E}{F_D}\frac{k(1-\theta\gamma)+1-\sigma}{\sigma-1} \tag{2.31}$$

Once the economy opens to costless trade, all producing firms can obtain an extra demand in exporting market for their varieties and a decreased demand in the domestic market. However, consistent with Bernard, Redding, and Schott (2007), the above equation shows that the movement from autarky to the costless trade does not impact the production unit-input threshold. The main reason behind this result is that all producing firms export and are affected symmetrically by trade openness. Thus, the zero-profit condition and the free-entry condition remain the same. Furthermore, all firms keep their quality choice as same as the autarky one.

2.5 The Costly Trade Model

The assumption that trade is costless provides a good benchmark to understand better the model with endogenous firms' product quality. However, in fact, there are always additional costs of exporting. Thus, this section introduces the trade cost, including variable trade costs and an exogenous fixed cost, into the model. Firms that export need to pay extra fixed costs for entering the export markets,[2] F_X units of intermediate inputs (where $F_X > F_D$) and variable trade costs that are assumed to be of the "iceberg" form. The "iceberg" form induces that τ ($\tau > 1$) units of a variety must be exported for one unit to arrive at a particular destination.

The fixed costs imply that not every firm can serve both markets as in free trade. In other words, there is a selection for exporting as in Melitz (2003). Firms need to decide whether they should produce and export. An exporter is expected

[2]Exporters always face significant fixed costs. They have to learn about foreign markets, such as research the foreign regulatory environment and adapt the products to ensure that these products conform to foreign standards, set up a new distribution system and also research consumers' behaviours and inform them about their products.

to choose a higher quality for its product which can be applied in both markets compared to the quality of a firm with the same unit-input requirement that serves the domestic market only as an increased market demand makes quality upgrading more profitable.[3]

2.5.1 Zero-profit and No-difference condition

Profit maximisation implies that firms still charge prices as a constant markup over the marginal cost in the domestic market but set higher prices in exporting markets that reflect the increased marginal cost τ of serving these markets. Consumers' utility functions are assumed to be the same in the two countries, and an extra fixed cost has to be paid for exporting. There are no firms that export without providing products for the domestic market, as the costs of exporting exist. Thus, given the pricing rules, a domestic firm produces varieties with the quality, q_{ijd}, and thus earns profits, π_{ijd}. Meanwhile, exporters choose product quality, q_{ijx}, and provide their varieties in domestic and foreign markets. Hence, they can earn profits, π_{ijx}. The profit functions of these two types of firms can be expressed as follows:

$$\pi_{ijd}(a_i) = [q_{ijd}(a_i)^{\gamma} a_i^{1-\sigma} B_{jd} - f_{ijd}(a_i) - F_D] p_{mj} \tag{2.32}$$

$$\pi_{ijx}(a_i) = [q_{ijx}(a_i)^{\gamma} a_i^{1-\sigma} (B_{jd} + B_{jx}) - f_{ijx}(a_i) - F_D - F_X] p_{mj} \tag{2.33}$$

where $B_{jd} = \frac{(\frac{\sigma}{\sigma-1})^{1-\sigma}}{\sigma(P_j^H)^{1-\sigma}} E_j^H (p_{mj})^{-\sigma}$, $B_{jx} = (\tau)^{1-\sigma} \frac{(\frac{\sigma}{\sigma-1})^{1-\sigma}}{\sigma(P_j^F)^{1-\sigma}} E_j^F (p_{mj})^{-\sigma}$. f_{ijd} and f_{ijx} are the upgrading costs for domestic firms and exporters, respectively. Since exporters serve both markets, there is expected to be a stronger incentive for them to invest more in product quality to affect consumers' demand positively.

[3] In this section, results are all expressed for a home firm as an example. Foreign country obtains in the same situation.

The relationship between B_{jd}^H and B_{jx}^H can be found as:

$$B_{jx} = A_j^H B_{jd} \tag{2.34}$$

where $A_j^H = \tau^{1-\sigma}(\frac{P_j^H}{P_j^F})^{1-\sigma}\frac{E_j^F}{E_j^H}$, which can be defined as the profitability of serving the foreign market relative to the domestic one in industry j of the Home country.

As Melitz (2003) mentioned, there are robust empirical correlations between a firm's export status and its productivity, implying that a firm makes export decisions after gaining knowledge of its productivity. Thus, I assume that a firm that wants to export makes a fixed cost, but the export decision is made after the firm's unit-input requirement, a_i, is revealed. There are two important conditions for firms to make production and export decisions: zero-profit and no-difference conditions (i.e. when firms find no difference between exporting and not). A firm with the production unit-input threshold (a_{Dj}) always finds its revenue equaling its costs, which can be expressed as:

$$\pi_{ijd}(a_{Dj}) = q_{ijd}(a_{Dj})^{\gamma}(a_{Dj})^{1-\sigma}B_{jd}p_{mj} - [f_{ijd}(a_{Dj}) + F_D]p_{mj} = 0 \tag{2.35}$$

A firm with the exporting unit-input threshold (a_{Xj}) always finds no difference between being a purely domestic firm and serving both markets, which can be expressed as:

$$\begin{aligned} \pi_{ijd}(a_{Xj}) &= \pi_{ijx}(a_{Xj}) \\ [q_{ijd}(a_{Xj})^{\gamma}(a_{Xj})^{1-\sigma}B_{jd} - f_{ijd}(a_{Xj}) - F_D]p_{mj} &= [q_{ijx}(a_{Xj})^{\gamma}(a_{Xj})^{1-\sigma}(B_{jd} + B_{jx}) \\ &\quad - f_{ijx}(a_{Xj}) - F_X - F_D]p_{mj} \end{aligned} \tag{2.36}$$

Firms consider Equations (2.35) and (2.36) to decide whether they should produce and export. As exporters, on the one hand, they are expected to improve their quality from q_{ijd} to the level of q_{ijx}. On the other hand, they also have to pay the related upgrading costs, f_{ijx}. Meanwhile, firms that only serve the domestic market obtain the level of quality, q_{ijd}, thus paying the upgrading costs, f_{ijd}.

2.5.2 Upgrading costs

Each firm chooses its quality and pays its associated upgrading cost to maximise its post-entry profits. An optimal quality choice of domestic firms and exporters can be yielded by the following first conditions of their profit functions respectively:

$$\frac{\partial f_{ijd}(q_{ijd})}{\partial q_{ijd}} = \gamma(q_{ijd})^{\gamma} a_i^{1-\sigma} B_{jd} = 0 \tag{2.37}$$

$$\frac{\partial f_{ijx}(q_{ijx})}{\partial q_{ijx}} = \gamma(q_{ijx})^{\gamma} a_i^{1-\sigma} (B_{jd} + B_{jx}) = 0 \tag{2.38}$$

The same functional forms for the cost of upgrading are assumed for domestic firms and exporters.

2.5.3 Optimal quality choice

In terms of the quality function of domestic firms, combining the first order condition of a domestic firm, Equation (2.37), and the upgrading cost function gives us a link between B_{jd} and q_{id}:

$$q_{ijd} = (\theta\gamma a_i^{1-\sigma} B_{jd})^{\frac{\theta}{1-\theta\gamma}} \tag{2.39}$$

Then this relationship can be used in the zero-profit condition, Equation (2.35), to arrive at a domestic firm's optimal quality choice and thus its associated upgrading cost, which provides similar solutions as in the autarky and the costless trade model:

$$q_{ijd}(a_i) = (\frac{\theta\gamma}{1-\theta\gamma}F_D)^{\theta}(\frac{a_i}{a_{Dj}})^{\frac{\theta}{1-\theta\gamma}(1-\sigma)} \tag{2.40}$$

$$f_{ijd}(a_i) = \frac{\theta\gamma}{1-\theta\gamma}F_D(\frac{a_i}{a_{Dj}})^{\frac{1-\sigma}{1-\theta\gamma}} \tag{2.41}$$

From this quality function, it can be found that quality for the marginal firms drawing the production unit-input threshold (i.e. a_{Dj}) are the same across industries, which is the lowest level of quality. In addition, this minimum level of product quality is unchanged from the autarky to the costly trade.

For exporters, the relationship between B_{jd}, B_{jx} and q_{ijx} can be firstly derived using the first order condition of an exporter, Equation (2.38), and the upgrading cost function,

$$q_{ijx} = [\theta\gamma a_i^{1-\sigma}(B_{jd}+B_{jx})]^{\frac{\theta}{1-\theta\gamma}} \tag{2.42}$$

which can be further expressed as using the relationship between B_{jd} and B_{jx}, Equation (2.34) as:

$$B_{jd} = \frac{1}{\theta\gamma}\frac{1}{a_i^{1-\sigma}}\frac{1}{1+A_j^H}(q_{ijx})^{\frac{1-\theta\gamma}{\theta}} \tag{2.43}$$

An exporter's optimal quality and its associated upgrading cost are then found by using the above relationship and the condition where a firm finds no difference between being a domestic firm and an exporter described in Equation (2.38),

$$q_{ijx}(a_i) = (\frac{\theta\gamma}{1-\theta\gamma}F_X)^{\theta}(\frac{a_i}{a_{Xj}})^{\frac{\theta}{1-\theta\gamma}(1-\sigma)}[1-(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-\theta} \tag{2.44}$$

$$f_{ijx}(a_i) = \frac{\theta\gamma}{1-\theta\gamma}F_X(\frac{a_i}{a_{Xj}})^{\frac{1-\sigma}{1-\theta\gamma}}[1-(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-1} \tag{2.45}$$

Equations (2.40), (2.41), (2.44) and (2.45) reveal that, regardless of its export status, a firm's optimal quality and upgrading cost are decreasing in its unit-input requirement, a_i, as in the autarky. However, quality and upgrading costs for a domestic firm and an exporter is increasing in the production and exporting unit-input threshold, (a_{Dj}) and (a_{Xj}). Moreover, $\partial q_{ijd}/\partial\theta > 0$, $\partial q_{ijd}/\partial\gamma > 0$, $\partial q_{ijx}/\partial\theta > 0$ and $\partial q_{ijx}/\partial\gamma > 0$ can be still drawn from above equations which mean that more intense quality upgrading in product quality (larger θ) or more attention consumers pay to product quality (larger γ) can motivate firms to invest more on their variety quality and provide a variety with higher quality.

In addition, comparing the quality functions of a domestic firm, Equation (2.40) and an exporter, Equation (2.44) concludes that a firm invests more in quality upgrading and improves product quality when it begins to export. This is due to that the expansion of the market allows exporters to find upgrading quality more profitable. Because the lowest quality level stays the same as in autarky with exporters all improving their product quality (i.e. the highest quality is higher than that in autarky) and foreign exporters also provide new varieties, the costly trade contributes to a wider range of product quality in each industry and consumers can enjoy more varieties with different qualities.

2.5.4 Free entry condition

As mentioned before, firms must pay fixed cost F_E units of intermediate input to enter the market prior to finding out their marginal costs. They will enter the market until the expected profits from entry equal to costs:

$$E(\tfrac{\pi_{ij}}{\delta}) = F_E p_{mj}$$

which can be further expressed as:

$$
\begin{aligned}
\delta F_E P_{mj} = & \int_{a_{Xj}}^{a_{Dj}} [(q_{ij}^{\gamma} a_i^{1-\sigma} B_{jd} - f_{ijd}(a_i) - F_D] p_{mj} g(a) da \\
+ & \int_{0}^{a_{Xj}} [(q_{ij}^{\gamma} a_i^{1-\sigma}(B_{jd} + B_{jx}) - f_{ijx}(a_i) - F_D - F_X] p_{mj} g(a) da
\end{aligned}
\tag{2.46}
$$

The zero-profit condition is the relationship between the production and exporting unit-input threshold,

$$
\frac{a_{Dj}}{a_{Xj}} = \{\frac{F_D}{F_X}[(1 + A_j^H)^{\frac{1}{1-\theta\gamma}} - 1]\}^{\frac{1-\theta\gamma}{1-\sigma}} = m_j^H \tag{2.47}
$$

The production unit-input threshold is higher than the exporting unit-input threshold when $m_j^H > 1$. There is a selection for exporting, which induces that only the most productive firms find it profitable to serve the export market. This equation also reflects that the distance in the unit-input requirements between the least productive firm surviving in the domestic market only and the least productive surviving firm in exporting market is determined by the profitability of serving the foreign market to the domestic one. In addition, this distance differs across countries and industries.

Assuming a Pareto distribution for marginal costs and integrating provide analytical solutions for the production and exporting unit-input threshold in the Home country:

$$
(a_{Dj})^k = \frac{\delta F_E}{F_D} \frac{k(1-\theta\gamma) + 1 - \sigma}{\sigma - 1} \{1 + (\frac{F_X}{F_D})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1} [(1 + A_j^H)^{\frac{1}{1-\theta\gamma}} - 1]^{\frac{k(1-\theta\gamma)}{\sigma-1}}\}^{-1} \tag{2.48}
$$

$$
(a_{Xj})^k = \frac{\delta F_E}{F_X} \frac{k(1-\theta\gamma) + 1 - \sigma}{\sigma - 1} \{1 + (\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1} [(1 + A_j^H)^{\frac{1}{1-\theta\gamma}} - 1]^{\frac{k(1-\theta\gamma)}{1-\sigma}}\}^{-1} \tag{2.49}
$$

2.6 Propositions

This section illustrates how exposure to trade affects firms' quality decisions and how this change varies across industries. The intuition for each proposition is provided here, and proofs are provided in the appendix.

Proposition 1. $a_{Dj}^{aut} > a_{Dj}$ (i.e. The production unit-input threshold is lower in costly trade than in autarky.)

Proof: See Appendix

Consistent with Melitz (2003), when the economy opens to trade, the opportunities created by trade increase the expected value of entry into each industry. However, the firms that draw the unit-input requirement between a_{Dj} and a_{Dj}^{aut} do not have access to foreign markets and suffer from the more intensive competition. Therefore, their profits are so reduced that they can no longer earn enough revenue to cover their production costs and exit the industry. As a result, the production unit-input threshold, a_{Dj}, decreases in both industries and countries.

From the view of the labour market, the expansion of markets induces more demand for goods, which causes an increase in the demand for production factors. This increase further bids up the prices of production factors, implying that now active firms have to pay more for production. Finally, the higher costs for production drive the firms that used to be marginal out of the markets. Thus, the production unit-input threshold, a_{Dj}^{H}, is driven down.

This proposition implies that international trade makes markets more competitive following the selection process, which induces a reallocation of market and resources within industries (from less productive firms to more productive firms).

Proposition 2. $q_{ijd}(a_i) < q_{ij}(a_i)$ (i.e. The non-exporters tend to lower their quality choice from autarky to costly trade) and $q_{ijx}(a_i) > q_{ij}(a_i)$ (i.e. The exporters choose a higher quality for their products.)

Proof: See Appendix

Trade openness causes two impacts on a firm's product quality. Firstly, the expansion of markets promotes quality upgrading. The second one is a negative impact. The expansion of markets attracts more entrants, demanding more production factors, pushing the prices of production factors up and leading to higher costs of quality upgrading. Let us name it the factor effect. All active firms in autarky turn to different types of firms (exporters, non-exporters or quitters) according to their unit-input requirements when a trade happens. Exporters can benefit from the expansion of markets and simultaneously suffer from the negative factor effect. However, non-exporters can only be affected negatively by the factor effect. This difference leads to that firms' responses to the trade over the quality choice differ across firms' export status.

Consistent with Ferguson (2010), the model shows domestic firms lower their quality while exporters improve product quality. In terms of non-exporters, they face a great increase in the costs of quality upgrading, which leads to a higher marginal cost of improving quality. Therefore, they cannot even keep their initial qualities anymore and finally decide to provide products with a lower quality to survive. On the other hand, although exporters also face an increasing marginal cost of quality upgrading, access to expanding markets allows them to exploit the increasing marginal return of improving quality. Therefore, they finally decide to improve the product quality to gain more profits, as the marginal return increases more than the marginal cost.

Proposition 3. $A_1^H > A_2^H$ and $A_1^F < A_2^F$ (i.e. The profitability of serving the foreign market to the domestic one is greater in a country's comparative advantage industry.)

Proof: See Appendix

Consistent with Bernard, Redding, and Schott (2007), firms in the comparative advantage industry find relatively larger profitability in serving the foreign market than the domestic market. The intuition behind this proposition is that a comparative advantage industry means that products can be produced at a relatively lower cost by domestic firms than their foreign competitors, and firms in such an industry in one country can take this advantage to obtain more profits from exporting market if they can afford the fixed cost of exporting.

Proposition 4.

- $a^H_{D1} < a^H_{D2}$ and $a^F_{D1} > a^F_{D2}$ (i.e. Under costly trade, the production unit-input threshold is lower in a country's comparative advantage industry.)
- $a^H_{X1} > a^H_{X2}$ and $a^F_{X1} < a^F_{X2}$ (i.e. Under costly trade, the export unit-input threshold is larger in a country's comparative advantage industry.)
- $\frac{a^H_{X1}}{a^H_{D1}} > \frac{a^H_{X2}}{a^H_{D2}}$ and $\frac{a^F_{X1}}{a^F_{D1}} < \frac{a^F_{X2}}{a^F_{D2}}$ (i.e. The proportion of firms exporting is larger in a country's comparative advantage industry.)

Proof: See Appendix

These findings are consistent with those in a model with no quality upgrading (Bernard, Redding, and Schott (2007)). From the last proposition, we already know that profit in the exporting market is greater in the comparative advantage industry, which leads to a relatively high expected value of the entry. A higher expected value of entry then causes more new entrants. Therefore, a more competitive market eliminates firms with relatively high unit-input requirements. As a result, a larger decrease in the production unit-input threshold can be found in a comparative advantage industry. The exit of the least efficient firms generates a greater reallocation of market shares in the comparative advantage industry (towards the most productive firms).

More firms find themselves able to compete with foreign producers in the comparative advantage industry. Even the firms with a unit-input requirement slightly higher than the exporting unit-input threshold of the comparative disadvantage industry can find exporting profitable and decide to export. Hence, the exporting unit-input threshold is higher in a comparative advantage industry. Since exporting is more profitable in a comparative advantage industry that attracts more firms to join the export market, the exporting unit-input threshold lies closer to the production unit-input threshold in a comparative advantage industry. A larger ratio of exporting firms to active firms can be observed in a comparative advantage industry.

From the view of the labour market, when the economy opens to costly trade, there will be a larger proportion of firms exporting in a comparative advantage industry. The intuition behind this result is that firms are asymmetrically exposed to different industry opportunities through trade. From autarky to trade, access to a larger market increases firms' profit opportunities. It allows them to exploit the increasing returns to scale associated with production and provide higher-quality products. However, these profit opportunities are larger in the industry where the economy has the comparative advantage (industry 1 for the Home country). These opportunities imply that more firms will find it profitable to export in this industry (i.e. the export unit-input threshold is larger in a comparative advantage industry).

The increases in exports thus demand both production factors more. Moreover, this increase in demand is relatively large for human capital. The factor is used intensively in the comparative advantage industry. Consequently, a positive impact would be caused by the relative factor price of abundant endowment, which increases firms' production costs more in the comparative advantage industry. Thus, it becomes more difficult for firms to survive. Marginal firms (i.e. firms with the lowest productivity) would be able to survive in a comparative disadvantage industry but fail to make positive profits in a comparative advantage one, then exit the market (i.e. the production unit-input threshold is lower in a country's comparative advantage industry). Furthermore, the proportion of firms exporting is larger in a country's comparative advantage industry.

Proposition 5.

- $q^H_{i1d}(a_i) < q^H_{i2d}(a_i)$ (i.e. Trade openness will induce non-exporting firms to invest less in quality. This effect will be stronger in the comparative advantage in dusty.)
- $q^H_{i1x}(a_i) > q^H_{i2x}(a_i)$ (i.e. Trade openness will induce exporting firms to invest more in quality. This effect will be stronger in the comparative advantage industry.)

Proof: See Appendix

The fact that the change in product quality is heterogeneous across industries based on comparative advantage is the main novel result. I have discussed above that all firms face higher costs of quality upgrading. This increases the cost of investing in quality and discourages firms from improving product quality. However, more entrants come into the comparative advantage industry as the profit opportunities are larger in the industry, which bids up the relative price of abundant factors (i.e. the relative price of human capital shifts up in the Home country and the relative price of physical capital is higher in Foreign country). Hence, the costs of quality upgrading increase more in the comparative advantage industry. Therefore, Firms that serve only the domestic market have to choose a lower quality in the comparative advantage industry conditional on the unit-input requirement.

Exporters are not only affected by the factor effect negatively but also by the expansion of markets positively. Following Proposition 2, the effect of expanding markets outweighs the factor effect. In the comparative advantage industry, access to export markets allows exporting firms to find higher profitability in improving product quality. Thus, this increase in the marginal return is much greater than the increase in marginal cost from upgrading quality. Hence, exporters tend to raise their quality choice to maximise their profits from autarky to costly trade. As a result, exporters produce higher-quality products in the comparative advantage industry than those with the same unit-input requirement in other industries.

2.7 Conclusion

This chapter has built and described a tractable trade model to show the interaction of countries with different endowments, industries with different factor intensities and heterogeneous firms choosing an endogenous quality choice. The analysis highlights the significance of placing the industry difference at the centre to examine firms' responses over product quality to international trade.

The contribution of this chapter to the literature is to show that the response to the quality of firms differs across industries. This model has emphasised the importance of inter-reallocations across industries when the economy faces trade openness. The inter-reallocations highlight the comparative advantage caused by relative endowment and differentiated factor intensity in industries. The comparative advantage exists in the industry that uses the relatively abundant endowment more intensively, ensuring that firms enjoy a greater benefit from the relatively higher demand of foreign countries than firms in the comparative disadvantage industry. This differential induces that the relative price of the abundant endowment is shifted up more, which causes more costs for all firms involved in the comparative advantage industry. As a result, the non-exporters in the comparative advantage industry respond to the trade through a lower-quality choice than those in the comparative disadvantage industry. However, for exporters, the higher demand from foreign markets outweighs the increased costs. As a result, they raise their quality more than exporters in the comparative disadvantage industry, conditional on the same productivity.

The implication behind this chapter for theory is that firms' endogenous investment is made for quality upgrading rather than productivity improvement. It would be a potential idea for trade theory to incorporate firms' quality investments based on other basic theoretical models. Furthermore, there are still opportunities for further research under Bernard, Redding, and Schott (2007). Comparing the aggregate qualities of industries is unrealised in this model, which will be included in Chapter 3.

In addition, following Melitz (2003), the model in this chapter features that more productive firms can produce at a lower production cost. Meanwhile, those firms will provide markets with higher-quality goods. Though they have to invest more in quality, the model still captures that more productive firms charge a lower price. This conflicts with the reality that firms providing high-quality products always have to purchase high-quality intermediate inputs and thus charge higher prices, supported by many empirical works such as E. A. Verhoogen (2008), Kugler and Verhoogen (2009) and Manova and Zhang (2012). The next chapter seeks to further extend the model by incorporating this reality.

2.8 Appendix

2.8.1 Proof of Propositions

Proof for Proposition 1

To prove $a_{Dj}^{aut} > a_{Dj}^{H}$, I can obtain the ratio between the production unit-input threshold in the autarky and in the costly trade one using Equation (2.21) and (2.48) as:

$$\begin{aligned}\frac{a_{Dj}^{H}}{a_{Dj}^{aut}} &= [\frac{\frac{\delta F_E}{F_D}\frac{k(1-\theta\gamma)+1-\sigma}{\sigma-1}\{1+(\frac{F_X}{F_D})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_j^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{\sigma-1}}\}^{-1}}{\frac{\delta F_E}{F_D}\frac{k(1-\theta\gamma)+1-\sigma}{\sigma-1}}]^{\frac{1}{k}} \\ &= \{1+(\frac{F_X}{F_D})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_j^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{\sigma-1}}\}^{-\frac{1}{k}}\end{aligned}$$

As the part, $(\frac{F_X}{F_D})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_j^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{\sigma-1}}$, is non-negative and $k > 0$, the above ratio is smaller than one. In other words, $a_{Dj}^{aut} > a_{Dj}^{H}$, the production marginal cost cutoff is smaller in costly trade than that in autarky.

Proof for Proposition 2

To prove $q_{ijd}^{H}(a_i) < q_{ij}(a_i)$, I can obtain the ratio of the non-exporters' quality choice and the autarky quality choices as:

$$[\frac{q_{ijd}^{H}(a_i)}{q_{ij}(a_i)}]^{\frac{1}{\theta}} = [\frac{a_{Dj}^{H}}{a_{DJ}^{aut}}]^{\frac{\sigma-1}{1-\theta\gamma}}$$

Given $\sigma > 1$ and $1 < \theta\gamma$ are assumed and $a_{Dj}^{aut} > a_{Dj}^{H}$ from Proposition 1, the above equation is smaller than 1 inducing $q_{ijd}^{H}(a_i) < q_{ij}(a_i)$.

To prove $q_{ijx}^{H}(a_i) > q_{ij}(a_i)$, I can also obtain the ratio of the exporter's quality choice and the autarky quality choices as:

$$
\begin{aligned}
[\frac{q_{ijx}^H(a_i)}{q_{ij}(a_i)}]^{\frac{1}{\theta}} &= \frac{\frac{\theta\gamma}{1-\theta\gamma}F_X(\frac{a_i}{a_{Xj}^H})^{\frac{1-\sigma}{1-\theta\gamma}}[1-(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-1}}{\frac{\theta\gamma}{1-\theta\gamma}F_D(\frac{a_i}{a_{Dj}^{aut}})^{\frac{1}{1-\theta\gamma}}} \\
&= \frac{F_X}{F_D}(\frac{a_{Xj}}{a_{Dj}^{aut}})^{\frac{\sigma-1}{1-\theta\gamma}}[1-(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-1}
\end{aligned}
$$

Then substitute the solutions for a_{Xj}^H and a_{Dj}^{aut} into the above equation,

$$
\begin{aligned}
[\frac{q_{ijx}^H(a_i)}{q_{ij}(a_i)}]^{\frac{1}{\theta}} &= \frac{F_X}{F_D}[\frac{F_D}{F_X}[1+(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_j^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{1-\sigma}}]^{-1}]^{\frac{\sigma-1}{k(1-\theta\gamma)}}[1-(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-1} \\
&= (\frac{F_X}{F_D})^{1-\frac{\sigma-1}{k(1-\theta\gamma)}}[1-(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-1}[1+(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_j^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{1-\sigma}}]^{\frac{1-\sigma}{k(1-\theta\gamma)}}
\end{aligned}
$$

And now for simplicity, I assume that $[(1+A_j^H)^{\frac{1}{1-\theta\gamma}}-1]^{-1}=\phi_j$, and I can find that $[1-(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-1}=\phi_j+1$. Then the equation can be expressed as:

$$
\begin{aligned}
[\frac{q_{ijx}^H(a_i)}{q_{ij}(a_i)}]^{\frac{1}{\theta}} &= (\frac{F_X}{F_D})^{1-\frac{\sigma-1}{k(1-\theta\gamma)}}(1+\phi_j)[1+(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}\phi_j^{\frac{k(1-\theta\gamma)}{\sigma-1}}]^{\frac{1-\sigma}{k(1-\theta\gamma)}} \\
&= \frac{(\frac{F_X}{F_D})^{1-\frac{\sigma-1}{k(1-\theta\gamma)}}(1+\phi_j)}{[1+(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}\phi_j^{\frac{k(1-\theta\gamma)}{\sigma-1}}]^{\frac{\sigma-1}{k(1-\theta\gamma)}}}
\end{aligned}
$$

As $\frac{\sigma-1}{k(1-\theta\gamma)}>0$ and $(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}>1$, thus this ratio is bigger than the following Equation (A.1), which can be expressed as:

$$
\begin{aligned}
&\frac{(\frac{F_X}{F_D})^{1-\frac{\sigma-1}{k(1-\theta\gamma)}}(1+\phi_j)}{[(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}(1+\phi_j^{\frac{k(1-\theta\gamma)}{\sigma-1}})]^{\frac{\sigma-1}{k(1-\theta\gamma)}}} \\
&= \frac{1+\phi_j}{(1+\phi_j^{\frac{k(1-\theta\gamma)}{\sigma-1}})^{\frac{\sigma-1}{k(1-\theta\gamma)}}}
\end{aligned}
\tag{A.1}
$$

And $\frac{k(1-\theta\gamma)}{\sigma-1} > 1$ can ensure that Equation (A.1) is bigger than the following Equation (A.2), which can be expressed as:

$$\begin{aligned} &\frac{1+\phi_j}{[(1+\phi_j)^{\frac{k(1=\theta\gamma)}{\sigma-1}}]^{\frac{\sigma-1}{k(1-\theta\gamma)}}} \\ &= \frac{1+\phi_j}{1+\phi_j} = 1 \end{aligned} \tag{A.2}$$

As a result, the initial ratio is bigger than Equation (A.1) and Equation (A.2) which equals to 1. Thus, it induces that $q^H_{ijx}(a_i) > q_{ij}(a_i)$.

