Quality, Variable Markups, and Welfare: A Quantitative General Equilibrium Analysis of Export Prices*

Haichao Fan† Fudan

Yao Amber Li‡ HKUST

Sichuang Xu§ HKUST

Stephen R. Yeaple¶ PSU, NBER and CESifo

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Abstract

Modern trade models attribute the dispersion of international prices to physical and man-made barriers to trade, to the pricing-to-market by heterogeneous producers, and to differences in the quality of output offered by firms. This paper analyzes a quantitative general equilibrium model that incorporates all three of these mechanisms. Estimating the model's parameters from Chinese firm-level trade data, we find that our model incorporating both endogenous quality and per unit trade costs implies lower gains from trade relative to the model without variable quality. This is because these costs, combined with "Washington Apples" effects, are a greater burden on the most productive firms and change the effective distribution of productivity. We also show that changes in specific trade costs induce larger shifts in export prices than do changes in ad valorem trade costs that equivalently restrict trade. The results highlight the importance of modeling "Washington Apples" effects in quantitative trade models.

JEL classification: F12, F14

Keywords: quality, welfare, variable markups, export price, "Washington Apples" effect, non-homothetic preferences, specific trade costs, heterogeneous firms

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†Fan: Institute of World Economy, School of Economics, Fudan University, Shanghai, China. Email: fan_haichao@fudan.edu.cn.

‡Li: Department of Economics and Faculty Associate of the Institute for Emerging Market Studies (IEMS), Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong SAR-PRC. Email: yaoli@ust.hk. Research Affiliate of the China Research and Policy Group at University of Western Ontario.

§Xu: Department of Economics, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong SAR-PRC. Email: sxuaf@connect.ust.hk.

¶Yeaple: Corresponding author. Department of Economics, Pennsylvania State University. Email: sry3@psu.edu. Research Associate at National Bureau of Economic Research and Research Affiliate at Ifo Institute.

1 Introduction

International trade is the study of geographic barriers to economic interaction. Across international borders, these frictions appear to be large as volumes of economic interactions fall dramatically and prices for the same goods diverge. Modern trade models attribute the imperfect correlation of prices across locations to physical and man-made barriers to trade, the pricing-to-market behavior on heterogeneous producers, and systematic differences in the quality of output offered by firms across markets. Naturally, these sources of price variation across markets, and their effect on the gains from trade, are not independent. For instance, if the costs of international trade are per unit shipped (specific) rather than on the value shipped (ad valorem), then producers have an incentive to ship only high quality (and presumably high cost) goods (Hummels and Skiba, 2004). Further, if the costs of international trade are specific rather than ad valorem, then the effect on the prices charged by the most productive firms are influenced more than are the prices charged by the least productive (Irarrazabal, Moxnes and Opromolla, 2015).

The analysis of international price dispersion, and the measurement of the gains from trade, has typically proceeded by considering only a subset of the individual mechanisms that are at its cause. In this paper we present and analyze a simple quantitative general equilibrium model that incorporates endogenous entry by heterogeneous firms, endogenous quality choice in the presence of specific (and ad valorem) trade costs, and endogenous and variable markups.

Our framework is unique in its treatment of the "Washington Apples" effect in that the inclusion of endogenous quality choice in the presence of specific trade costs is highly tractable and allows us to infer indirectly the welfare effects of trade restrictions. In our model, quality upgrading allows firms to reduce the burden of specific costs of shipping goods and this mechanism is most valuable to the most productive firms. In the presence of variable markups and quality upgrading, there is a positive relationship between the price charged by a firm and the total quantity demanded by consumers in equilibrium. The size of this relationship allows us to infer the extent to which firms can avail themselves of this mechanism. Intuitively, the more difficult it is to upgrade quality, the lower are the gains from trade for any given level of trade costs.

We calibrate our model's key parameters to a mixture of macroeconomic data (gravity) and to firm-product-destination export price and sales data from Chinese customs. We show that the model can reasonably capture the positive relationship between sales and prices at the firm level and that any simpler setting without endogenous quality cannot. Moreover, the model does a good job matching key features of the variation in observed prices across destinations both at the firm level and in the aggregate and that any simpler framework with variable quality but without variable markup cannot.

We show that the properly calibrated model does indeed imply lower gains from trade than does the properly calibrated model that contains solely the variable markup but lacks the "Washington Apples" mechanism. Intuitively, since our model features a weaker relationship between productivity and the quality adjusted price, specific trade costs hit the most productive firms more heavily than the less productive. As a result, introducing "Washington Apples" effect is akin to making the firm productivity distribution more skewed towards the less productive firms and reducing the average productivity of foreign firms that are active in any given market. Thus, our model generates lower gains from trade.

We also consider the comparative static of reducing specific and iceberg type trade costs such that the two shocks are isomorphic in terms of their impact on trade volumes between countries and in their effect on aggregate welfare. The object of interest in our comparative static is the differential effect of these shocks on the pattern of prices across countries. Increases in specific trade costs induce firms to upgrade their quality which has the effect of raising export price at the intensive margin. Meanwhile, at the extensive margin firm productivity cutoff also increases. As a result, average prices across countries increase after raising specific trade costs. On the other hand, increases in iceberg trade costs have the effect of reducing the quality of goods sold internationally such that export prices fall at the intensive margin, while shifting export market share to firms with higher productivity, leaving a small net impact on observed average export prices across country. This result has important implications for the analysis of the link between export price changes and the gains from trade. Specifically, to establish a link one needs to know what the nature of the shock was. Shocks to specific or to ad-valorem trade costs have very different effects on export prices even when they have identical effects on welfare and the volume of trade.

Our paper contributes to two strands of the literature that seek to understand the causes and implications of international prices.[1] First, our focus on endogenous quality puts our paper into a literature that includes the recent paper by Feenstra and Romalis (2014) who provide a monopolistic competition model that has been designed to estimate the quality of goods traded and sold domestically with the intention of purging price indices of quality variation across countries. Their analysis neglects variation in markups across countries by construction which allows them to allow for more complex mechanisms that give rise to quality dispersion. Finally, their paper is not concerned with measuring the gains from trade.

Second, our paper also contributes to the literature featuring variable markups. These papers include Simonovska (2015), Jung, Simonovska and Weinberger (2015), and Atkeson and Burstein (2008). As in Jung, Simonovska and Weinberger (2015), we consider non-homothetic preferences and a market structure that gives rise to variable markups across firms. Relative to their paper, we also consider vertically differentiated products, quality upgrading opportunities, and specific trade costs that give rise to the "Washington Apples" effect. Our framework, therefore, allows for much of the variation across countries and firms to be attributed not to variation in market power but to variation in quality of output. Allowing for quality upgrading helps to make the model with variable markups more consistent with the well-known pattern

[1] The literature on quality differences is very rich. Earlier contributions include Schott (2004), Kugler and Verhoogen (2009, 2012), Khandelwal (2010), Baldwin and Harrigan (2011), Manova and Zhang (2012), Johnson (2012), Harrigan, Ma and Shlychkov (2015), Bas and Strauss-Kahn (2015), and Fan, Li and Yeaple (2015, 2017).

in the data that the most successful exporters tend to charge the highest prices (e.g. Manova and Zhang (2012), Harrigan, Ma and Shlychkov (2015)). Moreover, our framework highlights the differential effect of specific and ad valorem trade costs on the international distribution of prices.

Our paper is also related to the recent work by Hottman, Redding and Weinstein (2016) who allow for both market power and quality heterogeneity to drive price dispersion across local prices in the United States. They find that a very substantial portion of heterogeneity in market shares can be attributed to quality heterogeneity but with firms' strategic pricing decisions also playing a non-trivial role. By considering a more parsimonious setting, we are able to conduct our analysis of the role of mark-up and quality dispersions to an international setting.

The remainder of this paper is organized into six sections. In Section 2, we develop a series of stylized facts concerning the international pricing behavior of Chinese firms that we will use to calibrate our model. In Section 3, we present a simple, quantitative general equilibrium model that is able to rationalize these stylized facts and which can be quantified with features of our data. In addition to characterizing the equilibria, we derive an expression for the welfare gains from shocks to the international trading environment. In Section 4, we calibrate the model, assess the model's fit to the data, and contrast the model's fit relative to other models that lack one or more of the features of our model. In Section 5, we discuss the model's quantitative implications for the gains from trade. Again, we contrast the model's predicted gains from trade relative to models that lack the "Washington Apples"quality mechanism. In Section 6, we illustrate how specific and ad valorem trade shocks that have iso-morphic effects on welfare and on trade volumes have very different effects on import prices. This is important as it shows how micro-econometric models that neglect specific trade costs may be misspecified. Finally, in Section 7, we provide concluding comments.

2 Stylized Facts

2.1 Data

To document the stylized facts regarding export prices across destinations and across firms within the same destination, we use two micro-level databases and one aggregate-level cross-country database. Specifically, these are (1) the transaction-level export data from China's General Administration of Customs; (2) the annual survey of industrial firms from the National Bureau of Statistics of China (NBSC); (3) the CEPII Gravity database which provides destination countries' characteristics such as population, GDP per capita, and distance to China. We use data at the year 2004 to be consistent with the calibration exercise later.[2]

[2]To calibrate our model, we construct bilateral trade share following the method in Ossa (2014) based on GTAP 9 Data Base for the year 2004 (see Section 4 for more details).

The China's Customs database records each export and import transaction for the universe of Chinese firms at the HS8 product level, including import or export values, quantities, products, source and destination countries, firm contacts (e.g., company name, telephone, zip code, and contact person), enterprise types (e.g., state owned, domestic private, foreign invested, or joint venture), and customs regimes (e.g., ordinary trade, or processing trade). We aggregate each transaction-level data to various levels, including firm-HS6-destination country, firm-HS6, or HS6-country for further analysis. We compute unit values (i.e., export values divided by export quantities) as a proxy for export prices and focus on ordinary trade exporters.[3]

To characterize firms' attributes such as TFP, employment, capital intensity, and wage, we use the NBSC firm-level data from the annual surveys of Chinese industrial firms. This database contains detailed firm-level production, accounting and firm identification information for all state-owned enterprises (SOEs) and non-state-owned enterprises with annual sales of at least 5 million *Renminbi* (RMB, Chinese currency). We use merged data of both the Customs data and the NBSC firm survey data when firms' characteristics are needed.[4]

2.2 Empirical Regularities

In this subsection, we report three stylized facts concerning export prices across destinations and across firms within destination as well as the number of firms that export to each destination. Note that the existing literature has documented many of these facts separately, but it is useful to show that they hold in the Chinese data. Moreover, it is these facts that we seek to be able to explain within a single model and that we will use to calibrate this model.

Fact 1: Export prices across destinations.— Based on the whole customs data in 2004, Table 1 reports the regression results using (log) export prices as dependent variable and destination country's GDP per capita as main explanatory variable, controlling for destination's population and distance to China. Columns 1-2 and 3-4 use the prices at the firm-HS6-country level and the HS6-country level, respectively. The coefficients on GDP per capita in all specifications are significantly positive, indicating that export prices increase in destination's income (e.g., Manova and Zhang, 2012). To better illustrate this pattern, we also plot (log) export prices against destination's GDP per capita for more than 200 destinations of China's exports in Figure 1 by regressing HS6-country level prices on HS6 product fixed effects and controlling for destination's population and distance, and then plotting the mean residuals for each destination. Clearly, a positive slope between export price and destination's income is observed. Thus, we summarize the following fact:

Stylized fact 1. *Firms set higher export prices for the same product in richer destinations.*

[3]Processing traders have very little control over the prices that they receive for their goods and are often the affiliates of foreign firms who directly control the prices in transactions. This is the key reason that processing traders are excluded from this analysis.

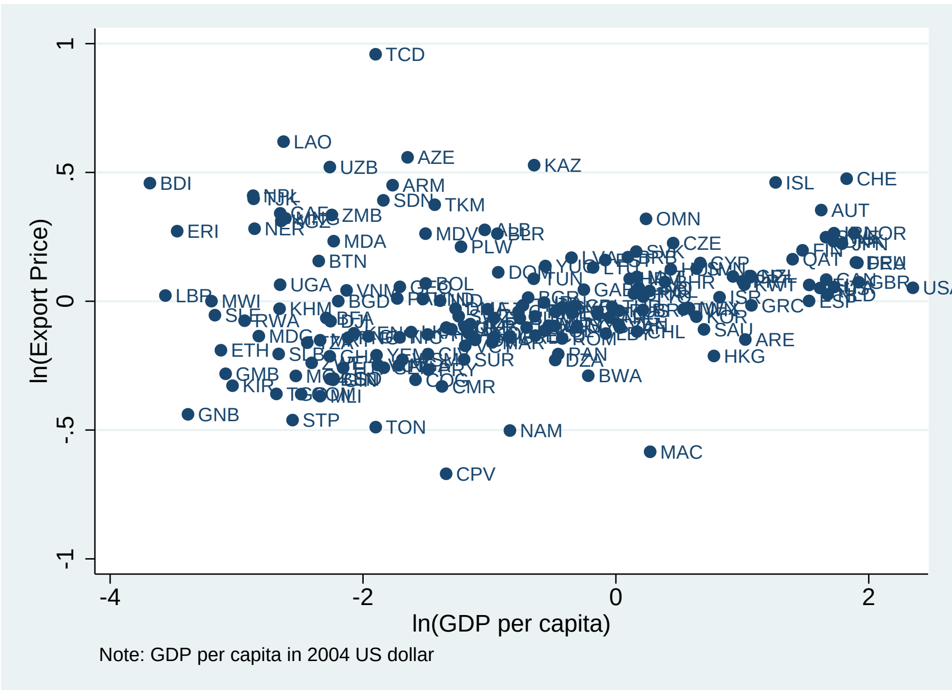
[4]Due to some mis-reporting, we follow Cai and Liu (2009) and use General Accepted Accounting Principles to delete the unsatisfactory observations in the NBSC database. See Fan, Li and Yeaple (2015) for more detailed description of data and the merging process.

Table 1: Export Prices across Destination

	Dependent Variable: ln(*price*)			
	$\ln(p_{fhc})$		$\ln(p_{hc})$	
	(1)	(2)	(3)	(4)
GDP per capita (current in US dollar)	0.024***	0.026***	0.042***	0.045***
	(0.005)	(0.005)	(0.010)	(0.009)
Country-level Other Control	no	yes	no	yes
Firm-Product Fixed Effect	yes	yes	no	no
Product Fixed Effect	no	no	yes	yes
Observations	1,441,468	1,441,468	173,055	173,055
R-squared	0.946	0.946	0.831	0.831

Notes: *** p < 0.01, ** p < 0.05, * p < 0.1. Robust standard errors corrected for clustering at the destination country level in parentheses. Robust standard errors corrected for clustering at the destination country level in parentheses. The dependent variable in specifications (1)-(2) is the (log) price at the firm-HS6-country level, and in specifications (3)-(4) is the (log) price at the HS6-country level. Country-level other controls include population and distance. All regressions include a constant term.

Figure 1: Export prices increase with destination income



Notes: Export prices for ordinary trade from China's Customs data in 2004. Prices (in logarithm) are drawn by regressing HS6-country level export prices on HS6 product fixed effects as well as controlling for destinations' population and distance and then plotting the mean residuals for each destination.

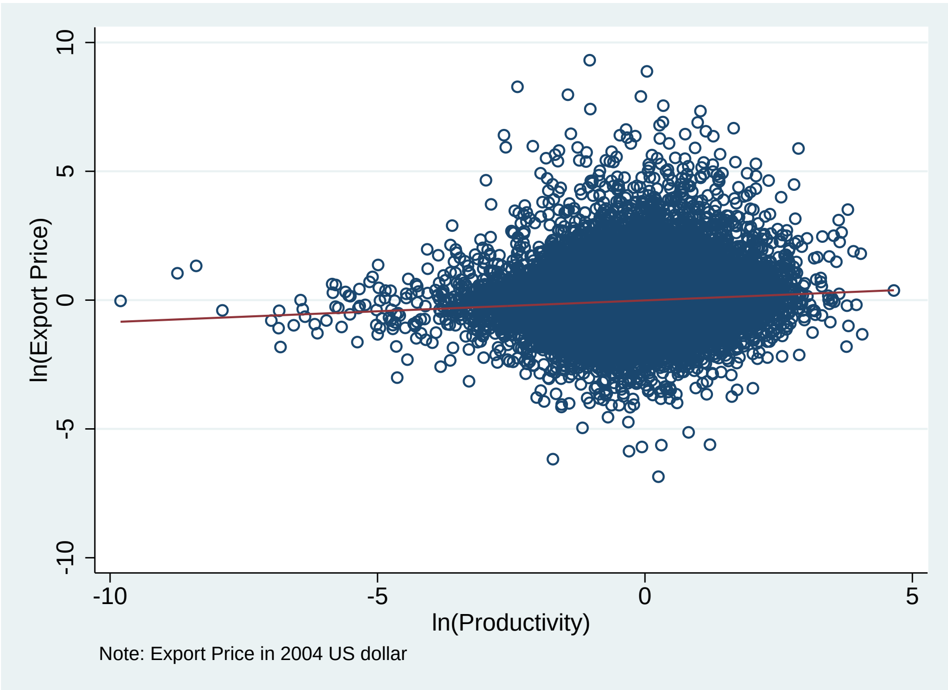
Fact 2: Export prices across firm.— To present export prices across firm, we use the merged data of the customs and the NBSC in 2004 in Table 2 and report the results by regressing export prices on firm productivity, controlling for firms' other characteristics such as employment, capital intensity, and the wage it pays. In columns 1-2, we use firm-HS6-country level price

Table 2: Export Prices across Firm

	Dependent Variable: ln(*price*)			
	$\ln(p_{fhc})$		$\ln(p_{fh})$	
	(1)	(2)	(3)	(4)
ln(TFP)	0.095***	0.050***	0.094***	0.050***
	(0.009)	(0.009)	(0.009)	(0.011)
Firm-level Other Control	no	yes	no	yes
Product-country Fixed Effect	yes	yes	no	no
Product Fixed Effect	no	no	yes	yes
Observations	504,813	504,627	185,689	185,607
R-squared	0.775	0.779	0.638	0.644

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors corrected for clustering at the firm level in parentheses. The dependent variable in specifications (1)-(2) is the (log) price at the firm-HS6-country level, and in specifications (3)-(4) is the (log) price at the firm-HS6 level. Firm-level other controls include employment, capital-labor ratio, and wage. All regressions include a constant term.