Through the proving process, the conclusion that exporters raise their product quality and non-exporters lower their quality choice can be derived from the theoretical model, which shows the response differential over quality from heterogeneous firms.

Proof for Proposition 3

As mentioned before, $A^H_j = \frac{E^F_j}{E^H_j}(\frac{P^H_j}{P^F_j})^{1-\sigma}$. Assume that both countries share the same ratio of expenditure spent in one industry to the total expenditure. Hence, I can obtain the ratio of A^H_1 and A^H_2.

$$\begin{aligned} \frac{A^H_1}{A^H_2} &= (\frac{P^H_1}{P^H_2})^{1-\sigma}(\frac{P^F_2}{P^F_1})^{1-\sigma}\frac{E^F_1}{E^H_1}\frac{E^H_2}{E^F_2} \\ &= (\frac{P^H_1}{P^H_2})^{1-\sigma}(\frac{P^F_2}{P^F_1})^{1-\sigma} \end{aligned}$$

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

$$(\frac{P^H_1}{P^H_2})^{1-\sigma} = \frac{N^H_{D1}(p^H_1(\overline{a^H_{D1}}))^{1-\sigma}q^H_{1d}(\overline{a^H_{D1}})^{\gamma}+N^H_{X1}(p^H_1(\overline{a^H_{X1}}))^{1-\sigma}q^H_{1x}(\overline{a^H_{X1}})^{\gamma}+N^F_{X1}(\tau p^F_1(\overline{a^F_{X1}}))^{1-\sigma}q^F_{1x}(\overline{a^F_{X1}})^{\gamma}}{N^H_{D2}(p^H_2(\overline{a^H_{D2}}))^{1-\sigma}q^H_{2d}(\overline{a^H_{D1}})^{\gamma}+N^H_{X2}(p^H_2(\overline{a^H_{X2}}))^{1-\sigma}q^H_{2x}(\overline{a^H_{X2}})^{\gamma}+N^F_{X2}(\tau p^F_2(\overline{a^F_{X2}}))^{1-\sigma}q^F_{2x}(\overline{a^F_{X2}})^{\gamma}}$$

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, one extreme situation that has to be noticed is 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 it. 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 $((1-m)m^{\frac{m}{1-m}}(a_{Dj}^{aut})^{\frac{1-\sigma-\alpha m}{1-m}}B_j^{\frac{1}{1-m}}(W_S^{\beta_j}W_K^{1-\beta_j})^{\frac{1-m-\sigma}{1-m}} - F_D W_S^{\beta_j}W_K^{1-\beta_j} = 0)$ contributes to the relative industry price index, which can be expressed as $(\frac{P_1^H}{P_2^H})^{1-\sigma} = \frac{\mu}{1-\mu}[(\frac{W_S^H}{W_K^H})^{\beta_1-\beta_2}]^{-\sigma}$, since the production unit-input threshold is indifferent across industries. Hence, the value of the ratio of A_1^H and A_2^H can be found as:

$$
\begin{aligned}
\frac{A_1^H}{A_2^H} &= \frac{\mu}{1-\mu}[(\frac{W_S^H}{W_K^H})^{\beta_1-\beta_2}]^{-\sigma}\frac{1-\mu}{\mu}[(\frac{W_S^F}{W_K^F})^{\beta_1-\beta_2}]^{\sigma} \\
&= [(\frac{W_S^H/W_K^H}{W_S^F/W_K^F})^{\beta_1-\beta_2}]^{-\sigma}
\end{aligned}
$$

where the production of industry 1 uses human capital more intensively inducing that $\beta_1 > \beta_2$. As human capital is relatively abundant in Home country, $\frac{W_S^H}{W_K^H} < \frac{W_S^F}{W_K^F}$ and then $A_1^H > A_2^H$.

Another extreme situation that has to be mentioned is when $\tau \to 1$, and $F_X \to 0$. All active firms can export (the whole economy returns 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 $A_1^H = A_2^H$.

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

Proof for Proposition 4

First, from Equation (2.47), $\{\frac{F_D}{F_X}[(1+A_j^H)^{\frac{1}{1-\theta\gamma}}-1]\}^{\frac{1-\theta\gamma}{1-\sigma}} = m_j^H > 1$ is assumed. As $\theta\gamma < 1$, $A_1^H > A_2^H$ and $\frac{1-\theta\gamma}{1-\sigma}$ is negative, I can derive the result that $m_1^H < m_2^H$.

To prove $a_{D1}^H < a_{D2}^H$, I can obtain the ratio between the production unit-input threshold in two industries using Equation (2.48) as:

$$
\begin{aligned}
\frac{a_{D1}^H}{a_{D2}^H} &= [\frac{\frac{\delta F_E}{F_D}\frac{k(1-\theta\gamma)+1-\sigma}{\sigma-1}\{1+(\frac{F_X}{F_D})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_1^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{\sigma-1}}\}^{-1}}{\frac{\delta F_E}{F_D}\frac{k(1-\theta\gamma)+1-\sigma}{\sigma-1}\{1+(\frac{F_X}{F_D})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_2^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{\sigma-1}}\}^{-1}}]^{\frac{1}{k}} \\
&= [\frac{\{1+(\frac{F_X}{F_D})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_1^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{\sigma-1}}\}^{-1}}{\{1+(\frac{F_X}{F_D})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_2^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{\sigma-1}}\}^{-1}}]^{\frac{1}{k}} \\
&= [\frac{[1+\frac{F_X}{F_D}(m_1^H)^{-k}]^{-1}}{[1+\frac{F_X}{F_D}(m_2^H)^{-k}]^{-1}}]^{\frac{1}{k}}
\end{aligned}
$$

As $m_1^H < m_2^H$ and $k > 0$, the above ratio is smaller than one. Thus, $a_{D1}^H < a_{D2}^H$. The proof for $a_{D1}^F > a_{D2}^F$ is similar. Therefore, it can be said that the production unit-input threshold in a comparative advantage industry is lower.

To prove $a_{X1}^H > a_{X2}^H$, I can obtain the ratio between the exporting unit-input threshold in two industries using Equation (2.49) as:

$$
\begin{aligned}
\frac{a_{X1}^H}{a_{X2}^H} &= [\frac{\frac{\delta F_D}{F_X}\frac{k(1-\theta\gamma)+1-\sigma}{\sigma-1}\{1+(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_1^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{1-\sigma}}\}^{-1}}{\frac{\delta F_D}{F_X}\frac{k(1-\theta\gamma)+1-\sigma}{\sigma-1}\{1+(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_2^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{1-\sigma}}\}^{-1}}]^{\frac{1}{k}} \\
&= [\frac{\{1+(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_1^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{1-\sigma}}\}^{-1}}{\{1+(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_2^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{1-\sigma}}\}^{-1}}]^{\frac{1}{k}} \\
&= [\frac{1+\frac{F_D}{F_X}(m_1^H)^k}{1+\frac{F_D}{F_X}(m_2^H)^k}]^{-\frac{1}{k}}
\end{aligned}
$$

As $m_1^H < m_2^H$ and $k > 0$, the above ratio is greater than one. Thus, $a_{X1}^H > a_{X2}^H$. The proof for $a_{X1}^F < a_{X2}^F$ is similar. Therefore, it can be said that the exporting unit-input threshold in a comparative advantage industry is higher.

To prove $\frac{a_{X1}^H}{a_{D1}^H} > \frac{a_{X2}^H}{a_{D2}^H}$, I use Equation (46), $\frac{a_{Dj}^H}{a_{Xj}^H} = \{\frac{F_D}{F_X}[(1+A_j^H)^{\frac{1}{1-\theta\gamma}}-1]\}^{\frac{1-\theta\gamma}{1-\sigma}} = m_j^H$. As $\frac{a_{Xj}^H}{a_{Dj}^H} = (m_j^H)^{-1}$ and $m_1^H < m_2^H$, $\frac{a_{X1}^H}{a_{D1}^H} > \frac{a_{X2}^H}{a_{D2}^H}$, the ratio of exporting firms is higher in the comparative advantage industry in one country.

Proof for Proposition 5

As obtained from the expression of $q_{ijx}^H(a_i)$, the ratio of relative quality choice can be expressed as:

$$
\begin{aligned}
[\frac{q_{i1x}^H(a_i)}{q_{i2x}^H(a_i)}]^{\frac{1}{\theta}} &= (\frac{a_{X2}}{a_{X1}})^{\frac{1-\sigma}{1-\theta\gamma}}\frac{[1-(\frac{1}{1+A_1^H})^{\frac{1}{1-\theta\gamma}}]^{-1}}{[1-(\frac{1}{1+A_2^H})^{\frac{1}{1-\theta\gamma}}]^{-1}} \\
&= [\frac{1+(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_1^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{1-\sigma}}}{1+(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_2^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{1-\sigma}}}]^{\frac{1-\sigma}{k(1-\theta\gamma)}}\frac{[1-(\frac{1}{1+A_1^H})^{\frac{1}{1-\theta\gamma}}]^{-1}}{[1-(\frac{1}{1+A_2^H})^{\frac{1}{1-\theta\gamma}}]^{-1}} \\
&= [\frac{1+(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}\phi_1^{\frac{k(1-\theta\gamma)}{\sigma-1}}}{1+(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}\phi_2^{\frac{k(1-\theta\gamma)}{\sigma-1}}}]^{\frac{1-\sigma}{k(1-\theta\gamma)}}\frac{1+\phi_1}{1+\phi_2}
\end{aligned}
\tag{A.3}
$$

where $\phi_1 < \phi_2$.

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

$$[\frac{q_{i1x}^H(a_i)}{q_{i2x}^H(a_i)}]^{\frac{1}{\theta}} = [\frac{\frac{F_X}{F_D}+(\frac{F_X}{F_D}\phi_1)^{\frac{k(1-\theta\gamma)}{\sigma-1}}}{\frac{F_X}{F_D}+(\frac{F_X}{F_D}\phi_2)^{\frac{k(1-\theta\gamma)}{\sigma-1}}}]^{\frac{1-\sigma}{k(1-\theta\gamma)}}\frac{1+\phi_1}{1+\phi_2}$$

Now I can propose Equation (A.4) is smaller than the original equation.

$$[\frac{(\frac{F_X}{F_D}+\frac{F_X}{F_D}\phi_1)^{\frac{k(1-\theta\gamma)}{\sigma-1}}}{(\frac{F_X}{F_D}+\frac{F_X}{F_D}\phi_2)^{\frac{k(1-\theta\gamma)}{\sigma-1}}}]^{\frac{1-\sigma}{k(1-\theta\gamma)}}\frac{1+\phi_1}{1+\phi_2} \tag{A.4}$$

Here, I add proof of proposing Equation (A.4) which is smaller than the original equation. Given $-1 < \frac{1-\sigma}{k(1-\theta\gamma)} < 0$, I have to prove that $\frac{(\frac{F_X}{F_D}+\frac{F_X}{F_D}\phi_1)^{\frac{k(1-\theta\gamma)}{\sigma-1}}}{(\frac{F_X}{F_D}+\frac{F_X}{F_D}\phi_2)^{\frac{k(1-\theta\gamma)}{\sigma-1}}} > \frac{\frac{F_X}{F_D}+(\frac{F_X}{F_D}\phi_1)^{\frac{k(1-\theta\gamma)}{\sigma-1}}}{\frac{F_X}{F_D}+(\frac{F_X}{F_D}\phi_2)^{\frac{k(1-\theta\gamma)}{\sigma-1}}}$. To do that, I am exploring the monotonicity of the function $y = \frac{\frac{F_X}{F_D}+x^z}{(\frac{F_X}{F_D}+x)^z}$. Since $\phi_2 > \phi_1$, I 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 $\frac{F_X}{F_D}\phi_1 > 1$, $\frac{F_X}{F_D}\phi_2 > 1$ (which means that $x > 1$) and $\frac{1-\sigma}{k(1-\theta\gamma)} > 1$ (which means that $z > 1$), the first order condition can be positive all the time. Furthermore, we can say that the function is monotonically increasing for x in the valid interval. Equation (A.4) is smaller than the original equation.

Then I can simplify Equation (A.4).

$$\frac{1+\phi_2}{1+\phi_1}\frac{1+\phi_1}{1+\phi_2} = 1$$

Since Equation (A.4) equalling one is smaller than the original equation, I can obtain $q^H_{ix1}(a_i) > q^H_{ix2}(a_i)$.

2.8.2 Proof of The Autarky Model

Proof for quality choice

Combining Equations (2.13) and (2.14) in the main text can contribute to a relationship between B_j, q_{ij} and a_i:

$$B_j = \frac{1}{\theta\gamma}\frac{q_{ij}^{\frac{1-\theta}{\theta}}}{q_{ij}^{\gamma-1}a_i^{1-\sigma}}$$

Once let $a_i = a^{aut}_{Dj}$, it becomes:

$$B_j(a^{aut}_{Dj}) = \frac{1}{\theta\gamma}\frac{q_{ij}(a^{aut}_{Dj})^{\frac{1-\theta}{\theta}}}{q_{ij}(a^{aut}_{Dj})^{\gamma-1}a_i^{1-\sigma}}$$

where although I name it as $B_j(a^{aut}_{Dj})$, B_j is in fact the same value for all a_i.

And then substitute $B_j(a^{aut}_{Dj})$ into the zero-profit condition described in Equation (2.12):

$$q_{ij}(a^{aut}_{Dj})^{\gamma}(a^{aut}_{Dj})^{1-\sigma}\frac{1}{\theta\gamma}\frac{q_{ij}(a^{aut}_{Dj})^{\frac{1-\theta}{\theta}}}{q_{ij}(a^{aut}_{Dj})^{\gamma-1}(a^{aut}_{Dj})^{1-\sigma}} = q_{ij}(a^{aut}_{Dj})^{\frac{1}{\theta}} + F_D$$

$$q_{ij}(a^{aut}_{Dj})^{\frac{1}{\theta}} = \frac{\theta\gamma}{1-\theta\gamma}F_D$$

Hence, $B_j(a^{aut}_{Dj})$ can be rewritten as:

$$B_j(a^{aut}_{Dj}) = \frac{1}{\theta\gamma}\frac{(\frac{\theta\gamma}{1-\theta\gamma}F_D)^{1-\theta}}{(\frac{\theta\gamma}{1-\theta\gamma}F_D)^{\theta(\gamma-1)}(a^{aut}_{Dj})^{1-\sigma}}$$

Finally, I use the new form of $B_j(a^{aut}_{Dj})$ to replace B_j (as B_j does not vary across i) in that relationship between B_j, q_{ij} and a_i:

$$\frac{1}{\theta\gamma}\frac{(\frac{\theta\gamma}{1-\theta\gamma}F_D)^{1-\theta}}{(\frac{\theta\gamma}{1-\theta\gamma}F_D)^{\theta(\gamma-1)}(a^{aut}_{Dj})^{1-\sigma}} = \frac{1}{\theta\gamma}\frac{q_{ij}^{\frac{1-\theta}{\theta}}}{q_{ij}^{\gamma-1}a_i^{1-\sigma}}$$

After simplifying this equation, I can obtain the quality choice equation as Equation (2.17):

$$q_{ij} = (\frac{\theta\gamma}{1-\theta\gamma}F_D)^{\theta}(\frac{a_i}{a^{aut}_{Dj}})^{\frac{\theta}{1-\theta\gamma}(1-\sigma)}$$

Proof for production unit-input threshold

To derive the production unit-input threshold, I start with the free entry condition, Equation (2.20) in the main text:

$$\delta F_E p_{mj} = \int_0^{a_{Dj}^{aut}} [(q_{ij}^{\gamma} a_i^{1-\sigma} B_j - f_{ij}(q_i j) - F_D) p_{mj}] g(a) da$$

First, I substitute B_j and $f_{ij} = q_{ij}^{\frac{1}{\theta}}$ into the free entry condition:

$$\delta F_E = \int_0^{a_{Dj}^{aut}} (q_{ij}^{\gamma} a_i^{1-\sigma} \frac{1}{\theta\gamma} \frac{q_{ij}^{\frac{1-\theta}{\theta}}}{q_{ij}^{\gamma-1} a_i^{1-\sigma}} - q_{ij}^{\frac{1}{\theta}} - F_D) g(a) da$$

Through simplifying this equation, I can obtain:

$$\delta F_E = \int_0^{a_{Dj}^{aut}} (\frac{1-\theta\gamma}{\theta\gamma} q_{ij}^{\frac{1}{\theta}} - F_D) g(a) da$$

Then $g(a) = ka^{k-1}$ and $q_{ij} = (\frac{\theta\gamma}{1-\theta\gamma} F_D)^{\theta} (\frac{a_i}{a_{Dj}^{aut}})^{\frac{\theta}{1-\theta\gamma}(1-\sigma)}$ can be used in solving this equation:

$$\delta F_E = k \int_0^{a_{Dj}^{aut}} (\frac{1-\theta\gamma}{\theta\gamma} \frac{\theta\gamma}{1-\theta\gamma} F_D (\frac{a_i}{a_{Dj}^{aut}})^{\frac{1-\sigma}{1-\theta\gamma}} a_i^{k-1} - F_D a_i^{k-1}) da$$
$$\delta F_E = k[\frac{1-\theta\gamma}{1-\sigma+k(1-\theta\gamma)} F_D (a_{Dj}^{aut})^k - F_D (a_{Dj}^{aut})^k]$$

Finally, the production unit-input threshold can be found after further simplifying and expressed as Equation (2.21) in the main text:

$$(a_{Dj}^{aut})^k = \frac{\delta F_E}{F_D} \frac{1-\sigma+k(1-\theta\gamma)}{\sigma-1}$$

2.8.3 Proof of The Costly Trade Model

Proof for exporters' quality choice

When a home firm makes no difference in exporting or not, that means it arrives at the situation described as Equation (2.36) in the main text:

$$[q_{ijd}^H(a_{Xj}^H)^{\gamma}(a_{Xj}^H)^{1-\sigma}B_{jd}^H - f_{ijd}^H(a_{Xj}^H) - F_D]p_{mj}^H =$$
$$[q_{ijx}^H(a_{Xj}^H)^{\gamma}(a_{Xj}^H)^{1-\sigma}(B_{jd}^H + B_{jx}^H) - f_{ijx}^H(a_{Xj}^H) - F_X - F_D]p_{mj}^H$$

Then this equation can be simplified as follows:

$$q_{ijd}^H(a_{Xj}^H)^{\gamma}(a_{Xj}^H)^{1-\sigma}B_{jd}^H - f_{ijd}^H(a_{Xj}^H) = q_{ijx}^H(a_{Xj}^H)^{\gamma}(a_{Xj}^H)^{1-\sigma}(B_{jd}^H + B_{jx}^H) - f_{ijx}^H(a_{Xj}^H) - F_X$$

Following the same logic, I use $B_{jd}^H(a_{Xj}^H)$ and $[B_{jd}^H(a_{Xj}^H) + B_{jx}^H(a_{Xj}^H)]$ which can be obtained from Equation (2.39) and (2.42) when $a = a_{Xj}^H$, and it can be further used in solving this equation:

$$q_{ijd}^H(a_{Xj}^H)^{\gamma}(a_{Xj}^H)^{1-\sigma}\frac{1}{\theta\gamma}\frac{q_{ijd}^H(a_{Xj}^H)^{\frac{1-\theta}{\theta}}}{q_{ijd}^H(a_{Xj}^H)^{\gamma-1}(a_{Xj}^H)^{1-\sigma}} - q_{ijd}^H(a_{Xj}^H)^{\frac{1}{\theta}} =$$
$$q_{ijx}^H(a_{Xj}^H)^{\gamma}(a_{Xj}^H)^{1-\sigma}\frac{1}{\theta\gamma}\frac{q_{ijx}^H(a_{Xj}^H)^{\frac{1-\theta}{\theta}}}{q_{ijx}^H(a_{Xj}^H)^{\gamma-1}(a_{Xj}^H)^{1-\sigma}} - q_{ijx}^H(a_{Xj}^H)^{\frac{1}{\theta}} - F_X$$

$$\frac{1-\theta\gamma}{\theta\gamma}q_{ijd}^H(a_{Xj}^H)^{\frac{1}{\theta}} = \frac{1-\theta\gamma}{\theta\gamma}q_{ijx}^H(a_{Xj}^H)^{\frac{1}{\theta}} - F_X$$

After this, use the same relationships in the last step to replace $q_{ijd}^H(a_{Xj}^H)$ and $q_{ijx}^H(a_{Xj}^H)$ by B_{jd}^H and $B_{jd}^H + B_{jx}^H$. Moreover, $B_{jx}^H = A_j^H B_{jd}^H$ can also be used to simplify the equation:

$$\frac{1-\theta\gamma}{\theta\gamma}[\theta\gamma B_{jd}^H(a_{Xj}^H)^{1-\sigma}]^{\frac{1}{1-\theta\gamma}} = \frac{1-\theta\gamma}{\theta\gamma}[\theta\gamma(B_{jd}^H + B_{jx}^H)(a_{Xj}^H)^{1-\sigma}+]^{\frac{1}{1-\theta\gamma}} - F_X$$

$$[(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta}} - 1][\theta\gamma B_{jd}^H(a_{Xj}^H)^{1-\sigma}]^{\frac{1}{1-\theta\gamma}} = \frac{\theta\gamma}{1-\theta\gamma}F_X$$

Finally, substitute Equation (2.43) in the main text into this equation:

$$[(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta}} - 1][\theta\gamma\frac{1}{\theta\gamma}\frac{1}{a_i^{1-\sigma}}\frac{1}{1+A_j^H}(q_{ijx}^H)^{\frac{1-\theta\gamma}{\theta}}(a_{Xj}^H)^{1-\sigma}]^{\frac{1}{1-\theta\gamma}} = \frac{\theta\gamma}{1-\theta\gamma}F_X$$

$$[(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta}} - 1](\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}(\frac{a_{Xj}^H}{a_i})^{\frac{1-\sigma}{1-\theta\gamma}}(q_{ijx}^H)^{\frac{1}{\theta}} = \frac{\theta\gamma}{1-\theta\gamma}F_X$$

To simplify this equation, I can obtain the final quality function for exporters as Equation (2.44) in the main text:

$$q_{ijx}^H(a_i) = (\frac{\theta\gamma}{1-\theta\gamma}F_X)^{\theta}(\frac{a_i}{a_{Xj}^H})^{\frac{\theta}{1-\theta\gamma}(1-\sigma)}[1 - (\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-\theta}$$

Proof for the relationship between two thresholds

Derive the ratio between $B_{jd}^H(a_{Xj}^H)$ and $[B_{jd}^H(a_{Xj}^H) + B_{jx}^H(a_{Xj}^H)]$:

$$\frac{B_{jd}^H + B_{jx}^H}{B_{jd}^H} = [\frac{q_{ijx}^H(a_{Xj}^H)}{q_{ijd}^H(a_{Xj}^H)}]^{\frac{1-\theta\gamma}{\theta}}$$

$$1 + A_j^H = [\frac{q_{ijx}^H(a_{Xj}^H)}{q_{ijd}^H(a_{Xj}^H)}]^{\frac{1-\theta\gamma}{\theta}}$$

Then substitute $q_{ijd}^H(a_{Xj}^H)$ and $q_{ijx}^H(a_{Xj}^H)$, and simplify it:

$$1 + A_j^H = [\frac{(\frac{\theta\gamma}{1-\theta\gamma}F_X)^\theta[1-(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-\theta}}{(\frac{\theta\gamma}{1-\theta\gamma}F_D)^\theta(\frac{a_{Xj}^H}{a_{Dj}^H})^{\frac{\theta}{1-\theta\gamma}(1-\sigma)}}]^{\frac{1-\theta\gamma}{\theta}}$$

$$1 + A_j^H = (\frac{F_X}{F_D})^{1-\theta\gamma}(\frac{a_{Dj}^H}{a_{Xj}^H})^{1-\sigma}[1 - (\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-\frac{1-\theta\gamma}{\theta}}$$

Finally, the relationship described in Equation (2.47) in the main text can be arrived at:

$$\frac{a_{Dj}^H}{a_{Xj}^H} = \{\frac{F_D}{F_X}[(1 + A_j^H)^{\frac{1}{1-\theta\gamma}} - 1]\}^{\frac{1-\theta\gamma}{1-\sigma}} = m_j$$

Proof for the production and exporting unit-input threshold

Based on the free entry condition, replace f_{ijd}^H and f_{ijx}^H by $(q_{ijd}^H)^{\frac{1}{\theta}}$ and $(q_{ijx}^H)^{\frac{1}{\theta}}$:

$$\delta F_E P_{mj}^H = \int_{a_{Xj}^H}^{a_{Dj}^H}[(q_{ij}^\gamma a_i^{1-\sigma}B_{jd}^H - f_{ijd}^H(a_i) - F_D]p_{mj}^H g(a)da + \int_0^{a_{Xj}^H}[(q_{ij}^\gamma a_i^{1-\sigma}(B_{jd} + B_{jx})^H - f_{ijx}^H(a_i) - F_D - F_X]p_{mj}^H g(a)da$$

Then substitute Equations (2.39) and (2.42) in the main text into the above equation:

$$\delta F_E = \int_{a_{Xj}^H}^{a_{Dj}^H}[(q_{ij}^\gamma a_i^{1-\sigma}(q_{ijd}^H)^{\frac{1-\theta}{\theta}}\frac{1}{\theta}\frac{1}{a_i^{1-\sigma}} - f_{ijd}^H(a_i) - F_D]g(a)da + \int_0^{a_{Xj}^H}[(q_{ij}^\gamma a_i^{1-\sigma}(q_{ijx}^H)^{\frac{1-\theta}{\theta}}\frac{1}{\theta}\frac{1}{a_i^{1-\sigma}} - f_{ijx}^H(a_i) - F_D - F_X]g(a)da$$

simplify it, and I can obtain the following:

$$\delta F_E = \int_{a_{Xj}^H}^{a_{Dj}^H}[\frac{1-\theta\gamma}{\theta\gamma}(q_{ijd}^H)^{\frac{1}{\theta}} - F_D]g(a)da + \int_0^{a_{Xj}^H}[\frac{1-\theta\gamma}{\theta\gamma}(q_{ijx}^H)^{\frac{1}{\theta}} - F_D - F_X]g(a)da$$

Substitute Equations (2.40) and (2.44) into the equation:

$$\delta F_E = \int_{a_{Xj}^H}^{a_{Dj}^H}[\frac{1-\theta\gamma}{\theta\gamma}[(\frac{\theta\gamma}{1-\theta\gamma}F_D)^{\theta}(\frac{a_i}{a_{Dj}^H})^{\frac{\theta}{1-\theta\gamma}(1-\sigma)}]^{\frac{1}{\theta}} - F_D]g(a)da +$$
$$\int_0^{a_{Xj}^H}[\frac{1-\theta\gamma}{\theta\gamma}[(\frac{\theta\gamma}{1-\theta\gamma}F_X)^{\theta}(\frac{a_i}{a_{Xj}^H})^{\frac{\theta}{1-\theta\gamma}(1-\sigma)}[1-(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-\theta}]^{\frac{1}{\theta}} - F_D - F_X]g(a)da$$

simplify it, and I can obtain the following:

$$\delta F_E =$$
$$\int_{a_{Xj}^H}^{a_{Dj}^H}[F_D(\frac{a_i}{a_{Dj}^H})^{\frac{1-\sigma}{1-\theta\gamma}} - F_D]g(a)da + \int_0^{a_{Xj}^H}[F_X(\frac{a_i}{a_{Xj}^H})^{\frac{1-\sigma}{1-\theta\gamma}}[1-(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-1} - F_D - F_X]g(a)da$$