Figure 2: Export prices increase with firm productivity



Notes: Export prices for ordinary trade from China's Customs data in 2004. Prices (in logarithm) are drawn by regressing firm-HS6 level export prices on HS6 product fixed effects and then plotting the mean residuals for each firm.

and include product-country fixed effect; in columns 3-4, we use firm-HS6 price and include HS6 product fixed effect. The coefficient on firm's TFP are all significantly positive, which is consistent with the quality-and-trade literature that high-productivity firms charge higher prices (e.g., Fan, Li and Yeaple, 2015). Figure 2 also plots export prices against firm's TFP by regressing firm-HS6 level export prices on HS6 product fixed effects and then plotting the mean residuals for each firm. Table 2 and Figure 2 yield the following fact:

Stylized fact 2. *Higher-productivity firms set higher export prices for the same product within the same market.*

Table 3: Firm Mass across Destination

	Dependent Variable: $\ln(FirmNumber)$			
	$\ln(N_{hc})$		$\ln(N_c)$	
	(1)	(2)	(3)	(4)
GDP per capita (current in US dollar)	0.236***	0.296***	0.687***	0.767***
	(0.042)	(0.020)	(0.070)	(0.042)
Country-level other Control	no	yes	no	yes
Product Fixed Effect	yes	yes	no	no
Observations	173,422	173,422	173	173
R-squared	0.322	0.528	0.292	0.808

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors corrected for clustering at the destination country level in parentheses. The dependent variable in specifications (1)-(2) is the (log) firm number at the HS6-country level, and in specifications (3)-(4) is the (log) firm number at the destination country level. Country-level other controls include population and distance. All regressions include a constant term.

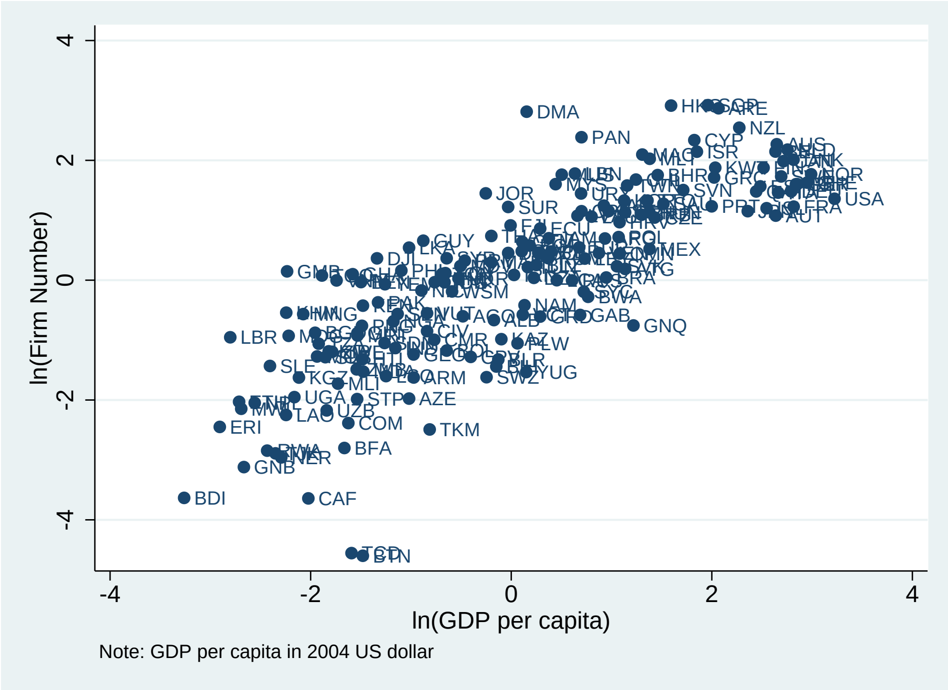
Fact 3: Extensive Margin of Firm Entry across Destinations.— We now turn to the number of exporting firms in different destinations. Table 3 reports the results of regressing (log) firm number at each HS6-country (in columns 1-2) and each country (in columns 3-4) on destination country's GDP per capita, including product fixed effects in columns 1-2 and controlling for destination's population and distance to China. The significantly positive coefficients on GDP per capita suggest that more firms export to richer destinations. Figure 3 further supports the following finding by plotting (log) firm number at each destination against destination's income:

Stylized fact 3. *More firms export to high-income destinations.*

3 Model

In this section, we introduce and solve our model. We first introduce the demand side of the model and solve for the optimal mark-up as a function of a firm's quality of output and marginal cost of production. We then endogenize quality choice and characterize a firm's decision to enter into a given market as a function of its heterogeneous cost draws. Third, we solve for the implied aggregate variables and close the model with labor market clearing/trade balance.

Figure 3: Firm Mass increases with destination income



Notes: Destination-level firm number (in logarithm) are drawn against destination's (log) GDP per capita by controlling for destinations' population and distance.

Finally, we derive a formula for the aggregate gains from trade and show how the model can be used to conduct comparative static exercises à la Dekle, Eaton and Kortum (2008).

3.1 Tastes and Endowments

Consider a world populated by J countries, indexed by i and j with country j endowed with L_j units of labor. The preferences of the representative consumer in each country are identical but are non-homothetic leading to different marginal valuations of quality and access to variety. Specifically, we extend the preference system considered by Simonovska (2015) augmented such that varieties vary in their perceived quality. We denote the source country by i and the destination country by j. Consumers in country j have access to a set of goods Ω_j, which is potentially different across countries. Specifically, the representative consumer has preferences of:

$$U_j = \left[\sum_i \int_{\omega \in \Omega_{ij}} \left(q_{ij}(\omega) x_{ij}^c(\omega) + \overline{x} \right)^{\frac{\sigma-1}{\sigma}} d\omega \right]^{\frac{\sigma}{\sigma-1}} \tag{1}$$

where $\sigma > 1$ is the elasticity of substitution, $x_{ij}^c(\omega)$ is the quantity of variety ω from country i consumed by the representative consumer in country j, $q_{ij}(\omega)$ is it's quality, and $\overline{x} > 0$ is a constant.

Utility maximization imples that the demand curve for variety ω is given by:

$$x_{ij}(\omega) = x_{ij}^c(\omega)L_j = \frac{L_j}{q_{ij}(\omega)}\left[\frac{y_j + \bar{x}P_j}{P_{j\sigma}^{1-\sigma}}\left(\frac{p_{ij}(\omega)}{q_{ij}(\omega)}\right)^{-\sigma} - \bar{x}\right] \tag{2}$$

where $p_{ij}(\omega)$ is the price of output from country i to country j, $P_j = \sum_i \int_{\omega\in\Omega_{ij}} p_{ij}(\omega)/q_{ij}(\omega)\, d\omega$ and $P_{j\sigma} = \left\{\sum_i \int_{\omega\in\Omega_{ij}} \left(p_{ij}(\omega)/q_{ij}(\omega)\right)^{1-\sigma} d\omega\right\}^{\frac{1}{1-\sigma}}$ denote aggregate price statistics, y_j is the representative consumer's income, reflecting GDP per capita in the destination country, and N_j is the mass of varieties consumed in country j (see Appendix A for detailed derivation).

To simplify our discussion and to keep our notation compact, we define the quality-adjusted price charged by firm ω from country i selling in market j to be $\tilde{p}_{ij}(\omega) = p_{ij}(\omega)/q_{ij}(\omega)$, and we define the country j "choke" price level to be $\tilde{p}_j^* = \left(\frac{y_j+\bar{x}P_j}{\bar{x}P_{j\sigma}^{1-\sigma}}\right)^{\frac{1}{\sigma}}$. Everything else equal, high nominal per-capita incomes and higher prices imply higher choke prices facing individual firms.

We thus can write quantity, sales, and profit for a given variety exported from i to j as follows,

$$x_{ij}(\omega) = \frac{\bar{x}L_j}{q_{ij}(\omega)}\left[\left(\frac{\tilde{p}_{ij}(\omega)}{\tilde{p}_j^*}\right)^{-\sigma} - 1\right] \tag{3}$$

$$r_{ij}(\omega) = \bar{x}L_j\tilde{p}_{ij}(\omega)\left[\left(\frac{\tilde{p}_{ij}(\omega)}{\tilde{p}_j^*}\right)^{-\sigma} - 1\right] \tag{4}$$

$$\pi_{ij}(\omega) = \bar{x}L_j\left[\tilde{p}_{ij}(\omega) - \tilde{c}_{ij}(\omega)\right]\left[\left(\frac{\tilde{p}_{ij}(\omega)}{\tilde{p}_j^*}\right)^{-\sigma} - 1\right] \tag{5}$$

where $\tilde{c}_{ij}(\omega) = c_{ij}(\omega)/q_{ij}(\omega)$ is the quality-adjusted marginal cost and $c_{ij}(\omega)$ is the marginal cost of production. Given the quality-adjusted marginal cost, firms maximize their profits.

Taking as given the pricing behavior of all other firms, the monopolistically competitive producer of variety ω chooses its quality-adjusted price of the good. The first-order condition for profit maximization implicitly yields the optimal price $\tilde{p}_{ij}(\omega)$.

$$\sigma\frac{\tilde{c}_{ij}(\omega)}{\tilde{p}_j^*} = \left(\frac{\tilde{p}_{ij}(\omega)}{\tilde{p}_j^*}\right)^{\sigma+1} + (\sigma-1)\frac{\tilde{p}_{ij}(\omega)}{\tilde{p}_j^*} \tag{6}$$

Note that the optimal prices and optimal profits depend only on the quality-adjusted marginal cost of production. In the next subsection, we endogenize a firm's choice of its quality-adjusted marginal cost of production.

3.2 Quality and Production

Firms are heterogeneous in productivity φ. Following Feenstra and Romalis (2014), for a firm from country i with productivity φ requires l of labor produce one unit of output with quality

q according to the production function:

$$l = \frac{q^\eta}{\varphi},$$

where $\eta > 1$ is a measure of the scope for quality differentiation. In addition, a firm from country i that wishes to sell its product in country j must incur two types of variable shipping costs. The first, $\tau_{ij} \geq 1$, is the standard iceberg-type shipping cost which requires τ_{ij} units to be shipped for one unit to arrive. The second, εT_{ij}, is a per-unit shipping cost that has a stochastic ε and a deterministic component, T_{ij}.[5] For simplicity, we assume that both shipping costs are in terms of country i labor.

For a firm from country i of productivity φ that has received country j idiosyncratic shipping cost ε the marginal cost of supply one unit of quality q_{ij} to country j is

$$c_{ij}(\varphi, \varepsilon) = \varepsilon T_{ij} w_i + \frac{w_i \tau_{ij}}{\varphi} q_{ij}^\eta$$

where τ_{ij} is ad valorem trade cost and εT_{ij} is a specific transportation cost from country i to country j. Hence, the quality adjusted marginal cost of production is given by

$$\frac{c_{ij}(\varphi, \varepsilon)}{q_{ij}} = \frac{\varepsilon T_{ij} w_i + \frac{w_i \tau_{ij}}{\varphi} q_{ij}^\eta}{q_{ij}}. \tag{7}$$

As will be obvious in a moment when solving for optimal quality choice by firm this formulation has several desirable features. First, it will exhibit the "Washington Apples" effect: higher specific trade costs will induce firms to upgrade their quality. Second, it will be consistent with the well documented fact that more productive firms charge higher prices (e.g. Kugler and Verhoogen (2009), Manova and Zhang (2012)). Third, it will prove to be highly tractable, allowing us to avoid the tractability issues that have prevented quality and variable markups analysis in the past.

From the first-order condition associated with equation (7), the optimal level of quality for a firm with productivity φ is

$$q_{ij}(\varphi, \varepsilon) = \left(\frac{\varepsilon T_{ij} \varphi}{(\eta - 1)\, \tau_{ij}} \right)^{\frac{1}{\eta}} \tag{8}$$

and hence the quality adjusted marginal cost of supplying market j from i could be rewritten:

$$\tilde{c}_{ij}(\varphi, \varepsilon) = \frac{c_{ij}(\varphi, \varepsilon)}{q_{ij}(\varphi, \varepsilon)} = \left(\frac{\eta}{\eta - 1} \varepsilon T_{ij} w_i \right)^{\frac{\eta-1}{\eta}} \left(\frac{\varphi}{\eta w_i \tau_{ij}} \right)^{-\frac{1}{\eta}}. \tag{9}$$

It is immediate from this expression that more productive firms produce higher quality goods but actually face lower quality-adjusted costs. Also the quality-adjusted cost is an

[5] We introduce the variable ε in order to generate sufficient price dispersion. Including this idiosyncratic draw across firms and locations allows us to account fully for degree of price dispersion across countries holding fixed the producing firm.

increasing geometric average of both types of shipping costs with the weights driven by η. As η goes to one, specific trade costs matter not at all and firm productivity is completely unimpaired. As η goes to infinity, however, firm productivity becomes complete irrelevant and the weight of the specific trade cost goes to one. As a result, it is important to note that the more costly it is to upgrade quality (higher η) the less quality-adjusted marginal cost is decreasing in firm productivity.[6] Hence, specific trade costs hit the most productive firms more heavily than the less productive.

Equation (3) implies that consumer does not have positive demand for goods with sufficiently high quality-adjusted prices. The quality adjusted price $\tilde{p}_{ij}$ can not exceeds the choke price, $\tilde{p}_j^*$. At the cutoff, equations (3) and (6) imply:

$$\tilde{p}_{ij}^* (\varphi, \varepsilon) = \tilde{c}_{ij}^* (\varphi, \varepsilon) = \tilde{p}_j^* \tag{10}$$

where $\tilde{p}_{ij}^* (\varphi, \varepsilon)$ and $\tilde{c}_{ij}^* (\varphi, \varepsilon)$ are the quality adjusted price and the quality adjusted marginal cost at the entry threshold, $\varphi_{ij}^* (\varepsilon)$. Hence, the previous equation, together with equation (9), imply that the productivity cutoff $\varphi_{ij}^* (\varepsilon)$ to sell goods from country i to country j satisfies:

$$\varphi_{ij}^* (\varepsilon) = \varphi_{ij}^* \varepsilon^{\eta - 1} = \frac{\eta^\eta}{(\eta - 1)^{\eta - 1}} T_{ij}^{\eta - 1} \tau_{ij} w_i^\eta \left(\tilde{p}_j^*\right)^{-\eta} \varepsilon^{\eta - 1}, \tag{11}$$

where

$$\varphi_{ij}^* = \frac{\eta^\eta}{(\eta - 1)^{\eta - 1}} T_{ij}^{\eta - 1} \tau_{ij} w_i^\eta \left(\tilde{p}_j^*\right)^{-\eta} \tag{12}$$

is the deterministic part of the productivity cutoff that is common across firms.

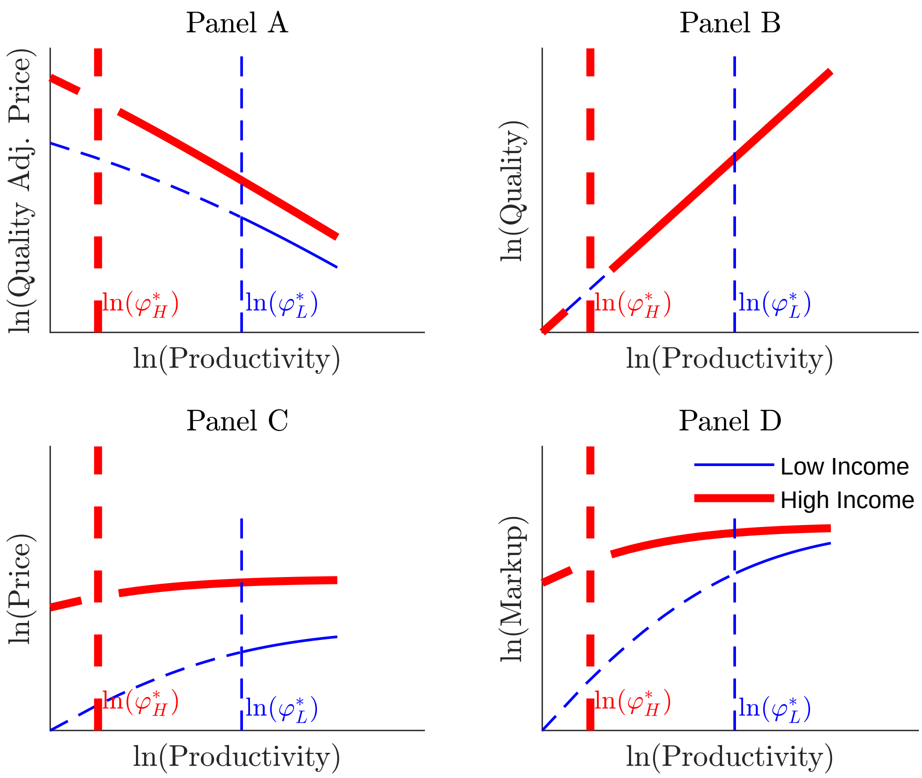
Figure 4 illustrates that the relationship of the quality-adjusted export price, export price, export quality and export markup with firm's productivity.[7] The blue solid line represents this relationship in the low-income destination country; the red, thicker line denotes it in the high-income destination country. Since markups over marginal cost vary systematically with market characteristics, both the quality-adjusted export price, and absolute export price are higher in higher-income country. This is due to the higher markups that can be charged in richer markets.[8]

[6] Compared with the conventional model without quality, the elasticity of quality-adjusted cost with respect to productivity becomes smaller (now it is $1/\eta$ rather than one).

[7] Note that Figure 4 is an illustration based on simulation since we do not have explicit expression for price and markup as function of productivity under CES, but we can derive explicit expressions under log utility function (see Appendix B).

[8] It is straightforward to show that were a portion of the cost of the specific trade cost incurred in the destination country, then richer countries would also be purchasing higher quality goods than poor countries. However, it would generate the endogenous aggregate net exports due to the assumption that the fixed specific transportation costs are paid in destination country labor which generates international transfers of income.

Figure 4: Illustration of Model Mechanism



3.3 Aggregation and Equilibrium

In order to analytically solve the model and to derive stark predictions at the firm and aggregate levels, we follow much of the literature and assume that firm productivities are drawn from a Pareto distribution with cdf $G_i(\varphi) = 1 - b_i\varphi^{-\theta}$ and pdf $g_i(\varphi) = \theta b_i \varphi^{-\theta-1}$, where shape parameter $\theta > 1$ and $b_i > 0$ summarizes the level of technology in country i. The specific transportation cost shock ε is drawn from a log normal distribution, where $\log \varepsilon$ follows the normal distribution with zero mean and variance σ_ε^2.