As $g(a) = ka^{k-1}$ is known, the above equation can be computed as:

$$\delta F_E = [F_D k(\frac{1}{a_{Dj}^H})^{\frac{1-\sigma}{1-\theta\gamma}}(a_{Dj}^H)^{\frac{1-\sigma}{1-\theta\gamma}+k}\frac{1-\theta\gamma}{1-\sigma+k(1-\theta\gamma)} - F_D(a_{Dj}^H)^k] -$$
$$[F_D k(\frac{1}{a_{Dj}^H})^{\frac{1-\sigma}{1-\theta\gamma}}(a_{Xj}^H)^{\frac{1-\sigma}{1-\theta\gamma}+k}\frac{1-\theta\gamma}{1-\sigma+k(1-\theta\gamma)} - F_D(a_{Xj}^H)^k] + [F_X k(\frac{1}{a_{Xj}^H})^{\frac{1-\sigma}{1-\theta\gamma}}[1 -$$
$$(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-1}(a_{Xj}^H)^{\frac{1-\sigma}{1-\theta\gamma}+k}\frac{1-\theta\gamma}{1-\sigma+k(1-\theta\gamma)} - (F_D + F_X)(a_{Xj}^H)^k]$$

simplify it, and I can obtain the following:

$$\delta F_E = \frac{\sigma-1}{1-\sigma+k(1-\theta\gamma)}F_D(a_{Dj}^H)^k - F_D(\frac{a_{Xj}^H}{a_{Dj}^H})^{\frac{1-\sigma}{1-\theta\gamma}}(a_{Xj}^H)^k\frac{k(1-\theta\gamma)}{1-\sigma+k(1-\theta\gamma)} + F_X[1 -$$
$$(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-1}(a_{Xj}^H)^k\frac{k(1-\theta\gamma)}{1-\sigma+k(1-\theta\gamma)} - F_X(a_{Xj}^H)^k$$

Then substitute the equation describing the relationship between two thresholds here to derive the above equation:

$$\delta F_E = \frac{\sigma-1}{1-\sigma+k(1-\theta\gamma)}F_D(a_{Dj}^H)^k - F_D\frac{F_X}{F_D}[(1+A_j^H)^{\frac{1}{1-\theta\gamma}} -$$
$$1]^{-1}a_{Xj}^H)^{\frac{1-\sigma}{1-\theta\gamma}}(a_{Xj}^H)^k\frac{k(1-\theta\gamma)}{1-\sigma+k(1-\theta\gamma)} + F_X[1-(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-1}(a_{Xj}^H)^k\frac{k(1-\theta\gamma)}{1-\sigma+k(1-\theta\gamma)} - F_X(a_{Xj}^H)^k$$

As $[(1+A_j^H)^{\frac{1}{1-\theta\gamma}} - 1]^{-1} + 1 = [1-(\frac{1}{1+A_j^H})^{\frac{1}{1-\theta\gamma}}]^{-1}$ is known, use this equation to simplify the above equation:

$$\delta F_E = \frac{\sigma-1}{1-\sigma+k(1-\theta\gamma)}F_D(a_{Dj}^H)^k + F_X(a_{Xj}^H)^k\frac{k(1-\theta\gamma)}{1-\sigma+k(1-\theta\gamma)} - F_X(a_{Xj}^H)^k$$

Then use the relationship equation again to derive the final expressions of two thresholds:

$$(a_{Dj}^{H})^{k} = \frac{\delta F_E}{F_D}\frac{k(1-\theta\gamma)+1-\sigma}{\sigma-1}\{1+(\frac{F_X}{F_D})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_j^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{\sigma-1}}\}^{-1}$$

$$(a_{Xj}^{H})^{k} = \frac{\delta F_D}{F_X}\frac{k(1-\theta\gamma)+1-\sigma}{\sigma-1}\{1+(\frac{F_D}{F_X})^{\frac{k(1-\theta\gamma)}{1-\sigma}+1}[(1+A_j^H)^{\frac{1}{1-\theta\gamma}}-1]^{\frac{k(1-\theta\gamma)}{1-\sigma}}\}^{-1}$$

Chapter 3

Comparative Advantage and Quality Choice of Heterogeneous Firms

3.1 Introduction

Based on the theoretical model, I started thinking about the empirical tests where I can find supporting evidence for those propositions in Chapter 2. Recent empirical works state that more productive firms produce higher quality goods (e.g. E. A. Verhoogen, 2008; Baldwin & Harrigan, 2011), consistent with the model in Chapter 2. However, the model in Chapter 2 follows the model of Melitz (2003), which features the monopolistic competition framework and increasing returns to scale, indicating that more productive firms will charge lower prices as their average cost is relatively low. Thus, it concludes that more productive firms produce higher-quality goods but charge lower prices. This result conflicts with the facts revealed in the literature that more productive firms produce higher quality goods and charge higher prices for their goods (e.g. Kugler & Verhoogen, 2012; Manova & Zhang, 2012).[1] Thus, it motivates me to rethink the theoretical model and to improve the work of Chapter 2.

This chapter extends the model in Chapter 2 by obtaining that more productive firms provide higher-quality goods and charge higher prices. Meanwhile, it tries to derive the same predictions as in Chapter 2 and to find some novel propositions. Exporters invest more in product quality than autarky, while non-exporters produce lower-quality goods. The existence of a fixed cost of exporting implies that only the most productive firms benefit from export opportunities. These opportunities encourage firms to invest in product quality which pushes up demand for production factors and costs, driving down the ex-post profitability of producers. Exporters with access to expanding markets find it profitable to improve quality, while non-exporters see their market size reduced, which induces firms to lower the quality of their products.

Finally, the framework in this chapter provides a novel prediction that there is an improvement in the aggregate or average industry quality when the trade opens, which is greater in a comparative advantage industry. Exporters improve product quality when moving from autarky to trade, while non-exporters produce lower-quality goods. The final improvement in aggregate quality is due to the positive effects of exporters and the least productive firms that exit the market, outweighing the negative effect of non-exporters. This difference is more pronounced in a comparative advantage industry, contributing to a relatively high aggregate quality level.

The framework in this chapter also features the same assumptions as the model

[1] Although all papers mentioned above use the unit value of products to index the quality and then provide potential explanations or hypotheses regarding product quality. More recent works have proved the positive relationship between product quality and price using the quality estimation from A. Khandelwal (2010), which is commonly used in the literature (e.g. Fan, Li, & Yeaple, 2015; Manova & Yu, 2017).

in Chapter 2 except for firms' choices of intermediate inputs. Specifically, this chapter allows firms to use differentiated rather than homogeneous intermediate inputs in one industry. They produce the intermediate inputs based on their quality choice for final products and use these inputs for the production of final products and quality upgrading. Thus, more productive firms that tend to produce higher-quality varieties have to produce and use more expensive (higher-quality) intermediate inputs, which increases the marginal costs of final products. Furthermore, this effect of intermediates inputs on the price of firms' final products outweighs the effect of firms' productivity, leading to more productive firms that produce higher-quality products charging higher prices for their products.

The rest of the chapter is organised as follows. Section 2 reviews the related quality literature. Section 3 introduces the autarky model showing how a firm chooses its product quality and produces the goods. Section 4 describes the costless-trade model where all active firms can service domestic and foreign markets. Section 5 specifies how a firm adjusts product quality according to its export status under costly trade and how this adjustment differs across industries. Section 6 presents several propositions drawn from the model. The final section concludes.

3.2 Literature Review

As this chapter and chapter 2 share the same goal, they are both based on the H-O model to derive a theoretical model that can explain how firms' product quality varies across industries. These two chapters share most of the literature. Here, to avoid being repetitive, the literature presented in chapter 2 is omitted.

More studies have stated a positive relationship between firms' production efficiency and product quality and price. E. A. Verhoogen (2008) establishes a model with heterogeneous firms and quality differentiation and proposes that more productive plants produce higher-quality products than less productive firms. Moreover, using the panel data on Mexican manufacturing plants and ISO 9000 certification as a sign of higher-quality products, he finds evidence that supports the above quality proposition. Baldwin and Harrigan (2011) introduce a taste for quality into the model of Melitz (2003), where firms capture heterogeneous productivity and fixed costs for entry. Thus, in their model, firms' competitiveness relies on their quality-adjusted price, and more productive firms produce higher-quality products and charge higher prices. Empirically, they use highly disaggregated U.S. trade data to establish facts that support theoretical predictions.

More literature focuses on intermediate inputs that firms use to produce the final outputs to understand further the positive relationship between firms' production efficiency and their product quality and price. Using the Colombian manufacturing census data, Kugler and Verhoogen (2012) observe that larger plants pay more for their input material and charge higher prices for their final products. They then extend the framework of Melitz (2003) model to incorporate the input and output quality to interpret those empirical facts. More productive firms produce higher-quality products using higher-quality inputs and thus charge higher prices. Meanwhile, Manova and Zhang (2012) use detailed export and import data on the universe of Chinese trade flows and uncover some stylised facts. First, given a certain product, exporters charging higher prices can enter more markets, have bigger sales, and gain greater revenues. Second, those firms charging higher prices, entering more markets, and earning greater revenues import more expensive inputs. To explain these stylised facts, they propose that more successful exporters produce higher-quality products by using higher-quality inputs. Using the same data from China, Fan et al. (2018) show that a tariff reduction contributed to firms increasing their exports' quality and inputs, concentrated in the least productive Chinese exporters.

This finding also indicates that firms can improve their product quality by accessing higher-quality intermediate inputs.

To fit the proposition that has been documented in the above literature, I make some changes for the intermediate-input sector where there is still a perfect competition environment. Firms are assumed to use different intermediate inputs to produce their final products, and they choose inputs based on the final products' quality. Less productive firms require more inputs to achieve a certain quality product. Thus, this framework features that more productive firms produce higher-quality products using more expensive (higher-quality) inputs and charge higher prices. This chapter shows the differential of heterogeneous firms' quality choices across industries conditional on their export status. Exporters raise more on product quality, and non-exporters choose a relatively lower quality in a comparative advantage industry conditional on the same productivity. Moreover, our framework also predicts an improvement in the aggregate or average industry quality when the trade opens, which is greater in a comparative advantage industry.

3.3 The Autarky Model

This section maintains the situation that economies are closed. It considers a world of two countries (Home country and Foreign country), two industries, two production factors (human capital and physical capital) and a continuum of firms with a heterogeneous unit-input requirement for one unit of final output within both industries. The standard H-O assumption is that countries are identical in preferences and technologies but feature different factor endowments. Factors of production can move between industries within countries but not across countries. The above assumptions are the same as the model of Bernard, Redding, and Schott (2007). H is used to index the Home country where the human capital is relatively abundant, and

F is used for the Foreign country where the physical capital is relatively abundant.

3.3.1 Demand

Consider one country consisting of a continuum of consumers. Their utility comes from consuming the output of two industries (denoted with C_j, $j = 1, 2$), each containing many differentiated varieties produced by heterogeneous firms. The utility function is specified as the Cobb-Douglas function form:

$$U = (C_1)^{\mu}(C_2)^{1-\mu} \qquad 0 < \mu < 1 \tag{3.1}$$

where μ measures the importance of industry 1 in the utility function (in equilibrium is also the proportion of total consumption expenditure devoted to the good of industry 1).

As quality is considered in the model, varieties are aggregated according to the standard Constant Elasticity of Substitution across varieties (CES) functional form expenditure associated with the expenditure function in industry j (defined over prices of varieties, p_{ij} and its quality, q_{ij}), which are different from that in Bernard, Redding, and Schott (2007).

$$C_j = \left[\int_{i \in \Omega} q_{ij}^{\frac{\gamma}{\sigma}} c_{ij}^{\frac{\sigma-1}{\sigma}} \, di \right]^{\frac{\sigma}{\sigma-1}} \tag{3.2}$$

$$E_j = \int_{i \in \Omega} p_{ij} c_{ij} di \tag{3.3}$$

where σ is the elasticity of substitution across varieties ($\sigma > 1$), and γ describes how much consumers care about product quality. I keep all the other parameters identical across industries since this model shows how differences in factor endowments shape quality differences across industries.

These aggregates can be used to derive the optimal consumption of each variety.

$$x_{ij} = \frac{p_{ij}^{-\sigma} q_{ij}^{\gamma}}{P_j^{1-\sigma}} E_j \tag{3.4}$$

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

$$P_j = \left[\int_{i\in\Omega} p_{ij}^{1-\sigma} q_{ij}^{\gamma} di \right]^{\frac{1}{1-\sigma}} \tag{3.5}$$

Until now, all the assumptions are the same as the model in the last chapter.

3.3.2 Production

Compared to Bernard, Redding, and Schott (2007), to explore product quality, I introduce the intermediate-input sector. Each variety in the final good sector is produced by a unique firm in a monopolistically competitive environment. Firms use linear technology in a unique intermediate input specific to that variety to produce. Any firm in the intermediate input sector can produce this intermediate input in a perfectly competitive environment with a Cobb-Douglas technology involving human (S_j) and physical capital (K_j) in proportions β_j and $1-\beta_j$ respectively. However, the input requirements of each firm in the final good sector depend on the quality of the final good produced with higher quality goods requiring firms to devote more resources in the intermediate input sector to produce one unit of intermediate input for them. More precisely, the production function of intermediate input can be expressed as:

$$y_{ij} = H_j S_j^{\beta_j} K_j^{1-\beta_j} T_{ij} \tag{3.6}$$

with $H_j = \beta_j{}^{-\beta_j}(1-\beta_j)^{-(1-\beta_j)}$ $(0 < H_j < 0)$ and β_j measures the degree of human-capital intensity of intermediate inputs used in industry j. Assume that $\beta_1 > \beta_2$, implying that industry 1 is human capital used intensively. Furthermore, we assume that $T_{ij} = q_{ij}^{-e}$ where q_{ij} is the quality choice of firm i in the industry j and e measures the elasticity of intermediate input unit requirements to quality in the intermediate input sector.

The price of intermediate inputs can be obtained by solving the firm's cost-minimisation problem and applying the fact that the price equals the marginal cost of production in perfect competition.

$$p_{mij} = W_S^{\beta_j} W_K^{1-\beta_j} q_{ij}^{e} \tag{3.7}$$

where p_{mij} is the price of intermediate inputs used by firm i in industry j, W_S and W_K are rewards of human and physical capital, respectively. Thus, it finds a positive relationship between the price of intermediate inputs and the quality of final outputs. This indicates that firms providing higher-quality products use more sophisticated inputs for their production. This relationship fits the reality that firms providing high-quality products always have to purchase more expensive (higher-quality suggested) intermediate inputs supported by many empirical works like E. A. Verhoogen (2008), Kugler and Verhoogen (2009) and Manova and Zhang (2012).

3.3.3 Investment in Quality

In the model where the quality is endogenous, firms choose the level of product quality via investing in the number of 'ideas' in the firm. The following function describes the mapping of ideas into quality:

$$q_{ij} = z_{ij} \tag{3.8}$$

where z_{ij} represents the number of ideas. This assumed positive relationship is consistent with Sethi (2000) where authors state the important role of the ideas for improving quality in producing high-quality products. For simplicity, a monopolistically competitive environment is assumed in the input sector, which means that firms produce intermediate inputs for themselves.

I then assume that firms use the same intermediate input used in production for the final output to produce ideas, and more productive firms require fewer inputs to produce an idea. The number of intermediate inputs required to produce a number of ideas z_{ij} can be expressed as:

$$f(z_{ij}) = a_{ij}^{\alpha} z_{ij}^{1-e} \tag{3.9}$$

where α ($\alpha > 0$) reflects the extent to which the number of inputs needed increases with an increase in a firm's unit-input requirement. The cost function associated with a number of ideas z_{ij} is given by,

$$c(z_{ij}) = a_{ij}^{\alpha} z_{ij}^{1-e} p_{mij} \tag{3.10}$$

Substituting the price function of the intermediate inputs presents the quality-upgrading cost function as $c(z_{ij}) = a_{ij}^{\alpha} z_{ij} W_S^{\beta_j} W_K^{1-\beta_j}$. This expression reveals that to obtain the same level of product quality (q_{ij} which equals to z_{ij}), less productive firms (the firms with a higher a_{ij}) have to pay more for the quality upgrading compared to more productive firms. Andrews, Criscuolo, and Gal (2015) define the most productive firms as larger, more profitable and more likely to patent. More productive firms thus have better access to more advanced technology to develop product quality.

In addition to quality investment, firms must pay fixed and variable costs to produce in an industry. For simplicity, I assume that the intermediate input involved in the fixed costs ($F_D W_S^{\beta_j} W_K^{1-\beta_j}$) is generic across firms within one industry and it does not depend on the quality of the final good in question. However, it is produced with a technology that uses the same input intensity as the final good technology. Furthermore, the cost function shows that to obtain a certain quality of products, less productive firms (i.e. with a higher a_{ij}) have to invest more. Finally, profit maximisation implies the equilibrium price of final outputs, which equals a constant mark-up over marginal cost:

$$p_{ij} = \frac{\sigma}{\sigma - 1} a_i q_{ij}^e W_S^{\beta_j} W_K^{1-\beta_j} \tag{3.11}$$

Therefore, the operating profits of a firm with a final good of quality q_{ij} can be expressed as the revenues subtracting the quality investment and fixed entry costs, which can be expressed:

$$\pi_{ij} = \frac{p_{ij} x_{ij}}{\sigma} - c(z_{ij}) - F_D W_S^{\beta_j} W_K^{1-\beta_j} \tag{3.12}$$

Then the profit function can be simplified as:

$$\pi_{ij} = a_i^{(1-\sigma)} q_{ij}^{\gamma+e(1-\sigma)} (W_S^{\beta_j} W_K^{1-\beta_j})^{1-\sigma} B_j - a_i^{\alpha} q_{ij} W_S^{\beta_j} W_K^{1-\beta_j} - F_D W_S^{\beta_j} W_K^{1-\beta_j} \tag{3.13}$$

where B_j ($B_j = \frac{(\frac{\sigma}{\sigma-1})^{1-\sigma}}{\sigma(P_j)^{1-\sigma}} E_j$), is common across firms within the same industry, and it captures, among other things, changes in the industry demand.

Firms choose the optimal level of quality q_{ij} by maximising profits. Its first condition is given by,

$$\frac{\partial \pi_{ij}}{\partial q_{ij}} = [\gamma + e(1-\sigma)] a_i^{(1-\sigma)} q_{ij}^{\gamma + e(1-\sigma)-1} (W_S^{\beta_j} W_K^{1-\beta_j})^{-\sigma} B_j - a_i^{\alpha} = 0 \tag{3.14}$$

The quality function can be obtained by simplifying the first condition as follows:

$$z_{ij} = q_{ij} = [\frac{[\gamma + e(1-\sigma)] B_j}{a_i^{\alpha-(1-\sigma)} (W_S^{\beta_j} W_K^{1-\beta_j})^{\sigma}}]^{\frac{1}{1-[\gamma+e(1-\sigma)]}} \tag{3.15}$$

From this quality function, let us assume that $0 < \gamma + e(1-\sigma) < 1$. Based on this assumption, quality is positive, ensuring the maximum solution identified in the first-order condition. So, it can be seen that quality increases with B_j (i.e. a higher demand from the market is related to a higher quality for goods). A higher demand gives firms a higher marginal return, inducing firms to choose a higher quality for their goods in this situation. At the same time, given that $\alpha + \sigma - 1 > 0$, the conclusion that more productive firms invest more in quality (q_{ij} is decreasing with a_i) can be obtained.

However, this writing quality function contains B_j containing the aggregate price index, an endogenous variable. This function may cause difficulty in further comparing qualities in different situations. So I would like to find another expression of quality where I can replace B_j by a_{Dj}^{aut} (the number of intermediate inputs required for one unit of the final output of marginal firms). However, the above quality function will still be used for the following model set-up, which is more convenient.

For simplicity, let me denote that $[\gamma + e(1-\sigma)] = m$. A firm drawing the production unit-input threshold can cover the fixed costs of production, which is defined as the zero-profit condition:

$$(a_{Dj}^{aut})^{(1-\sigma)} q_{ij}(a_{Dj}^{aut})^{\gamma+e(1-\sigma)} (W_S^{\beta_j} W_K^{1-\beta_j})^{-\sigma} B_j - (a_{Dj}^{aut})^{\alpha} q_{ij}(a_{Dj}^{aut}) = F_D \tag{3.16}$$

Combining the first-order condition, Equation (3.14) and the zero-profit condition, Equation (3.16) can contribute to the following quality expression for the marginal firms as:

$$q_{ij}(a_{Dj}^{aut}) = \frac{mF_D}{1-m}(a_{Dj}^{aut})^{-\alpha} \tag{3.17}$$

According to the above equation, the marginal firm's quality is negatively associated with the autarky unit-input threshold. It means that in those industries in which there is more selection, the quality of the marginal firm is higher.

Based on Equation (3.14), I can obtain a ratio between a_i and a_{Dj}^{aut}.

$$(\frac{a_i}{a_{Dj}^{aut}})^{1-\sigma}\frac{q_{ij}^{m-1}}{q_{ij}(a_{Dj}^{aut})^{m-1}} = (\frac{a_i}{a_{Dj}^{aut}})^{\alpha} \tag{3.18}$$

Then the quality function can be found after substituting Equation (3.17),

$$q_{ij} = \frac{mF_D}{1-m} a_i^{\frac{\alpha+\sigma-1}{m-1}} (a_{Dj}^{aut})^{\frac{\alpha m+\sigma-1}{1-m}} \tag{3.19}$$

3.3.4 Firm Entry

After firms' entry, they draw their unit input, a_i, from a distribution, $g(a)$, which is assumed to be common across industries and countries. Firms then face a natural death rate each period, δ.[2] Given the quality function, the operating profits can be further expressed as:

$$\pi_{ij} = (1-m)m^{\frac{m}{1-m}} a_i^{\frac{1-\sigma-\alpha m}{1-m}} B_j^{\frac{1}{1-m}} (W_S^{\beta_j} W_K^{1-\beta_j})^{\frac{1-m-\sigma}{1-m}} - F_D W_S^{\beta_j} W_K^{1-\beta_j} \tag{3.20}$$

It can be said that profits decrease with a_i (i.e. more productive firms will obtain higher profits) since $\frac{1-\sigma-\alpha m}{1-m} < 0$.[3]

[2] The assumption that the probability of death is exogenous which is not related to firm characteristics follows Melitz (2003) and Bernard, Redding, and Schott (2007)

[3] It can be derived from $\alpha + \sigma - 1 > 0$ and $0 < m < 1$.

The existence of potential future positive profits motivates firms to invest in the fixed cost, $F_E W_S^{\beta_j} W_K^{1-\beta_j}$, to enter the industry. Entrants will enter the industry until the expected value of entry ($EV(\frac{\pi_{ij}}{\delta})$) equals the entry fixed costs $F_E W_S^{\beta_j} W_K^{1-\beta_j}$. The free entry condition can be defined as:

$$EV(\frac{\pi_{ij}}{\delta}) = F_E W_S^{\beta_j} W_K^{1-\beta_j} \tag{3.21}$$

which can further be expressed as:

$$\begin{aligned}\int_0^{a_{Dj}^{aut}} [(1-m)m^{\frac{m}{1-m}} a_i^{\frac{1-\sigma-\alpha m}{1-m}} B_j^{\frac{1}{1-m}} (W_S^{\beta_j} W_K^{1-\beta_j})^{\frac{1-m-\sigma}{1-m}} - F_D W_S^{\beta_j} W_K^{1-\beta_j}] g(a) da \\ = \delta F_E W_S^{\beta_j} W_K^{1-\beta_j}\end{aligned} \tag{3.22}$$

To obtain a closed solution for the production unit-input threshold, I further assume that the random variable a_i follows a Pareto distribution with density function $g(a) = ka^{k-1}$ and cumulative distribution function $G(a) = a^k$ where k is the shape parameter.[4] Thus, the threshold can be found and expressed as:

$$(a_{Dj}^{aut})^k = \frac{\delta F_E}{F_D} \frac{1-\sigma-\alpha m + k(1-m)}{\alpha m + \sigma - 1} \tag{3.23}$$

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 firm producing goods in industry j. Furthermore, the expression of a_{Dj}^{aut} reveals that in autarky, the production threshold does not depend on industry variables, provided that the parameters are the same across industries.

[4]Following this assumption, commonly used in the literature, I can obtain closed solutions for key variables.

3.4 The Costless Trade Model

This section maintains the assumption that international trade is costless, which means that all firms that produce can export now at no extra costs. To simplify notation, the country superscript will be omitted except where important.

3.4.1 Demand and Production

Profit maximisation implies that a firm will follow the same price in both markets since there are no trade costs and the elasticity of demand in both the domestic and export markets is the same.[5] The price charged in both markets are the same, which can be expressed as:

$$p_{ij} = p_{ijd} = p_{ijx} = \frac{\sigma}{\sigma - 1} a_i q_{ij}^e (W_S^H)^{\beta_j} (W_K^H)^{1-\beta_j} \tag{3.24}$$

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:

$$\pi_{ij} = \frac{p_{ij} x_{ij}^H}{\sigma} + \frac{p_{ij} x_{ij}^F}{\sigma} - c(z_{ij}) - F_D (W_S^H)^{\beta_j} (W_K^H)^{1-\beta_j} \tag{3.25}$$

which can be simplified as:

$$\begin{aligned} \pi_{ij} = a_i^{1-\sigma} q_{ij}^m (B_j^H + B_j^F) [(W_S^H)^{\beta_j} (W_K^H)^{1-\beta_j}]^{1-\sigma} - a_i^\alpha q_{ij} (W_S^H)^{\beta_j} (W_K^H)^{1-\beta_j} \\ - F_D (W_S^H)^{\beta_j} (W_K^H)^{1-\beta_j} \end{aligned} \tag{3.26}$$

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

[5] In the following analysis, I write out expressions for Home only; those for Foreign are analogous.

3.4.2 Investment in Quality

Given the profit function, firms tend to choose the optimal level of quality, q_{ij}, to maximise profits. Its first condition is given by,

$$\frac{\partial \pi_{ij}}{\partial q_{ij}} = m a_i^{1-\sigma} q_{ij}^{m-1} ((W_S^H)^{\beta_j} (W_K^H)^{1-\beta_j})^{-\sigma} (B_j^H + B_j^F) - a_i^{\alpha} = 0 \tag{3.27}$$

Simplify it and the quality function can be expressed as:

$$z_{ij} = q_{ij} = [\frac{m(B_j^H + B_j^F)}{a_i^{\alpha+\sigma-1} ((W_S^H)^{\beta_j} (W_K^H)^{1-\beta_j})^{\sigma}}]^{\frac{1}{1-m}} \tag{3.28}$$

It can be seen that quality increases with $(B_j^H + B_j^F)$ (i.e. a higher demand from both markets is related to a higher quality for goods) from the quality function.

Again, I want to find another expression of quality where replace B_j^H and B_j^F by a_{Dj}^{ft}, which will give a better idea of how quality changes from autarky to costless trade. However, the above quality function will be still used for the following model set-up.

First, I find the zero-profit condition where $\pi_{ij}(a_{Dj}^{ft}) = F_D (W_S^H)^{\beta_j} (W_K^H)^{1-\beta_j}$, which can be further expressed as:

$$(a_{Dj}^{ft})^{1-\sigma} q_{ij}^{m} (a_{Dj}^{ft}) [(W_S^H)^{\beta_j} (W_K^H)^{1-\beta_j}]^{-\sigma} (B_j^H + B_j^F) - (a_{Dj}^{ft})^{\alpha} q_{ij} (a_{Dj}^{ft}) = F_D \tag{3.29}$$

Combining the first-order condition, Equation (3.27) and the zero-profit condition, Equation (3.29) contributes to the quality function of the marginal firm:

$$q_{ij}(a_{Dj}^{ft}) = \frac{m F_D}{1-m} (a_{Dj}^{ft})^{-\alpha} \tag{3.30}$$

Then taking the ratio from Equation (3.27) between a_i and a_{Dj}^{ft} and substituting the equation of $q_{ij}(a_{Dj}^{ft})$ leads to the final expression of the quality as:

$$q_{ij} = \frac{mF_D}{1-m} a_i^{\frac{\alpha+\sigma-1}{m-1}} (a_{Dj}^{ft})^{\frac{\alpha m+\sigma-1}{1-m}} \tag{3.31}$$

3.4.3 Firm Entry

Profits earned by firms can be expressed after substituting q_{ij}:

$$\begin{aligned}\pi_{ij} = a_i^{1-\sigma}[&\frac{m(B_j^H+B_j^F)}{a_i^{\alpha+\sigma-1}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\sigma}}]^{\frac{m}{1-m}}(B_j^H+B_j^F)((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{1-\sigma} \\ - a_i^{\alpha}[&\frac{m(B_j^H+B_j^F)}{a_i^{\alpha+\sigma-1}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\sigma}}]^{\frac{1}{1-m}}(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} - F_D(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j}\end{aligned} \tag{3.32}$$

which can be further simplified as:

$$\begin{aligned}\pi_{ij} = (1-m)m^{\frac{m}{1-m}} a_i^{\frac{1-\sigma-\alpha m}{1-m}} ((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\frac{1-m-\sigma}{1-m}}(B_j^H+B_j^F)^{\frac{1}{1-m}} \\ - F_D(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j}\end{aligned} \tag{3.33}$$

where profits decrease with a_i.

Firms enter industries until the expected profits are equal to the fixed entry cost.

$$EV(\tfrac{\pi_{ij}}{\delta}) = F_E(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j}$$

which can be further expressed as:

$$\begin{aligned}\int_0^{a_{Dj}^{ft}} [(1-m)m^{\frac{m}{1-m}} a_i^{\frac{1-\sigma-\alpha m}{1-m}} ((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\frac{-\sigma}{1-m}}(B_j^H+B_j^F)^{\frac{1}{1-m}} - F_D]g(a)da \\ = \delta F_E\end{aligned} \tag{3.34}$$

Substituting the density function $g(a)$ the zero-profit condition can lead to the final result of the production unit-input threshold in the costless trade as:

$$(a_{Dj}^{ft})^k = \frac{\delta F_E}{F_D} \frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1} \tag{3.35}$$

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 in export markets due to trade openness and reduced demand in domestic markets due to import competition. Indeed, this change 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 will stay the same as before (which can be seen from the second expression of quality).

3.5 The Costly Trade Model

The assumption that trade is costless provides a good benchmark to understand better the forces at work in our model. However, it is unrealistic. Recent empirical evidence reveals the importance of fixed costs of exporting, such as costs of building up distribution channels, investment of getting knowledge about foreign markets, and developing appropriate marketing strategies (Roberts & Tybout, 1997; Bernard & Jensen, 2004).

This section analyses the more realistic case where firms that export need to bear a fixed cost, $F_X W_S^{\beta_j} W_K^{1-\beta_j}$ (where $F_X > F_D$), and a variable cost of the "iceberg" type as in Bernard, Redding, and Schott (2007). This variable cost means that firms need to ship a fraction τ ($\tau > 1$) units of a good in order for one unit to arrive. These fixed and variable costs mean that some firms may not export, conditional on their production ability.

It shows us a clear picture of how these trade costs interact with comparative advantage to determine production, exporting and quality choice. In addition, factor intensity and factor endowment determining reallocations of resources between industries and within-industry also play an essential role in shaping a firm's product quality.

3.5.1 Demand and Production

Profit maximisation implies that the domestic equilibrium price is a constant mark-up over marginal cost. However, due to the variable costs of exporting, the export price is a constant multiple of the domestic price:

$$p_{ijd} = p_{ij} \tag{3.36}$$

$$p_{ijx} = \tau p_{ijd} = \tau p_{ij} \tag{3.37}$$

As there is a fixed cost for exporting, not all firms can make enough profits to cover the fixed costs of exporting. As a result, more productive firms that can cover extra exporting costs sell goods in domestic and foreign markets, while less productive firms only serve the domestic market. The least productive firms are unable to make positive profits and exit industries. Given firms' pricing rules, the profits of firms can be expressed as:

$$\pi_{ij} = \frac{p_{ijd}x_{ij}^H}{\sigma} + \lambda\frac{p_{ijx}x_{ij}^F}{\sigma} - c(z_{ij}) - F_D(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} - \lambda F_X(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} \tag{3.38}$$

which can be further simplified as:

$$\begin{aligned}\pi_{ij} = a_i^{1-\sigma}q_{ij}^m(B_j^H + \lambda\tau^{1-\sigma}B_j^F)((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{1-\sigma} - a_i^\alpha q_{ij}(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} \\ - F_D(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} - \lambda F_X(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j}\end{aligned} \tag{3.39}$$

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

Then I assume that $B_j^F = A_jB_j^H$ where $A_j = \frac{E_j^F}{E_j^H}(\frac{P_j^H}{P_j^F})^{1-\sigma}$. The profit function can be further expressed as:

$$\begin{aligned}\pi_{ij} = a_i^{1-\sigma}q_{ij}^m B_j^H(1 + \lambda\tau^{1-\sigma}A_j^H)((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{1-\sigma} - a_i^\alpha q_{ij}(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} \\ - F_D(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} - \lambda F_X(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j}\end{aligned} \tag{3.40}$$

where λ takes the value of 1, firms exports and 0 otherwise.

3.5.2 Investment in Quality

Given the profit function, firms can choose the optimal level of quality q_{ij} to maximise profits. Its first condition is given by,

$$\frac{\partial\pi_{ij}}{\partial q_{ij}} = ma_i^{1-\sigma}q_{ij}^{m-1}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{-\sigma}B_j^H(1 + A_j\lambda\tau^{1-\sigma}) - a_i^\alpha = 0 \tag{3.41}$$

Similarly, the quality function can be expressed as:

$$z_{ij} = q_{ij} = [\frac{mB_j^H(1 + A_j\lambda\tau^{1-\sigma})}{a_i^{\alpha+\sigma-1}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\sigma}}]^{\frac{1}{1-m}} \tag{3.42}$$

This quality function shows that quality increases with B_j^H which means that firms will provide higher-quality goods inspired by a higher demand regardless of being exporters or non-exporters.

Besides, Equation (3.42) reveals that firms will change their quality choice once they decide to export. More precisely, within the same industry, firms that are capable of exporting will be exporters and invest in higher quality rather than serve the only domestic market with lower-quality goods as $A_j^H\tau^{1-\sigma} > 0$. The improvement in product quality is because the increase in market size from serving the foreign market makes investing in higher quality more profitable.

Again, I want to find another expression of quality where B_j^H and A_j^H are replaced with a_{Dj} (the production unit-input threshold) and a_{Xj} (the exporting unit-input threshold). Thus, there will be two profit functions, π_{ijd}, profits of firms servicing only the domestic market; π_{ijx}, profits of exporters and also two quality functions, q_{ijd}, quality of firms servicing only domestic market; q_{ijx}, quality of exporters. This expression will give a better idea of how quality changes from autarky to costly trade. However, the above quality function will be still used for the following model set-up.

First, I find the zero-profit condition where $\pi_{ij}^H(a_{Dj}) = F_D(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j}$.

$$a_{Dj}^{1-\sigma}q_{ijd}^m(a_{Dj})((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{-\sigma}B_j^H - a_{Dj}^{\alpha}q_{ijd} = F_D \tag{3.43}$$

Combining Equation (3.41) and (3.43) contributes to the quality function of the marginal firm as:

$$q_{ijd}(a_{Dj}) = \frac{mF_D}{1-m} a_{Dj}^{-\alpha} \tag{3.44}$$

Then taking the ratio from Equation (3.41) between a_i and a_{Dj} and substituting Equation (3.44) leads to the quality function of the firms that serve the domestic market only, which can be expressed as:

$$q_{ijd} = \frac{mF_D}{1-m} a_i^{\frac{\alpha+\sigma-1}{m-1}} (a_{Dj})^{\frac{\alpha m+\sigma-1}{1-m}} \tag{3.45}$$

The exporting unit-input threshold is low relative to the production unit-input threshold when $\frac{F_D}{F_X}[(1+A_j^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1] < 1$. In this case, there is an exporting selection effect (i.e. only the most productive firms export). Since empirical evidence commonly states selection into export markets, we obtain the results in the rest of the chapter based on the assumption that $\frac{F_D}{F_X}[(1+A_j^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1] < 1$.[6]

In costly trade, firms will export until the alternative profits of being just a domestic firm overcome the profits of being a global firm. Thus, the condition where some firms find no difference in profits between paying the fixed costs of exporting or remaining a purely domestic firm can be expressed as:

$$\pi_{ijd}(a_{Xj}) = \pi_{ijx}(a_{Xj}) \tag{3.46}$$

where

$$\begin{aligned}\pi_{ijd}(a_{Xj}) = {} & a_{Xj}^{1-\sigma} q_{ijd}^{m}(a_{Xj}) B_j^H ((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{1-\sigma} \\ & - a_{Xj}^{\alpha} q_{ijd}(a_{Xj})(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} - F_D (W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j}\end{aligned} \tag{3.47}$$

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

and

$$\pi_{ijx}(a_{Xj}) = a_{Xj}^{1-\sigma} q_{ijx}^{m}(a_{Xj}) B_j^H (1+\tau^{1-\sigma} A_j^H)((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{1-\sigma}$$
$$- a_{Xj}^{\alpha} q_{ijx}(a_{Xj})(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} - F_D (W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j}$$
$$- F_X (W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} \quad (3.48)$$

The Equation (3.41) and (3.43) are used to simplify this condition as:

$$\frac{1-m}{m} q_{ijd}(a_{Xj}) a_{Xj}^{\alpha} = \frac{1-m}{m} q_{ijx}(a_{Xj}) a_{Xj}^{\alpha} - F_X \quad (3.49)$$

Then substituting $q_{ijd}(a_{Xj})$ can lead to the quality function for marginal exporters,

$$q_{ijx}(a_{Xj}) = \frac{mF_X}{1-m} a_{Xj}^{-\alpha} [\frac{F_D}{F_X} (\frac{a_{Xj}}{a_{Dj}})^{\frac{\alpha m+\sigma-1}{m-1}} + 1] \quad (3.50)$$

Here, from the zero-profit condition, Equation (3.41), the relation of unit-input thresholds can be derived,

$$\frac{a_{Xj}}{a_{Dj}} = \{\frac{F_D}{F_X}[(1+A_j^H \tau^{1-\sigma})^{\frac{1}{1-m}} - 1]\}^{\frac{1-m}{\alpha m+\sigma-1}} \quad (3.51)$$

Then taking the ratio from Equation (3.41) between a_i and a_{Xj} and substituting Equation (3.50) and the relation between two thresholds, Equation (3.51) leads to the quality function of the exporters, which can be expressed as:

$$q_{ijx} = \frac{mF_X}{1-m} a_i^{\frac{\alpha+\sigma-1}{m-1}} (a_{Xj})^{\frac{\alpha m+\sigma-1}{1-m}} \{[(1+A_j \tau^{1-\sigma})^{\frac{1}{1-m}} - 1]^{-1} + 1\} \quad (3.52)$$

3.5.3 Firm Entry

Profits earned by firms can be expressed after substituting q_{ij}:

$$\begin{aligned}\pi_{ij} = a_i^{1-\sigma}[\frac{mB_j^H(1+\lambda A_j^H\tau^{1-\sigma})}{a_i^{\alpha+\sigma-1}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\sigma}}]^{\frac{m}{1-m}} B_j^H(1+\lambda A_j^H\tau^{1-\sigma})((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{1-\sigma} \\ - a_i^{\alpha}[\frac{mB_j^H(1+\lambda A_j^H\tau^{1-\sigma})}{a_i^{\alpha+\sigma-1}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\sigma}}]^{\frac{1}{1-m}}(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} \\ - F_D(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} - \lambda F_X(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} \quad (3.53)\end{aligned}$$

The profit function can be expressed after simplifying:

$$\begin{aligned}\pi_{ij} = (1-m)m^{\frac{m}{1-m}} a_i^{\frac{1-\sigma-\alpha m}{1-m}}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\frac{1-m-\sigma}{1-m}}(B_j^H)^{\frac{1}{1-m}}(1+\lambda A_j^H\tau^{1-\sigma})^{\frac{1}{1-m}} \\ - F_D(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} - \lambda F_X(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} \quad (3.54)\end{aligned}$$

where profits decrease with a_i.

In an equilibrium with positive production of both goods, firms enter industries until the expected profits equal the fixed entry cost.

$$E(\frac{\pi_{ij}}{\delta}) = F_E(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j} \quad (3.55)$$

which can be further expressed as:

$$\begin{aligned}\int_0^{a_{Xj}}[(1-m)m^{\frac{m}{1-m}} a_i^{\frac{1-\sigma-\alpha m}{1-m}}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\frac{-\sigma}{1-m}}(B_j^H)^{\frac{1}{1-m}}(1+A_j^H\tau^{1-\sigma})^{\frac{1}{1-m}} - F_D \\ - F_X]g(a)da + \int_{a_{Xj}}^{a_{Dj}}[(1-m)m^{\frac{m}{1-m}} a_i^{\frac{1-\sigma-\alpha m}{1-m}}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\frac{-\sigma}{1-m}}(B_j^H)^{\frac{1}{1-m}} \\ - F_D]g(a)da = \delta F_E \quad (3.56)\end{aligned}$$

After substituting the density function $g(a)$ and the relation between two thresholds and simplifying, it can be expressed as:

$$\delta F_E = \frac{k(1-m)}{1-\sigma-\alpha m+k(1-m)} F_X a_{Xj}^k - F_X a_{Xj}^k + \frac{k(1-m)}{1-\sigma-\alpha m+k(1-m)} F_D a_{Dj}^k - F_D a_{Dj}^k \quad (3.57)$$

Finally, the relation of two thresholds is used to derive the final results.

$$a_{Dj}^k = \frac{\delta F_E}{F_D} \frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1} \{1+(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_j^H \tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}\}^{-1} \quad (3.58)$$

$$a_{Xj}^k = \frac{\delta F_E}{F_X} \frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1} \{1+(\frac{F_X}{F_D})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_j^H \tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(m-1)}{\sigma-1+\alpha m}}\}^{-1} \quad (3.59)$$

3.5.4 Aggregation

Changes in the product quality of endogenous firms may also lead to different aggregate or average quality levels across industries, and the differences in product quality across industries when trade is open have already been found. Following the model, I first derive the aggregate quality of non-exporters, $\overline{q_{jd}^H}$ and that of exporters, $\overline{q_{jx}}$ respectively as:

$$\overline{q_{jd}^H} = \frac{1}{G(a_{Dj}^H) - G(a_{Xj}^H)} \int_{a_{Xj}^H}^{a_{Dj}^H} q_{ijd}^H(a_i) g(a) da \quad (3.60)$$

$$\overline{q_{jx}^H} = \frac{1}{G(a_{Xj}^H)} \int_0^{a_{Xj}^H} q_{ijx}^H(a_i) g(a) da \quad (3.61)$$

Based on these two average qualities, I can further obtain the overall average quality of one industry as:

$$\overline{q_j^H} = \frac{G(a_{Dj}^H) - G(a_{Xj}^H)}{G(a_{Dj}^H)}\overline{q_{id}^H} + \frac{G(a_{Xj}^H)}{G(a_{Dj}^H)}\overline{q_{ix}^H} \tag{3.62}$$

As the final result, the aggregate quality of one industry can be expressed as:

$$\overline{q_j} = (\frac{1}{a_{Dj}})^{\alpha}\frac{mkF_D}{1-\alpha-\sigma+k(1-m)}[1+(\frac{F_X}{F_D})^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}}M_j^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}}] \tag{3.63}$$

3.6 Propositions

Based on the above model, several analytical results can be derived concerning how the world changes when international trade occurs. More precisely, this section illustrates how exposure to trade affects firms' decisions for production, exporting and quality choice and how the comparative advantage contributes to those decisions. The framework of this chapter obtains all the propositions (1-6) derived in Chapter 2 and provides a new proposition (7) about the average or aggregate quality of the industry.

Proposition 1. $a_{Dj}^{aut} > a_{Dj}^H$ (i.e. The production unit-input threshold is lower in costly trade than in autarky.)

Proof: See Appendix

Consistent with Melitz (2003), when trade is costly, only a subset of firms find it profitable to export. Trade brings a differential effect on profits for exporters and non-exporters through two impacts, the expansion of markets and competition. Moving from autarky to costly trade, access to a larger market (the sum of two markets) makes the profits of more productive firms (exporters) rise, increasing the expected value of entering industries. A higher expected entry value causes more entrants and increases the demand for production factors. The increasing demand pushes up the prices of factors and thus increases a firm's production costs. Therefore, the production unit-input threshold below firms exit the industry becomes higher. Therefore, firms with a_i lying between a_{Dj}^{aut} and a_{Dj}^{H} are not able to receive enough revenue to cover fixed production costs and exit industries.

From the view of the factor market, the exposure to trade brings a larger market to exporters, which increases factor demand. This increase bids up factor prices, leading to higher production costs and thus lower profits for firms. As a result, the least productive firms can not survive in costly trade, and we can observe a lower production unit-input threshold than in autarky.

Intuitively, international trade brings a selection process of active firms through increasing competition, which further induces a reallocation of market and resources from less productive firms towards more productive firms within one industry.

Proposition 2. $q_{idj}^{H}(a_i) < q_{ij}(a_i)$ and $q_{ixj}^{H}(a_i) > q_{ij}(a_i)$ (i.e. Non-exporters lower their quality while exporters improve their quality from autarky to costly trade.)

Proof: See Appendix

In our model, quality choice is an endogenous variable for firms. They maximise profits by choosing the optimal product quality. Thus, they compare the marginal cost and the marginal benefit of upgrading quality and decide on their quality choice.

In terms of non-exporters who have no chance of benefiting from the expansion of markets, they face more competitors in both industries, leading to lower demand for their products and a lower marginal benefit of upgrading quality. Meanwhile, they also find an increase in the price of production factors contributing to a higher marginal cost of upgrading quality. As a result, the enlarging difference between the marginal cost and the marginal benefit makes them decide to lower the quality to survive.

Exporters face more competitors but simultaneously enjoy the expansion of markets. The access to a larger market makes it profitable to produce goods with a higher quality (a higher marginal cost but a much higher marginal benefit of upgrading quality). Finally, they raise their quality choice to earn more profits in international trade.

Proposition 3. $A_1^H > A_2^H$ (i.e. The profitability of serving the exporting market compared to the domestic market is greater in a country's comparative advantage industries.)

Proof: See Appendix

Consistent with Bernard, Redding, and Schott (2007), the comparative advantage can bring firms active in a comparative advantage industry higher profitability in serving the exporting market than the domestic market. In addition, the comparative advantage makes firms that serve in comparative advantage industries produce goods at a lower relative cost than foreign competitors, which gives them a better opportunity to make larger profits in international trade.

Proposition 4. $a_{D1}^H < a_{D2}^H$ and $a_{X1}^H > a_{X2}^H$ (i.e. The production unit-input threshold is lower, and the exporting unit-input threshold is higher in the comparative advantage industries.)

Proof: See Appendix

This proposition is consistent with the findings of Bernard, Redding, and Schott (2007). As exporting is more profitable in comparative advantage industries, the expected entry profit must be higher, which appeals to more new entrants. Then a more competitive market eliminates firms with relatively low productivity, and a lower production unit-input threshold can be found in comparative advantage industries.

Meanwhile, firms within one country's comparative advantage industries can produce goods at relatively lower costs than foreign competitors. As a result, more firms find it profitable to export in these industries, and a higher exporting unit-input threshold can be found in comparative advantage industries.

The factor market is another way to gain an intuition for the greater exit of low-productivity firms in comparative advantage industries. The exposure to trade leads to a greater increase in factor demand for exporters in comparative advantage industries. This increasing demand for factors will bid up the prices. However, it results in a rise in the relative price of the abundant factor (human capital for Home and physical capital for Foreign in our model). This increase in the relative price causes higher costs for production and fewer profits for non-exporters in comparative advantage industries. As a result, it decreases the production unit-input threshold by more in comparative advantage industries. This differential across industries does not occur in costless trade because all active firms can benefit from access to export markets.

Proposition 5. $q^H_{id1}(a_i) < q^H_{id2}(a_i)$ (i.e. Non-exporters will lower their quality by more in the comparative advantage industries.)

Proof: See Appendix

The quality choice made by firms differs across industries. In terms of non-exporters that suffer from competition impact, they have to decrease quality. The comparative advantage gives a higher expected entry profit to potential entrants inducing more entrants and more competition. Non-exporters in comparative industries face a more significant increase in production costs and a lower marginal benefit of upgrading quality). Hence, they have to lower quality more to survive than non-exporters in other industries conditional on productivity.

Proposition 6. $q^H_{ix1}(a_i) > q^H_{ix2}(a_i)$ (i.e. Exporters will improve their quality by more in the comparative advantage industries.)

Proof: See Appendix

Exporters suffer from increasing costs of production and exporting, while access to the export market benefits them. Following the above proposition, we know the impact of the expansion of markets overweighs the competition impact. The comparative advantage makes the differential between the two impacts even greater. As a result, exporters in the comparative advantage industries find the differential between the increased marginal benefit and the increased marginal cost of improving quality greater than exporters in other industries conditional on productivity. Therefore, exporters in the comparative advantage industries choose relatively high quality to maximise profits.

Proposition 7. $\overline{q^H_j} > q^{adj}_j$ (i.e. The average or aggregate quality of an industry is improved when trade happens.); $\overline{q^H_1} > \overline{q^H_2}$ (i.e. The aggregate quality of a comparative advantage industry is higher than that of a comparative disadvantage industry.)

Proof: See Appendix

The aggregate quality will be improved when a country opens to trade, for the most productive firms acting as exporters raise their product quality, and the least productive firms are forced to exit markets. Though the firms servicing only the domestic markets produce goods of a lower quality now, which will negatively affect the aggregate quality, the positive effect caused by exporting firms and exiting firms outweighs the negative effect.

Generally, when a country opens to trade, it makes the average quality of industries higher for all industries. However, the average quality of a comparative advantage industry is higher as firms within this industry in this country can produce and sell products at relatively low costs compared to their international competitors. More specifically, within a comparative advantage industry, more firms with the least productivity will exit, and more productive firms will choose to improve product quality and export, increasing the aggregate quality more than those in a comparative disadvantage industry conditional on productivity. Furthermore, this will outweigh the effect of lowered quality of non-exporters contributing to a higher aggregate quality of a comparative advantage industry.

3.7 Conclusion

Despite the extensive studies on firms' product quality, how it differs across industries has received less attention in the literature. This chapter attempts to fill the gap in patterns of firms' product quality and comparative advantage of industries in international trade. I have examined how firms choose product quality based on their productivity and industries.

This chapter extends the framework in Chapter 2 by allowing firms to produce and use different intermediate inputs for their final products, which contributes to the fact that more productive firms use more expensive (which could be interpreted as a proxy for higher-quality) intermediate inputs to produce higher-quality final goods and charge higher prices. This chapter obtains all the propositions in Chapter 2 and a new proposition. I first reveal that firms respond differently to the choice of product quality to trade openness based on their productivity. Exporters (more productive firms) find quality upgrading more profitable as they have access to bigger markets, while non-exporters (less productive firms) lower their product quality to survive more intense competition. Linked these responses to the comparative advantage, I further find that exporters (non-exporters) improve (lower) their product quality more in the comparative advantage industries than those in other industries conditional on productivity. This differential is because the comparative advantage provides exporters in the comparative advantage industries with a relatively bigger market, inspiring them to improve product quality. In contrast, more entrants in comparative advantage industries make non-exporters bear an increase in production costs and lower product quality. Furthermore, a higher aggregate quality of a comparative advantage industry can be found because the improved quality of exporters outweighs the effect of lowered quality of non-exporters.

Given these novel propositions from the model, it would be interesting to provide some empirical evidence in the next chapter, which will make this thesis more complete and convincing. Interesting areas for further research include extensions of the theory to incorporate firms' ability to produce multiple goods within industries.

3.8 Appendix

3.8.1 Proof of Propositions

Proof for Proposition 1

Get the ratio of a_{Dj}^{aut} and a_{Dj}^{H} and substitute the closed solutions for them.

$$[\frac{a_{Dj}^{aut}}{a_{Dj}^{H}}]^k = \frac{\frac{\delta F_E}{F_D}\frac{1-\sigma-\alpha m+k(1-m)}{\sigma-1+\alpha m}}{\frac{\delta F_E}{F_D}\frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}\{1+(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_j^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}\}^{-1}}$$

Simplify it.

$$[\frac{a_{Dj}^{aut}}{a_{Dj}^{H}}]^k = 1+(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_j^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}$$

where $(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_j^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}$ and k are positive, so it can be said that $a_{Dj}^{aut} > a_{Dj}^{H}$.

Proof for Proposition 2

For all comparisons of qualities, I will use the second expression of quality. Get the ratio of qualities of a non-exporter first in costly trade and autarky.

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

Simplify it.

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

Here, I already know that $\alpha m+\sigma-1>0$, $1-m>0$ and $a_{Dj}<a_{Dj}^{aut}$. So $\frac{q_{idj}}{q_{ij}}<1$, it can be said that firms servicing only the domestic market will choose to lower their quality from autarky to costly trade.

Then I get the ratio of qualities of an exporter in costly trade and autarky.

$$\frac{q_{ixj}}{q_{ij}} = \frac{\frac{mF_X}{1-m}a_i^{\frac{\alpha+\sigma-1}{m-1}}(a_{Xj})^{\frac{\alpha m+\sigma-1}{1-m}}\{[(1+A_j\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}+1\}}{\frac{mF_D}{1-m}a_i^{\frac{\alpha+\sigma-1}{m-1}}(a_{Dj}^{aut})^{\frac{\alpha m+\sigma-1}{1-m}}}$$

Simplify it.

$$\frac{q_{ixj}}{q_{ij}}=\frac{F_X}{F_D}(\frac{a_{Xj}}{a_{Dj}^{aut}})^{\frac{\alpha m+\sigma-1}{1-m}}\{1+[(1+A_j\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}\}$$

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

Simplify it.

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

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

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

I can propose Equation (B.1) which is smaller than the above equation, as I know $-1<\frac{1-\sigma-\alpha m}{k(1-m)}<0$ and $[\frac{F_X}{F_D}+(\frac{F_X}{F_D}M)]^{\frac{k(m-1)}{1-\sigma-\alpha m}}>\frac{F_X}{F_D}+(\frac{F_X}{F_D}M)^{\frac{k(m-1)}{1-\sigma-\alpha m}}$. However, to prove the latter one, I 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 $\ln(\frac{F_X}{F_D}+x)(\frac{F_X}{F_D}+x)^z-\ln x(x^z)$ which is always positive given $\frac{F_X}{F_D}>1$, $x>1$ and $z>1$ inducing that this fiction is monotonically increasing for z in the valid interval. Then I can find $y(z)$ is always bigger than 0 as $y(1)=0$. So I can obtain that $[\frac{F_X}{F_D}+(\frac{F_X}{F_D}M)]^{\frac{k(m-1)}{1-\sigma-\alpha m}}>\frac{F_X}{F_D}+(\frac{F_X}{F_D}M)^{\frac{k(m-1)}{1-\sigma-\alpha m}}$ given that $\frac{F_X}{F_D}>1$, $\frac{F_X}{F_D}M>1$ and $\frac{k(m-1)}{1-\sigma-\alpha m}>1$.

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

Simplify it.

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

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

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

As Equation (B.1) is smaller than the original equation, it can be said the original equation is greater than 1 and then I can obtain that $q_{ixj} > q_{ij}$, inducing that exporters improve the quality from autarky to costly trade.

Proof for Proposition 3

As mentioned before, $A_j^H = \frac{E_j^F}{E_j^H}(\frac{P_j^H}{P_j^F})^{1-\sigma}$. Assume that both countries share the same ratio of expenditure spent in one industry to the total expenditure. Hence, I can obtain the ratio of A_1^H and A_2^H.

$$\begin{aligned}\frac{A_1^H}{A_2^H} &= (\frac{P_1^H}{P_2^H})^{1-\sigma}(\frac{P_2^F}{P_1^F})^{1-\sigma}\frac{\mu R^F}{\mu R^H}\frac{(1-\mu)R^H}{(1-\mu)R^F} \\ &= (\frac{P_1^H}{P_2^H})^{1-\sigma}(\frac{P_2^F}{P_1^F})^{1-\sigma}\end{aligned}$$

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

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

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, I 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 it. 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 $((1-m)m^{\frac{m}{1-m}}(a_{Dj}^{aut})^{\frac{1-\sigma-\alpha m}{1-m}}B_j^{\frac{1}{1-m}}(W_S^{\beta_j}W_K^{1-\beta_j})^{\frac{1-m-\sigma}{1-m}} - F_D W_S^{\beta_j}W_K^{1-\beta_j} = 0)$ contributes to the relative industry price index which can be expressed as $(\frac{P_1^H}{P_2^H})^{1-\sigma} = \frac{\mu}{1-\mu}[(\frac{W_S^H}{W_K^H})^{\beta_1-\beta_2}]^{-\sigma}$, since the production cut-off is indifferent across industries. Hence, the value of the ratio of A_1^H and A_2^H can be found as:

$$
\begin{aligned}
\frac{A_1^H}{A_2^H} &= \frac{\mu}{1-\mu}[(\frac{W_S^H}{W_K^H})^{\beta_1-\beta_2}]^{-\sigma}\frac{1-\mu}{\mu}[(\frac{W_S^F}{W_K^F})^{\beta_1-\beta_2}]^{\sigma} \\
&= [(\frac{W_S^H/W_K^H}{W_S^F/W_K^F})^{\beta_1-\beta_2}]^{-\sigma}
\end{aligned}
$$

where the production of industry 1 uses skilled labour more intensively inducing that $\beta_1 > \beta_2$. As skilled labour is relatively abundant in Home, $\frac{W_S^H}{W_K^H} < \frac{W_S^F}{W_K^F}$ and then $A_1^H > A_2^H$.