We first derive the measure of the subset of entrants from i who surpass the productivity threshold $\varphi_{ij}^*(\varepsilon)$ and so serve destination j. The exporting firm mass from i to j, N_{ij}, is defined as

$$N_{ij} = J_i \int_0^\infty \Pr\left[\varphi > \varphi_{ij}^*(\varepsilon)\right] f(\varepsilon)\, d\varepsilon,$$

where J_i is the potential firm mass in country i and $f(\varepsilon)$ is the pdf distribution of ε. As shown in Appendix C, the following simple expression of this mass of entrants can be obtained

$$N_{ij} = \kappa J_i b_i \left(\varphi_{ij}^*\right)^{-\theta}, \tag{13}$$

where κ is a constant, and φ_{ij}^* is the deterministic component of the productivity cutoff given by equation (12).[9]

Note how the measure of entrants from i into market j depends on the "choke price," $\tilde{p}_j^*$ through equation (12). An increase in the choke price induces a lower deterministic productivity cutoff and this expands the measure of firm operating there. The elasticity of the measure of active firms with respect to the choke price is $\theta\eta$, and this illustrates how the "Washington Apples" effect interacts with the underlying productivity dispersion across firms. Ceteris paribus, an increase in the cost of upgrading quality acts like a decrease in the dispersion in firm productivity.

We will see that all of the other aggregates in the economy are tightly linked to (13). In deriving these aggregates it is useful to define the conditional density function for the productivity of firms from i operating in j is

$$\mu_{ij}(\varphi,\varepsilon) = \begin{cases} \theta\left[\varphi_{ij}^*(\varepsilon)\right]^{\theta}\varphi^{-\theta-1} & \text{if } \varphi > \varphi_{ij}^*(\varepsilon) \\ 0 & \text{otherwise} \end{cases} \tag{14}$$

With these definitions in mind, the aggregate price statistics, P_j and $P_{j\sigma}$, can be rewritten as

$$P_j = \sum_i N_{ij}\int_0^\infty \int_{\varphi_{ij}^*(\varepsilon)}^\infty \tilde{p}_{ij}(\varphi,\varepsilon)\,\mu_{ij}(\varphi,\varepsilon)\,f(\varepsilon)\,d\varphi d\varepsilon, \text{ and}$$
$$P_{j\sigma} = \left\{\sum_i N_{ij}\int_0^\infty \int_{\varphi_{ij}^*(\varepsilon)}^\infty \tilde{p}_{ij}(\varphi,\varepsilon)^{1-\sigma}\,\mu_{ij}(\varphi,\varepsilon)\,f(\varepsilon)\,d\varphi d\varepsilon\right\}^{\frac{1}{1-\sigma}}.$$

As shown in Appendix C that contains detailed derivation for aggregate variables P_j, $P_{j\sigma}$, X_{ij} and π_i, all variation in prices due to the idiosyncratic trade cost shocks integrate out so that we may write these price statistics as

$$P_j = \beta\tilde{p}_j^* N_j, \tag{15}$$
$$P_{j\sigma} = \beta_\sigma^{\frac{1}{1-\sigma}}\tilde{p}_j^* N_j^{\frac{1}{1-\sigma}}, \tag{16}$$

where $N_j = \sum_i N_{ij}$ is the total mass of firms from all countries that have positive sales in country j, and β and β_σ are constants that obtain after integrating out ε from each expression (see Appendix C). Similar constants will also appear in each of the aggregate relationships displayed below.

The expression of $\tilde{p}_j^*$, together with equation (15) and (16), imply that the quality-adjusted choke price is

$$\tilde{p}_j^* = \frac{1}{\bar{x}\left[\beta_\sigma - \beta\right]}\frac{w_j}{N_j}. \tag{17}$$

Importantly, an increase in the per capita income in a country, w_j, is associated with a greater choke price, while an increase in competition, N_j, is associated with a lower quality-adjusted

[9] $\kappa = \int_0^\infty \varepsilon^{-\theta(\eta-1)} f(\varepsilon)\,d\varepsilon = \exp\left(\frac{1}{2}\left[(1-\eta)\,\theta\sigma_\varepsilon\right]^2\right)$.

choke price.

Having derived expressions for the "choke price" and the price indices, it is straightforward to show that the total expenditure of country j on the goods from country i, given by

$$X_{ij} = N_{ij} \int_0^\infty \int_{\varphi_{ij}^*(\varepsilon)}^\infty r_{ij} (\varphi, \varepsilon) \mu_{ij} (\varphi, \varepsilon) f (\varepsilon) d\varphi d\varepsilon,$$

can be written as

$$X_{ij} = X_j \frac{N_{ij}}{N_j}, \tag{18}$$

where $X_j \equiv w_j L_j$ is total absorption. Equation (18) shows that our model shares with many commonly used models in the literature the feature that variation in trade volumes across country occur entirely along the extensive margin.

The expected profits can be calculated using

$$\pi_i = \sum_j \int_0^\infty \int_{\varphi_{ij}^*(\varepsilon)}^\infty \pi_{ij} (\varphi, \varepsilon) g_{ij} (\varphi) f (\varepsilon) d\varphi d\varepsilon.$$

As shown in the appendix, these expected profits can be shown to be

$$\pi_i = \frac{1}{J_i} \frac{\beta_\pi}{\beta_\sigma - \beta} \sum_j \frac{N_{ij}}{N_j} X_j \tag{19}$$

where β_π is also a constant.[10]

The household budget equation implies that total income equals to total expenditure

$$w_i L_i = \sum_j X_{ij} \tag{20}$$

Free entry, $\pi_i = w_i f$, together with (18), (19), and (20) pin down the measure of entrants:

$$J_i = \frac{\beta_\pi}{\beta_\sigma - \beta} \frac{L_i}{f}. \tag{21}$$

So, as in standard models of monopolistic competition in the Krugman tradition, the measure of entrants is proportional to country size and invariant to the trading environment. Finally, we assume trade is balanced:

$$\sum_j X_{ij} = \sum_j X_{ji}. \tag{22}$$

This concludes our characterization of the equilibrium. In the next subsection, we show how the gains from trade and how comparative statics on shifting trade costs can be inferred from existing data and estimates of the key model parameters, η, θ, and σ.

[10] Notice here we have that firms' total variable profit is proportional to total revenue as Arkolakis, Costinot and Rodríguez-Clare (2012).

3.4 Welfare

In this section, we show how the measurement of the gains from trade, and the welfare implications of any shock to trade costs, are related to the key parameters of the model. We first derive an Arkolakis, Costinot and Rodríguez-Clare (2012) inspired formula relating changes in the level of domestic absorption to changes in real income and then derive the Dekle, Eaton and Kortum (2008) system of equations. The latter system of equations are novel in that they allow for both iceberg-type and specific trade cost shocks to be analyzed. We present these results as propositions whose proofs can be found in the appendix (see Appendix D). In the end of the section we present a multi-sector extension and its welfare implication.

Gains from Trade

Combining the utility expression (1), equation (3), and equation (C.5) (in the appendix), the measure of indirect utility can be expressed as a function of the nominal wage relative to the equilibrium choke price:

$$U_j = \beta_u \left(\frac{w_j}{\tilde{p}_j^*} \right)^{\frac{\sigma}{\sigma-1}}$$

where $\beta_u = \bar{x}^{\frac{1}{1-\sigma}} \left(\frac{\beta_\sigma}{\beta_\sigma - \beta} \right)^{\frac{\sigma}{\sigma-1}}$ is a constant. We define the share of expenditure on goods from i in j, λ_{ij}, as:

$$\lambda_{ij} = \frac{X_{ij}}{\sum_{i'} X_{i'j}} \tag{23}$$

We denote the post adjustment value of any variable x as x' and the change in its value as $\widehat{x} = \frac{x'}{x}$, that is, a hat denotes the ratio between the counterfactual and factual value. Then the change in welfare associated with any foreign shock in country j satisfies the following Proposition:

Proposition 1. *The change in welfare associated with any foreign shock in country j can be computed as:*

$$\widehat{U}_j = \left(\widehat{\lambda}_{jj} \right)^{-\frac{\sigma}{\sigma-1} \frac{1}{1+\eta\theta}} \tag{24}$$

Equation (24) show that the key parameters for assessing welfare implications of shocks are the taste parameter σ which plays a key role in the mark-up given a firm's choice of quality and its productivity, θ which governs the degree of dispersion in productivity, and η which governs the cost of quality upgrading in the model. As η rises, more productive firms become more exposed to the specific trade costs and less related with firm's productivity which explains why the two parameters η and θ interact.

Were we to strip the model of its "Washington Apples" mechanism, the model would be essentially identical to Jung, Simonovska and Weinberger (2015).[11] In that case, it can be shown that the coefficient on the change in the domestic consumption share $\widehat{\lambda}_{jj}$ becomes $-\frac{\sigma}{\sigma-1} \frac{1}{1+\theta}$

[11] This involves fixing the quality level to unity and setting all specific trade costs to zero.

(see Appendix E for detailed derivation). Intuitively, the "Washington Apples" changes the effective distribution of productivity.

In order to evaluate the changes in welfare associated with any foreign shock, we need to measure $\widehat{\lambda}_{jj}$ and calibrate the parameters (σ, η, θ). Given the value of parameters (μ, η, θ) and initial value of X_{ij} before shocks, we have the following proposition:

Proposition 2. *The percentage change in welfare associated with any change in trade costs in country j can be computed using equation (24) combined with*

$$\widehat{\lambda}_{jj} = \frac{(\widehat{w}_j)^{-\eta\theta}}{\sum_i \lambda_{ij}\left[\widehat{T}_{ij}^{\eta-1}\widehat{\tau}_{ij}\right]^{-\theta}(\widehat{w}_i)^{-\eta\theta}} \tag{25}$$

where $\widehat{w}_j$ are implicitly given by the solution:

$$\widehat{w}_i = \sum_j \frac{\lambda_{ij} w_j L_j \left(\widehat{T}_{ij}^{\eta-1}\widehat{\tau}_{ij}\right)^{-\theta}(\widehat{w}_i)^{-\eta\theta}}{w_i L_i \sum_{i'} \lambda_{i'j}\left(\widehat{T}_{i'j}^{\eta-1}\widehat{\tau}_{i'j}\right)^{-\theta}(\widehat{w}_{i'})^{-\eta\theta}}\widehat{w}_j \tag{26}$$

Equations (25) and (26) are interesting in that they show that the elasticities associated with changes in trade costs differ depending on whether they are associated with ad valorem trade costs $\widehat{\tau}_{ij}$, or specific trade costs $\widehat{T}_{ij}$. Intuitively, shocks to both types of trade costs affect the extensive margin of entry of firms in markets and so involve the Pareto parameter θ. Shocks to specific trade costs, however, have an additional effect that works through quality upgrading and so the effect of these types of shocks depend on the elasticity of the costs associated with quality upgrading, η.

Multi-Sector Extension

The tractability of our model can be also extended to a multi-sector setup, which corresponds to the sectoral heterogeneity of quality scope that has been featured by the recent literature.[12] Given a two-layer utility function $U_j = \prod_s C_{js}^{\alpha_s}$ with subscript s indexing sector and α_s denoting the Cobb-Douglas sector share, the demand function is similar with that of the one-sector benchmark model and is given by

$$x_{ijs}^c(\omega) = \frac{\overline{x}_s L_j}{q_{ijs}(\omega)}\left\{\left[\frac{\tilde{p}_{ijs}(\omega)}{\tilde{p}_{js}^*}\right]^{-\sigma_s} - 1\right\}$$

where $\tilde{p}_{js}^* = \left(\frac{\alpha_s\left(\sum_s \bar{x}_s P_{js} + y_j\right)}{\overline{x}_s P_{j\sigma s}^{1-\sigma_s}}\right)^{\frac{1}{\sigma_s}}$ is the corresponding quality-adjusted price cut-off for the multi-sector model.[13] We have the following proposition:

[12] The literature points out that firms' export pricing decision crucially depends on the quality scope that varies across sectors, e.g., Manova and Zhang (2012), Johnson (2012), Fan, Li and Yeaple (2015, 2017).

[13] Here we leave detailed derivation to Appendix F.1.

Proposition 3. *The percentage change in welfare associated with any changes in trade costs in country j can be computed as:*

$$\widehat{U}_j = \prod_s \left(\widehat{\lambda}_{jjs}\right)^{-\frac{\alpha_s \sigma_s}{\sigma_s - 1}\frac{1}{1+\eta_s \theta_s}}, \tag{27}$$

where λ_{ijs} denotes the share of expenditure on goods in sector s from i in j, η_s is the quality scope parameter in sector s, and θ_s is the sector specific Pareto distribution shape parameter.[14] Since the multi-sector model is in spirit similar to the one-sector model, in all the following quantitative exercises we shall refer to one-sector model as benchmark.

4 Quantification

The quantitative section contains 3 steps: (1) we need to estimate the parameters of the model. There are two sets of parameters. The first set we define as Θ_1 includes η, the quality scope, θ, the productivity shape, and σ_ε, the standard deviation of fixed cost shocks, and finally σ, the elasticity of substitution. The second set of parameters includes all endogenous macro variables: $\Theta_2 = \left\{\left\{w_j, P_{j\sigma}, P_j, fJ_i, T_{ij}^{\eta-1}\tau_{ij}, b_i, N_j\right\}_{i=1}^{I}\right\}_{j=1}^{I}$. We show that our model specification enables us to identify Θ_1 without information about Θ_2. That is, we can first identify Θ_1 and then recover Θ_2. The macro level parameters in Θ_2 are recovered through the structural equations implied by the model. We then simulate the model using our estimated parameter set Θ_1 and Θ_2. Finally, we generate pseudo-Chinese exporters that is comparable with the custom data and analyze the model fit by comparing the real data and model generated one.

4.1 Identification of Θ_1

We begin by discussing the estimation of θ. Following Caliendo and Parro (2015) and Arkolakis et al. (2017*b*), we estimate θ from the coefficient on tariffs in a gravity equation. Equations (12), (13), and (18) imply

$$\frac{\lambda_{ij}}{\lambda_{jj}} = \frac{J_i b_i \left(T_{ij}^{\eta-1}\tau_{ij} w_i^{\eta}\right)^{-\theta}}{J_j b_j \left(T_{jj}^{\eta-1}\tau_{jj} w_j^{\eta}\right)^{-\theta}}. \tag{28}$$

Taking the logarithm of this expression yields an estimation equation:

$$\log\left(\frac{\lambda_{ij}}{\lambda_{jj}}\right) = \underbrace{\log\left[J_i b_i w_i^{-\theta\eta}\right]}_{S_i} - \underbrace{\log\left[J_j b_j \left(T_{jj}^{\eta-1}\tau_{jj} w_j^{-\eta}\right)^{\theta}\right]}_{S_j} - \theta\left(\eta - 1\right)\log T_{ij} - \theta \log \tau_{ij}, \tag{29}$$

where S_i is the exporter fixed effect, and S_j is the importer fixed effect. To estimate θ we must make some auxiliary assumptions. In particular, we assume that both $\log T_{ij}$ and the physically shipping costs associated with $\log \tau_{ij}$ are linear in bilateral pair geography. Further,

[14] The detailed proof of Proposition 3 is in Appendix F.2.

we assume that the majority of the tariff variation observed for manufacturing goods are ad valorem. Hence, by controlling for geography and exporter and importer fixed effects, we can separately identify θ as the coefficient on tariffs.

Specifically, we assume that specific and ad valorem trade costs are related to observables. Following Waugh (2010) and Jung, Simonovska and Weinberger (2015), we use a set of gravity variables to proxy for T_{ij} and for τ_{ij} through the following equations:

$$\begin{aligned}(\eta-1)\log(T_{ij}) &= \alpha^T + ex_i^T + \gamma_h^T d_h + \gamma_d^T \log(dist_{ij}), \\ \log\tau_{ij} &= \alpha^\tau + ex_i^\tau + \gamma_h^\tau d_h + \gamma_d^\tau \log(dist_{ij}) + \log tar_{ij},\end{aligned}$$

where α^T and α^τ are constants. As in Waugh (2010), we also add an exporter fixed effect, ex_i, a set of three dummy variables, d_h, indicating whether (1) the trade is internal; (2) whether the two country use the same currency; (3) whether the two country use the same official language, and the logarithm of distance from country i to country j, $\log(dist_{ij})$. Our key identifying assumption is that tariffs, tar_{ij}, are primarily part of ad valorem trade costs, τ_{ij}, and not specific trade costs. This assumption is particularly reasonable for manufactured goods relative to commodities. This yields the following estimation equation

$$\log\left(\frac{\lambda_{ij}}{\lambda_{jj}}\right) = S_i - S_j - \theta\left(\left(\alpha^T+\alpha^\tau\right) + \left(ex_i^T + ex_i^\tau\right) + (\gamma_h^T+\gamma_h^\tau)d_h + \left(\gamma_d^T+\gamma_h^\tau\right)\log(dist_{ij})\right) - \theta\log tar_{ij} + \varepsilon_{ij}, \tag{30}$$

where ε_{ij} is assumed to be Gaussian measurement error. Note how the coefficient on tariffs has a structural interpretation. Further, also note that with an estimate θ it becomes possible to back out from these estimates the aggregate trade cost $(T_{ij})^{\eta-1}\tau_{ij}$.[15]

The bilateral trade share λ_{ij} is constructed following the method in Ossa (2014) by using the GTAP 9 data for the year 2004.[16] Bilateral gravity variables: $dist_{ij}$, d_h (common currency, common official language) is taken from the CEPII dataset. The tariff data is from WITS, where we compute the average tariff rate for all HS6 sectors of each destination to represent tar_{ij}.[17] We let $tar_{ij}=1$ if trade is internal. We also let $tar_{ij}=1$ if both i and j belongs to EU, NAFTA, ASEAN members countries. For the case of EU, we apply common external tariff by the EU for non-EU members. The summary statistics are presented in Table 4.

The coefficients on the gravity variables and tariffs obtained by estimating equation (29) via OLS are shown in Table 5. The estimates on the standard gravity variables all of their

[15]It is possible to tease apart the contribution of the two components of trade costs via the geography of firm price levels as quality choices are increasing in specific costs and decreasing in ad valorem shipping costs. We choose not to do so here because knowledge of these costs are not necessary to answer the questions of interest in this paper.

[16]The bilateral trade shares λ_{ij} are only constructed for our selected 36 countries. For any $i \neq j$, we first compute X_{ij} as the sum of trade flow from i to j across all GTAP sectors. We then compute X_{jj} as the total domestic output, X_j, minus its total export, $\sum_{i\neq j} X_{ji}$. We then compute $\lambda_{ij} = X_{ij}/\sum_i X_{ij}$. One important advantage of using GTAP is that we do not get missing/negative value for our constructed X_{jj}, and hence all the values for λ_{ij} are valid.

[17]2004 tariff data for Russia is not available. We use the year 2005 instead. We also try year 2002 as an alternative, the result is very similar.

Table 4: Summary Statistics of Gravity Variables

Variable	Mean	Std. Dev.	Min.	Max.	N
$\log(\lambda_{ij}/\lambda_{jj})$	-5.221	1.842	-10.491	0	1296
$\log(tar_{ij})$	0.066	0.067	0	0.264	1296
$\log(dist_{ij})$	8.432	1.059	2.258	9.811	1296

Table 5: Estimation of Gravity Equation

Dependent variable: $\log(\lambda_{ij}/\lambda_{jj})$	
$\log(tar_{ij})$	-6.097***
	(0.795)
$\log(dist_{ij})$	-0.765***
	(0.031)
Common language	0.349***
	(0.071)
Common currency	0.165*
	(0.086)
Same country Dummy	2.658***
	(0.139)
Importer Fixed Effects	YES
Exporter Fixed Effects	YES
Observations	1,296
R-squared	0.988

Notes: Standard errors in parentheses.

expected sign and fall in common ranges for gravity equations (see Head and Mayer, 2014). For instance, a 10 percent increase in distance is associated with an approximately 7.65 percent reduction in the volume of trade. Most important, the coefficient on tar, which is paramount to our quantitative exercise, obtains a very sensible value of 6.1 and is measured with a high degree of precision. This number falls in the range of estimates in Arkolakis et al. (2017*b*). We now discuss the estimation of the model's other key parameters.

Our approach to estimating the remaining coefficients is very different. To identify the idiosyncratic dispersion in trade costs, σ_ε, the taste parameter σ, and the quality upgrading cost elasticity η, we make use of our estimate of θ, the model, and moments from firm-country-product data on unit values ($p_{ij}(\omega)$ in the model) and export values ($r_{ij}(\omega)$ in the model). The core of our estimation strategy involves using the first-order condition for price determination (6) and values of σ, σ_ε, and η to generate an artificial dataset that match the standard deviation of the logarithm of price charged by Chinese firms, the standard deviation of the logarithm of the corresponding sales, and the correlation of the logarithm of prices with the logarithm of sales.

Combining equations (9), (10), and (11) with (6), yields the following expression:

$$\sigma\left(\frac{\varphi}{\varphi^*_{ij}(\varepsilon)}\right)^{-\frac{1}{\eta}} = \left(\frac{\tilde{p}_{ij}(\varphi,\varepsilon)}{\tilde{p}^*_j}\right)^{\sigma+1} + (\sigma-1)\frac{\tilde{p}_{ij}(\varphi,\varepsilon)}{\tilde{p}^*_j}. \tag{31}$$

Note that if we focus on productivity draws that exceed the cutoff, the inverse of the term $\left(\varphi/\varphi^{*}_{ij}\left(\varepsilon\right)\right)^{\frac{1}{\eta}}$ on the left hand side of this expression follows a Pareto distribution with location parameter 1 and shape parameter $\eta\theta$.[18] Given that the distribution shares a common support across all destination countries, we can define $\xi = \left(\varphi/\varphi^{*}_{ij}\left(\varepsilon\right)\right)^{\frac{1}{\eta}}$, and rewrite the pricing equation as

$$\frac{\sigma}{\xi} = \left(\frac{\tilde{p}_{ij}\left(\xi\right)}{\tilde{p}^{*}_{j}}\right)^{\sigma+1} + \left(\sigma-1\right)\frac{\tilde{p}_{ij}\left(\xi\right)}{\tilde{p}^{*}_{j}}. \tag{32}$$

To connect the implied pricing behavior in the model with the Chinese firm-product-country data, we define the following transformation:

$$p_{ij}\left(\xi,\varepsilon\right) = \frac{\tilde{p}_{ij}\left(\xi\right)}{\tilde{p}^{*}_{j}} c_{ij}\left(\varepsilon\right)\frac{\tilde{p}^{*}_{j}}{\tilde{c}_{ij}\left(\xi\right)},$$

where $c_{ij}\left(\varepsilon\right) = \frac{\eta}{\eta-1} w_i T_{ij}\varepsilon$ is the endogenous (unadjusted) marginal cost of firms. Using equations (9) and (11) and taking logarithms yields

$$\log p_{ij}\left(\xi,\varepsilon\right) = \log\left(\frac{\tilde{p}_{ij}\left(\xi\right)}{\tilde{p}^{*}_{j}}\right) + \log\left(\varepsilon\right) + \log\left(\xi\right) + \log\left(\frac{\eta}{\eta-1}T_{ij}w_i\right) \tag{33}$$

this implies that the standard deviation of log exporter price, once we subtract the destination average to eliminate the constant term (the last term on the right), will only depend on $\eta\theta$ and σ_{ε}, and is not destination specific.

Making similar transformations for the logarithm of the sales revenue of a firm, given by (4), we obtain:

$$\log r_{ij}\left(\xi\right) = \log\left(\frac{\tilde{p}_{ij}\left(\xi\right)}{\tilde{p}^{*}_{j}}\right) + \log\left(\left(\frac{\tilde{p}_{ij}\left(\xi\right)}{\tilde{p}^{*}_{j}}\right)^{-\sigma} - 1\right) + \log(\overline{x}L_j), \tag{34}$$

This expression shows that the standard deviation of country-product exports by Chinese firms, once it has been demeaned by subtracting its sector-destination mean, depends only on parameters $\eta\theta$ and σ. Notice that two types of relationships here are relevant. First, both parameters drive the standard deviation of $\log r_{ij}\left(\xi\right)$, while only σ governs the dependence of $\log r_{ij}\left(\xi\right)$ on $\tilde{p}_{ij}\left(\xi\right)/\tilde{p}^{*}_{j}$. Our discussion suggests that these three moments are sufficient to identify our three parameters $\eta\theta$, σ_{ε}, and σ via simulated Generalized Method of Moments, while our gravity estimate of θ allows us to separate η from θ.

We now summarize the estimation strategy. First, we calibrate σ to target the standard deviation of the log of export sales. To see this, notice that in equation (34), $\tilde{p}_{ij}\left(\xi\right)/\tilde{p}^{*}_{j}$ is bounded from 0 to 1 (the marginal exporter to destination j takes value 1 while for the most productive firms it tends toward 0). An increase in σ makes sales more responsive to productivity and so

[18] Since φ follows an Pareto distribution, and only firms with $\varphi > \varphi^{*}\left(\varepsilon\right)$ exports, $\frac{\varphi}{\varphi^{*}_{ij}\left(\varepsilon\right)}$ follows a Pareto distribution with location parameter 1 and shape parameter θ. The property of the Pareto distribution thus implies $\left(\frac{\varphi}{\varphi^{*}_{ij}\left(\varepsilon\right)}\right)^{\frac{1}{\eta}}$ is also follows a Pareto distribution with shape parameter $\eta\theta$.

leads to larger sales dispersion. Second, we choose σ_ε to target the standard deviation of the log of export price. Firms' marginal cost depends on the specific trade cost draw ε (see equation (33)), so greater dispersion of these shocks yields greater dispersion of price. Third, the correlation between log-sale and log-price helps to identify $\eta\theta$. In a model without quality, as in Jung, Simonovska and Weinberger (2015), price and sales exhibit negative relationship because the productive firms have lower marginal cost. This negative relationship is overturned here because high productive firms produce higher quality which allows firms to raise their prices. This mechanism is captured in the $\log(\xi)$ term in equation (33): a higher ξ implies a higher price and also a higher sales. The distribution of ξ is governed by the value of $\eta\theta$. We now turn to our construction of the data moments.

To construct the 3 micro moments for the data, we use the customs' ordinary trade data at the year 2004. We aggregate the data into firm-country-HS6 level, construct our data moments for by each country-HS6 pair and choose the median among them. The parameters are jointly identified through the following minimization routine:

$$\min_{\eta\theta,\sigma_\varepsilon,\sigma} \left\{ \left[m^D - m^M(\eta\theta,\sigma_\varepsilon,\sigma)\right]' W \left[m^D - m^M(\eta\theta,\sigma_\varepsilon,\sigma)\right] \right\}$$

where m^D is the (column) vector that contains the data moments, and $m^M(\eta\theta,\sigma_\varepsilon,\sigma)$ contains the corresponding model moments. W is identity weighting matrix.

Table 6 lists our calibration results:

Table 6: Calibration of Θ_1

Moments	Data	Model	Parameters	Values
std. dev. of log-sale	1.39	1.39	σ	4.87
std. dev. of log-price	0.602	0.602	σ_ε	0.6
corr. of log-sale and log-price	0.054	0.054	$\eta\theta$	10.7
trade elasticity w.r.t. tariff	6.097	6.097	θ	6.097

Notes: The first three moments **jointly** calibrate parameters $\{\sigma,\sigma_\varepsilon,\eta\theta\}$, though the way the table presents looks like they are separately calibrated by each moment.

4.2 Solving for Θ_2

In this subsection, we simulate our model in order to assess model fit and so unearth parameters of independent interest. We begin by describing how we uncover wages, measure of total entrants per market, and aggregate prices statistics.

To solve wage w_i for each country, we use the labor market clearing condition, which is given by

$$w_i L_i = \sum_j X_{ij} = \sum_j \lambda_{ij} w_j L_j$$

Here we normalize the wage in US to be 1 so that every other countries' wages are all relative to the US. Market size L_i is proxied by total population of that country, which is from the CEPII dataset. Note that market size immediately pins down the number of entrants per country, fJ_i, from equation (21).

To recover b_j, we use the importer fixed effect from the gravity estimation in equation (28) which is equal to

$$S_j = \log\left[(fJ_j)\, b_j w_j^{-\eta\theta}\right],$$

where S_j is our estimated importer fixed effects.[19] Since we've known all other variables in the estimation equation (28), the bilateral trade cost $\left(T_{ij}^{\eta-1}\tau_{ij}\right)$ can be recovered from the gravity equation estimates.[20] We then solve firm mass N_j using equation (13), and equation (17). In particular, combining the two equations yields the relationship between the measure of firms that exports from i to j, and the total firm mass of j:

$$N_j = \frac{(\eta-1)^{\frac{\eta-1}{\eta}}}{\eta\bar{x}\left[\beta_\sigma - \beta\right]}\left(T_{ij}^{\eta-1}\tau_{ij}\right)^{-\frac{1}{\eta}}\frac{w_j}{w_i}\left(\frac{\kappa J_i b_i}{N_{ij}}\right)^{\frac{1}{\eta\theta}},$$

then using the Chinese custom data, we can compute the total number of firms that exports from China to country j, $N_{China,j}$, except for China itself. Then N_j $(j \neq China)$ can be computed from the above equation given that we already know the rest variables up to the constant.

4.3 Model Simulation

Having our estimates of the full set of model parameters, we can simulate the model to assess its ability to reproduce the facts that were illuminated in Section 2. Our simulation strategy follows that of Eaton, Kortum and Kramarz (2011) and Jung, Simonovska and Weinberger (2015). First, we define $u = b_c\varphi^{-\theta}$, where b_c corresponds for the China's productivity. The cumulative density function of u is

$$\Pr(U < u) = \Pr\left(b_c\varphi^{-\theta} < u\right) = \Pr\left(\varphi > \left(\frac{b_c}{u}\right)^{\frac{1}{\theta}}\right) = u.$$

It proves convenient to write productivity in terms of u: $\varphi = \left(\frac{b_c}{u}\right)^{\frac{1}{\theta}}$. Similarly, the conditional productivity entry cutoff $\varphi_{ij}^*(\varepsilon)$ can also be written in terms of u,

$$u_{cj}^*(\varepsilon) = b_c\left[\frac{\eta^\eta}{(\eta-1)^{\eta-1}}T_{ij}^{\eta-1}\tau_{ij}w_i^\eta\left(\tilde{p}_j^*\right)^{-\eta}\varepsilon^{\eta-1}\right]^{-\theta}. \tag{35}$$

[19] In the above regression, we've added both the importer and exporter fixed effect. This induces multicollinearity. To avoid this, we follow Levchenko and Zhang (2016) and normalize the importer fixed effect S_j for US to 0. Essentially, we choose US for the reference country, and the importer fixed effect estimates for all other countries are all relative to the reference country.

[20] Note that $T_{jj}^{\eta-1}\tau_{jj}$ equals one.

Equation (35) implies that a firm that has received specific trade cost shock ε will export when $u < u^*_{cj}(\varepsilon)$. As discussed in the previous section, all of these parameters can be recovered. Also note that, $\tilde{u} = \frac{u}{u^*_{cj}(\varepsilon)}$ follows a uniform distribution from $(0, 1]$.

Now, we discuss how we simulate the model. Our simulation involves four steps.

(1) Obtain 1,000,000 independent $\tilde{u}$ draws from the uniform distribution defined on $(0, 1]$ and 1,000,000$\times I$ draws of $\tilde{\varepsilon}$ from a standard normal distribution for each country in our model where $I = 36$ is the number of calibrated countries. We then make the transformation $\varepsilon = \exp(\sigma_\varepsilon \tilde{\varepsilon})$ to obtain the simulated specific trade cost shocks. For each draw of $\tilde{u}$, we construct entry hurdles $u^*_{cj}(\varepsilon)$ for each country j using equation (35).

(2) For each $\tilde{u}$, we compute $u^{*\max}_{cj} = \max_{j \neq China} \left\{ u^*_{cj}(\varepsilon) \right\}$. This is the minimum requirement productivity for a firm to sell their product in countries other than China. We then construct $u = u^{*\max}_{cj} \tilde{u}$ using our draw of $\tilde{u}$ in step (1). Because in the model, the measure of firms that export from China to country j is $u^{*\max}_{cj}$, our artificial exporter u is assigned a sampling weight of $u^{*\max}_{cj}$.

(3) For each u, we set the export status δ_{cj} indicating whether firm u exports to j to be given by

$$\delta_{cj}(u) = \begin{cases} 1, & \text{if } u \leq u^*_{cj}(\varepsilon) \\ 0, & \text{otherwise} \end{cases}$$

(4) We recover firm level variables, which include productivity, price and sales. First, we obtain firm level productivity from $\varphi = \left(\frac{b_c}{u}\right)^{\frac{1}{\theta}}$. Second, we construct exporter-destination quality $q_{ij}(\varphi, \varepsilon) = \left(\frac{\varepsilon\varphi}{\eta - 1} \frac{T_{ij}}{\tau_{ij}}\right)^{\frac{1}{\eta}}$. Note that at this juncture, we have to take a stand on the relative magnitudes and cross-country variation in T_{ij} and τ_{ij}. Motivated by the discussion in Hummels and Skiba (2004), we assume that T_{ij} specific costs account for all of the geographic variation in the gravity equation and τ_{ij} is driven exclusively by tariffs. Finally, we compute firm-level prices that are not adjusted for quality:

$$p_{ij}(u, \varepsilon) = \frac{\tilde{p}_{ij}(u, \varepsilon)}{\tilde{p}^*_j} \tilde{p}^*_j q_{ij}(u, \varepsilon),$$

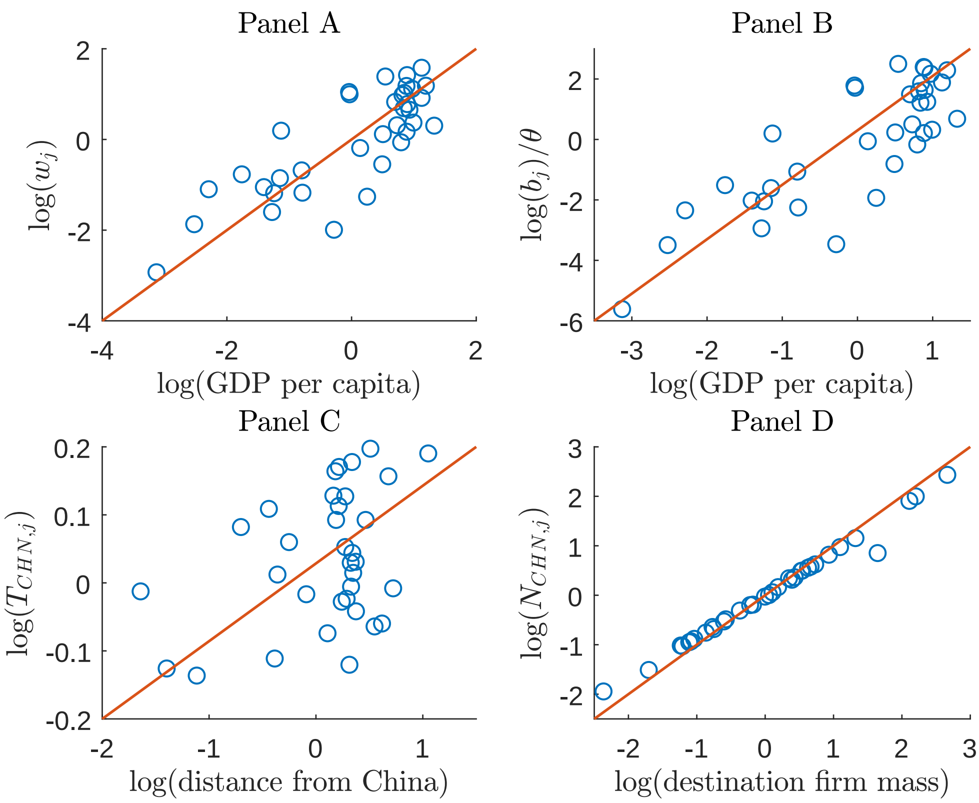
where $\tilde{p}_{ij}(u, \varepsilon)$ are solved through the pricing equation (32). Finally, firm sales can be constructed from equation (4).

In summary, after dropping non-exporting Chinese firms, we have constructed a dataset that contains one million exporting firms, each firm has a maximum destination of I countries. In the next section, we report on how the model fits the targeted and untargeted data.

4.4 Model Fit

In this section, we first discuss the model's fit and compare it to other models that abstract from quality variation and/or mark-up variation across firms and markets. We will show that, particularly with respect to the price-sales relationship that the "Washington Apples" mechanism was designed to address, our model substantially out performs others. This gives support to the need for this mechanism in making welfare predictions and for predicting how price distributions shift when trade costs change as we analyze below.