Another extreme situation that I 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 $A_1^H = A_2^H$.

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. $A_1^H > A_2^H$).

Proof for Proposition 4

First, get the ratio of a_{D1}^H and a_{D2}^H from the expression of a_{Dj}^H.

$$
\frac{a_{D1}^H}{a_{D2}^H} = [\frac{\frac{\delta F_E}{F_D}\frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}\{1+(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_1^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}\}^{-1}}{\frac{\delta F_E}{F_D}\frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}\{1+(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_2^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}\}^{-1}}]^{\frac{1}{k}}
$$

Simplify it.

$$
\frac{a_{D1}^H}{a_{D2}^H} = [\frac{1+(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_2^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}}{1+(\frac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_1^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}}]^{\frac{1}{k}}
$$

As $\frac{k(1-m)}{\sigma-1+\alpha m} > 1$ and $A_1^H > A_2^H$, this ratio is smaller than 1. Therefore, I can prove that $a_{D1}^H < a_{D2}^H$.

Get the ratio of a_{X1}^H and a_{X2}^H from the expression of a_{Xj}^H.

$$\frac{a_{X1}^H}{a_{X2}^H} = [\frac{\frac{\delta F_E}{F_X}\frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}\{1+(\frac{F_X}{F_D})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_1^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(m-1)}{\sigma-1+\alpha m}}\}^{-1}}{\frac{\delta F_E}{F_X}\frac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}\{1+(\frac{F_X}{F_D})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_2^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(m-1)}{\sigma-1+\alpha m}}\}^{-1}}]^{\frac{1}{k}}$$

Simplify it.

$$\frac{a_{X1}^H}{a_{X2}^H} = [\frac{1+(\frac{F_X}{F_D})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_2^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(m-1)}{\sigma-1+\alpha m}}}{1+(\frac{F_X}{F_D})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_1^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(m-1)}{\sigma-1+\alpha m}}}]^{\frac{1}{k}}$$

As $\frac{k(m-1)}{\sigma-1+\alpha m} < -1$ and $A_1^H > A_2^H$, this ratio is greater than 1. Therefore, I can prove that $a_{X1}^H > a_{X2}^H$.

Proof for Proposition 5

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

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

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

Proof for Proposition 6

Get the ratio of qualities of exporters with same productivity in two industries.

$$\frac{q_{ix1}^H}{q_{ix2}^H} = \frac{\frac{mF_X}{1-m}a_i^{\frac{\alpha+\sigma-1}{m-1}}(a_{X1}^H)^{\frac{\alpha m+\sigma-1}{1-m}}}{\frac{mF_X}{1-m}a_i^{\frac{\alpha+\sigma-1}{m-1}}(a_{X2}^H)^{\frac{\alpha m+\sigma-1}{1-m}}}\frac{1+[(1+A_1^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}}{1+[(1+A_2^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}}$$

Then simplify it.

$$\frac{q_{ix1}^H}{q_{ix2}^H} = (\frac{a_{X1}^H}{a_{X2}^H})^{\frac{\alpha m+\sigma-1}{1-m}}\frac{1+[(1+A_1^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}}{1+[(1+A_2^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}}$$

Substitute the closed solutions for a_{X1}^H and a_{X2}^H.

$$\frac{q^H_{ix1}}{q^H_{ix2}} = [\frac{1+(\frac{F_X}{F_D})^{\frac{k(1-m)}{\alpha m+\sigma-1}-1}[(1+A_1^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(m-1)}{\alpha m+\sigma-1}}}{1+(\frac{F_X}{F_D})^{\frac{k(1-m)}{\alpha m+\sigma-1}-1}[(1+A_2^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(m-1)}{\alpha m+\sigma-1}}}]^{\frac{\alpha m+\sigma-1}{k(m-1)}}\frac{1+[(1+A_1^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}}{1+[(1+A_2^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}}$$

Here, for simplicity, I denote that $[(1+A_1^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1} = M_1$ and $[(1+A_2^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1} = M_2$, and I can obtain that $M_1 < M_2$ from $A_1^H > A_2^H$ and $0 < m < 1$. So this can be expressed as:

$$\frac{q^H_{ix1}}{q^H_{ix2}} = [\frac{1+(\frac{F_X}{F_D}M_1)^{\frac{k(1-m)}{\alpha m+\sigma-1}}\frac{F_D}{F_X}}{1+(\frac{F_X}{F_D}M_2)^{\frac{k(1-m)}{\alpha m+\sigma-1}}\frac{F_D}{F_X}}]^{\frac{\alpha m+\sigma-1}{k(m-1)}}\frac{1+M_1}{1+M_2}$$

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

$$\frac{q^H_{ix1}}{q^H_{ix2}} = [\frac{\frac{F_X}{F_D}+(\frac{F_X}{F_D}M_1)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}{\frac{F_X}{F_D}+(\frac{F_X}{F_D}M_2)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}]^{\frac{\alpha m+\sigma-1}{k(m-1)}}\frac{1+M_1}{1+M_2}$$

Now I am able to propose Equation (B.2) is smaller than the original equation.

$$[\frac{(\frac{F_X}{F_D}+\frac{F_X}{F_D}M_1)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}{(\frac{F_X}{F_D}+\frac{F_X}{F_D}M_2)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}]^{\frac{\alpha m+\sigma-1}{k(m-1)}}\frac{1+M_1}{1+M_2} \tag{B.2}$$

Here, I add an additional prove of proposing Equation (B.2) which is smaller than the original equation. Given $-1 < \frac{\alpha m+\sigma-1}{k(m-1)} < 0$, I have to prove that $\frac{(\frac{F_X}{F_D}+\frac{F_X}{F_D}M_1)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}{(\frac{F_X}{F_D}+\frac{F_X}{F_D}M_2)^{\frac{k(1-m)}{\alpha m+\sigma-1}}} > \frac{\frac{F_X}{F_D}+(\frac{F_X}{F_D}M_1)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}{\frac{F_X}{F_D}+(\frac{F_X}{F_D}M_2)^{\frac{k(1-m)}{\alpha m+\sigma-1}}}$. In order to do that, I am exploring the monotonicity of the function $y = \frac{\frac{F_X}{F_D}+x^z}{(\frac{F_X}{F_D}+x)^z}$. Since $M_2 > M_1$, I 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 $\frac{F_X}{F_D}M_1 > 1$, $\frac{F_X}{F_D}M_2 > 1$ (which means that $x > 1$) and $\frac{k(1-m)}{\alpha m+\sigma-1} > 1$ (which means that $z > 1$), the first order condition can be positive all the time. Furthermore, I can say that the function is monotonically increasing for x in the valid interval. Equation (A.2) is smaller than the original equation.

Then I simplify Equation (A.2).

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

Since Equation (A.2) equalling 1 is smaller than the original equation, I am able to obtain $q^H_{ix1}(a_i) > q^H_{ix2}(a_i)$.

Proof for Proposition 7

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

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

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

$$\overline{q^{aut}_j} = (\frac{1}{a^{aut}_{Dj}})^{\alpha}\frac{mkF_D}{1-\alpha-\sigma+k(1-m)} \tag{B.3}$$

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

$$\overline{q_{jd}} = \frac{1}{G(a_{Dj})-G(a_{Xj})}\int_{a_{Xj}}^{a_{Dj}} q_{ijd}(a_i)g(a)da$$
$$= \frac{1}{G(a_{Dj})-G(a_{Xj})}\int_{a_{Xj}}^{a_{Dj}} \frac{mF_D}{1-m}a_i^{\frac{\alpha+\sigma-1}{m-1}}(a_{Dj})^{\frac{\alpha m+\sigma-1}{1-m}}ka_i^{k-1}da$$
$$= \frac{1}{G(a_{Dj})-G(a_{Xj})}\frac{mF_Dk}{1-m}(a_{Dj})^{\frac{\alpha m+\sigma-1}{1-m}}\frac{m-1}{\alpha+\sigma-1+k(m-1)}$$
$$[(a_{Dj})^{\frac{\alpha+\sigma-1}{m-1}+k} - (a_{Xj})^{\frac{\alpha+\sigma-1}{m-1}+k}]$$
$$= \frac{1}{G(a_{Dj})-G(a_{Xj})}\frac{mF_Dk}{1-m}(a_{Dj})^{\frac{\alpha m+\sigma-1}{1-m}}\frac{m-1}{\alpha+\sigma-1+k(m-1)}$$
$$(a_{Dj})^{\frac{\alpha+\sigma-1}{m-1}+k}[1 - (\frac{a_{Xj}}{a^H_{Dj}})^{\frac{\alpha+\sigma-1}{m-1}+k}]$$

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

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

Then aggregate quality of exporters can be given by,

$$\begin{aligned}\overline{q_{jx}} &= \tfrac{1}{G(a_{Xj})}\int_0^{a_{Xj}} q_{ijx}(a_i)g(a)da \\ &= \tfrac{1}{G(a_{Xj})}\int_0^{a_{Xj}} \tfrac{mF_X}{1-m}a_i^{\frac{\alpha+\sigma-1}{m-1}}(a_{Xj})^{\frac{\alpha m+\sigma-1}{1-m}}\{[(1+A_j\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}+1\}ka_i^{k-1} \\ &= \tfrac{1}{G(a_{Xj})}\tfrac{mF_Xk}{1-m}a_{Xj}^{\frac{\alpha+\sigma-1}{m-1}+k}(a_{Xj})^{\frac{\alpha m+\sigma-1}{1-m}}\{[(1+A_j\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{-1}+1\}\tfrac{m-1}{\alpha+\sigma-1+k(m-1)}\end{aligned}$$

I can further simplify the quality equation of exporters as,

$$\overline{q_{jx}} = \frac{1}{G(a_{Xj})}\frac{mkF_X}{1-\alpha-\sigma+k(1-m)}(1+M_j)a_{Xj}^{k-\alpha} \quad \text{(B.5)}$$

Finally, I calculate the average quality of one industry within one country using average quality of non-exporters and exporters (Equation (B.4) and (B.5)) with their weight respectively.

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

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

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

Combine a_{Dj}.

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

Extract the common factor.

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

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

$$\overline{q_j} = \tfrac{1}{a_{Dj}^\alpha}\tfrac{mk}{1-\alpha-\sigma+k(1-m)}\{F_D-(\tfrac{F_X}{F_D}M_j)^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}}[F_D-F_X(1+M_j)(\tfrac{F_X}{F_D}M_j)^{-1}]\}$$

Simplify it.

$$\overline{q_j} = \tfrac{1}{a_{Dj}^\alpha}\tfrac{mk}{1-\alpha-\sigma+k(1-m)}[F_D-(\tfrac{F_X}{F_D}M_j)^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}}(F_D-F_D\tfrac{1+M_j}{M_j})]$$

Extract the common factor F_D and simplify it.

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

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

$$\overline{q_j} = (\frac{1}{a_{Dj}})^\alpha\frac{mkF_D}{1-\alpha-\sigma+k(1-m)}[1+(\frac{F_X}{F_D})^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}}M_j^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}}] \tag{B.6}$$

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

$$\overline{q_j}/\overline{q_j^{aut}} = (\frac{a_{Dj}^{aut}}{a_{Dj}})^{\alpha}[1 + (\frac{F_X}{F_D})^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}} M_j^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}}]$$

As I know that the threshold of input required for one unit final good is lower in costly trade ($a_{Dj} < a_{Dj}^{aut}$), α is positive ($\alpha > 0$), and the latter part of the above equation is bigger than one ($1 + (\frac{F_X}{F_D})^{\frac{\alpha+\sigma-1+k(m-1)}{\alpha m+\sigma-1}} M_j^{\frac{(\alpha-k)(1-m)}{\alpha m+\sigma-1}} > 1$) 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.

Also, given that in Home country $a_{D1} < a_{D2}$, $M_1 < M_2$ and $0 < m < 1$, we cannot arrive at the conclusion that $\overline{q_1} > \overline{q_2}$ (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 (3.9) in the main text and k is a shape parameter in the distribution function for ex-ante firm input-requirement).

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

After substituting the expression of a_{Dj}, the average quality can be expressed as,

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

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

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

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

$$\begin{aligned}\frac{\partial\overline{q_j}}{\partial(\frac{F_X}{F_D}M_j)} &= A\{\frac{\alpha}{k}[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j)^{\frac{k(m-1)}{\alpha m+\alpha-1}}]^{\frac{\alpha}{k}-1}\frac{F_X}{F_D}\frac{k(m-1)}{\alpha m+\sigma-1}(\frac{F_X}{F_D}M_j)^{\frac{k(m-1)}{\alpha m+\alpha-1}-1} \\ &\quad [1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j)^{\frac{(\alpha-k)(1-m)}{\alpha m+\alpha-1}}]+\frac{F_X}{F_D}\frac{(\alpha-k)(1-m)}{\alpha m+\alpha-1}(\frac{F_X}{F_D}M_j)^{\frac{(\alpha-k)(1-m)}{\alpha m+\alpha-1}-1} \\ &\quad [1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j)^{\frac{k(m-1)}{\alpha m+\alpha-1}}]^{\frac{\alpha}{k}}\} \\ &= A\frac{F_X}{F_D}\frac{m-1}{\alpha m+\sigma-1}(\frac{F_X}{F_D}M_j)^{\frac{k(m-1)}{\alpha m+\alpha-1}-1}[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j)^{\frac{k(m-1)}{\alpha m+\alpha-1}}]^{\frac{\alpha}{k}} \\ &\quad \{\frac{\alpha}{k}k[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j)^{\frac{k(m-1)}{\alpha m+\alpha-1}}]^{-1}[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j)^{\frac{(\alpha-k)(1-m)}{\alpha m+\alpha-1}}] \\ &\quad -(\alpha-k)(\frac{F_X}{F_D}M_j)^{\frac{\alpha(1-m)}{\alpha m+\sigma-1}}\}\end{aligned}$$

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

$$\begin{aligned}\frac{\partial\overline{q_j}}{\partial(\frac{F_X}{F_D}M_j)} &= A\frac{F_X}{F_D}\frac{1-m}{\alpha m+\sigma-1}(\frac{F_X}{F_D}M_j)^{\frac{k(m-1)}{\alpha m+\alpha-1}-1}[1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j)^{\frac{k(m-1)}{\alpha m+\alpha-1}}]^{\frac{\alpha}{k}} \\ &\quad [(\alpha-k)(\frac{F_X}{F_D}M_j)^{\frac{\alpha(1-m)}{\alpha m+\sigma-1}}-\alpha\frac{1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j)^{\frac{(\alpha-k)(1-m)}{\alpha m+\alpha-1}}}{1+\frac{F_X}{F_D}(\frac{F_X}{F_D}M_j)^{\frac{k(m-1)}{\alpha m+\alpha-1}}}]\end{aligned}$$

From the final expression, I can see that when $\alpha < k$, the second row will be negative which causes the first order condition negative too. In this condition, I am able to conclude that the average quality function is monotonically decreasing for $\frac{F_X}{F_D}M_j$ and I will find that the average quality of industry 1 (the comparative advantage industry) is higher given $M_1 < M_2$.

3.8.2 Proof for The Autarky Model

Proof for the price index and variety demand

To derive the price index, P_j and the variety demand, x_{ij}, I first maximise consumers' utility (consumption) (Equation (3.2) in the main text) in each industry subject to the consumer budget constraint (Equation (3.3) in the main text) using Lagrange function,

$$\theta = [\int_{i\in\Omega} q_{ij}^{\frac{\gamma}{\sigma}} c_{ij}^{\frac{\sigma-1}{\sigma}} di]^{\frac{\sigma}{\sigma-1}} + \lambda[\int_{i\in\Omega} p_{ij}c_{ij}di]$$

Then find the first order condition of θ subject to c_{ij} and a certain variety in industry j, c_1 respectively,

$$\frac{\partial\theta}{\partial c_{ij}} = \frac{\sigma}{\sigma-1}[\int_{i\in\Omega} q_{ij}^{\frac{\gamma}{\sigma}} c_{ij}^{\frac{\sigma-1}{\sigma}} di]^{\frac{\sigma}{\sigma-1}} \frac{\sigma-1}{\sigma} q_{ij}^{\frac{\gamma}{\sigma}} c_{ij}^{\frac{\sigma-1}{\sigma}-1} - \lambda p_{ij} = 0$$

$$\frac{\partial\theta}{\partial c_1} = \frac{\sigma}{\sigma-1}[\int_{i\in\Omega} q_{ij}^{\frac{\gamma}{\sigma}} c_{ij}^{\frac{\sigma-1}{\sigma}} di]^{\frac{\sigma}{\sigma-1}} \frac{\sigma-1}{\sigma} q_1^{\frac{\gamma}{\sigma}} c_1^{\frac{\sigma-1}{\sigma}-1} - \lambda p_1 = 0$$

Then these two conditions lead to an expression of c_{ij} as,

$$c_{ij} = (\frac{p_1}{p_{ij}})^{\sigma}(\frac{q_{ij}}{q_1})^{\gamma} c_1 \tag{B.7}$$

Substitute Equation (B.7) into the consumption and expenditure equation,

$$C_j = p_1^{\sigma} q_1^{-\gamma} c_1 [\int_{i\in\Omega} p_{ij}^{1-\sigma} q_{ij}^{\gamma} di]^{\frac{\sigma}{\sigma-1}}$$

$$E_j = p_1^{\sigma} q_1^{-\gamma} c_1 \int_{i\in\Omega} p_{ij}^{1-\sigma} q_{ij}^{\gamma} di$$

As $E_j = C_j P_j$, then the price index, P_j, can be derived from the ratio between the above equations as:

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

Finally, substituting the expression of the price index into the consumption equation and normalizing c_1 can lead to the variety demand equation described in Equation (3.4) in the main text as:

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

Proof for the price of intermediate inputs

To derive the price of intermediate inputs, I start with the production function of intermediate inputs (Equation (3.6) in the main text). To derive the price of intermediate inputs, P_{mij}, I first minimise firms' production costs of intermediate inputs (consisting of two-factor payments)subject to their production of intermediate inputs using the Lagrange function,

$$\theta = W_S S_j + W_K K_j + \lambda(y_{ij} - H_j S_j^{\beta_j} K_j^{1-\beta_j} T_{ij})$$

Then find the first order condition of θ subject to S_j, K_j and λ respectively,

$$\frac{\partial \theta}{\partial S_j} = W_S - \beta_j H_j S_j^{\beta_j - 1} K_j^{1-\beta_j} T_{ij} = 0$$

$$\frac{\partial \theta}{\partial K_j} = W_K - (1-\beta_j) H_j S_j^{\beta_j} K_j^{-\beta_j} T_{ij} = 0$$

$$\frac{\partial \theta}{\partial \lambda} = y_{ij} - H_j S_j^{\beta_j} K_j^{1-\beta_j} T_{ij} = 0$$

The first two conditions contributes to a relation between the two factors used,

$$\frac{K_j}{S_j} = \frac{1-\beta_j}{\beta_j} \frac{W_S}{W_K}$$

Then substitute this relation into the production function of the intermediate inputs. Two factors used can be expressed using y_{ij} and factor rewards as:

$$S_j = y_{ij} \frac{1}{H_j} (\frac{1-\beta_j}{\beta_j})^{\beta_j - 1} (\frac{W_K}{W_S})^{1-\beta_j} T_{ij}^{-1}$$

$$K_j = y_{ij} \frac{1}{H_j} (\frac{1-\beta_j}{\beta_j})^{\beta_j} (\frac{W_K}{W_S})^{-\beta_j} T_{ij}^{-1}$$

Substitute these two expressions of two factors into the total costs of intermediate-input production,

$$TC = y_{ij} \frac{1}{H_j} W_K^{1-\beta_j} W_S^{\beta_j} (1-\beta_j)^{\beta_j - 1} \beta_j^{-\beta_j} T_{ij}^{-1}$$

Finally, the price of intermediate inputs can equal the marginal cost of production (also the average costs of production)in perfect competition as:

$$p_{mij} = \frac{TC}{y_{ij}} = \frac{1}{H_j} W_K^{1-\beta_j} W_S^{\beta_j} (1-\beta_j)^{\beta_j - 1} \beta_j^{-\beta_j} T_{ij}^{-1}$$

With the assumptions, $H_j = \beta_j^{-\beta_j}(1-\beta_j)^{-(1-\beta_j)}$ for simplicity and $\tau_{ij} = q_{ij}^{-e}$, the final expression of the intermediate-input price can be described as in Equation (3.7) in the main text,

$$p_{mij} = W_S^{\beta_j} W_K^{1-\beta_j} q_{ij}^{e}$$

Proof for production unit-input threshold

To derive the production unit-input threshold, I start with the free entry condition, Equation (3.21) in the main text:

$$EV(\frac{\pi_{ij}}{\delta}) = F_E W_S^{\beta_j} W_K^{1-\beta_j}$$

which can be further expressed as:

$$\int_0^{a_{Dj}^{aut}} [(1-m)m^{\frac{m}{1-m}} a_i^{\frac{1-\sigma-\alpha m}{1-m}} B_j^{\frac{1}{1-m}} (W_S^{\beta_j} W_K^{1-\beta_j})^{\frac{1-m-\sigma}{1-m}} - F_D W_S^{\beta_j} W_K^{1-\beta_j}] g(a) da$$
$$= \delta F_E W_S^{\beta_j} W_K^{1-\beta_j} \quad \text{(B.8)}$$

Simplify it based on the assumption of a Pareto distribution for unit input regarding intermediate inputs $g(a) = ka^{k-1}$ (with its cumulative density function $G(a) = a^k$, where k is a shape parameter).

$$\int_0^{a_{Dj}^{aut}} [(1-m)m^{\frac{m}{1-m}} a_i^{\frac{1-\sigma-\alpha m}{1-m}} B_j^{\frac{1}{1-m}} (W_S^{\beta_j} W_K^{1-\beta_j})^{\frac{-\sigma}{1-m}} - F_D] k a_i^{k-1} da = \delta F_E$$

Then, the equation can be calculated as:

$$(1-m)m^{\frac{m}{1-m}}B_j^{\frac{1}{1-m}}(W_S^{\beta_j}W_K^{1-\beta_j})^{\frac{-\sigma}{1-m}}\frac{k(1-m)}{1-\sigma-\alpha m+k(1-m)}(a_{Dj}^{aut})^{\frac{1-\sigma-\alpha m}{1-m}+k} - F_D(a_{Dj}^{aut})^k = \delta F_E \quad \text{(B.9)}$$

Finally, substitute the zero-profit condition into the above equation.

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

After simplifying, the production unit-input threshold can be obtained as:

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

3.8.3 Proof for The Costly Trade Model

Proof for the relationship between two thresholds

To derive the relationship between two thresholds, a ratio between a marginal exporter's quality and a marginal domestic firm's quality can be found from Equation (3.41) in the main text:

$$\frac{\partial \pi_{ij}}{\partial q_{ij}} = ma_i^{1-\sigma}q_{ij}^{m-1}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{-\sigma}B_j^H(1+A_j\lambda\tau^{1-\sigma}) - a_i^{\alpha} = 0$$

I can get a ratio between the quality choice of being exporters and the quality choice of being purely domestic firms for firms with the exporting unit-input threshold as:

$$q_{ijx}(a_{Xj}) = q_{ijd}(a_{Xj})(1+A_j\tau^{1-\sigma})^{\frac{1}{1-m}} \quad \text{(B.10)}$$

Notice the condition when firms find no difference in profits between exporting or remaining a purely domestic firm described in Equation (3.46), which can be simplified as Equation (3.49) in the main text:

$$\tfrac{1-m}{m}q_{ijd}(a_{Xj})a_{Xj}^{\alpha} = \tfrac{1-m}{m}q_{ijx}(a_{Xj})a_{Xj}^{\alpha} - F_X$$

Substituting Equation (B.9) into the above condition and simplifying it,

$$\frac{1-m}{m}a_{Xj}^{\alpha}q_{ijd}(a_{Xj})[(1+A_j\tau^{1-\sigma})^{\frac{1}{1-m}}-1] = F_X \tag{B.11}$$

Then get a ratio between the quality choice for a firm with the production unit-input threshold and the quality choice for a firm with the exporting unit-input threshold being a purely domestic firm as:

$$q_{ijd}(a_{Xj}) = (\tfrac{a_{Xj}}{a_{Dj}})^{\frac{\alpha+\sigma-1}{m-1}}q_{ijd}(a_{Dj})$$

Finally substituting Equation (B.10) and $q_{ijd}(a_{Dj}) = \frac{mf_D}{1-m}a_{Dj}^{-\alpha}F_D$ into the above equation can lead to the relation between two thresholds described as in Equation (3.51) in the main text as:

$$\tfrac{a_{Xj}}{a_{Dj}} = \{\tfrac{F_D}{F_X}[(1+A_j^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]\}^{\frac{1-m}{\alpha m+\sigma-1}}$$

Proof for exporters' quality choice

To derive the quality function for exporters, I start with the condition when firms find no difference in profits between exporting or remaining a purely domestic firm described in Equation (3.46), which can be simplified as Equation (3.49) in the main text as:

$$\tfrac{1-m}{m}q_{ijd}(a_{Xj})a_{Xj}^{\alpha} = \tfrac{1-m}{m}q_{ijx}(a_{Xj})a_{Xj}^{\alpha} - F_X$$

Then substitute $q_{ijd}(a_{Xj})$ as:

$$q_{ijx}(a_{Xj}) = \tfrac{mF_X}{1-m}a_{Xj}^{-\alpha}[\tfrac{F_D}{F_X}(\tfrac{a_{Xj}}{a_{Dj}})^{\frac{\alpha m+\sigma-1}{m-1}}+1]$$

Next, I can get the quality function for marginal exporters that export using the relation between two thresholds described in Equation (3.51) in the main text as:

$$q_{ijx}(a_{Xj}) = \frac{mF_X}{1-m} a_{Xj}^{-\alpha}\{[(1 + A_j\tau^{1-\sigma})^{\frac{1}{1-m}} - 1]^{-1} + 1\}$$

Then get the ratio from Equation (3.41) in the main text about a_i and a_{Xj}.

$$(\frac{a_i}{a_{Xj}})^{1-\sigma}\frac{q_{ijx}^{m-1}}{q_{ijx}^{m-1}(a_{Xj})} = (\frac{a_i}{a_{Xj}})^{\alpha}$$

Finally, substituting $q_{ijx}(a_{Xj})$ can lead to the quality function for exporters as Equation (3.52) in the main text.

$$q_{ijx} = \frac{mF_X}{1-m} a_i^{\frac{\alpha+\sigma-1}{m-1}}(a_{Xj})^{\frac{\alpha m+\sigma-1}{1-m}}\{[(1 + A_j\tau^{1-\sigma})^{\frac{1}{1-m}} - 1]^{-1} + 1\}$$

Proof for the production and exporting unit-input threshold

To derive two thresholds, I start with Equation (3.55) in the main text,

$$E(\frac{\pi_{ij}}{\delta}) = F_E(W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j}$$

Substitute the profit function into it,

$$\int_0^{a_{Xj}}[(1-m)m^{\frac{m}{1-m}}a_i^{\frac{1-\sigma-\alpha m}{1-m}}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\frac{-\sigma}{1-m}}(B_j^H)^{\frac{1}{1-m}}(1+A_j^H\tau^{1-\sigma})^{\frac{1}{1-m}} - F_D - F_X]g(a)da + \int_{a_{Xj}}^{a_{Dj}}[(1-m)m^{\frac{m}{1-m}}a_i^{\frac{1-\sigma-\alpha m}{1-m}}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\frac{-\sigma}{1-m}}(B_j^H)^{\frac{1}{1-m}} - F_D]g(a)da = \delta F_E$$

Then substitute $g(a)$ into this expression.

$$\int_0^{a_{Xj}}[(1-m)m^{\frac{m}{1-m}}a_i^{\frac{1-\sigma-\alpha m}{1-m}}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\frac{-\sigma}{1-m}}(B_j^H)^{\frac{1}{1-m}}(1+A_j^H\tau^{1-\sigma})^{\frac{1}{1-m}} - F_D - F_X]ka_i^{k-1}da + \int_{a_{Xj}}^{a_{Dj}}[(1-m)m^{\frac{m}{1-m}}a_i^{\frac{1-\sigma-\alpha m}{1-m}}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\frac{-\sigma}{1-m}}(B_j^H)^{\frac{1}{1-m}} - F_D]ka_i^{k-1}da = \delta F_E$$

Calculate the equation as

$$\delta F_E = (1-m)m^{\frac{m}{1-m}} a_{Xj}^{\frac{1-\sigma-\alpha m}{1-m}+k}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\frac{-\sigma}{1-m}}(B_j^H)^{\frac{1}{1-m}}(1+A_j^H\tau^{1-\sigma})^{\frac{1}{1-m}}$$
$$\frac{k(1-m)}{1-\sigma-\alpha m+k(1-m)} - F_D a_{Xj}^k - F_X a_{Xj}^k + (1-m)m^{\frac{m}{1-m}} a_{Dj}^{\frac{1-\sigma-\alpha m}{1-m}+k}$$
$$((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\frac{-\sigma}{1-m}}(B_j^H)^{\frac{1}{1-m}} \frac{k(1-m)}{1-\sigma-\alpha m+k(1-m)} - F_D a_{Dj}^k$$
$$-(1-m)m^{\frac{m}{1-m}} a_{Xj}^{\frac{1-\sigma-\alpha m}{1-m}+k}((W_S^H)^{\beta_j}(W_K^H)^{1-\beta_j})^{\frac{-\sigma}{1-m}}(B_j^H)^{\frac{1}{1-m}} \frac{k(1-m)}{1-\sigma-\alpha m+k(1-m)}$$
$$+ F_D a_{Xj}^k$$

Then simplify this equation and substitute two threshold conditions into it.

$$\delta F_E = \tfrac{k(1-m)}{1-\sigma-\alpha m+k(1-m)} F_X a_{Xj}^k - F_X a_{Xj}^k + \tfrac{k(1-m)}{1-\sigma-\alpha m+k(1-m)} F_D a_{Dj}^k - F_D a_{Dj}^k$$

Finally, the relation of two thresholds is used to derive the final results of two thresholds described in Equation (3.58) and (3.59) in the main text:

$$a_{Dj}^k = \tfrac{\delta F_E}{F_D}\tfrac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}\{1+(\tfrac{F_D}{F_X})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_j^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(1-m)}{\sigma-1+\alpha m}}\}^{-1}$$

$$a_{Xj}^k = \tfrac{\delta F_E}{F_X}\tfrac{1-\sigma-\alpha m+k(1-m)}{\alpha m+\sigma-1}\{1+(\tfrac{F_X}{F_D})^{\frac{k(1-m)}{\sigma-1+\alpha m}-1}[(1+A_j^H\tau^{1-\sigma})^{\frac{1}{1-m}}-1]^{\frac{k(m-1)}{\sigma-1+\alpha m}}\}^{-1}$$

Chapter 4

Comparative Advantage and Quality Choice of Heterogeneous Firms: Evidence from China

4.1 Introduction

In recent years, a large amount of literature has emerged to explore firms' exporting product quality. Some prior studies have focused on endogenous factors that would affect the product quality of firms, like productivity, size, and the choice of intermediate inputs (e.g. E. A. Verhoogen, 2008; Manova & Zhang, 2012). Others have explored firm exogenous variables, including trade liberalisation and characteristics of destination countries (e.g. Amiti & Khandelwal, 2013; Bas & Strauss-Kahn, 2014).