Figure 5: A Check on the Solution of the Model

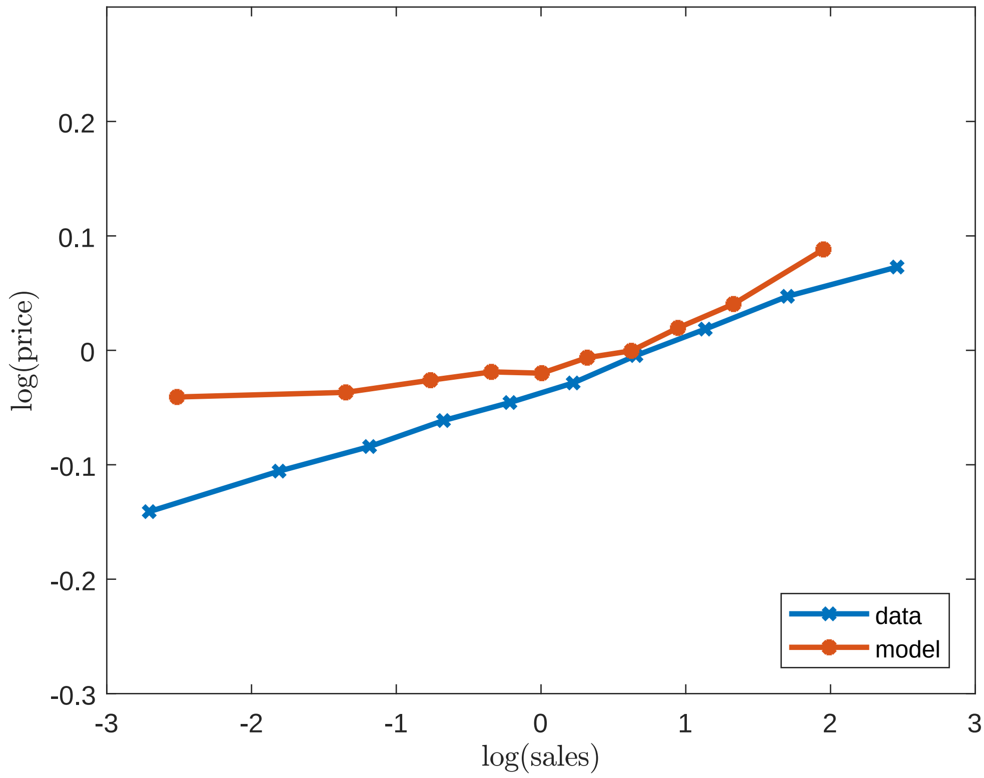


We begin with a check on the solution of our model. The four panels of Figure 5 demonstrate the fit of our model to data. The first panel shows that the logarithm of the wage by country relative to country averages implied by the model closely follows the logarithm of GDP per capita relative to country averages as reported in the CEPII data set, explaining over 80% of the variation in cross country incomes. In the second panel, we plot the implied productivity by country versus its GDP per capita. This too shows a very strong fit. In the third panel, we plot model generated specific trade costs against the real data of distance from China to each destination country and observe a very strong positive slope. In the last panel is the number of Chinese firms that serve a particular country predicted by the model against the actual number of entrants. Our model's predictions closely mirror the variation across countries in terms of the extensive margin.

We now turn our attention to the key object of interest in our paper, the relationship between the price charged by a firm and its sales. Figure 6 illustrates the price and sales relationship for both data and model. For the data, we first construct firm's normalized sales by subtracting each firm's log sales by its HS6×destination average. We do the same treatment for the firm's price. Then, for each HS6×destination pair, we sort firm's normalized sales by

10 deciles. In this step, we require that each HS6×destination have at least 10 firms so that the 10 deciles can be properly obtained. We then compute the median of both the normalized price and sales at each decile for each HS6×destination pairs. We finally aggregate the median value for all HS6×destination pairs, leaving only one value for each sales decile. For the model, we follow a similar procedure. Thus, each dot in the figure represents deviations of log sales from their relevant industry mean relative to the deviations of log price from their relevant industry mean.

Figure 6: Model Fit: Price-Sales Relationship



Quantitatively, the model traces the data reasonably well. In the data, when log firm sales increase from -3 to +3, the logarithm of the firm price increases by 0.25, whereas in the model, it increases by about 0.15. Hence, the model explains about 60% of the positive relationship between price and sales. The increase for the model mostly comes from large firms, i.e. firms that have higher sales than average. For the small firms, the model predicts a higher price level than that of the data. The reason appears to stem from the endogenous cut-off price induced by non-homothetic preferences that limit the scope for variation among small firms.

To assess how large the "Washington Apples" effect is in our model, we present calibration results for restricted versions of our model. These include a specification in which the "Washington Apples" mechanism is removed (labeled "no q").[21] Finally, we consider the standard

[21] This means that there are no specific trade costs and q is set to one for all firms. See Appendix E for the details.

Krugman-type model with neither quality nor price variation (labeled "no q, no var mkp").[22] For models without quality (no q and no q, no var markup case), we only target the price and sales dispersion. For models with quality (benchmark), we also target price sales correlation. The various parameter estimates for each calibration are shown in Table 7.[23]

Table 7: Parameter Values of the Three Alternative Models

parameters	benchmark	no q	no q, no var mkp
σ	4.87	3.4	7.097
σ_ε	0.6	NaN	NaN
$\eta\theta$	10.7	NaN	NaN
θ	6.097	6.097	6.11

We now turn to the fit of the three alternative models. In all models, the dispersion of price and sales are matched but clearly our benchmark model does a better job. More importantly, the positive relationship between price and sales is only be matched through our benchmark model (see Table 8).

Table 8: Fit of the Three Alternative Models

	data	benchmark	no q	no q, no var mkp
std. dev. of log-sale	1.39	1.39	1.39	0.98
std. dev. of log-price	0.602	0.602	0.102	0.164
corr. of log-sale and log-price	0.054	0.054	-0.783	-1
trade elasticity w.r.t. tariff	6.097	6.097	6.097	6.097

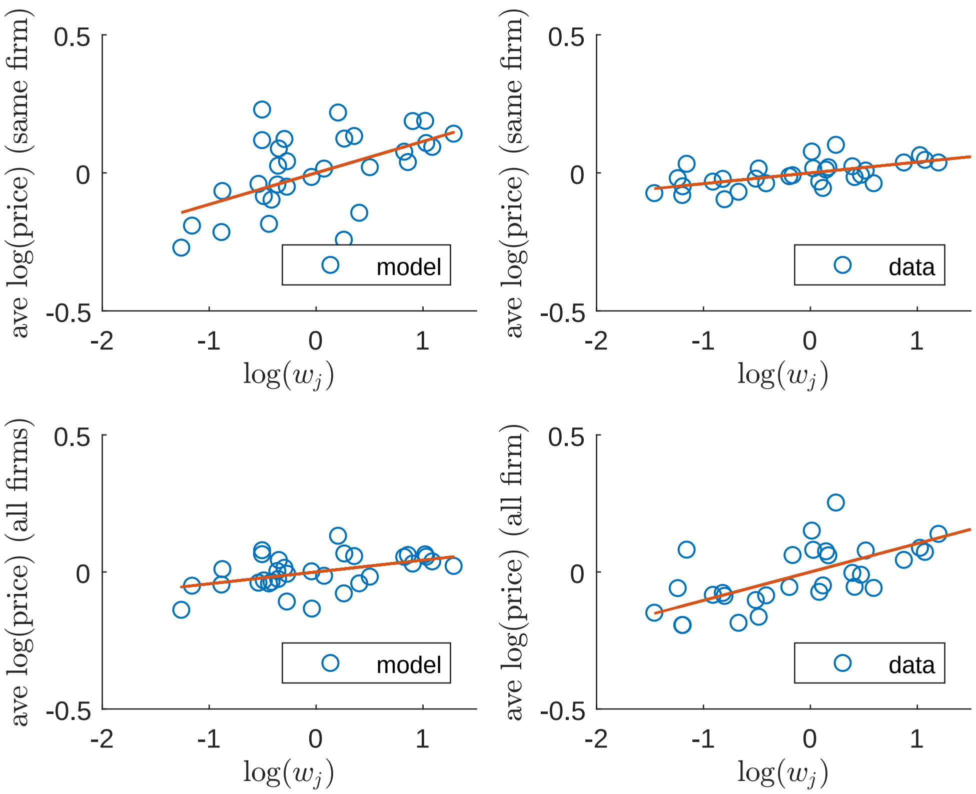
As noted earlier, not all alternative models fit data well. Without the "Washington Apples" effect interacting with the variable markup induced by non-homothetic preferences, it is not possible to generate a positive relationship between sales and observed prices at the firm level. This is important because the models have very different implications for the gains from openness as we will see in the next section.

We conclude this section by considering the model fit along dimensions not directly fit in our calibration procedure. We first consider the within and across firm variation in prices as a function of the GDP per capita of the destination country. Figure 7 shows this relationship for the model in the left-hand panels and in the data in the right hand panels. The top two panels are the variation across country within firms (intensive margin) and the bottom two panels are the relationships averaged across all firms (intensive and extensive margin). The

[22]This means that there are no specific trade costs, q is set to one and $\bar{x}$ is set to zero.

[23]The calibration of the "no q" model consists $\{\sigma, \theta\}$. In this model, the trade elasticity w.r.t. tariff is θ, which is the same as in the benchmark. We target σ to match the standard deviation of log(firm sales). In the calibration of the "no q, no var mkp" model, the trade elasticity is simply $\sigma - 1$. We then use the restriction $\sigma - 1 = 6.097$ to get $\sigma = 7.097$. Next we use θ to target standard deviation of log(firm sales). In the calibration procedure, we impose restriction condition that $\sigma - 1 < \theta$.

Figure 7: Model Fit: Price-Wage Relationship

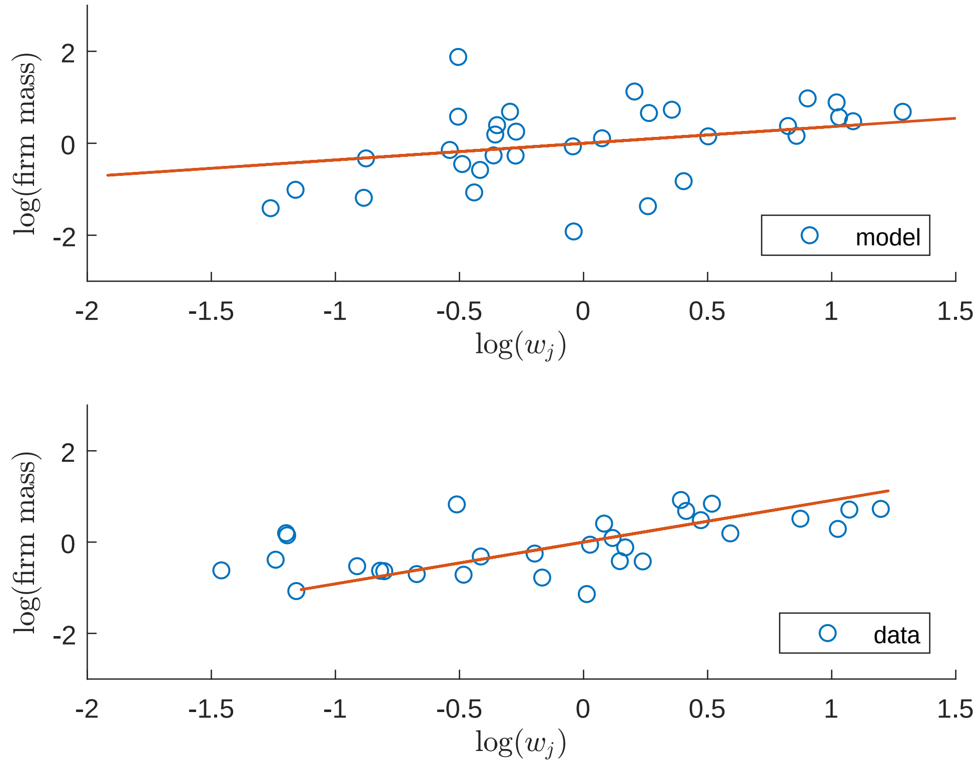


Notes: In the top two panels, we normalize each exporter's price by it's price at USA $(\log(p_{CHN,j}(\varphi,\varepsilon)/p_{CHN,US}(\varphi,\varepsilon)))$. we then calculate the average destination price as the mean of this normalized price across firms on each destination. For the bottom two panels, we calculate the average destination price as the simple average of log price for all exporters on that destination. For the model, w_j is model predicted wage rate; for the data, w_j is the 2004 destination GDP per capita in CEPII. For consistency with our empirical exercise, we control for log destination population, and log distance for both the data and the model. Since the model does not have an exact counterpart for distance, we thus use T_{ij} as a proxy.

model predicts slightly stronger correlation between price and GDP per capita than appears in the data but slightly less variation than in the average across all firms. Both deviations can be understood with respect to the price-revenue relationship shown in Figure 6. Looking at only the intensive margin disproportionately picks up firms in the higher end of the productivity distribution that have high prices and high revenue, while the average price that includes the extensive margin picks up the small firms whose behavior the model has trouble fitting.

We now look more closely at the extensive margin in Figure 8. The top panel is the model prediction of the measure of entrants as a function of country per capita income while the bottom is the actual data. The model correctly predicts a positive relationship between the two, but there is slightly less variation in the model predictions than there is in the data.

Figure 8: Model Fit: Entrants-Wage Relationship



5 Welfare Analysis

In this section, we compare the gains from trade implied by our benchmark model (accommodating both the "Washington Apples" mechanism and the variable markups) with the "no q" model (containing only variable markup but no endogenous quality) and the "no q, no var mkp" model (lacking both variable markup and variable quality). As shown in proposition one, the gains from trade in our benchmark model are given by

$$GT_j^{bmark} = 1 - (\lambda_{jj})^{\frac{\sigma}{\sigma-1}\frac{1}{1+\eta\theta}},$$

where the parameters are given in Table 7 above. As shown in Appendix E, the gains from trade under variable markups but no Washington Apples mechanism are given by

$$GT_j^{Vmkup} = 1 - (\lambda_{jj})^{\frac{\sigma}{\sigma-1}\frac{1}{1+\theta}},$$

where the parameters are given in Table 7. Finally, for model with neither mechanism imply gains from trade of

$$GT_j = 1 - (\lambda_{jj})^{\frac{1}{\sigma-1}}.$$

Note that the latter model uses homothetic, CES preferences and so implies no extensive margin. Hence, it falls into the class of models considered in Arkolakis, Costinot and Rodríguez-

Clare (2012).

Table 9: Welfare Comparison

Countries	(1) benchmark	(2) large scope	(3) small scope	(4) no q	(5) no q, no var mkp
BEL	10.5	15.4	2.06	18.5	15.5
CAN	5.79	8.63	1.12	10.5	8.69
CHN	1.6	2.41	0.303	2.94	2.42
DEU	3.85	5.76	0.735	7	5.8
FRA	3.4	5.1	0.648	6.2	5.13
GBR	4.6	6.88	0.882	8.34	6.92
IND	1.01	1.53	0.191	1.87	1.54
JPN	1.26	1.9	0.239	2.32	1.92
SGP	13.1	19.1	2.6	22.9	19.2
USA	2.08	3.13	0.395	3.82	3.15
⋮	⋮	⋮	⋮	⋮	⋮
MEDIAN	4.3	6.44	0.824	7.82	6.48

Table 9 shows the various estimates of the gains from trade by each of the models for a subset of the countries in our dataset (see Appendix G for all countries). Column 1 shows the gains from trade estimated from our benchmark model. Columns (2) and (3) correspond to alternative values of η to demonstrate the sensitivity of the results to the scope that exists for quality-upgrading. Column (4) corresponds to the model with only variable markups ("no q") while the last column corresponds to a Krugman-type model with heterogeneous firms but no extensive margin ("no q, no var mkp"). We label this the ACR-type model as it falls within the set of models analyzed by Arkolakis, Costinot and Rodríguez-Clare (2012).

We begin our discussion of the results by first comparing columns (4) and (5). The model with variable markups only tends to produce gains from trade that exceed those of the standard ACR-type model with median gains of 7.82% versus 6.48%. This is because, in the model without "Washington Apples" effects (column 4), the trade elasticity corresponds to the parameter θ. But, in the standard ACR-type model (column 5), the trade elasticity corresponds to $\sigma - 1$. Given the value of trade elasticity in both models, the welfare gains in the model without "Washington Apples" effects but with variable markup should be larger since $\frac{\sigma}{\sigma-1}\frac{1}{1+\theta} > \frac{1}{\theta}$ when $\sigma - 1 < \theta$ given the parameter restriction in the model.[24] Hence, the welfare gains in column (4) is larger than in column (5).

Turning now to our benchmark results, we see that the gains from trade tend to be substantially lower than the model without "Washington Apple" effects and than for the standard ACR-type model. Specifically, compared with the variable mark-up model, the benchmark

[24]Here, the right hand side of the inequality, $\frac{1}{\theta}$, corresponds to $\frac{1}{\sigma-1}$ in the ACR-type model, where $\sigma - 1$ is estimated based on the elasticity of trade flows with respect to tariff. Also see footnote 23 for details of calibration of parameter values for alternative models.

model estimates median gains from trade of 4.3% that are slightly more than half of the 7.8% generated by the model without specific trade costs.

To illustrate the role of the parameter η, which measures the scope for avoiding specific trade costs through quality up-grading, we re-estimate the gains from trade when $\eta = 1.1$ (large scope) and when $\eta = 10$ (small scope). When the scope for quality upgrading is large (column 2), it is very easy to avoid the impact of specific trade costs and this results in gains from trade that are very close to those associated with the markup only model. As the scope for quality upgrading becomes smaller (column 3), the gains from trade become much smaller.

In summary, the gains from trade depend not only on the level of trade costs, but also on the nature of these trade costs. If trade costs are largely specific as argued by Hummels and Skiba (2004), then standard models may substantial overestimate the gains from trade. We now turn to the effect of different types of trade cost on the structure of international export prices.

6 Comparative Static

Consider a 5% increase in trade costs between country i and j as measured by $T_{ij}^{\eta-1}\tau_{ij}$. As can be seen in proposition 2 and in the gravity equation, whether this increase was due to an increase in $T_{ij}^{\eta-1}$ or τ_{ij} or some mixture of the two has no bearing on welfare or trade volume effects of the liberalization. As shown in this section, there are very big differences in the effect of these trade liberalizations on prices. Intuitively, an increase in $T_{ij}^{\eta-1}$ raises the cost of serving the market and induces quality upgrading which leads to higher prices, whereas an increase in τ_{ij} induces firms to reduce their quality. Combined with the extensive margin effect through a change in firm productivity cutoff after increases in trade costs, the overall effects on average export prices are different for two types of trade costs. In this section we demonstrate how these shocks lead to changes in prices quantitatively and then contrast the price effects of a 5% increase in trade costs that are due to specific trade costs with the effects of a 5% increase in ad valorem trade costs.

Applying "hat" algebra to the choke price $\tilde{p}_j^*$ and equations (12) and (13), it is straightforward to show that[25]

$$\widehat{\tilde{p}}_j^* = \frac{\widehat{w}_j}{\sum_i \lambda_{ij}\left(\widehat{\varphi}_{ij}^*\right)^{-\theta}}, \text{ and} \tag{36}$$

$$\widehat{\varphi}_{ij}^* = \widehat{T}_{ij}^{\eta-1}\widehat{\tau}_{ij}(\widehat{w}_i)^{\eta}\left(\widehat{\tilde{p}}_j^*\right)^{-\eta}, \tag{37}$$

where $\widehat{w}_j$ can be solved from the system of equations (26). We can obtain other macro variables in a similar way by applying the hat algebra.

Next, we re-simulate the model to generate pseudo exporters using our solved macro vari-

[25]The exact steps are omitted here to save space.

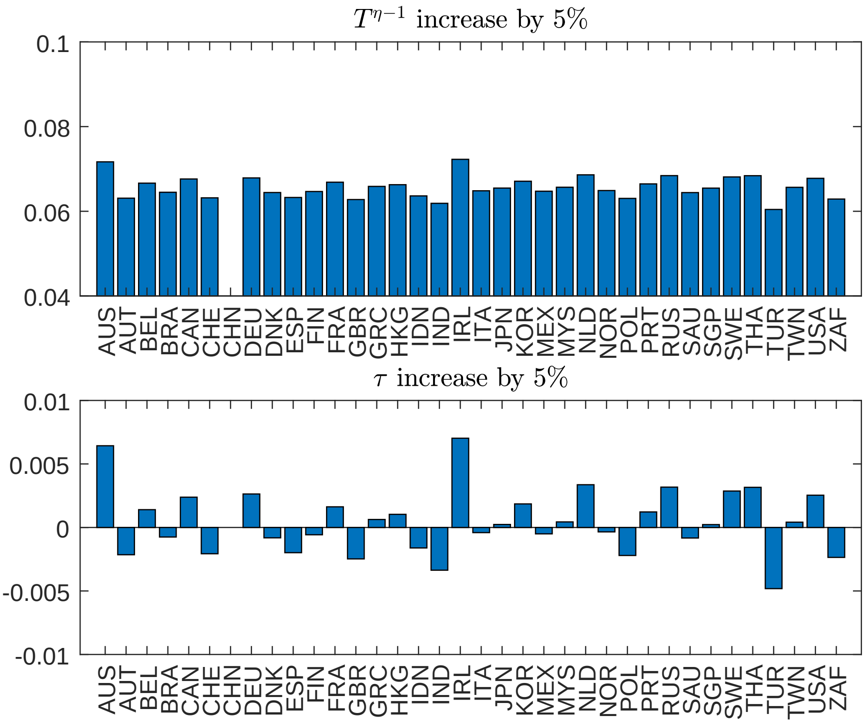
ables after the trade shock. We use the same firm productivity draw (φ) and cost shock draw (ε) in the benchmark simulation. This guarantees that our comparative statics are performed on the same set of firms and cost draws, and all the changes are solely driven by the change in T_{ij} or the change in τ_{ij}. Specifically, for a firm with productivity φ and cost draw ε, we construct after-shock firm price using

$$\left(p_{CHN,j}\left(\varphi,\varepsilon\right)\right)' = \left(\frac{\tilde{p}_{CHN,j}\left(\varphi,\varepsilon\right)}{\tilde{p}_j^*}\right)' \left(\tilde{p}_j^*\right)' \left(q_{CHN,j}\left(\varphi,\varepsilon\right)\right)',$$

where $\left(\tilde{p}_{CHN,j}\left(\varphi,\varepsilon\right)/\tilde{p}_j^*\right)'$ depends on $\left(\varphi/\left(\varphi^*_{CHN,j}\left(\varepsilon\right)\right)'\right)^{\frac{1}{\eta}}$ via the firm pricing equation (31) and where $\left(\varphi^*_{CHN,j}\left(\varepsilon\right)\right)' = \left(\varphi^*_{CHN,j}\right)'\varepsilon^{\eta-1}$ denotes the after-shock productivity cut-off.[26] Similarly, $\left(\tilde{p}_j^*\right)' = \widehat{\tilde{p}}_j^*\tilde{p}_j^*$ is the after-shock quality adjusted choke price and $\left(q_{CHN,j}\left(\varphi,\varepsilon\right)\right)' = \left(\varepsilon T'_{CHN,j}\varphi/\left(\eta-1\right)\tau'_{CHN,j}\right)^{\frac{1}{\eta}}$ is the after-shock optimal quality choice. Finally, we compute the mean of log-price across firms for each destination.

Figure 9 shows the results of our comparative static. The top panel shows the impact of $\widehat{T}_{ij}^{\eta-1} = 1.05$ for $i \neq j$ on average export prices set by our model simulated Chinese firms across a range of countries in our data set while the bottom panel shows the results across the same set of countries for $\widehat{\tau}_{ij} = 1.05$ for $i \neq j$.

Figure 9: Different role of T and τ on prices



Notes: y-axis is average destination (log) price increase after the shock.

The differences in the results are both striking and intuitive. On average a 5% increase in

[26] Due to an increase in $\varphi^*_{CHN,j}$, some unproductive firms that use to export to destination j before the shock will not be able to export after the shock.

specific trade costs induces an approximately 6.5% increase in export prices as the shock both raises the cost of serving the market and induces firms to upgrade their quality. The increase in firm productivity cutoff magnifies this latter effect so that there appears to be more than 100% pass through. For the case of a shock to ad valorem trade costs, the effect on average is very close to zero because there are competing effects of roughly equal magnitude. On the one hand, higher ad valorem trade costs induce firms to downgrade their quality and so reduce their prices. On the other hand, higher ad valorem trade costs raise the firm productivity cutoff which induces weaker firms to exit and thus increase average prices. These two effect offset each other so the overall effects of ad valorem trade costs on export prices are small.

The key point to take away from this comparative static is that when trade costs are mixture of ad valorem and specific as must be so in the real world, the relationship between import prices, export volumes, and the gains from trade becomes complicated. The nature of the shock determines this relationship.

7 Conclusion

In this paper, we analyzed a model that contains three mechanisms that contribute to price dispersion across firms and countries. These include firm heterogeneity in productivity, non-homothetic preferences that give rise to variable markups, and a "Washington Apples" mechanism that features specific trade costs and quality choice by producers. These three mechanisms allow our model to fit well the rich pattern of cross-country and cross-firm price variation observed in the data. We showed analytically that the presence of specific trade costs had important welfare implications as these costs disproportionately penalize the most productive exporters. In addition, our quality upgrading mechanism allows us to turn the very difficult computational problem associated with the interaction between specific trade costs and firm heterogeneity into a relatively simple and tractable one whose strength relies on a single parameter.

Turning to the data, we showed how the aggregate trade elasticity, combined with price and sales moments from the universe of Chinese exporters could be used to pin down the model's key parameters. A key moment used to fit the "Washington Apples" parameter is the positive correlation between firm-destination-product prices and firm-destination-product sales. Relying on the calibrated parameters, the model fit this data reasonably well, while other standard model cannot generate the appropriate sign.

Comparing the gains from trade implied by our model to recalibrated variants of the model that lacked the "Washington Apples" mechanism, we found the gains from trade to be substantially lower in our framework. Intuitively, while quality upgrading allows the most productive firms to evade part of the burden of specific trade costs, the size of the estimated "Washington Apples" parameter indicates that the scope for quality upgrading is sufficiently low that the most productive firms remain heavily burdened by trade costs.

Finally, we showed that the relationship between export prices and the gains from trade depends substantially on the nature of trade costs. Specifically, among trade cost shocks with equivalent welfare implications, shocks to specific trade costs generated outsized shifts in export prices while shocks to ad valorem trade costs had little impact on these prices. This means that in the absence of accounting for quality upgrading and for its interaction with pricing-to-market, it is hard to infer the relationship between export prices and the welfare effects of trade shocks.

Going forward, we hope that research in the field of international trade will become more cognizant of the importance of modeling trade costs more flexibly. We hope that our framework will encourage more research by demonstrating the potential quantitative importance of specific trade costs and by showing that it is possible to write down relatively simple models that allow for both firm heterogeneity and non-iceberg-type variable trade costs.

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The Online Appendix for "Quality, Variable Markups, and Welfare: A Quantitative General Equilibrium Analysis of Export Prices"

A Derivation of Demand Function

The utility of a consumer in country j takes the following form:

$$U_j = \left[\sum_i \int_{\omega \in \Omega_{ij}} \left(q_{ij}(\omega) x_{ij}^c(\omega) + \overline{x} \right)^{\frac{\sigma-1}{\sigma}} d\omega \right]^{\frac{\sigma}{\sigma-1}} \tag{A.1}$$

subject to the following budget constraint:

$$\sum_i \int_{\omega \in \Omega_{ij}} p_{ij}(\omega) x_{ij}^c(\omega) d\omega \leq y_j \tag{A.2}$$

So that the Lagrange function can be written as: $\mathcal{L} = \left[\sum_i \int_{\omega \in \Omega_{ij}} \left(q_{ij}(\omega) x_{ij}^c(\omega) + \overline{x} \right)^{\frac{\sigma-1}{\sigma}} d\omega \right]^{\frac{\sigma}{\sigma-1}} + \lambda \left(y_j - \sum_i \int_{\omega \in \Omega_{ij}} p_{ij}(\omega) x_{ij}^c(\omega) d\omega \right)$,where λ is the Lagrange multiplier, y_j denotes the consumer's income. Taking the first order condition with respect to $x_{ij}^c(\omega)$ yields:

$$\lambda p_{ij}(\omega) = U_j^{\frac{1}{\sigma}} \left(q_{ij}(\omega) x_{ij}^c(\omega) + \overline{x} \right)^{-\frac{1}{\sigma}} q_{ij}(\omega), \tag{A.3}$$

Following Jung, Simonovska and Weinberger (2015), we define $P_{j\sigma} = \left\{ \sum_i \int_{\omega \in \Omega_{ij}} \tilde{p}_{ij}(\omega)^{1-\sigma} d\omega \right\}^{\frac{1}{1-\sigma}}$, and $P_j = \sum_i \int_{\omega \in \Omega_{ij}} \tilde{p}_{ij}(\omega) d\omega$, where $\tilde{p}_{ij}(\omega) = p_{ij}(\omega) / q_{ij}(\omega)$ is the quality adjusted price. The first order condition (A.3) can be rewritten as:

$$q_{ij}(\omega) x_{ij}^c(\omega) + \overline{x} = U_j \left(\lambda \tilde{p}_{ij}(\omega) \right)^{-\sigma} \tag{A.4}$$

Plugging equation (A.4) into equation (A.1), we have:

$$\lambda = \frac{1}{P_{j\sigma}}$$

Then substituting the above equation into equation (A.4) yield the solution for $x_{ij}^c(\omega)$:

$$q_{ij}(\omega) x_{ij}^c(\omega) = \left[\frac{\tilde{p}_{ij}(\omega)}{P_{j\sigma}} \right]^{-\sigma} U_j - \bar{x}, \tag{A.5}$$

Plugging the previous equation (A.5) into the budget constraint, we have:

$$
\begin{aligned}
y_j &= \sum_i \int_{\omega \in \Omega_{ij}} \tilde{p}_{ij}(\omega) q_{ij}(\omega) x_{ij}^c(\omega) d\omega \\
&= \sum_i \int_{\omega \in \Omega_{ij}} \left[\frac{\tilde{p}_{ij}(\omega)}{P_{j\sigma}}\right]^{-\sigma} U_j \tilde{p}_{ij}(\omega) d\omega - \bar{x} \sum_i \int_{\omega \in \Omega_{ij}} \tilde{p}_{ij}(\omega) d\omega \\
&= U_j P_{j\sigma} - \bar{x} P_j,
\end{aligned}
$$

Hence, we have:

$$
U_j = \frac{y_j + \bar{x} P_j}{P_{j\sigma}} \tag{A.6}
$$

Combing the previous equation (A.6) with equation (A.5) implies:

$$
x_{ij}(\omega) = x_{ij}^c(\omega) L_j = \frac{L_j}{q_{ij}(\omega)} \left[\frac{y_j + \bar{x} P_j}{P_{j\sigma}^{1-\sigma}} \left(\frac{p_{ij}(\omega)}{q_{ij}(\omega)}\right)^{-\sigma} - \bar{x}\right] \tag{A.7}
$$

B Log Utility Function

The representative consumer in country j has preferences of

$$
U_j = \sum_i \int_{\omega \in \Omega_{ij}} \log\left(q_{ij}(\omega) x_{ij}^c(\omega) + \overline{x}\right) d\omega,
$$

The representative consumer in country j's demand satisfies:

$$
x_{ij}(\omega) = x_{ij}^c(\omega) L_j = \frac{\overline{x} L_j}{q_{ij}(\omega)} \left[\frac{\psi_j}{\tilde{p}_{ij}(\omega)} - 1\right] \tag{B.1}
$$

where $\tilde{p}_{ijs}(\omega) = \frac{p_{ij}(\omega)}{q_{ij}(\omega)}$ and $\psi_j = \frac{y_j + \bar{x} P_j}{\bar{x} N_j}$. The aggregate prices satisfies $P_j = \sum_i \int_{\omega \in \Omega_{ij}} \tilde{p}_{ij}(\omega) d\omega$. Now, sales and profit for a given variety exported from i to j are as follows,

$$
r_{ij}(\omega) = \bar{x} L_j \tilde{p}_{ij}(\omega) \left[\frac{\psi_j}{\tilde{p}_{ij}(\omega)} - 1\right] \tag{B.2}
$$

$$
\pi_{ij}(\omega) = \bar{x} L_j \left[\tilde{p}_{ij}(\omega) - \tilde{c}_{ij}(\omega)\right] \left[\frac{\psi_j}{\tilde{p}_{ij}(\omega)} - 1\right] \tag{B.3}
$$

where $\tilde{c}_{ij}(\omega) = \frac{c_{ij}(\omega)}{q_{ij}(\omega)}$ is the quality-adjusted marginal cost. Given the quality adjusted marginal cost, firms maximize their profits. This implies that the optimal price of the good satisfies:

$$
\tilde{p}_{ij}(\omega) = \sqrt{\psi_j \tilde{c}_{ij}(\omega)}
$$

We assume that the marginal cost of producing a variety of final good with quality q_{ij} by a firm with productivity φ is given by:

$$c_{ij}(\varphi,\varepsilon)=\varepsilon T_{ij}w_i+\frac{w_i\tau_{ij}}{\varphi}q_{ij}^{\eta}$$

where τ_{ij} is ad valorem trade cost and εT_{ij} is a specific transportation cost from country i to country j. Maximizing the profit is equivalent to minimizing the quality-adjusted cost $\tilde{c}_{ij}(\omega)$ by the envelop theorem. Choosing the quality to minimize the quality-adjusted marginal cost implies that the optimal level of quality for a firm with productivity φ is:

$$q_{ij}(\varphi,\varepsilon)=\left(\frac{\varepsilon T_{ij}\varphi}{(\eta-1)\,\tau_{ij}}\right)^{\frac{1}{\eta}} \tag{B.4}$$

and hence the quality adjusted marginal cost of production now is:

$$\tilde{c}_{ij}\left(\varphi,\varepsilon\right)=\left(\frac{\eta}{\eta-1}\varepsilon T_{ij}w_i\right)^{\frac{\eta-1}{\eta}}\left(\frac{\varphi}{\eta w_i\tau_{ij}}\right)^{-\frac{1}{\eta}} \tag{B.5}$$

At the productivity cutoff $\varphi_{ij}^*\left(\varepsilon\right)$, we have $\tilde{p}_{ij}^*\left(\varphi,\varepsilon\right)=\tilde{c}_{ij}^*\left(\varphi,\varepsilon\right)=\psi_j$, which implies that the productivity cutoff $\varphi_{ij}^*\left(\varepsilon\right)$ takes the following form:

$$\varphi_{ij}^*\left(\varepsilon\right)=\varphi_{ij}^*\varepsilon^{\eta-1}=\frac{\eta^{\eta}}{(\eta-1)^{\eta-1}}T_{ij}^{\eta-1}\tau_{ij}w_i^{\eta}\left(\psi_j\right)^{-\eta}\varepsilon^{\eta-1},$$

In the log utility function, price could be written as:

$$p_{ij}(\varphi,\varepsilon)=\left[\frac{\varphi}{\varphi_{ij}^*\left(\varepsilon\right)}\right]^{\frac{1}{2\eta}}\frac{\eta}{\eta-1}T_{ij}\varepsilon.$$

Different from the CES utility function, now the markup function could be expressed explicitly as $\left[\frac{\varphi}{\varphi_{ij}^*(\varepsilon)}\right]^{\frac{1}{2\eta}}$.