Inspired by the increasing availability of micro-data on manufacturing firms, more studies have empirically explored the role of firm heterogeneity in firms' exporting product quality. E. A. Verhoogen (2008) analyses Mexican manufacturing data and reports that more productive plants produced higher quality goods than less productive plants. Kugler and Verhoogen (2012) find that larger firms produce higher quality goods and charge a relatively high price. Manova and Zhang (2012), using Chinese data, show that more productive firms produced higher quality products using higher quality inputs. Fan et al. (2018) use Chinese data to show that China's tariff reductions led to a quality upgrading, which is more concentrated in the least-productive Chinese exporters.

On the other hand, many papers highlight the role played by the differences between industries and countries in international trade. Krugman (1980) reports that countries traded more the more similar they were (regarding the number of labour within one country). However, Schott (2004) finds differences in unit values of the same products from high- and low-wage countries and provides evidence of endowment-driven specialisation within products suggesting that capital- and skill-abundant countries use their endowment advantage to produce relatively capital- or skill-intensive varieties and possess added features or higher quality. Hummels and Klenow (2005) show that richer countries export more products with relatively higher prices. Hallak (2006) points out that rich countries imported relatively more from countries that produced high-quality goods.

Despite the extensive literature that has explored how firm heterogeneity or variation across countries shapes firms' exporting product quality, few studies have provided empirical evidence of how this product quality varies across the comparative advantage of industries. To examine this relationship, which is one novel and important prediction drawn from the theoretical models in previous chapters, I use highly disaggregated matched firm-transaction level data from 2000 to 2007 (transaction-level data from China Customs and firm-level data from the National Bureau of Statistics of China) to test how the comparative advantage enhances the export quality of Chinese firms.

I define quality as unobserved attributes of a variety that make consumers willing to purchase relatively large quantities holding prices across varieties constant. Therefore, these attributes are broadly defined and include tangible features such as build quality and intangible attributes such as a brand image. This chapter applies the estimation method from A. K. Khandelwal et al. (2013) to estimate firms' exporting product quality at the firm-product level and uses the Balassa Index of revealed comparative advantage, a standard measure used in international trade to identify those industries in which a country reveals a comparative advantage, to measure the industry difference in one country. The central prediction of Chapter 2 and 3 that exporters produce higher-quality goods in comparative advantage industries is robust.

Furthermore, I explore where the comparative advantage comes from. According to the theoretical model in the last chapter, this comparative advantage comes from relative factor endowment differences. In this chapter, I use physical capital and human capital per worker as factor endowments and construct the relative factor endowment of China. Then, using a Two-Stage Least Squares (2SLS) regression, I estimate the comparative advantage using the data of relative factor endowment and regress this estimated comparative advantage on product quality. The result shows a positive relationship between the exporting product quality and the comparative advantage and suggests that the comparative advantage stems from the relative factor endowment difference.

The rest of the chapter is organised as follows. Section 2 reviews the literature in terms of quality measurement and factor endowments. Section 3 describes the data and presents the econometric model and ways of constructing several key variables. Section 4 provides the main results. Section 5 presents robustness exercises concerning the firms' total factor productivity (TFP), product quality estimation, potential endogeneity and sample selection. The final section concludes.

4.2 Literature Review

4.2.1 Quality Measurement

Product quality has been challenging to be measured in the literature as it can not be unobserved directly from the data. Consumers can not always tell whether the product is high or low quality when they are purchasing (e.g. the market for "lemons" and used cars). E. Verhoogen (2021) summarises different measures of quality. Research in the international trade literature has attempted to deal with this problem based on the strong quality-equals-price assumption, as quality differentiation is often viewed as the main determinant of variation in unit values (Hallak, 2006). For instance, Schott (2004) uses unit values to proxy product quality and shows that capital- and skill-abundant countries may use their endowment advantage to produce higher-quality products and ask for a relatively high price. Hummels and Klenow (2005) propose that richer countries export higher-quality goods.

This approach is convenient because of its simplicity and easy data availability. However, apart from quality, there are also other determinants of unit values like manufacturing costs. An example discussed in A. Khandelwal (2010) is that the U.S. imported Malaysian and Portuguese women's trousers at unit values $146 and $371 in 1999, respectively. That means the quality of Malaysian trousers is only about half of the quality of Portuguese trousers if prices can perfectly reflect product quality. However, the huge differences between the prices of trousers in the two countries can be partly explained by the different annual wages in the apparel sector (i.e. variations in manufacturing costs) and imperfect competition.

As unit values can not reflect product quality perfectly, many works can only show some facts about the unit values of products and then propose potential explanations or hypotheses in terms of product quality. For instance, Manova and Zhang (2012) state that given a certain product, Chinese exporters that charge higher prices earn greater revenues, have bigger sales, and enter more markets while they import more expensive inputs. These facts suggest a trade pattern of successful exporters producing higher-quality products using higher-quality inputs. Similarly, Kugler and Verhoogen (2012) show that larger Colombian manufacturing plants charge more for their outputs while paying more for their material inputs and propose an endogenous input and output quality choice model to explain the observed trade patterns.

Without an effective product quality estimation, the literature was too limited to directly show the relationship between product quality and other characteristics at the firm, industry or country level. Many works attempted to take advantage of observable quality information. For example, Macchiavello (2010) and Crozet, Head, and Mayer (2012) obtain direct quality measures from wine guides; Bai (2021) measure the quality of watermelon from the biweekly quality checks using sweet meters; Bai, Gazze, and Wang (2022) use the information of inspections to index the quality of Chinese dairy products.

At the time, some economists disentangle quality from trade unit values (e.g. A. Khandelwal, 2010; Hallak & Schott, 2011). A. Khandelwal (2010) develops a solution using unit values and market share data to estimate product quality. This estimation stems from a nested logit demand system based on Berry (1994). Quality is defined as unobserved attributes of a variety that make consumers willing to purchase relatively large quantities, holding the price constant. It uses both unit values and quantity information to infer quality and provides an intuition: varieties with more quantity are assigned higher quality conditional on price. A. K. Khandelwal et al. (2013) then estimate Chinese exporters' product quality within the textile and clothing industry. This estimation requires no special data and reveals quality at the finest product level, and it has been commonly applied in recent literature.

Fan et al. (2015) show that a reduction in import tariffs makes Chinese exporters increase the quality of their outputs and raise their prices in industries with a large scope of quality differentiation, and lower their prices in industries where the scope is small based on using the quality measurement from A. K. Khandelwal et al. (2013). Manova and Yu (2017) proxy product quality using the same method and reveal that Chinese multi-product firms vary their output quality across their products by using different-quality material inputs. Furthermore, their core competence varieties are of superior quality, and they charge a higher price for them. Based on this quality measurement, Dingel (2017) estimates the product quality and documents that the high-income locations focus on producing and exporting high-quality products among the U.S. cities. Bas and Paunov (2021) show that trade liberalisation allows Ecuadorian firms to improve the quality of imported inputs, the skill intensity and the skill premium. Thus, this chapter follows the literature and applies the quality estimation from A. K. Khandelwal et al. (2013) to show how the product quality of Chinese exporters varies across industries.

4.2.2 Factor Endowments

It is important to deliver evidence on the role of a country's factor endowment in determining its comparative advantage to show a good fit of the theoretical model in that last chapter to the data. The first factor-endowment study was by Leontief (1953), who used U.S. data and found that U.S. exports were less capital-intensive than imports. In later works, Trefler (1993) and Trefler (1995) measure ten factors. He defines the aggregate labour endowment as the economically active population and capital endowment as the discounted sum of constant-price investment flows.

Hall and Jones (1999) measure the country's factor endowments, including human capital and physical capital per worker. They define human capital as average educational attainment, measured in 1985 for the population aged 25 and over, as reported by Barro and Lee (1993) while defining physical capital as the investment flows. As a final result, they reveal that the differences in factor endowments (human capital and physical capital) can only partially explain why output per worker varies across countries. Since then, these measures of country endowments have been commonly used in the literature.

Romalis (2004) adopts the measures of factor endowments from Hall and Jones (1999) and proposes a prediction that countries that feature larger shares of world production and trade of commodities use their abundant factors more intensively. Chor (2010) finds the evidence that skill-abundant countries exported more in more skill-intensive industries, and capital-abundant countries tended to export more in capital-intensive industries using the country endowment measures from Hall and Jones (1999). Following the literature, this chapter also applies these measures of factor endowment to show that a country's comparative advantage is highly related to the differences in relative factor endowments.

4.3 Data and empirical strategy

Theoretical models in the last two chapters have already delivered several predictions about firms' quality choices and provided some explanations. It will better understand if some supporting facts can be found in the data, especially for the novel propositions. Thus, this chapter empirically tests Proposition 6 in the last chapter (i.e., exporters in a comparative advantage industry increase their quality by more than exporters in a comparative disadvantage industry).[1] Proposition 6 is a novel finding, and it will emphasise the importance of one country's comparative advantage in decisions of exporters' quality choices if this proposition is confirmed.

This section describes the data, the matching strategy, and the econometric model used and presents how key variables that are not observable from the data, like product quality, are measured.

4.3.1 Data

This chapter mainly uses a matched sample from two data sources. First, Chinese firm-level data from the Chinese Annual Survey of Industrial Firms are carried out by the National Bureau of Statistics of China (NBS). Second, international trade transaction-level data from Chinese Customs Trade Statistics (CCTS) provide exporters' transaction-level data. I use data from both sources over the sample from 2000 to 2007.[2] This matched sample has been important recently as it is both informative in terms of the characteristics of China's manufacturing firms and their international transactions. Thus, many works have used it (e.g. Defever, Imbruno, & Kneller, 2020; A. K. Khandelwal et al., 2013; Manova & Yu, 2016; Upward, Wang, & Zheng, 2013).

Firm-level Survey Data

The NBS data includes all state-owned and non-state-owned industrial enterprises with annual sales of greater than 5 million Chinese Yuan (RMB). It has been com-

[1] No empirical evidence for the propositions in terms of non-exporters can be provided, as there is no transaction-level or product-level data available for Chinese domestic firms.

[2] In terms of firm-level database, the data after 2007 does not include several main production variables like total intermediate inputs, which are necessary for total factor productivity (TFP) estimation. Additionally, the literature commonly used this data before the year 2007. In terms of the transaction-level database, its record starts from the year 2000. Thus, this chapter follows the literature to use the data from 2000 to 2007.

monly used to investigate Chinese manufacturing firms' performance (e.g. Cai & Liu, 2009; Brandt, Van Biesebroeck, & Zhang, 2012; Feenstra, Li, & Yu, 2014). For each firm-year observation, the data provides information on output, sales, fixed assets, intermediate inputs, number of employees, location and industry (which is classified by the National Standard Classification).[3] The main variables of interest are firm characteristics, such as total factor productivity (TFP), employment, capital intensity and average wage bill per worker, as the firm-level controls later. Due to some misreporting, I follow Cai and Liu (2009) and use General Accepted Accounting Principles to clean the data.[4] Following Brandt et al. (2012), I first link firms from each year of the data using firm registration identification numbers.

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. For each trade transaction, it records detailed information, including import and export values, quantities, products, company name, and customs type (e.g. "Processing and Assembling", and "Ordinary Trade"). This chapter applies the method of estimating quality that uses the unit value and quantity of variety to estimate the product quality of Chinese manufacturing enterprises. Including the processing trade would make the quality overestimated as those manufacturing firms can only contribute to part of the final value of products. I only focus on transactions under the ordinary trade regime.

While I observe all trade transactions monthly at the HS 8-digit product level, I aggregate them to the firm-HS6 product level at the yearly frequency as most firms

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

[4]I use the following rules to construct the 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; (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).

do not record sales of the same product every month.[5] For each HS 6-digit product, I use export values and quantities to compute the unit value by each firm. Furthermore, I drop export-import enterprises that serve exclusively as intermediaries, which is standard practice in literature (e.g. Ahn, Khandelwal, & Wei, 2011). The data do not directly flag trade intermediaries, so I identify them based on Chinese characters that mean "importer", "exporter", or "trading" in English in the firms' names.

Data Matching

The empirical analysis merges the two data sources described above. Firms use different registration numbers in each dataset, and the Chinese authorities have not released a unique firm identifier. Therefore, I have to use company names recorded in Chinese characters as the primary matching variable following the literature (e.g. Defever et al., 2020; Fan et al., 2018;Manova & Yu, 2016).[6] I 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 because of the lack of other identification variables in both datasets, such as zip code, telephone number and contact person. Details of the matching method are described in the appendix.

In the final sample, I obtained a matched firm-transaction dataset of 73,611 unique exporters and 1,465,150 firm-product observations over the 2000-2007 period. Table 4.1 provides the breakdown of observations by year. I note that the two datasets do not completely intersect as, firstly, many non-trade firms do not appear

[5]China changed HS 8-digit codes in 2002 and 2007. To ensure the consistency of the product categorisation over time (2000-2007), I 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, I can only choose to adopt HS 6-digit codes maintained by the World Customs Organization (WCO).

[6]The firm name is a reliable match variable as it suffers the least from missing value problems. By law, in China no firm can have the same name in the same administrative region. Firms always contain their local region name as part of their firm name.

in the Customs database but are included in the NBS database. Secondly, some firms in the NBS database trade through trading agents. Their transactions will be recorded under the name of trading agents in the Customs database. Thirdly, the Customs database records all trade transactions made by small firms and firms in non-manufacturing sectors. In contrast, the NBS database only includes larger firms in the manufacturing sectors. Overall, the matched sample covers 53% of the total export value reported by the Customs Database. This result is consistent with previous works using these datasets.[7]

4.3.2 Methodology

I would like to test the main prediction of the theoretical framework, which states that exporters in a comparative advantage industry offer higher quality than exporters in a non-comparative advantage industry. Then, inspired by the previous chapters' theoretical models that relate product quality to comparative advantage and a firm's productivity, I estimate the following econometric model by incorporating more firm characteristics:

$$\ln(q_{fht}) = \beta_0 + \beta_1 RCA_{ht} + \beta_2 \ln(Z_{ft}) + \varphi_h + \varphi_f + \varphi_{fh} + \varphi_t + \varepsilon_{fht} \tag{4.1}$$

where $ln(q_{fht})$ denotes the estimated quality of good h produced by firm f in year t in log; RCA_{ht} as a dummy variable indicates if China has a comparative advantage in the production of a variety h (as the portion of more than one firm for each product-year category is 99.7% in the data, RCA_{ht} is explained as an industry-level variable); $ln(Z_{ft})$ denotes the total factor productivity (TFP), and other firm-level control variables that may affect firms' quality choice and are controlled in the

[7] Manova and Yu (2016) cover nearly 50% of China's total exports in 2005. Merged sample in Fan et al. (2018) cover 52.4% of total export value in 2001-2006 reported by the Customs Database.

literature (e.g. Fan et al., 2018) such as the capital intensity in year t. In addition, I also control for the HS 6-digit level product fixed effects, firm fixed effects, prodct-firm fixed effects and year fixed effects. Finally, β_0 is a constant term, and ε_{fht} is unobserved shocks that affect export product quality.

In addition, to show a good fit of the theoretical model, it is important to show that the comparative advantage of industry is related to the different factor endowments across countries. Thus, I further use the 2SLS regression, where the relative factor endowment is used as an instrument variable for the comparative advantage in the first stage. The model is expected to show that countries' relative factor endowments are correlated with the comparative advantage of industry and are not correlated directly with firms' product quality. Thus, the relative factor endowment can be a good instrument.

4.3.3 Key Variables

In the above econometric model, I use product quality as the dependent variable, TFP as the main control variable, revealed comparative advantage as the main explanatory variable and other firm-level control variables and relative factor endowment. In this subsection, I will introduce and construct the variables that are not observed directly from the data.

Estimated Quality

I follow A. K. Khandelwal et al. (2013) and Fan et al. (2018) to measure product quality. As mentioned before, I define quality as unobserved attributes of a variety that make consumers willing to purchase relatively large quantities, holding prices across varieties constant rather than using the unit value as a coarse proxy for quality. According to the demand equation in my theoretical model ($x_{ij} = \frac{p_{ij}^{-\sigma} q_{ij}^{\gamma}}{P_j^{1-\sigma}} E_j$), I can estimate the quality of exported product h produced by firm f in year t, using an OLS regression through the following empirical demand equation in our model:

$$\ln(x_{fhjt}) + \sigma \ln(p_{fhjt}) = \eta_h + \varphi_{jt} + \varepsilon_{fhjt} \tag{4.2}$$

where x_{fhjt} denotes the demand of exported product h produced by firm f in year t; p_{fhjt} is the unit value; σ is the elasticity of substitution across products; the industry-year fixed effect φ_{jt} collects both industry price index and expenditure; the product fixed effect η_h captures the difference in prices and quantities across product categories. Given the value of the elasticity of substitution, I can estimate quality from the above equation. The estimated quality is $ln(\hat{q}_{fhjt}) = \hat{\varepsilon}_{fhjt}$.[8] The intuition behind this is that a variety with a higher price is assigned higher quality conditional on quantity.

The literature employs various values of σ. For example, Manova and Yu (2017) use the value at $\sigma = 5$. Fan et al. (2015) use different values at $\sigma = 5$ and $\sigma = 10$ and allow the elasticity of substitution to vary across industries using the estimates of Broda and Weinstein (2006). Thus, following the literature, I set sigma at $\sigma = 5$ and $\sigma = 10$ and use the estimates of Broda and Weinstein (2006) as well.[9] The distribution of estimated quality using different values of σ is provided in Figure 4.1. To exclude the influence of outliers, I remove 0.1% of the lowest and the highest values. The figure shows that exporting product qualities are centred at the same quality level regardless of which value of σ is used. It also reveals the highest variation when using $\sigma = 10$ and the lowest variation when the σ is allowed to vary across industries. As a robustness check, I estimate σ using the data. I also use an

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

[9] Using the existing values of estimated σ from the literature is a common approach used in the prior studies (A. K. Khandelwal et al., 2013; Fan et al., 2018). Broda and Weinstein (2006) estimate the elasticity of substitution for disaggregated categories. I use their estimates and merge them with the sample.

IV strategy to estimate product quality, and the related details will be presented in the section on robustness checks.

Total Factor Productivity

The standard approach to estimating the TFP is to estimate a Cobb-Douglas production function with its input, output, and capital. While OLS estimation assumes the independence of firms' inputs and efficiency, firms' input choices are likely determined simultaneously by unobserved productivity shocks. Approaches with assumptions alongside the evolution of firms' productivity and input choices over time, such as Olley and Pakes (1992) and Levinsohn and Petrin (2003), correct for endogeneity between inputs and unobserved productivity. While both studies allow for firm-specific productivity differences exhibiting idiosyncratic changes over time, in this paper, I use the LP method to estimate firms' productivity due to the lack of information on firms' investments. As a robustness check, I also estimate the TFP using the method from Wooldridge (2009).

To estimate the TFP, I 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 different deflators, which are the same used in Brandt et al. (2012), a capital price deflator, an intermediate input deflator and an output price deflator. Furthermore, since firms in different industries may have different factor inputs, I estimate the production function for each 2-digit industry separately rather than estimating the entire manufacturing sector.

Revealed Comparative Advantage

Given that my interest is in how the comparative advantage affects firms' product quality, I measure the comparative advantage using the Revealed Comparative Advantage (RCA) index created by Balassa (1965), which is commonly used in the literature. According to the RCA formula: $RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_{wt}}$ where E_{ht} and E_{wht} respectively denote the export value in the industry of producing product h in year t of one country and the rest of world, TE is the total export value. It indicates the relative ability to produce a good compared to the rest of the world. Then I follow Navas (2018) to use the data from the BACI trade database that provides disaggregated data (at HS 6-digit level) on bilateral trade flows for more than 200 countries from 2000 to 2007 and compute the RCA index at HS 6-digit level.

In the design of the empirical test, I treat the world consisting of China and the rest of the world to measure China's comparative advantage in each industry. I introduce the variable RCA in two ways, RCA index, a continuous variable and a dummy variable, RCA_D, created using the RCA index. Figure 4.2 presents the distribution of the RCA index. I remove 1 per cent of the highest values to exclude the influence of outliers. This figure shows that the RCA indexes of China compared to the rest of the world are centred at the value of 1 with a right-tail. Once RCA_{ht} is greater than 1, meaning that China does have a comparative advantage in the industry of producing product h in year t, the dummy variable, RCA_D takes a value of 1; otherwise, the dummy variable takes 0.

Relative Factor Endowment

Finally, to discriminate from other neoclassical trade theories, it is important to show that the comparative advantage stems from relative factor endowment. I follow Hall and Jones (1999) to measure two factors: 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. The data used, including capital stock at current PPPs, human capital index, and persons engaged, is from the Penn World Table (PWT).[10]

To measure the relative factor endowment of China compared to the rest of the world, I construct a variable named RFE as the ratio of physical capital over human capital of China and physical capital over human capital of the rest of the world as expected. From Figure 4.3, it can be found that human capital was more abundant in China than in the rest of the world during the period. There is also a clear increasing trend in the relative physical capital in China, consistent with Heckman (2005) where he reports a higher ratio of annual investment in physical capital to human capital for China compared to most countries and the investment proportion of human capital is only 3.3% of GDP while that proportion of physical capital is 45% in 2002.

4.4 Empirical Results

This section presents the main results using a sample of Chinese manufacturing exporters. I begin by looking at some summary statistics. Given the interest in comparative advantage, I group firms into exporters within comparative advantage industries and exporters within non-comparative advantage industries. Table 4.2 provides a comparison of the characteristics of firms from different groups. Most Chinese exporters (71.69%) come from comparative advantage industries. Regardless of the various estimations of product quality that I have used, as mentioned above, exporters in comparative advantage industries outperform others in terms of product quality and firm performance.[11]

[10] I must first calculate the average years of schooling for the population aged 25 and over in each country. Then, I can compute the human capital of China since there is only a human capital index. Finally, in terms of the human capital of the rest of the world, I 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.

[11] This table shows no sufficient evidence to state the mean quality of products between firms with a comparative advantage industry and those in a comparative disadvantage industry is different

The baseline analysis proceeds in three steps to examine the cross-industry variation in exporting product quality. I first run the baseline specification, Equation (4.1) with different fixed effects (with year fixed effects only; with product fixed effects and year fixed effects; with product fixed effects, firm fixed effects and year fixed effects; with product fixed effects, firm fixed effects, year fixed effects and product-firm fixed effects). It reports a positive effect of the comparative advantage on product quality. I next turn to use the RCA as a continuous variable and reveal how changes in the RCA index can affect exporters' product quality. Finally, considering that firms may decide their product quality at time t according to the RCA at time $t-1$, I run the baseline specification again by using the lagged RCA as the main explanatory variable.

4.4.1 Baseline Specifications

In Equation (4.1), I include firm-level control variables potentially affecting product quality from the literature, the TFP, the capital intensity (capital to labour ratio), the total employment, and the average wage bill per worker. In Table 4.3, different columns correspond to different values of the elasticity of substitution used to estimate quality with different fixed effects. Columns 1, 3 and 5 present a significantly positive relationship between the dummy variable of RCA and estimated product quality with only controlling year fixed effect. More specifically, they show that if China has a comparative advantage in one industry, exporters within this industry, on average, offer 40.4%, 109.8% or 15.1% more quality.[12] Columns 2, 4 and 6 report

when $\sigma = 10$ is introduced to estimate the quality. It also reveals that the mean quality is different at 10% when $\sigma = 5$ is used, and the mean quality is different at 1% when the σ is allowed to vary across industries.

[12]Here, column 3 presents a relatively high coefficient because a higher value of σ gives the estimated product quality a more violent swing (a higher standard deviation). The coefficients on RCA decrease significantly when the product fixed effect is introduced in columns 1, 2, 3 and 4 as the same value of σ is used for all industries leading to the industry variation contained in the estimated quality. In contrast, columns 5 and 6 show an increase in the coefficient on RCA

similar results when the product fixed effect is included as well. The relationships between exporting product quality and almost all firm-level variables are enhanced, which shows the necessity of incorporating the product fixed effect.

Table 4.4 shows the effects of RCA on exporting product quality, including more fixed effects. Columns 1, 3 and 5 report the results of adding the firm fixed effect, while columns 2, 4 and 6 report the results after adding firm and product-firm fixed effects. These effects account for firm-product-specific characteristics that are invariant across export markets. Note that though adding more fixed effects causes changes in coefficients on all variables and the coefficient on the dummy variable of RCA in column 4 is insignificant, coefficients in columns 2 and 6 are statistically significant and enhanced compared to the results in columns 1 and 5. Specifically, column 2 reports that if China has a comparative advantage in one industry, exporters within this industry, on average, offer 20.7% more quality. Column 6 states that exporters provide 26.7% more average quality in a comparative advantage industry. These facts are consistent with the proposition that exporters in a comparative advantage industry raise their product quality more. These exporters find it more profitable to improve quality in international trade. Thus, these results predict that by holding prices across varieties constant, Chinese exporters in a comparative advantage industry, on average, provide 20.7% and 26.7% more quantity (i.e. holding quantities across varieties constant, the average price that consumers pay for products produced by exporters in a comparative advantage industry is 20.7% and 26.7% higher). Additionally, all coefficients on firms' control variables are significantly positive, consistent with expectations and theoretical results that more productive firms produce higher-quality goods.

Given the interest in estimating how changes in the RCA index can affect ex-

when the product fixed effect is introduced. This happens as the σ is allowed to vary across industries capturing the industry variation when estimating the product quality and incorporating the product fixed effect enhances the effect of RCA on product quality.

porters' quality decisions, I regress the baseline equation again and treat the RCA as a continuous variable. As shown in Table 4.5, all coefficients on the RCA index are significantly positive. More specifically, it shows that exporters increase average quality by 2.7%, 1.6% and 2.9%, respectively, in columns 1, 2 and 3 when China's relative export share of one industry increases by one unit. In addition, the coefficients on firm-level control variables are statistically significant and positive and are similar when using different estimations of quality.

Finally, given the theoretical models, the comparative advantage stems from the relative factor endowment difference across countries and relative factor intensity across industries. Firms may spend time applying factor endowments, such as capital, to their production process or quality upgrading. That means that lagged rather than current values of RCA may be a good predictor of quality measurement. Thus, I explore the baseline equation using the lagged RCA as the main independent variable. Table 4.6 shows a positive relationship between exporters' estimated quality and the lagged RCA except when $\sigma = 10$ is used to estimate product quality. Columns 1 and 5 report that exporters will provide the goods with 13.4% or 9.9% more quality on average if China observed a comparative advantage in the previous period in one industry last year. Furthermore, columns 2 and 6 present the result that exporters improve quality by 1.4% or 1.7% when China's relative export share of one industry increased by one unit last year. Compared to the results when the present RCA is used in the specifications, these relatively low coefficients shed the implication of the dynamic changes in product quality. Chinese exporters adjust their product quality quickly based on the comparative advantage year to year.

Overall, all these results induce that exporters in a comparative advantage industry within one country will provide goods with a higher quality level. This differential can be explained as those firms in a comparative advantage industry can produce goods at a relatively low cost and find upgrading quality more profitable than foreign competitors, which is due to that exposure to trade bringing them access to a bigger market improves their marginal benefit of upgrading the product quality more.

4.4.2 Comparative Advantage and Relative Factor Endowment

I already showed the difference in product quality for exporters across industries, consistent with the proposition. To further prove a good fit of our theoretical model, I would like to shed light on the fact that the comparative advantage stems from different relative factor endowments of China compared to the rest of the world. To explore this, I run the baseline equation (4.1) again. However, I use the 2SLS regression where the RFE describing China's relative physical capital over human capital compared to the rest of the world is used as an instrument variable to estimate the RCA index in the first stage. Based on the basic assumptions and the quality equation of the theoretical model, the comparative advantage stems from the relative factor endowment, and the relative factor endowment only affects a firm's quality choice through the comparative advantage. Table 4.7 shows a result consistent with the baseline specifications, a statistically significant and positive coefficient on the RCA index of estimated quality in the first two columns.[13]

Furthermore, Table 4.8 reports the first-stage regression results of the RCA index. Different columns denote specifications using different values of estimated quality.[14] All specifications present a statistically significant and negative coefficient

[13] In all specifications, I conduct a Kleibergen and Paap (2006) rk statistic test (where the null hypothesis that the model is underidentified is rejected) and a Kleibergen and Paap (2006) Wald statistic test (where the null hypothesis that the first stage is weakly identified). The results induce that the instruments fit well in the first stage and perform as valid instruments.

[14] Here, the difference between coefficients on RFE is only due to different samples used for different estimated quality.

on the relative factor endowment, which is expected from the theoretical model. As mentioned before, China is more abundant in human capital, which contributes to a comparative advantage in industries using human capital more intensively; therefore, an increase in RFE (i.e. a higher ratio of physical capital over human capital in China compared to the rest of world) would lower China's comparative advantage.

4.4.3 Heterogeneity Analysis

In this subsection, I further explore the above results by conducting the heterogeneity analysis to understand the mechanisms at play better. To be more specific, I test the heterogeneity of the enhanced effect on the export quality of the comparative advantage across quartiles of the comparative advantage distribution, exploit how this effect is different across different groups of countries (i.e. OECD countries vs Non-OECD countries), compare this effect of firms with high export intensity with firms with low export intensity, and explore the variation in export quality for different products (with comparative advantage or without comparative advantage) within firms.

Quantile Analysis

To test the heterogeneity of the enhanced effect on export quality across quartiles of the comparative advantage distribution, I split the regression by quartiles of the RCA index. In this sense, it allows all the control variables to find new coefficients at each quartile. However, the coefficients that vary across the RCA distribution can not indicate the true effects on export quality. Thus, I did Chow tests to test whether the RCA has different impacts across the comparative advantage distribution. Table 4.9,

Table 4.10 and Table 4.11 report the results of using different quality estimations.[15]

Columns 1, 2, 3 and 4 in these tables present the results for the sample in the first, second, third and fourth quartiles, respectively. Overall, they report a positive and significant relationship between export quality and the RCA index most of the time, which is consistent with previous results. The first column shows that export quality increases by 51.7%, 99.9%, and 23.5%, respectively when China's relative export share of one industry increases by one unit for industries with a low comparative advantage.

The value of RCA is larger when the RCA is settled in the second, third and fourth quartiles, contributing to lower coefficients. For instance, the second column presents that export quality increases by 13.9%, 31.8% and 6%. Thus, it requires testing whether the true coefficients on the RCA are different across the RCA distribution. Results of the Chow test, where the null hypothesis is the coefficients are indifferent, are also presented in these tables. According to the p-values that are equal to zero, we can conclude that the coefficients on the RCA are different from each other across the RCA distribution. In other words, it ensures the heterogeneity of the enhanced effect on the export quality of the comparative advantage across the RCA distribution. In addition, the coefficients on firm-level control variables change differently. For some of them, we can still obtain some patterns. For example, in the upper interval of the RCA, the coefficient on the average wage bill is lower. It means that the effect of average wage on export quality varies across industries, and the effect is less significant for industries with a higher relative export share. Although it is not the interest of this chapter, it can be a good starting point for future work.

[15] In Stata, suest is used to perform the Chow test. However, it cannot be estimated either xtreg or reghdfe which I have used to include fixed effects. Thus, I used reg and included the year-dummy variables and then used the saved estimates to do the Chow test.

Destination Dimension

So far, as I mentioned before, I have largely treated destinations anonymously and symmetrically. However, this enhanced effect on export quality can still vary across destinations. I further include information about the destinations to detect how it varies across destinations and follow the logic of the empirical design. Specifically, I tell destination countries or regions from Organisation for Economic Co-operation and Development (OECD) countries to Non-OECD countries. To fit the data sample period, I followed the information from the official website to identify thirty OECD countries that joined no later than 2000.[16] In this sense, I split the sample into two categories, OECD countries and Non-OECD countries. I ran the main regression respectively to explore the heterogeneity of the effect across destination countries.

Table 4.12 reports the effects of the RCA on export quality across destination countries. Columns 1, 3 and 5 record the results for the OECD countries, while columns 2, 4 and 6 record the results for the Non-OECD countries. Regardless of different quality estimations, the table shows the same pattern: this effect on export quality is positively related to the RCA, and this enhanced effect is more pronounced when the destination belongs to the OECD group. For instance, when the quality is estimated using the $\sigma = 5$, the export quality increases by 2.7% for the OECD group and 2.2% for the Non-OECD group when China's relative export share of one industry increases by one unit. It shows the variation across destinations preliminary, although the RCA index is still calculated for China compared to the rest of the world. This difference might be explained by the fact recorded in the literature: firms vary the quality of their products across destinations (e.g. Manova & Zhang, 2012). In addition, it can be interesting to estimate the RCA index

[16]These OECD countries include Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Türkiye, United Kingdom and the United States.

of China compared to different country groups to detect the heterogeneity of the effects and the relationships between export quality and firm-level control variables in future work.[17]

Export Intensity

This subsection tends to explore the heterogeneity of the effects across firms with different levels of export intensity. Taking advantage of firm-level data, a firm's export intensity can be calculated as total export divided by total sales. I then split the sample into two categories, firms with high export intensity and firms with low export intensity. Firms with an export intensity below the median value of the export intensity of the whole sample belong to the low export-intensity group, and the rest firms belong to the high export-intensity group. During the processing, I dropped 169,351 out of 1,270,076 observations (around 13%) with zero export intensity. This is due to the misreporting issues in the firm-level database.

Table 4.13 compares the effects of the RCA on export quality for firms with high and low export intensity. Columns 1, 3 and 5 record the results for the firms with high export intensity, while columns 2, 4 and 6 record the results for those with low export intensity. From columns 1, 2, 5 and 6, where the coefficients on the RCA are statistically significant, we can see an interesting variation in the effects of the RCA. Firms with high export intensity increase quality by 2.4% or 2.5% when China's relative export share of one industry increases by one unit. Compared with them, the enhanced effects on export quality are larger for firms with low export intensity: they increase quality by 3.5% or 3.7%. This exercise shows the heterogeneity of the effects across firms with high and low export intensity. However, the result was not what I expected. It does not show that lower-quality products are produced by firms

[17]As shown in Table 4.12, the coefficients on firm-level control variables are relatively high when the destination belongs to Non-OECD countries.

with low export intensity. It can not be used to proxy the effects on domestic firms concluded in the model. This may be because product quality here is estimated for exporting products rather than products for the domestic markets, or there are some unexplored mechanisms at play, which remains a research direction for future work.

Within-firm Variations

In this subsection, I further explore within-firm variations in export quality if firms provide different qualities for products with and without a comparative advantage. To achieve it, I need to distinguish different products within the same firm. I do this considering the following two principles. Firstly, firms in the sample should produce at least two HS6-level varieties. Then, this subsection also requires the sample to include firms that produce at least an HS6-level variety with a comparative advantage and a variety without a comparative advantage each year. As a result, I finally kept 781,256 out of 1,270,076 observations (around 61.51%) during the sample period.

Table 4.14 presents within-firm variations in effects on the export quality of the RCA. As shown in the table, I include the year, firm and product-firm fixed effects. Then the coefficients on the RCA are identified purely from the variation in export quality across varieties (with and without a comparative advantage) for a given firm and variety. Columns 1 and 3 provide significant positive coefficients on the RCA. These results show that in China within firms, firms increase product quality by 21.2% or 25.6% for the product with a comparative advantage compared to the product without a comparative advantage. It indicates the within-firm variations in these enhanced effects on the export quality.

4.5 Robustness Checks

In this section, I conduct several exercises to show the statistical robustness of the results. First, I present the results based on the alternative estimation of TFP. Second, I confirm the robustness of the results to the alternative estimation of product quality, where I estimate the elasticity of substitutions from the sample. Third, I use the IV estimation to address the potential issue of the endogeneity of comparative advantage and obtain similar results. Then, I use the balanced sample to confirm that the results are not biased because of sample selection. Finally, to avoid the fact that small changes in the RCA index generate abrupt changes in the dummy variable, RCA_D, it takes a value of 1 if the RCA index is above 1.1 and takes a value of 0 if the RCA index is below 0.9.

4.5.1 Alternative Estimation of TFP

In section 4, I applied the LP method to estimate a firm's TFP. This measure has benefited from keeping more observations in the estimation. I now use the method from Wooldridge (2009) and show how this alternative TFP estimation affects firms' product quality choices.

Table 4.15 presents the results with alternative TFP estimation. Columns 1 and 5 show that Chinese exporters provide 20.7% and 26.7% more quality on average in a comparative advantage industry. Columns 2, 4 and 6 present that Chinese exporters increase average quality by 2.7%, 1.6% and 2.9%, respectively, when there is one unit increase in the RCA index. This result and effect sizes are consistent with the result when using LP to estimate the TFP. It indicates that firms in the comparative advantage industries produce and export higher-quality products conditional on productivity.

4.5.2 Alternative Estimation of Quality

To avoid the potential bias from parameterising σ based on the values given in the existing literature, I also estimate quality using IV estimation following Fan et al. (2015). The method is as follows. I first estimate σ_j industry by industry at HS 2-digit level using the sample by transforming Equation (4.2) to the following:

$$\ln(x_{fhjt}) = -\sigma_j \ln(p_{fhjt}) + \varphi_h + \varphi_{jt} + \varepsilon_{fhjt} \tag{4.3}$$

where σ_j refers to the industry j where product h is located. I estimate it by regressing export quantity on price, product fixed effects, and industry-year fixed effects for each industry j. Since the error term is potentially correlated with the product price, I use local average wages as an instrument variable to correct the parameters as in Fan et al. (2015). I 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. At the same time, this also raises concerns that local wages may be related to product quality (workers with higher wages produce higher-quality products). However, the exclusion restriction remains valid as long as average wages do not impact deviations from average quality. In other words, if a Chinese exporter chooses to produce and export higher-quality varieties because of the shocks in local wages, the instruments remain valid as long as shocks do not affect deviations from the firm's average quality choice.[18] Hence, I use this IV estimation in each industry and obtain 95 industries after dropping three industries with less than ten observations.

Then I infer product quality using the estimate of the residual $\hat{\varepsilon}_{fhjt}$ from Equation (4.2) as the method described in section 4. Finally, Table 4.16 presents the

[18]Here, I share the similar spirit of A. Khandelwal (2010) to illustrate the validity of instruments.

effects of comparative advantage on product quality based on the alternative estimation. Again, I obtain statistically significant and positive coefficients on RCA_D and RCA. The first column shows that the average quality of exporters is 21.0% higher if China has a comparative advantage in this industry. More specifically, a one-unit increase in the RCA index increases the average quality by 2.5%. With a similar effect size, both results confirm the proposition that exporters in the comparative advantage industries produce higher-quality goods.

4.5.3 Endogeneity

Given the interest in the effects of comparative advantage on a firm's quality choice, I now address the issue surrounding the potential endogeneity of the comparative advantage. However, I believe that the comparative advantage of one industry is arguably exogenous from the individual firms' perspective, and the use of industry-specific comparative advantage should alleviate the endogeneity issue.[19] It does not completely eliminate the concern.

Inspired by the case of an autarky country opening up to trade in the theoretical model, China's WTO accession in 2001 that substantially reduced trade barriers[20] can be regarded as an instrument variable, as it could be viewed from the firm's perspective as an exogenous shock of trade liberalisation. The idea is that China's WTO accession affects relative factor endowments of China, which is correlated with its comparative advantage. However, this event does not affect each exporter's quality choice differently for a certain good or within one industry. Thus, I re-estimate the baseline specification using a WTO dummy variable (WTO takes a

[19] As mentioned before, though I measure the RCA index at HS 6-digit product level, it can be explained as an industry-level variable as there is always more than one firm producing one variety.

[20] Fan et al. (2018) shows that the export tariff reductions imposed on China's exports by trading partners are around 1% while the average import tariff reductions by China are around 6% from 2001 to 2006.

value of 0 if the observation was recorded before the year 2002; otherwise, it takes a value of 1) as an instrument for the RCA index. As shown in Table 4.17, I find the coefficients on the RCA index are positive and significant in all specifications.[21] This implies that its inclusion leaves the key results unchanged that firms export higher-quality products in a comparative advantage industry.

In addition, Table 4.18 presents a statistically significant and negative relationship between RCA and WTO. It shows that China's WTO accession decreases the RCA index by 0.541 or 0.544, supporting our explanation based on the relative factor endowment. After China's WTO accession, China's physical capital per worker increased more than its human capital per worker. The comparative advantage stemming from the relative factor endowment of China thus decreased following this increase in RFE (the ratio between physical capital and human capital per worker in China). As a result, there is a negative relationship between the RCA index and China's WTO accession.

This instrument variable is not very good, as it is a year-variant variable. It does not feature industry or product variation within one year. Thus, the results are less significant when using it as the instrument variable for the RCA index, which is an industry-year-level variable. However, finding a good instrument variable is always challenging for economists. I will keep looking for a more appropriate instrument variable.

4.5.4 Balanced Sample Test

So far, the results are based on a merged sample, including all firms shown in the NBS firm production data and the customs data. To remove any effects of entering

[21]In all specifications, I conduct a Kleibergen and Paap (2006) rk statistic test (where the null hypothesis that the model is underidentified is rejected) and a Kleibergen and Paap (2006) Wald statistic test (where the null hypothesis that the first stage is weakly identified). The results induce that the instruments provide a good fit in the first stage and perform as valid instruments.

and exiting firms, I now focus on a merged sample between the balanced sample of NBS firm production data and the customs data.[22] I select observations of firms that have been active through the whole period to observe how the comparative advantage affects firms' product quality. Regarding exporters, not all of them export specific goods each year. Finally, this sample includes 487,385 product-firm-year observations.

The results of quality are presented in Table 4.19. Although the coefficients on RCA are not statistically significant when setting $\sigma = 10$, the overall result is strongly consistent with our baseline result. Column 1 and 5 show that Chinese exporters provide 29.2% and 33.6% more quality in a comparative advantage industry, and column 2 and 6 present that exporters offer 2.3% and 2.5% more quality on average when there is one unit increase in the RCA index, confirming the proposition still holds. Furthermore, effect sizes on the comparative advantage dummy variable are slightly higher among continuing firms, which indicates that those firms in a comparative advantage industry, on average, take more advantage of industry characteristics and invest in product quality by more.

4.5.5 Alternative Construction of the RCA Dummy

In the last section, the dummy variable, RCA_D takes the value of 1 if the RCA index is above 1, indicating that China has a comparative advantage. Otherwise, it takes the value of 0 indicating that China does not have a comparative advantage. One concern about this construction method is a small change in the RCA_D index around the threshold could lead to an abrupt change in RCA_D. To eliminate this concern, in this subsection, the RCA_D takes a value of 1 if the RCA index is above 1.1, indicating that China has a comparative advantage and takes a value of 0 if

[22] I choose a balanced sample at the firm level rather than at the product-firm level since I can only obtain 28,088 observations if I want a balanced sample at the product-firm level.

the RCA index is below 0.9. The observations in the middle are regarded as the "neutral".

Table 4.20 presents the effects of the new RCA_D of product quality. Column 1 reports that if China has a comparative advantage in one industry, exporters in this industry, on average, offer 32.2% more quality. Column 3 states that exporters provide 42.3% more average quality in a comparative advantage industry. With higher effect sizes on the comparative advantage dummy variable, these results are consistent with the main specifications confirming that exporters in the comparative advantage industries produce higher-quality goods.

4.6 Conclusion

This chapter provides supporting evidence for one of the propositions drawn from the theoretical models in the previous chapters. To test the model's main predictions, I use rich and detailed firm-transaction level data over the period 2000-2007.

Controlling for a firm's characteristics, including productivity and other variables that may affect a firm's quality choice, and the firm, industry, and year fixed effects, I find robust evidence that Chinese exporters in the comparative advantage industries improve their product quality more than those in other industries. This chapter also shows that this comparative advantage stems from countries' different factor endowments. Therefore, it suggests that exporters decide their product quality based on a country's comparative advantage from relative factor endowment, pointing out the fruitfulness of placing different industries in the research of firms' endogenous quality decisions.

This chapter aims to empirically illustrate the mechanism behind exporters' quality choices across industries. Since the results show a significant relationship between a country's comparative advantage and the relative factor endowment, it further underlines the importance and correctness of the theoretical model in the last chapter. Limited by the data, this chapter can only test one of the novel propositions from the theoretical models. However, with access to the product-level data of domestic firms, the empirical tests for the rest of the propositions drawn from the theoretical model can be implemented in future work.

4.7 Appendix

4.7.1 Matching between the Firm-level (CASIF) and the Transaction-level (CCTS) Data

The matching strategy links firms in CASIF to those in CCTS by matching their names. I, therefore, follow Manova and Yu (2016) and construct a concordance matching the firm's different identifiers across these two datasets. The matching procedure is as follows where I use "ID" to denote the firm identifier code in the CASIF and "CODE" to denote those in the CCTS).

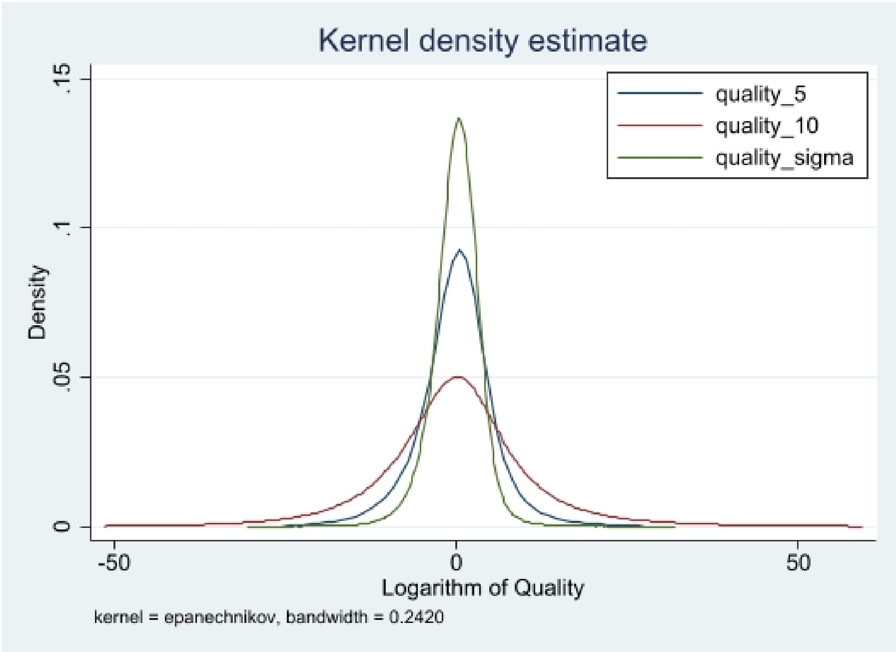
The basic idea of this matching method is that I use all the different names ever used by a firm to match firm identifiers in both datasets. More specifically, a NBS ID will be matched to a CCTS CODE, as long as one of the names used by the ID in the firm-level data can match one of the names ever registered by the CODE in the CCTS data. Using this method, I can achieve maximum flexibility in company name changes and minimise the chance of not identifying a matching company simply because of the name change.

After processing the above steps, I do some checks to assess the quality of the match. Firstly, I drop the duplicates. Secondly, I found 1,885 matches where more than one NBS ID match within a given year with one CCTS CODE constituting a negligible proportion of the sample (accounting for less than 0.1% of export and import) and excluded them. Thirdly, I check if multiple CCTS CODEs match with one NBS ID for the same year. There are 34,633 matches from the sample where multiple CODEs match with one ID in the same year. After checking these in the original CCTS data, I found that firms changed their CCTS code during the same year in different months while keeping their names unchanged. This finding indicates that the same firm does these transactions under multiple CCTS codes. Therefore, I keep these duplicates and aggregate them into the same ID.

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

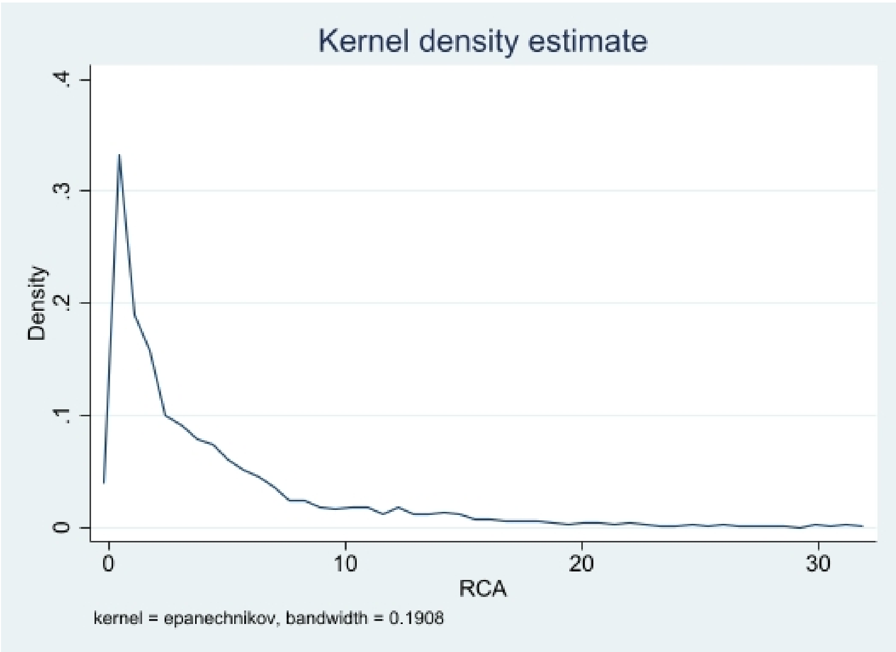
4.7.2 Supplementary Figures and Tables

Figure 4.1: The distribution of the product quality



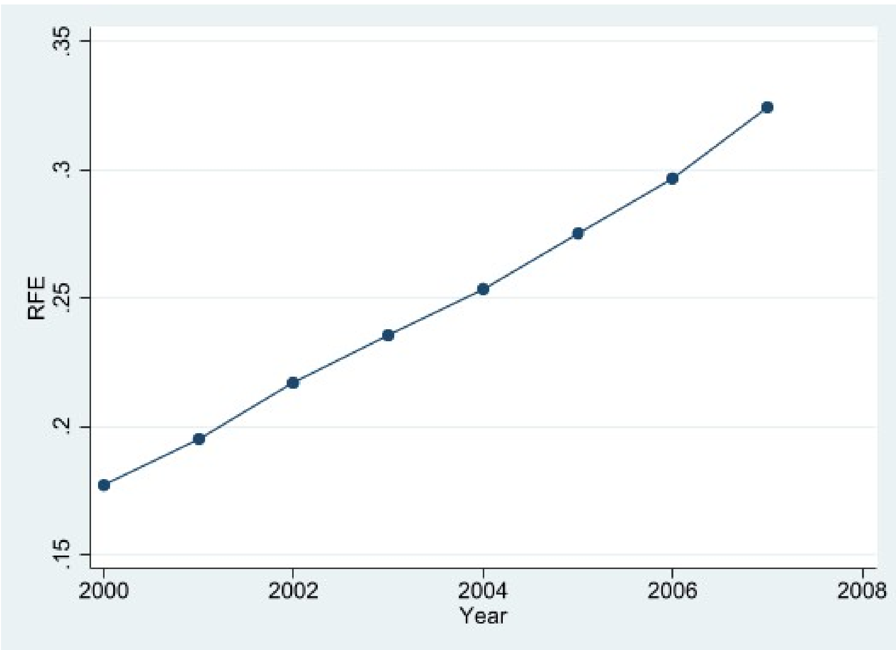
This figure shows the estimated quality distribution, given the elasticity of the elasticity of substitution σ, 5, 10, and the estimates of Broda and Weinstein (2006) during the period 2000-2007. To exclude the influence of outliers, I remove 0.1 per cent of the lowest and the highest values.

Figure 4.2: The distribution of the RCA index



This figure shows the distribution of the Revealed Comparative Advantage (RCA) index calculated at HS 6-digit level from 2000-2007. To exclude the influence of outliers, I remove 1 per cent of the highest values.

Figure 4.3: Relative factor endowment of China compared to the rest of the world



This figure describes how the relative factor endowment (RFE) of China compared to the rest of the world changed during the period 2000-2007. The RFE is defined as the relative ratio between physical capital and human capital per worker.