C Derivation for P_j, $P_{j\sigma}$, X_{ij} and π_i

To derive the aggregate variables, we define $t_{ij}=\tilde{p}_{ij}\left(\omega\right)/p_j^*$. Following the insight of Arkolakis et al. (2017*a*) and Jung, Simonovska and Weinberger (2015), this will make the integration not country specific. From equations (9) and (11), we have:

$$\frac{\tilde{c}_{ij}\left(\varphi,\varepsilon\right)}{\tilde{p}_j^*}=\frac{\tilde{c}_{ij}\left(\varphi,\varepsilon\right)}{\tilde{c}_{ij}^*\left(\varphi,\varepsilon\right)}=\left(\frac{\varphi}{\varphi_{ij}^*\left(\varepsilon\right)}\right)^{-\frac{1}{\eta}} \tag{C.1}$$

Combining the above equation with equation (6) we have:

$$\sigma\left(\frac{\varphi}{\varphi_{ij}^*\left(\varepsilon\right)}\right)^{-\frac{1}{\eta}}=t_{ij}^{\sigma+1}+\left(\sigma-1\right)t_{ij} \tag{C.2}$$

which implies that t_{ij} is a monotonically decreasing function of φ. Note that t_{ij} will lies between $(0,1]$ since $\varphi \in \left[\varphi_{ij}^{*}(\varepsilon), \infty\right)$. Totally differentiating both sides gives us:

$$d\varphi = -\eta\sigma^{\eta}\varphi_{ij}^{*}(\varepsilon)\frac{(\sigma+1)\,t_{ij}^{\sigma}+(\sigma-1)}{\left[t_{ij}^{\sigma+1}+(\sigma-1)\,t_{ij}\right]^{1+\eta}}dt_{ij} \tag{C.3}$$

First, we derive $P_{j\sigma}$. By definition, we have:

$$\begin{aligned} P_{j\sigma} &= \left\{\sum_i N_{ij}\int_0^{\infty}\int_{\varphi_{ij}^{*}(\varepsilon)}^{\infty}\tilde{p}_{ij}(\varphi,\varepsilon)^{1-\sigma}\mu_{ij}(\varphi,\varepsilon)\,f(\varepsilon)\,d\varphi d\varepsilon\right\}^{\frac{1}{1-\sigma}} \\ &= \tilde{p}_j^{*}\left\{\sum_i N_{ij}\int_0^{\infty}\left[\int_{\varphi_{ij}^{*}(\varepsilon)}^{\infty}t_{ij}^{1-\sigma}\mu_{ij}(\varphi,\varepsilon)\,d\varphi\right]f(\varepsilon)\,d\varepsilon\right\}^{\frac{1}{1-\sigma}} \end{aligned} \tag{C.4}$$

Plugging in the expression of conditional density $\mu_{ij}(\varphi,\varepsilon)$ into equation (C.4) and then we transform the integration variable from φ to t_{ij} by using the relationship between φ and t_{ij}, the inner integration with respect to productivity can be written as:

$$\int_{\varphi_{ij}^{*}(\varepsilon)}^{\infty}t_{ij}^{1-\sigma}\mu_{ij}(\varphi,\varepsilon)\,d\varphi = \frac{\eta\theta}{\sigma^{\eta\theta}}\int_0^1 t_{ij}^{1-\sigma}\left[t_{ij}^{\sigma+1}+(\sigma-1)\,t_{ij}\right]^{\eta\theta-1}\left[(\sigma+1)\,t_{ij}^{\sigma}+(\sigma-1)\right]dt_{ij}$$

which is a constant, and we denote it as β_{σ}. Thus,

$$P_{j\sigma} = \beta_{\sigma}^{\frac{1}{1-\sigma}}\tilde{p}_j^{*}N_j^{\frac{1}{1-\sigma}}$$

Second, we derive P_j. By definition, we have

$$\begin{aligned} P_j &= \sum_i N_{ij}\int_0^{\infty}\int_{\varphi_{ij}^{*}(\varepsilon)}^{\infty}\tilde{p}_{ij}(\varphi,\varepsilon)\,\mu_{ij}(\varphi,\varepsilon)\,f(\varepsilon)\,d\varphi d\varepsilon \\ &= \tilde{p}_j^{*}\sum_i N_{ij}\int_0^{\infty}\left[\int_{\varphi_{ij}^{*}(\varepsilon)}^{\infty}t_{ij}\mu_{ij}(\varphi,\varepsilon)\,d\varphi\right]f(\varepsilon)\,d\varepsilon \\ &= \beta\tilde{p}_j^{*}N_j \end{aligned}$$

In the last equality, we use the same variable transformation method as before where β is a constant, defined by:

$$\beta = \frac{\eta\theta}{\sigma^{\eta\theta}}\int_0^1 t_{ij}\left[t_{ij}^{\sigma+1}+(\sigma-1)\,t_{ij}\right]^{\eta\theta-1}\left[(\sigma+1)\,t_{ij}^{\sigma}+(\sigma-1)\right]dt_{ij}$$

To derive the equations (C.5) and (C.6), we plug in $\tilde{p}_j^{*} = \left(\frac{w_j+\bar{x}P_j}{\bar{x}P_{j\sigma}^{1-\sigma}}\right)^{\frac{1}{\sigma}}$ into $P_{j\sigma}$ and P_j, we have:

$$P_{j\sigma} = \beta_\sigma^{\frac{1}{1-\sigma}} \left(\frac{w_j + \bar{x}P_j}{\bar{x}P_{j\sigma}^{1-\sigma}} \right)^{\frac{1}{\sigma}} N_j^{\frac{1}{1-\sigma}}$$

$$P_j = \beta \left(\frac{w_j + \bar{x}P_j}{\bar{x}P_{j\sigma}^{1-\sigma}} \right)^{\frac{1}{\sigma}} N_j,$$

which provide us with 2 equations to solve for $P_{j\sigma}$ and P_j. Solving the system yields:

$$\bar{x}P_j = \frac{\beta}{\beta_\sigma - \beta} w_j \tag{C.5}$$

$$\bar{x}P_{j\sigma} = \frac{\beta_\sigma^{\frac{1}{1-\sigma}}}{\beta_\sigma - \beta} N_j^{\frac{\sigma}{1-\sigma}} w_j \tag{C.6}$$

Next, we derive bilateral trade flow X_{ij}, which is given by:

$$\begin{aligned} X_{ij} &= N_{ij} \int_0^\infty \left[\int_{\varphi_{ij}^*(\varepsilon)}^\infty r_{ij}(\varphi, \varepsilon)\, \mu_{ij}(\varphi, \varepsilon)\, d\varphi \right] f(\varepsilon)\, d\varepsilon \\ &= N_{ij} \left(\bar{x}\tilde{p}_j^* L_j \right) \int_0^\infty \left[\int_{\varphi_{ij}^*(\varepsilon)}^\infty t_{ij} \left(t_{ij}^{-\sigma} - 1 \right) \mu_{ij}(\varphi, \varepsilon)\, d\varphi \right] f(\varepsilon)\, d\varepsilon \\ &= (\beta_\sigma - \beta)\, \bar{x}\tilde{p}_j^* L_j N_{ij} = X_j \frac{N_{ij}}{N_j} \end{aligned}$$

where $X_j = \sum_i X_{ij}$ is total absorption.

Finally, we derive firm's expected average profit π_i, which satisfies:

$$\begin{aligned} \pi_i &= \frac{1}{J_i} \sum_j N_{ij} \int_0^\infty \int_{\varphi_{ij}^*(\varepsilon)}^\infty \pi_{ij}(\varphi, \varepsilon)\, \mu_{ij}(\varphi)\, f(\varepsilon)\, d\varphi d\varepsilon \\ &= \frac{1}{J_i} \beta_\pi \sum_j \bar{x}\tilde{p}_j^* L_j N_{ij} = \frac{1}{J_i} \frac{\beta_\pi}{\beta_\sigma - \beta} \sum_j X_{ij} \\ &= \frac{1}{J_i} \frac{\beta_\pi}{\beta_\sigma - \beta} \sum_j \frac{N_{ij}}{N_j} X_j \end{aligned}$$

where

$$\beta_\pi = \frac{\eta\theta}{\sigma^{\eta\theta}} \int_0^1 \frac{\left(t_{ij}^{\sigma+1} - t_{ij} \right) \left(t_{ij}^{-\sigma} - 1 \right)}{\sigma} \left[t_{ij}^{\sigma+1} + (\sigma - 1)\, t_{ij} \right]^{\eta\theta - 1} \left[(\sigma + 1)\, t_{ij}^\sigma + (\sigma - 1) \right] dt_{ij}$$

D Proof of Propositions

D.1 Proof of Proposition 1

The percentage change of U_j satisfies:

$$d\ln U_j = \frac{\sigma}{\sigma-1}\left(d\ln w_j - d\ln \tilde{p}_j^*\right) \tag{D.1}$$

Based on equations (11), (13) and (21), we can rewrite N_{ij} as:

$$N_{ij} = \frac{\kappa\beta_\pi}{f\beta_X} b_i L_i \left[\frac{\eta^\eta}{(\eta-1)^{\eta-1}} T_{ij}^{\eta-1}\tau_{ij} w_i^\eta \left(\tilde{p}_j^*\right)^{-\eta}\right]^{-\theta} \tag{D.2}$$

where $\beta_X = \beta_\sigma - \beta$ is a constant. This implies that

$$\lambda_{jj} = \frac{X_{jj}}{\sum_i X_{ij}} = \frac{N_{jj}}{\sum_i N_{ij}} = \frac{b_j L_j \left(T_{jj}^{\eta-1}\tau_{jj} w_j^\eta\right)^{-\theta}}{\sum_i b_i L_i \left(T_{ij}^{\eta-1}\tau_{ij} w_i^\eta\right)^{-\theta}} \tag{D.3}$$

Consider the foreign shocks: $(b_i, L_i, T_{ij}, \tau_{ij})$ is changed to $(b_i', L_i', T_{ij}', \tau_{ij}')$ for $i \neq j$ such that $b_j = b_j', L_j = L_j', T_{jj} = T_{jj}', \tau_{jj} = \tau_{jj}'$. Totally differentiating the previous equation implies:

$$d\ln \lambda_{jj} = \sum_i \lambda_{ij}\left[\theta\eta\left(d\ln w_i - d\ln w_j\right) - d\ln \xi_{ij}\right] \tag{D.4}$$

where $d\ln \xi_{ij}$ reflects any foreign shock, which satisfies:

$$d\ln \xi_{ij} = -\theta\left(\eta-1\right) d\ln T_{ij} - \theta d\ln \tau_{ij} + d\ln b_i + d\ln L_i$$

The expression of $\tilde{p}_j^*$, together with equation (C.5) and (C.6), imply that:

$$d\ln \tilde{p}_j^* = \frac{1}{\sigma} d\ln w_j + \frac{\sigma-1}{\sigma} d\ln P_{j\sigma} = d\ln w_j - \sum_i \lambda_{ij} d\ln N_{ij} \tag{D.5}$$

Totally differentiating the expression of N_{ij} and substituting the percentage change of N_{ij} into the previous equation, we have:

$$\begin{aligned} d\ln \tilde{p}_j^* &= d\ln w_j - \sum_i \lambda_{ij} d\ln N_{ij} \\ &= d\ln w_j + \sum_i \lambda_{ij}\left[\theta\eta\left(d\ln w_i - d\ln \tilde{p}_j^*\right) - d\ln \xi_{ij}\right] \\ &= \frac{1}{1+\eta\theta} d\ln w_j + \frac{1}{1+\eta\theta}\sum_i \lambda_{ij}\left[\theta\eta d\ln w_i - d\ln \xi_{ij}\right] \end{aligned} \tag{D.6}$$

Hence, the percentage change in welfare satisfies:

$$\begin{aligned} d\ln U_j &= \frac{\sigma}{\sigma-1}\left(d\ln w_j - d\ln \tilde{p}_j^*\right) \\ &= -\frac{\sigma}{\sigma-1}\frac{1}{1+\eta\theta}\sum_i \lambda_{ij}\left[\theta\eta\left(d\ln w_i - d\ln w_j\right) - d\ln \xi_{ij}\right] \\ &= -\frac{\sigma}{\sigma-1}\frac{1}{1+\eta\theta}d\ln\lambda_{jj} \end{aligned} \tag{D.7}$$

Integrating the previous expression between the initial equilibrium (before the shock) and the new equilibrium (after the shock), we finally get

$$\widehat{U}_j = \left(\widehat{\lambda}_{jj}\right)^{-\frac{\sigma}{\sigma-1}\frac{1}{1+\eta\theta}} \tag{D.8}$$

It shows that the changes in welfare at country j can be inferred from changes in the share of domestic expenditure, λ_{jj}, using the parameter, $-\frac{\sigma}{\sigma-1}\frac{1}{1+\eta\theta}$.

D.2 Proof of Proposition 2

We consider an arbitrary change in trade costs from τ_{ij} to τ'_{ij} and T_{ij} to T'_{ij}. The share of expenditure on domestic goods in the initial and new equilibrium, respectively, are given by:

$$\lambda_{jj} = \frac{X_{jj}}{\sum_i X_{ij}} = \frac{b_j L_j \left(T_{jj}^{\eta-1}\tau_{jj}w_j^{\eta}\right)^{-\theta}}{\sum_i b_i L_i \left(T_{ij}^{\eta-1}\tau_{ij}w_i^{\eta}\right)^{-\theta}} \tag{D.9}$$

$$\lambda'_{jj} = \frac{b_j L_j \left(T_{jj}^{\eta-1}\tau_{jj}\left(w'_j\right)^{\eta}\right)^{-\theta}}{\sum_i b_i L_i \left(\left(T'_{ij}\right)^{\eta-1}\tau'_{ij}\left(w'_i\right)^{\eta}\right)^{-\theta}} \tag{D.10}$$

Combing the previous two equations, we obtain:

$$\widehat{\lambda}_{jj} = \frac{\left(\widehat{w}_j\right)^{-\eta\theta}}{\sum_i \lambda_{ij}\left[\left(\widehat{T}_{ij}\right)^{\eta-1}\widehat{\tau}_{ij}\right]^{-\theta}\left(\widehat{w}_i\right)^{-\eta\theta}} \tag{D.11}$$

Labor market clearing condition implies that:

$$w_i L_i = \sum_j \lambda_{ij} w_j L_j = \sum_j \frac{b_i L_i \left[T_{ij}^{\eta-1}\tau_{ij}\right]^{-\theta} w_i^{-\eta\theta}}{\sum_{i'} b_{i'} L_{i'} \left[T_{i'j}^{\eta-1}\tau_{i'j}\right]^{-\theta} w_{i'}^{-\eta\theta}} w_j L_j \tag{D.12}$$

After τ_{ij} becomes τ'_{ij} and T_{ij} becomes T'_{ij}, the previous equation becomes:

$$w_i' L_i = \sum_j \frac{b_i L_i \left[\left(T_{ij}'\right)^{\eta-1} \tau_{ij}'\right]^{-\theta} \left(w_i'\right)^{-\eta\theta}}{\sum_{i'} b_{i'} L_{i'} \left[\left(T_{i'j}'\right)^{\eta-1} \tau_{i'j}'\right]^{-\theta} \left(w_{i'}'\right)^{-\eta\theta}} w_j' L_j$$

We can rearrange the previous expression as:

$$\widehat{w}_i w_i L_i = \sum_j \frac{\lambda_{ij} \left[\widehat{T}_{ij}^{\eta-1} \widehat{\tau}_{ij}\right]^{-\theta} \left(\widehat{w}_i\right)^{-\eta\theta}}{\sum_{i'} \lambda_{i'j} \left[\widehat{T}_{i'j}^{\eta-1} \widehat{\tau}_{i'j}\right]^{-\theta} \left(\widehat{w}_{i'}\right)^{-\eta\theta}} \widehat{w}_j w_j L_j$$

which implies the equation (26).

E Fixed quality case without T_{ij}

We prove the welfare implication of our model without q_{ij} and T_{ij}. From the demand system, we have the representative consumer in country j's demand given by:

$$x_{ij}(\omega) = L_j \left[\frac{y_j + \bar{x} P_j}{P_{j\sigma}^{1-\sigma}} p_{ij}(\omega)^{-\sigma} - \bar{x}\right] \tag{E.1}$$

where $P_j = \sum_i \int_{\omega \in \Omega_{ij}} p_{ij}(\omega) d\omega$ and $P_{j\sigma} = \left\{\sum_i \int_{\omega \in \Omega_{ij}} p_{ij}(\omega)^{1-\sigma} d\omega\right\}^{\frac{1}{1-\sigma}}$. Now, quantity, sales, and profit for a given variety exported from i to j are as follows,

$$x_{ij}(\omega) = \bar{x} L_j \left[\left(\frac{p_{ij}(\omega)}{p_j^*}\right)^{-\sigma} - 1\right] \tag{E.2}$$

$$r_{ij}(\omega) = \bar{x} L_j p_{ij}(\omega) \left[\left(\frac{p_{ij}(\omega)}{p_j^*}\right)^{-\sigma} - 1\right] \tag{E.3}$$

$$\pi_{ij}(\omega) = \bar{x} L_j \left[p_{ij}(\omega) - c_{ij}(\omega)\right] \left[\left(\frac{p_{ij}(\omega)}{p_j^*}\right)^{-\sigma} - 1\right] \tag{E.4}$$

where $p_j^* = \left(\frac{y_j + \bar{x} P_j}{\bar{x} P_{j\sigma}^{1-\sigma}}\right)^{\frac{1}{\sigma}}$ is the choke price. Given the quality adjusted marginal cost, firms maximize their profits. This implies that the optimal price of the good satisfies:

$$\sigma \frac{c_{ij}(\omega)}{p_j^*} = \left(\frac{p_{ij}(\omega)}{p_j^*}\right)^{\sigma+1} + (\sigma - 1) \frac{p_{ij}(\omega)}{p_j^*} \tag{E.5}$$

For the production, we assume that the marginal cost of production is

$$c_{ij} = \frac{w_i \tau_{ij}}{\varphi}$$

where φ follows the Pareto distribution with c.d.f. $G_i(\varphi) = 1 - b_i \varphi^{-\theta}$. At the productivity cutoff φ_{ij}^* to sell goods from country i to country j, we have $p_{ij}^*(\varphi) = c_{ij}^*(\varphi) = p_j^*$, which implies:

$$\varphi_{ij}^* = \frac{w_i \tau_{ij}}{p_j^*} \tag{E.6}$$

Based on the similar derivation in Section 3, we know that the exporting firm mass N_{ij}, the aggregate price P_j and $P_{j\sigma}$, the trade flow X_{ij}, the expected average profit π_i and the potential firm mass J_i satisfy:

$$N_{ij} = \kappa' J_i b_i \left(\varphi_{ij}^*\right)^{-\theta} \tag{E.7}$$

$$\bar{x} P_j = \beta' p_j^* N_j \tag{E.8}$$

$$\bar{x} P_{j\sigma} = \beta'_\sigma p_j^* N_j^{\frac{1}{1-\sigma}} \tag{E.9}$$

$$X_{ij} = \beta'_X \bar{x} p_j^* N_{ij} L_j \tag{E.10}$$

$$\pi_i = \beta'_\pi \sum_j \bar{x} \kappa' b_i \left(\varphi_{ij}^*\right)^{-\theta} p_j^* L_j \tag{E.11}$$

$$J_i = \frac{\beta'_\pi}{\beta'_X} \frac{L_i}{f} \tag{E.12}$$

where κ', β', β'_σ, β'_X and β'_π are constant. The expression of choke price p_j^*, together with the equation (E.8) and (E.9), implies

$$\bar{x} P_j = \frac{\beta'}{\beta'_\sigma - \beta'} w_j \tag{E.13}$$

$$\bar{x} P_{j\sigma} = \frac{\left(\beta'_\sigma\right)^{\frac{1}{1-\sigma}}}{\beta'_\sigma - \beta'} N_j^{\frac{\sigma}{1-\sigma}} w_j \tag{E.14}$$

$$p_j^* = \frac{1}{\bar{x}\left(\beta'_\sigma - \beta'\right)} \frac{w_j}{N_j} \tag{E.15}$$

Now, the welfare still satisfy:

$$U_j = \beta_u \left(\frac{w_j}{p_j^*}\right)^{\frac{\sigma}{\sigma-1}}$$

where $\beta_u = \bar{x}^{\frac{1}{1-\sigma}} \left(\frac{\beta'_\sigma}{\beta'_\sigma - \beta'}\right)^{\frac{\sigma}{\sigma-1}}$ is a constant. The percentage change of U_j satisfies:

$$d \ln U_j = \frac{\sigma}{\sigma - 1} \left(d \ln w_j - d \ln p_j^*\right) \tag{E.16}$$

Now, λ_{jj} satisfies:

$$\lambda_{jj} = \frac{N_{jj}}{\sum_i N_{ij}} = \frac{b_j L_j \left(\tau_{jj} w_j\right)^{-\theta}}{\sum_i b_i L_i \left(\tau_{ij} w_i\right)^{-\theta}} \tag{E.17}$$

Consider the foreign shocks: (b_i, L_i, τ_{ij}) is changed to (b'_i, L'_i, τ'_{ij}) for $i \neq j$ such that $b_j = b'_j, L_j = L'_j, T_{jj} = T'_{jj}, \tau_{jj} = \tau'_{jj}$. Totally differentiating the previous equation implies:

$$d \ln \lambda_{jj} = \sum_i \lambda_{ij} \left[\theta \left(d \ln w_i - d \ln w_j\right) - d \ln \xi_{ij}\right] \tag{E.18}$$

where $d\ln\xi_{ij}$ reflects any foreign shock, which satisfies:

$$d\ln\xi_{ij} = -\theta d\ln\tau_{ij} + d\ln b_i + d\ln L_i$$

The expression of p_j^* imply that:

$$d\ln p_j^* = d\ln w_j - \sum_i \lambda_{ij} d\ln N_{ij} \tag{E.19}$$

Totally differentiating the expression of N_{ij} and substituting the percentage change of N_{ij} into the previous equation, we have:

$$\begin{aligned} d\ln p_j^* &= d\ln w_j + \sum_i \lambda_{ij}\left[\theta\left(d\ln w_i - d\ln p_j^*\right) - d\ln\xi_{ij}\right] \\ &= \frac{1}{1+\theta} d\ln w_j + \frac{1}{1+\theta}\sum_i \lambda_{ij}\left[\theta d\ln w_i - d\ln\xi_{ij}\right] \end{aligned} \tag{E.20}$$

Hence, the percentage change in welfare satisfies:

$$\begin{aligned} d\ln U_j &= \frac{\sigma}{\sigma-1}\left(d\ln w_j - d\ln p_j^*\right) \\ &= -\frac{\sigma}{\sigma-1}\frac{1}{1+\theta} d\ln\lambda_{jj} \end{aligned}$$

Integrating the previous expression between the initial equilibrium (before the shock) and the new equilibrium (after the shock), we finally get

$$\widehat{U}_j = \left(\widehat{\lambda}_{jj}\right)^{-\frac{\sigma}{\sigma-1}\frac{1}{1+\theta}} \tag{E.21}$$

It shows that the changes in welfare at country j can be inferred from changes in the share of domestic expenditure, λ_{jj}, using the parameter, $-\frac{\sigma}{\sigma-1}\frac{1}{1+\theta}$.

F Multi Sector Extension

F.1 Derivation of Multi Sector

Household utility in country j can be written as:

$$U_j = \prod_s C_{js}^{\alpha_s}, \tag{F.1}$$

with

$$C_{js} = \left[\sum_i \int_{\omega\in\Omega_{ijs}} \left(q_{ijs}(\omega) x_{ijs}^c(\omega) + \overline{x}_s\right)^{\frac{\sigma_s-1}{\sigma_s}} d\omega\right]^{\frac{\sigma_s}{\sigma_s-1}}, \tag{F.2}$$

The representative consumer in country j's demand satisfies:

$$x_{ijs}^{c}(\omega) = \frac{\overline{x}_s}{q_{ijs}(\omega)} \left\{ \left[\frac{\tilde{p}_{ijs}(\omega)}{\tilde{p}_{js}^{*}} \right]^{-\sigma_s} - 1 \right\} \tag{F.3}$$

where $\tilde{p}_{ijs}(\omega) = \frac{p_{ijs}(\omega)}{q_{ijs}(\omega)}$ and $\tilde{p}_{js}^{*} = \left[\frac{\alpha_s \left(\sum_s \bar{x}_s P_{js} + y_j \right)}{\bar{x}_s P_{j\sigma s}^{1-\sigma_s}} \right]^{\frac{1}{\sigma_s}}$. The aggregate prices satisfy $P_{js} = \sum_i \int_{\omega \in \Omega_{ijs}} \tilde{p}_{ijs}(\omega) \, d\omega$ and $P_{j\sigma s} = \left\{ \sum_i \int_{\omega \in \Omega_{ijs}} \tilde{p}_{ijs}(\omega)^{1-\sigma} \, d\omega \right\}^{\frac{1}{1-\sigma}}$. Now, quantity, sales, and profit for a given variety exported from i to j in sector s are as follows,

$$x_{ijs}(\omega) = \frac{\bar{x}_s L_j}{q_{ijs}(\omega)} \left[\left(\frac{\tilde{p}_{ijs}(\omega)}{p_{js}^{*}} \right)^{-\sigma_s} - 1 \right] \tag{F.4}$$

$$r_{ijs}(\omega) = \bar{x}_s L_j \tilde{p}_{ijs}(\omega) \left[\left(\frac{\tilde{p}_{ijs}(\omega)}{p_{js}^{*}} \right)^{-\sigma_s} - 1 \right] \tag{F.5}$$

$$\pi_{ijs}(\omega) = \bar{x}_s L_j \left[\tilde{p}_{ijs}(\omega) - \tilde{c}_{ijs}(\omega) \right] \left[\left(\frac{\tilde{p}_{ijs}(\omega)}{p_{js}^{*}} \right)^{-\sigma_s} - 1 \right] \tag{F.6}$$

where $\tilde{c}_{ijs}(\omega) = \frac{c_{ijs}(\omega)}{q_{ijs}(\omega)}$ is the quality-adjusted marginal cost. Given the quality adjusted marginal cost, firms maximize their profits. This implies that the optimal price of the good satisfies:

$$\sigma \frac{\tilde{c}_{ijs}(\omega)}{p_{js}^{*}} = \left(\frac{\tilde{p}_{ijs}(\omega)}{p_{js}^{*}} \right)^{\sigma+1} + (\sigma - 1) \frac{\tilde{p}_{ijs}(\omega)}{p_{js}^{*}} \tag{F.7}$$

We assume that the marginal cost of producing a variety of final good with quality q_{ijs} by a firm with productivity φ is given by:

$$c_{ijs}(\varphi, \varepsilon) = \varepsilon T_{ijs} w_i + \frac{w_i \tau_{ijs}}{\varphi} q_{ijs}^{\eta_s}$$

where τ_{ijs} is ad valorem trade cost and εT_{ijs} is a specific transportation cost from country i to country j in sector s. Productivity φ follows the Pareto distribution with c.d.f. $G_i(\varphi) = 1 - b_{is}\varphi^{-\theta_s}$, and ε represents the log-normally distributed fixed cost draw as specified before with the variance σ_s in sector s. Maximizing the profit is equivalent to minimizing the quality-adjusted cost $\tilde{c}_{ijs}(\omega)$ by the envelop theorem. Choosing the quality to minimize the quality-adjusted marginal cost implies that the optimal level of quality for a firm with productivity φ is:

$$q_{ijs}(\varphi, \varepsilon) = \left(\frac{\varepsilon T_{ijs} \varphi}{(\eta_s - 1) \tau_{ijs}} \right)^{\frac{1}{\eta_s}} \tag{F.8}$$

and hence the quality adjusted marginal cost of production now is:

$$\tilde{c}_{ijs}(\varphi, \varepsilon) = \left(\frac{\eta_s}{\eta_s - 1} \varepsilon T_{ijs} w_i \right)^{\frac{\eta_s - 1}{\eta_s}} \left(\frac{\varphi}{\eta_s w_i \tau_{ijs}} \right)^{-\frac{1}{\eta_s}} \tag{F.9}$$

At the productivity cutoff $\varphi^*_{ijs}(\varepsilon)$, we have $p^*_{ijs}(\varphi, \varepsilon) = c^*_{ijs}(\varphi, \varepsilon) = p^*_{js}$, which implies that the productivity cutoff $\varphi^*_{ijs}(\varepsilon)$ takes the following form:

$$\varphi^*_{ijs}(\varepsilon) = \varphi^*_{ijs}\varepsilon^{\eta_s - 1} = \frac{\eta_s^{\eta_s}}{(\eta_s - 1)^{\eta_s - 1}} T_{ijs}^{\eta_s - 1} \tau_{ijs} w_i^{\eta_s} \left(\tilde{p}^*_{js}\right)^{-\eta_s} \varepsilon^{\eta_s - 1},$$

Based on the similar derivation in the one-sector model in Section 3, we know that the exporting firm mass N_{ijs}, the aggregate price P_{js} and $P_{j\sigma s}$, the trade flow X_{ijs}, the expected average profit π_{is} and the potential firm mass J_{is} in sector s satisfy:

$$N_{ijs} = \kappa_s J_{is} b_{is} \left(\varphi^*_{ijs}\right)^{-\theta_s} \tag{F.10}$$
$$\bar{x}_s P_{js} = \beta_s \tilde{p}^*_{js} N_{js} \tag{F.11}$$
$$\bar{x}_s P_{j\sigma s} = \beta_{\sigma s}^{\frac{1}{1-\sigma_s}} \tilde{p}^*_{js} N_{js}^{\frac{1}{1-\sigma_s}} \tag{F.12}$$
$$X_{ijs} = \beta_{Xs} \bar{x}_s \tilde{p}^*_{js} N_{ijs} L_j \tag{F.13}$$
$$\pi_{is} = \beta_{\pi s} \sum_j \bar{x}_s \kappa_s b_{is} \left(\varphi^*_{ijs}\right)^{-\theta_s} \tilde{p}^*_{js} L_j \tag{F.14}$$
$$J_{is} = \frac{\beta_{\pi s}}{\beta_{Xs}} \frac{\alpha_s L_i}{f_s} \tag{F.15}$$

where κ_s, β_s, $\beta_{\sigma s}$, $\beta_{\pi s}$ and β_{Xs} are constant. Now, the expression of choke price $\tilde{p}^*_{js}$, together with the equation (F.11) and (F.12), implies[27]

$$\bar{x}_s P_{js} = \gamma_s w_j \tag{F.16}$$
$$\bar{x}_s P_{j\sigma s} = \frac{\gamma_s}{\beta_s} \beta_{\sigma s}^{\frac{1}{1-\sigma_s}} N_{js}^{\frac{\sigma_s}{1-\sigma_s}} w_j \tag{F.17}$$
$$\tilde{p}^*_{js} = \frac{\gamma_s}{\beta_s} \frac{w_j}{N_{js}} \tag{F.18}$$

where γ_s are determined by $\beta_s \alpha_s \left(\sum_s \gamma_s + 1\right) = \beta_{\sigma s} \overline{x}_s^{\sigma_s} \gamma_s$.

[27] We can get them by first conjecturing $\overline{x}_s P_{js} = \gamma_s w_j$, where γ_s is sector level constant. Then $\sum_s \bar{x}_s P_{js} = \left(\sum_s \gamma_s\right) w_j$, which implies the price cut-off $\tilde{p}^*_{js}$ can be written as:

$$\left(\tilde{p}^*_{js}\right)^{\sigma_s} = \frac{\alpha_s \left(\sum_s \gamma_s + 1\right) w_j}{\overline{x}_s P_{j\sigma s}^{1-\sigma_s}} = \frac{\beta_s^{1-\sigma_s} \alpha_s \left(\sum_s \gamma_s + 1\right)}{\beta_{\sigma s} \overline{x}_s^{\sigma_s} \gamma_s^{1-\sigma_s}} \left(\frac{w_j}{N_{js}}\right)^{\sigma_s}$$

Hence, we have

$$\bar{x}_s P_{js} = \beta_s (\sigma_s, \theta_s, \eta_s) \tilde{p}^*_{js} N_{js} = \left[\frac{\beta_s \alpha_s \left(\sum_s \gamma_s + 1\right)}{\beta_{\sigma s} \overline{x}_s^{\sigma_s} \gamma_s^{1-\sigma_s}}\right]^{\frac{1}{\sigma_s}} w_j = \gamma_s w_j$$

Hence, γ_s is determined by

$$\beta_s \alpha_s \left(\sum_s \gamma_s + 1\right) = \beta_{\sigma s} \overline{x}_s^{\sigma_s} \gamma_s$$

Hence, we have equations (F.16), (F.17) and (F.18).

F.2 Proof of Proposition 3

The percentage change of U_j satisfies:

$$d\ln U_j = \sum_s \frac{\alpha_s \sigma_s}{\sigma_s - 1}\left(d\ln w_j - d\ln \tilde{p}^*_{js}\right) \tag{F.19}$$

Based on equations (11), (13) and (21), we can rewrite N_{ij} as:

$$N_{ijs} = \frac{\kappa \beta_{\pi s}}{\beta_{Xs} f_s} \alpha_s b_{is} L_i \left(\frac{\eta_s^{\eta_s}}{(\eta_s - 1)^{\eta_s - 1}} T_{ijs}^{\eta_s - 1} \tau_{ijs} w_i^{\eta_s} \left(\tilde{p}^*_{js}\right)^{-\eta_s}\right)^{-\theta_s} \tag{F.20}$$

which implies that

$$\lambda_{jjs} = \frac{X_{jjs}}{\sum_i X_{ijs}} = \frac{N_{jjs}}{\sum_i N_{ijs}} = \frac{b_{js} L_j \left(T_{jjs}^{\eta-1} \tau_{jjs} w_j^{\eta}\right)^{-\theta}}{\sum_i b_{is} L_i \left(T_{ijs}^{\eta-1} \tau_{ijs} w_i^{\eta}\right)^{-\theta}} \tag{F.21}$$

Consider the foreign shocks: $(b_{is}, L_i, T_{ijs}, \tau_{ijs})$ is changed to $(b'_{is}, L'_i, T'_{ijs}, \tau'_{ijs})$ for $i \neq j$ such that $b_{js} = b'_{js}, L_j = L'_j, T_{jjs} = T'_{jjs}, \tau_{jjs} = \tau'_{jjs}$. Totally differentiating the previous equation implies:

$$d\ln \lambda_{jjs} = \sum_i \lambda_{ijs} \left[\theta\eta \left(d\ln w_i - d\ln w_j\right) - d\ln \xi_{ijs}\right] \tag{F.22}$$

where $d\ln \xi_{ijs}$ reflects any foreign shock, which satisfies:

$$d\ln \xi_{ijs} = -\theta_s \left(\eta_s - 1\right) d\ln T_{ijs} - \theta_s d\ln \tau_{ijs} + d\ln b_{is} + d\ln L_i$$

The expression of $\tilde{p}^*_j$, together with equation (C.5) and (C.6), imply that:

$$d\ln \tilde{p}^*_{js} = \frac{1}{\sigma_s} d\ln w_j + \frac{\sigma_s - 1}{\sigma_s} d\ln P_{j\sigma s} = d\ln w_j - \sum_i \lambda_{ijs} d\ln N_{ijs} \tag{F.23}$$

Totally differentiating the expression of N_{ij} and substituting the percentage change of N_{ij} into the previous equation, we have:

$$\begin{aligned} d\ln \tilde{p}^*_{js} &= d\ln w_j - \sum_i \lambda_{ijs} d\ln N_{ijs} \\ &= d\ln w_j + \sum_i \lambda_{ijs} \left[\eta_s \theta_s \left(d\ln w_i - d\ln \tilde{p}^*_{js}\right) - d\ln \xi_{ijs}\right] \\ &= \frac{1}{1 + \eta_s \theta_s} d\ln w_j + \frac{1}{1 + \eta_s \theta_s} \sum_i \lambda_{ijs} \left[\eta_s \theta_s d\ln w_i - d\ln \xi_{ijs}\right] \end{aligned} \tag{F.24}$$

Hence, the percentage change in welfare satisfies:

$$
\begin{aligned}
d\ln U_j &= \sum_s \frac{\alpha_s \sigma_s}{\sigma_s - 1} \left(d\ln w_j - d\ln \tilde{p}^*_{js} \right) \\
&= -\sum_s \frac{\alpha_s \sigma_s}{\sigma_s - 1} \frac{1}{1+\eta_s\theta_s} \sum_i \lambda_{ijs} \left[\eta_s \theta_s \left(d\ln w_i - d\ln w_j \right) - d\ln \xi_{ijs} \right] \\
&= -\sum_s \frac{\alpha_s \sigma_s}{\sigma_s - 1} \frac{1}{1+\eta_s\theta_s} d\ln \lambda_{jjs} \qquad \text{(F.25)}
\end{aligned}
$$

Integrating the previous expression between the initial equilibrium (before the shock) and the new equilibrium (after the shock), we finally get

$$
\widehat{U}_j = \prod_s \left(\widehat{\lambda}_{jjs} \right)^{-\frac{\alpha_s \sigma_s}{\sigma_s - 1} \frac{1}{1+\eta_s\theta_s}} \qquad \text{(F.26)}
$$

It shows that the changes in welfare at country j can be inferred from changes in the share of domestic expenditure, λ_{jjs}, using the parameter, $\frac{\alpha_s \sigma_s}{\sigma_s - 1} \frac{1}{1+\eta_s\theta_s}$.

G Supplementary Table: Welfare Comparison for All Countries

Countries	(1) benchmark	(2) large scope	(3) small scope	(4) no q	(5) no q, no var mkp
AUS	4.04	6.04	0.772	7.34	6.08
AUT	6.25	9.3	1.21	11.3	9.36
BEL	10.5	15.4	2.06	18.5	15.5
BRA	1.09	1.64	0.206	2	1.65
CAN	5.79	8.63	1.12	10.5	8.69
CHE	7	10.4	1.35	12.6	10.5
CHN	1.6	2.41	0.303	2.94	2.42
DEU	3.85	5.76	0.735	7	5.8
DNK	5.82	8.67	1.12	10.5	8.73
ESP	3.62	5.42	0.691	6.59	5.46
FIN	3.72	5.57	0.71	6.77	5.61
FRA	3.4	5.1	0.648	6.2	5.13
GBR	4.6	6.88	0.882	8.34	6.92
GRC	4.2	6.28	0.803	7.63	6.32
HKG	10.6	15.5	2.08	18.7	15.6
IDN	2.51	3.77	0.476	4.59	3.79
IND	1.01	1.53	0.191	1.87	1.54
IRL	7.78	11.5	1.51	13.9	11.6
ITA	2.22	3.34	0.422	4.07	3.36
JPN	1.26	1.9	0.239	2.32	1.92
KOR	2.26	3.4	0.429	4.14	3.42
MEX	4.41	6.6	0.845	8.01	6.64
MYS	6.38	9.5	1.23	11.5	9.56
NLD	5.84	8.7	1.13	10.5	8.76
NOR	5.07	7.57	0.974	9.18	7.62
POL	3.37	5.06	0.644	6.15	5.09
PRT	4.54	6.78	0.87	8.23	6.83
RUS	2.39	3.59	0.454	4.38	3.62
SAU	4.58	6.85	0.879	8.31	6.89
SGP	13.1	19.1	2.6	22.9	19.2
SWE	4.61	6.89	0.883	8.36	6.93
THA	4.85	7.24	0.931	8.79	7.29
TUR	2.38	3.58	0.452	4.36	3.6
TWN	4.93	7.36	0.947	8.93	7.41
USA	2.08	3.13	0.395	3.82	3.15
ZAF	2.06	3.11	0.392	3.78	3.13
MEDIAN	4.3	6.44	0.824	7.82	6.48