Table 4.1: Matching results

Year	Number of exporters	Number of transactions
2000	13,462	97,863
2001	16,709	122,919
2002	20,007	158,049
2003	24,049	208,682
2004	26,669	75,792
2005	36,430	261,709
2006	43,681	258,914
2007	47,117	281,222
Total	73,611	1,465,150

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

Table 4.2: Summary statistics of key variables

Variable	All exporters	Exporters within CA industries	Exporters within Non-CA industries	Mean difference
$Quality\_5$	0.000	0.005	-0.014	0.019
	(5.794)	(5.199)	(7.081)	(0.0911)
$Quality\_10$	0.000	0.004	-0.009	0.013
	(11.725)	(10.373)	(14.599)	(0.5764)
$Quality\_\sigma$	0.000	0.007	-0.018	0.025
	(4.926)	(4.711)	(5.431)	(0.0095)
TFP	2.438	2.430	2.458	-0.028
	(0.641)	(0.624)	(0.683)	(0.0000)
$CapitalIntensity$	10.555	10.344	11.089	-0.745
	(1.316)	(1.282)	(1.247)	(0.0000)
$Employment$	5.557	5.541	5.599	-0.058
	(1.207)	(1.150)	(1.337)	(0.0000)
$WagePerWorker$	9.612	9.552	9.764	-0.213
	(0.655)	(0.630)	(0.691)	(0.0000)
Observations	1,270,076	910,523	359,553	550,970
(% of total)	(100%)	(71.69%)	(28.31%)	

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 4.3: Effects of RCA on product quality (1)

Dependent variable	ln(quality)					
	$\sigma = 5$		$\sigma = 10$		$\sigma = \sigma_i$	
	(1)	(2)	(3)	(4)	(5)	(6)
RCA_D	0.339***	0.204***	0.741***	0.192*	0.141***	0.234***
	(0.018)	(0.038)	(0.037)	(0.078)	(0.016)	(0.039)
$ln(TFP)$	0.133***	0.138***	0.261***	0.261***	0.033***	0.030***
	(0.011)	(0.013)	(0.022)	(0.026)	(0.010)	(0.011)
$ln(Capital/Labour)$	0.167***	0.206***	0.345***	0.436***	0.074***	0.088***
	(0.006)	(0.006)	(0.011)	(0.012)	(0.006)	(0.006)
$ln(Employment)$	0.143***	0.164***	0.320***	0.370***	0.045***	0.052***
	(0.006)	(0.007)	(0.013)	(0.014)	(0.006)	(0.006)
$ln(WagePerWorker)$	0.836***	0.902***	2.029***	2.190***	0.258***	0.278***
	(0.012)	(0.012)	(0.025)	(0.025)	(0.011)	(0.012)
Product fixed effect	No	Yes	No	Yes	No	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,264,787	1,264,784	1,264,787	1,264,784	1,262,183	1,262,180
R-squared	0.013	0.014	0.017	0.019	0.002	0.002

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). 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. 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. Significant at ***1%, **5%, and *10%. Robust standard errors are corrected for clustering at the firm-product level in parentheses.

Table 4.4: Effects of RCA on product quality (2)

Dependent variable	ln(quality)					
	$\sigma = 5$		$\sigma = 10$		$\sigma = \sigma_i$	
	(1)	(2)	(3)	(4)	(5)	(6)
RCA_D	0.165***	0.188***	0.151*	0.099	0.174***	0.237***
	(0.035)	(0.035)	(0.070)	(0.069)	(0.038)	(0.029)
$ln(TFP)$	0.189***	0.222***	0.305***	0.287***	0.125***	0.185***
	(0.019)	(0.017)	(0.038)	(0.033)	(0.016)	(0.013)
$ln(Capital/Labour)$	0.027*	0.076***	0.037***	0.069***	0.020*	0.088***
	(0.011)	(0.009)	(0.021)	(0.018)	(0.009)	(0.008)
$ln(Employment)$	0.128***	0.372***	0.158***	0.391***	0.103***	0.369***
	(0.017)	(0.015)	(0.033)	(0.029)	(0.015)	(0.013)
$ln(WagePerWorker)$	0.066***	0.145***	0.075**	0.164***	0.061***	0.147***
	(0.013)	(0.012)	(0.026)	(0.022)	(0.011)	(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	No	Yes	No	Yes	No	Yes
Observations	1,256,879	848,962	1,256,879	848,962	1,254,269	847,246
R-squared	0.281	0.790	0.319	0.808	0.213	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). 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. 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. Significant at ***1%, **5%, and *10%. Robust standard errors are corrected for clustering at the firm-product level in parentheses.

Table 4.5: Effects of RCA as a continuous variable on product quality

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

Notes: This table examines the relationship between export quality and the RCA index. 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). RCA is calculated according to the formula: $RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_wt}$ 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 4.6: Effects of the lag of RCA on product quality

Dependent variable	ln(quality)					
	$\sigma = 5$		$\sigma = 10$		$\sigma = \sigma_i$	
	(1)	(2)	(3)	(4)	(5)	(6)
Lag RCA_D	0.126**		0.095		0.094*	
	(0.048)		(0.095)		(0.038)	
Lag RCA		0.012***		-0.002		0.017***
		(0.003)		(0.006)		(0.004)
$ln(TFP)$	0.205***	0.206***	0.264***	0.264***	0.170***	0.170***
	(0.023)	(0.023)	(0.044)	(0.044)	(0.018)	(0.018)
$ln(Capital/Labour)$	0.051***	0.051***	0.048	0.048	0.058***	0.059***
	(0.013)	(0.013)	(0.025)	(0.025)	(0.012)	(0.012)
$ln(Employment)$	0.373***	0.372***	0.393***	0.394***	0.358***	0.356***
	(0.022)	(0.022)	(0.040)	(0.040)	(0.017)	(0.017)
$ln(WagePerWorker)$	0.166***	0.166***	0.200***	0.200***	0.159***	0.158***
	(0.016)	(0.016)	(0.029)	(0.029)	(0.013)	(0.013)
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	356,817	356,817	356,817	356,817	356,227	356,227
R-squared	0.833	0.833	0.849	0.849	0.865	0.865

Notes: This table examines the relationship between export quality and the lagged 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). Lag RCA_D is the lag of the dummy variable, RCA_{ht}, which 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. Lag RCA is the lag of RCA, which is calculated according to the formula: $RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_wt}$ 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 4.7: Results of using RFE as an IV for RCA

Dependent variable	ln(quality)		
	$\sigma = 5$	$\sigma = 10$	$\sigma = \sigma_i$
	(1)	(2)	(3)
RCA	0.457***	1.251***	-0.080*
	(0.060)	(0.119)	(0.046)
$ln(TFP)$	0.203***	0.252***	0.165***
	(0.017)	(0.033)	(0.012)
$ln(Capital/Labour)$	0.062***	0.042**	0.072***
	(0.009)	(0.019)	(0.008)
$ln(Employment)$	0.279***	0.170***	0.338***
	(0.014)	(0.028)	(0.011)
$ln(WagePerWorker)$	0.062***	-0.025	0.115***
	(0.011)	(0.022)	(0.009)
Product fixed effect	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes
Product&Firm fixed effect	Yes	Yes	Yes
Kleibergen-Paap rk LM χ^2 statistic	1827.473†	1827.473†	1815.473†
Kleibergen-Paap rk Wald F statistic	1202.982†	1202.982†	1195.251†
Observations	848,962	848,962	847,246
Prob > F	0.000	0.000	0.000

Notes: This table examines the relationship between export quality and the RCA index by using RFE 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). The RFE denotes the relative physical capital over the human capital of China compared to the rest of the world, in log. RCA is calculated according to the formula: $RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_{wt}}$ 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 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 4.8: Results of first stage regression of RCA using RFE as an IV

Dependent variable	RCA		
	(1)	(2)	(3)
$ln(RFE)$	-0.236***	-0.236***	-0.236***
	(0.007)	(0.007)	(0.007)
$ln(TFP)$	-0.076***	-0.076***	-0.077***
	(0.009)	(0.009)	(0.009)
$ln(Capital/Labour)$	-0.051***	-0.051***	-0.051***
	(0.006)	(0.006)	(0.006)
$ln(Employment)$	-0.042***	-0.042***	0.043***
	(0.008)	(0.008)	(0.008)
$ln(WagePerWorker)$	-0.058***	-0.058***	0.059***
	(0.006)	(0.006)	(0.006)
Observations	848,962	848,962	847,246
Prob > F	0.000	0.000	0.000

Notes: This table shows the results of the first stage regression of RCA when exploring the relationship between export quality and the RCA by using RFE as an instrument variable. The RFE denotes the relative physical capital over human capital compared to the rest of the world, in log. 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. Significant at ***1%, **5%, and *10%. Robust standard errors are corrected for clustering at the firm-product level in parentheses.

Table 4.9: Results of regressions by quartiles of RCA (1)

Dependent variable	ln(quality) ($\sigma = 5$)			
	(1)	(2)	(3)	(4)
RCA	0.517***	0.139***	0.030**	0.001
	(0.060)	(0.025)	(0.010)	(0.001)
$ln(TFP)$	0.082***	0.097***	0.269***	0.073***
	(0.019)	(0.016)	(0.015)	(0.014)
$ln(Capital/Labour)$	0.245***	0.0223***	0.193***	0.068***
	(0.011)	(0.009)	(0.007)	(0.007)
$ln(Employment)$	0.065***	0.094***	0.216***	0.221***
	(0.010)	(0.009)	(0.008)	(0.008)
$ln(WagePerWorker)$	1.044***	0.915***	0.780***	0.541***
	(0.021)	(0.019)	(0.016)	(0.015)
Year fixed effect	Yes	Yes	Yes	Yes
Observations	316,137	316,341	316,265	316,044
R-squared	0.015	0.015	0.016	0.008
chi2(3)	118.51	118.51	118.51	118.51
Prob > chi2	0.000	0.000	0.000	0.000

Notes: This table examines the relationship between export quality and the RCA index across the RCA distribution. For each firm-product-year triplet, the dependent variable is the estimated quality, given the value of the elasticity of substitution equals 5. RCA is calculated according to the formula: $RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_wt}$ 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. Spilt the regressions by quartiles of the RCA. 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 and year fixed effects. Significant at ***1%, **5%, and *10%. It also reports the results of a chi2 test of the difference between coefficients on the RCA.

Table 4.10: Results of regressions by quartiles of RCA (2)

Dependent variable	ln(quality) ($\sigma = 10$)			
	(1)	(2)	(3)	(4)
RCA	0.999***	0.318***	0.072***	0.003
	(0.123)	(0.051)	(0.019)	(0.002)
$ln(TFP)$	-0.021	0.232***	0.597***	0.285***
	(0.039)	(0.033)	(0.029)	(0.028)
$ln(Capital/Labour)$	0.446***	0.445***	0.418**	0.194***
	(0.023)	(0.019)	(0.015)	(0.013)
$ln(Employment)$	0.256***	0.268***	0.374***	0.366***
	(0.020)	(0.018)	(0.016)	(0.015)
$ln(WagePerWorker)$	2.518***	2.306***	1.863***	1.272***
	(0.043)	(0.038)	(0.032)	(0.029)
Year fixed effect	Yes	Yes	Yes	Yes
Observations	316,137	316,341	316,265	316,044
R-squared	0.018	0.020	0.020	0.010
chi2(3)	121.89	121.89	121.89	121.89
Prob > chi2	0.000	0.000	0.000	0.000

Notes: This table examines the relationship between export quality and the RCA index across the RCA distribution. For each firm-product-year triplet, the dependent variable is the estimated quality, given that the elasticity of substitution equals 10. RCA is calculated according to the formula: $RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_wt}$ 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. Spilt the regressions by quartiles of the RCA. 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 and year fixed effects. Significant at ***1%, **5%, and *10%. It also reports the results of a chi2 test of the difference between coefficients on the RCA.

Table 4.11: Results of regressions by quartiles of RCA (3)

Dependent variable	ln(quality) ($\sigma = \sigma_i$)			
	(1)	(2)	(3)	(4)
RCA	0.235***	0.060**	-0.007	0.000
	(0.046)	(0.020)	(0.011)	(0.001)
$ln(TFP)$	0.111***	-0.0002	0.027	-0.043***
	(0.014)	(0.013)	(0.017)	(0.011)
$ln(Capital/Labour)$	0.106***	0.098***	0.107***	0.011*
	(0.009)	(0.007)	(0.009)	(0.005)
$ln(Employment)$	-0.048***	0.008	0.112***	0.156***
	(0.007)	(0.007)	(0.009)	(0.006)
$ln(WagePerWorker)$	0.286***	0.237***	0.311***	0.203***
	(0.016)	(0.015)	(0.019)	(0.011)
Year fixed effect	Yes	Yes	Yes	Yes
Observations	315,736	315,642	314,761	316,044
R-squared	0.003	0.002	0.002	0.004
chi2(3)	36.54	36.54	36.54	36.54
Prob > chi2	0.000	0.000	0.000	0.000

Notes: This table examines the relationship between export quality and the RCA index across the RCA distribution. For each firm-product-year triplet, the dependent variable is the estimated quality, given the value of the elasticity of substitution using the estimates of Broda and Weinstein (2006). RCA is calculated according to the formula: $RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_{wt}}$ 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. Spilt the regressions by quartiles of the RCA. 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 and year fixed effects. Significant at ***1%, **5%, and *10%. It also reports the results of a chi2 test of the difference between coefficients on the RCA.

Table 4.12: Results of regressions by different destination groups

Dependent variable	ln(quality)					
	$\sigma = 5$		$\sigma = 10$		$\sigma = \sigma_i$	
	(1)	(2)	(3)	(4)	(5)	(6)
RCA	0.027***	0.022***	0.017***	0.009	0.030***	0.021***
	(0.003)	(0.005)	(0.006)	(0.010)	(0.003)	(0.005)
$ln(TFP)$	0.180***	0.293***	0.201***	0.424***	0.168***	0.217***
	(0.021)	(0.035)	(0.040)	(0.068)	(0.016)	(0.026)
$ln(Capital/Labour)$	0.071***	0.081***	0.062***	0.065*	0.079***	0.097***
	(0.012)	(0.017)	(0.023)	(0.033)	(0.010)	(0.013)
$ln(Employment)$	0.364***	0.384***	0.388***	0.407***	0.363***	0.373***
	(0.019)	(0.029)	(0.036)	(0.056)	(0.017)	(0.0223)
$ln(WagePerWorker)$	0.133***	0.133***	0.153***	0.147***	0.131***	0.135***
	(0.015)	(0.022)	(0.028)	(0.042)	(0.013)	(0.016)
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	500,102	259,319	500,102	259,319	499,339	258,623
R-squared	0.789	0.829	0.807	0.844	0.825	0.882

Notes: This table examines the relationship between export quality and the RCA across OECD countries and Non-OECD countries. Columns 1, 3, and 5 record the results for the OECD countries, while Columns 2, 4, and 6 record the results for the Non-OECD countries. 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). RCA is calculated according to the formula: $RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_wt}$ 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 4.13: Results of regressions by firms with different export intensity

Dependent variable	ln(quality)					
	$\sigma = 5$		$\sigma = 10$		$\sigma = \sigma_i$	
	(1)	(2)	(3)	(4)	(5)	(6)
RCA	0.024***	0.035***	0.018**	0.016	0.025***	0.037***
	(0.003)	(0.005)	(0.006)	(0.010)	(0.003)	(0.005)
$ln(TFP)$	0.210***	0.276***	0.253***	0.388***	0.168***	0.229***
	(0.028)	(0.033)	(0.052)	(0.064)	(0.021)	(0.024)
$ln(Capital/Labour)$	0.055***	0.116***	0.024	0.126***	0.070***	0.118***
	(0.014)	(0.019)	(0.025)	(0.038)	(0.011)	(0.016)
$ln(Employment)$	0.338***	0.446***	0.340***	0.486***	0.347***	0.426***
	(0.023)	(0.030)	(0.042)	(0.058)	(0.020)	(0.025)
$ln(WagePerWorker)$	0.165***	0.165***	0.198***	0.203***	0.156***	0.167***
	(0.018)	(0.022)	(0.033)	(0.043)	(0.015)	(0.021)
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	347,651	318,223	347,651	318,223	347,223	317,371
R-squared	0.779	0.808	0.794	0.826	0.830	0.842

Notes: This table examines the relationship between export quality and the RCA across firms with high and low export intensity. Columns 1, 3, and 5 record the results for the firms with high export intensity, while Columns 2, 4, and 6 record the results for the firms with low export intensity. 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). RCA is calculated according to the formula: $RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_{wt}}$ 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 4.14: Within-firm variations in effects of RCA on product quality

Dependent variable	ln(quality)		
	$\sigma = 5$	$\sigma = 10$	$\sigma = \sigma_i$
	(1)	(2)	(3)
RCA_D	0.192***	0.124	0.228***
	(0.043)	(0.084)	(0.035)
$ln(TFP)$	0.176***	0.221***	0.152***
	(0.024)	(0.046)	(0.017)
$ln(Capital/Labour)$	0.081***	0.082**	0.094***
	(0.015)	(0.028)	(0.013)
$ln(Employment)$	0.342***	0.364***	0.341***
	(0.023)	(0.044)	(0.019)
$ln(WagePerWorker)$	0.101***	0.103***	0.106***
	(0.017)	(0.033)	(0.014)
Firm fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Product&Firm fixed effect	Yes	Yes	Yes
Observations	469,760	469,760	468,498
R-squared	0.791	0.807	0.834

Notes: This table examines the relationship between export quality and the RCA index. 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). 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. 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 4.15: Effects of RCA on product quality with the alternative estimation of TFP

Dependent variable	ln(quality)					
	$\sigma = 5$		$\sigma = 10$		$\sigma = \sigma_i$	
	(1)	(2)	(3)	(4)	(5)	(6)
RCA_D	0.188***		0.099		0.237***	
	(0.035)		(0.069)		(0.029)	
RCA		0.027***		0.016***		0.029***
		(0.003)		(0.005)		(0.002)
$ln(TFP)$	0.207***	0.208***	0.258***	0.259***	0.178***	0.179***
	(0.016)	(0.016)	(0.031)	(0.031)	(0.013)	(0.013)
$ln(Capital/Labour)$	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***	0.365***	0.384***	0.383***	0.363***	0.362***
	(0.015)	(0.015)	(0.029)	(0.029)	(0.013)	(0.013)
$ln(WagePerWorker)$	0.145***	0.144***	0.164***	0.164***	0.146***	0.146***
	(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). 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. RCA is calculated according to the formula: $RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_{wt}}$ 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) estimated by the method from Wooldridge (2009), 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 4.16: Effects of RCA on product quality with the alternative estimation of quality

Dependent variable	ln(quality)	
	(1)	(2)
RCA_D	0.191***	
	(0.040)	
RCA		0.025***
		(0.002)
$ln(TFP)$	0.181***	0.181***
	(0.014)	(0.014)
$ln(Capital/Labour)$	0.066***	0.067***
	(0.008)	(0.008)
$ln(Employment)$	0.368***	0.367***
	(0.013)	(0.013)
$ln(WagePerWorker)$	0.140***	0.139***
	(0.009)	(0.009)
Product fixed effect	Yes	Yes
Firm fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
Product&Firm fixed effect	Yes	Yes
Observations	848,962	848,962
R-squared	0.738	0.738

Notes: This table examines the relationship between export quality and the RCA, where the quality is estimated from our data using an IV estimation. 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. RCA is calculated according to the formula: $RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_wt}$ 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 4.17: Results of using WTO as an IV for RCA

Dependent variable	ln(quality)		
	$\sigma = 5$	$\sigma = 10$	$\sigma = \sigma_i$
	(1)	(2)	(3)
RCA	0.372***	0.691***	0.212***
	(0.032)	(0.060)	(0.028)
$ln(TFP)$	0.196***	0.208***	0.188***
	(0.017)	(0.033)	(0.013)
$ln(Capital/Labour)$	0.057***	0.010	0.089***
	(0.010)	(0.018)	(0.008)
$ln(Employment)$	0.275***	0.145***	0.352***
	(0.015)	(0.028)	(0.012)
$ln(WagePerWorker)$	0.057***	-0.061**	0.133***
	(0.011)	(0.021)	(0.009)
Product fixed effect	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes
Product&Firm fixed effect	Yes	Yes	Yes
Kleibergen-Paap rk LM χ^2 statistic	1588.744†	1588.744†	1596.873†
Kleibergen-Paap rk Wald F statistic	1539.607†	1539.607†	1547.754†
Observations	848,962	848,962	847,246
Prob > F	0.000	0.000	0.000

Notes: This table examines the relationship between export quality and the RCA index by using WTO 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). WTO is a dummy variable; it takes a value of 1 if the observation is recorded after 2001; otherwise, it takes a value of 0. RCA is calculated according to the formula: $RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_{wt}}$ 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 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 4.18: Results of first stage regression of RCA using WTO as an IV

Dependent variable	RCA		
	(1)	(2)	(3)
WTO	-0.541***	-0.541***	-0.544***
	(0.014)	(0.014)	(0.014)
$ln(TFP)$	-0.039***	-0.039***	-0.040***
	(0.010)	(0.010)	(0.010)
$ln(Capital/Labour)$	-0.032***	-0.032***	-0.032**
	(0.007)	(0.007)	(0.007)
$ln(Employment)$	0.035***	0.035***	0.034***
	(0.010)	(0.010)	(0.011)
$ln(WagePerWorker)$	0.002	0.002	0.001
	(0.006)	(0.006)	(0.006)
Observations	848,962	848,962	847,246
Prob > F	0.000	0.000	0.000

Notes: This table shows the results of the first stage regression of RCA when exploring the relationship between export quality and the RCA by using WTO as an instrument variable. WTO is a dummy variable; it takes a value of 1 if the observation is recorded after 2001; otherwise, it takes a value of 0. 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. Significant at ***1%, **5%, and *10%. Robust standard errors are corrected for clustering at the firm-product level in parentheses.

Table 4.19: Results of balanced sample test

Dependent variable	ln(quality)					
	$\sigma = 5$		$\sigma = 10$		$\sigma = \sigma_i$	
	(1)	(2)	(3)	(4)	(5)	(6)
RCA_D	0.256***		0.214*		0.290***	
	(0.051)		(0.099)		(0.046)	
RCA		0.023***		0.007		0.025***
		(0.004)		(0.007)		(0.003)
$ln(TFP)$	0.131***	0.132***	0.188***	0.189***	0.094***	0.095***
	(0.020)	(0.020)	(0.039)	(0.039)	(0.016)	(0.016)
$ln(Capital/Labour)$	0.071***	0.071***	0.061	0.061	0.072***	0.073***
	(0.017)	(0.017)	(0.032)	(0.032)	(0.014)	(0.014)
$ln(Employment)$	0.404***	0.403***	0.460***	0.461***	0.384***	0.383***
	(0.025)	(0.025)	(0.048)	(0.048)	(0.022)	(0.022)
$ln(WagePerWorker)$	0.137***	0.137***	0.165***	0.165***	0.139***	0.139***
	(0.019)	(0.019)	(0.036)	(0.036)	(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	361,116	361,116	361,116	361,116	360,423	360,423
R-squared	0.759	0.759	0.778	0.778	0.790	0.790

Notes: This table examines the relationship between export quality and the 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). 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. RCA is calculated according to the formula: $RCA_{ht} = \frac{E_{ht}/TE_t}{E_{wht}/TE_wt}$ 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 4.20: Effects of RCA on product quality with alternative construction of RCA_D

Dependent variable	ln(quality)		
	$\sigma = 5$	$\sigma = 10$	$\sigma = \sigma_i$
	(1)	(2)	(3)
RCA_D	0.279***	0.137	0.353***
	(0.049)	(0.095)	(0.046)
$ln(TFP)$	0.225***	0.292***	0.184***
	(0.017)	(0.033)	(0.013)
$ln(Capital/Labour)$	0.079***	0.075***	0.088***
	(0.009)	(0.018)	(0.008)
$ln(Employment)$	0.374***	0.395***	0.372***
	(0.015)	(0.029)	(0.013)
$ln(WagePerWorker)$	0.141***	0.157***	0.145***
	(0.012)	(0.022)	(0.010)
Product fixed effect	Yes	Yes	Yes
Firm fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Product&Firm fixed effect	Yes	Yes	Yes
Observations	815,295	815,295	813,724
R-squared	0.791	0.810	0.833

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). RCA_D is a dummy variable, and it equals 1 when the RCA index is above 1.1 and takes a value of 0 when the index is below 0.9. 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.

Chapter 5

Conclusion

This thesis focuses on how firms' investments in product quality differ across industries based on a country's comparative advantage. Chapter 2 extends a standard 2x2x2 (two countries, two industries and two production factors) H-O model with firm heterogeneity, allowing firms to choose product quality endogenously. It concludes that the comparative advantage stems from different factor endowments across countries and different factor intensities across industries. Firms would determine their product quality depending on the export status and the industry characteristics. Chapter 3 further improves the theoretical model by allowing firms to use different intermediate inputs within industries. This leads to more productive firms producing higher-quality products using higher-quality (more expensive) intermediate inputs and commanding higher prices. However, it still holds all propositions obtained in Chapter 2. In addition, it also reveals that a country's comparative advantage industry features a higher aggregate or average quality level. The last chapter employs the panel data from China and provides empirical evidence showing that Chinese exporters export higher-quality products in a comparative advantage industry. Inspired by the theoretical model, it further addresses the endogeneity of the comparative advantage using China's WTO accession. The trade literature has overlooked the differences in product quality across industries. Thus, this thesis provides insights into how firms' product quality varies across industries theoretically and empirically.

5.1 Summary of Findings

In Chapter 2 and Chapter 3, both theoretical models draw several propositions of firms' quality choices. Exporters raise their product quality, and non-exporters produce lower-quality products when the trade opens. Firms maximise profits by choosing the optimal product quality. Thus, they compare the marginal cost and the marginal benefit of upgrading quality and decide on their quality choice. In terms of non-exporters who have no chance of benefiting from the expansion of markets, they face more competitors in both industries, leading to lower demand for their products and a lower marginal benefit of upgrading quality. Meantime they also find an increase in the price of production factors contributing to a higher marginal cost of upgrading quality. As a result, the enlarging difference between the marginal cost and the marginal benefit makes them decide to lower the quality to survive. Exporters face more competitors but simultaneously enjoy the expansion of markets. The access to a larger market makes it profitable to produce goods with a higher quality (a higher marginal cost but a much higher marginal benefit of upgrading quality). Finally, they raise their quality choice to earn more profits in international trade.

Furthermore, the quality choice made by firms differs across industries. In terms of non-exporters that suffer from competition impact, they have to decrease quality. The comparative advantage gives a higher expected entry profit to potential entrants inducing more entrants and more competition. Non-exporters in comparative industries face a more significant increase in production costs and a greater decrease in profits (also a higher marginal cost and a lower benefit of upgrading quality). Hence, they have to lower quality more to survive than non-exporters in other industries conditional on productivity. Exporters suffer from increasing costs of production and exporting, while access to the export market benefits them. The above propositions reveal that the impact of the expansion of markets overweighs the competition impact. Furthermore, the comparative advantage makes the differential between the two impacts even greater. As a result, exporters in the comparative advantage industries find the differential between the increased marginal benefit and the increased marginal cost of improving quality greater than exporters in other industries conditional on productivity. Therefore, exporters in the comparative advantage industries choose relatively high quality to maximise profits.

In addition, Chapter 3 also reveals that the aggregate or average quality of exporters in a comparative advantage industry is higher. When a country opens to trade, it makes the average quality of industries higher for all industries. However, the average quality of a comparative advantage industry is higher as firms within this industry in this country can produce and sell products at relatively low costs compared to their international competitors. More specifically, within a comparative advantage industry, more firms with the least productivity will exit, and more productive firms will choose to improve product quality and export, increasing the aggregate quality more than those in a comparative disadvantage industry conditional on productivity. Furthermore, this will outweigh the effect of lowered quality of non-exporters contributing to a higher aggregate quality of a comparative advantage industry.

Chapter 4 empirically tests one of the propositions using detailed transaction-firm-level data from China. Based on the measurements of the product quality and the comparative advantage, it provides supporting evidence showing that Chinese exporters export higher-quality products in China's comparative advantage industries. Furthermore, it measures the relative factor endowment and the comparative advantage and uses 2SLS to prove that the comparative advantage stems from differences between the relative factor endowment. Finally, it proves the results robust using alternative estimations of the total factor productivity (TFP), different estimating quality, and different samples.

5.2 Implications, Limitations and Future Research

Improving productivity is always a key objective for policymakers. However, firms use different strategies to increase value-added per worker, such as improving the quality of their products. Since quality is reflected in the price consumers are willing to pay for the products, increasing the firm's product quality may generate substantial welfare gains for consumers. This thesis supports the view that product quality is important for international trade firms, industries, and countries. It theoretically and empirically relates firms' quality choice to a country's comparative advantage over industries stemming from its factor endowment. It reminds policymakers of the importance of the relative endowment of production factors of one country in international trade.

This thesis has some limitations. First, the empirical analysis can only test one of the propositions drawn from the theoretical model limited by the data. With access to more data, more supporting evidence for those novel propositions can be derived in future work, which will make this research more complete. For the theory, it can be interesting to incorporate firms' ability to produce multiple goods in future research to show trade patterns over the quality of multi-product firms.

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