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Essays on Economic Development and Gains from Trade

by

Minho Kim

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ABSTRACT OF THE DISSERTATION

Essays on Economic Development and Gains from Trade

by

Minho Kim

Doctor of Philosophy in Economics

Washington University in St. Louis, 2014

Doctor B. Ravikumar, Chair

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In each of the three essays, I investigate gains from trade originating at three sources: i) vertical specialization through intermediate goods trade, ii) improving allocation of resources across heterogeneous firms, and iii) developing countries' technological advancement towards particular factors of production, either skilled labor or unskilled labor. I develop three models of trade, featuring multi-stage production, micro-distortions with endogenous entry and exit, and directed technical change. First, I show quantitatively that trade barriers play an important role in hindering the integration of poor countries in global market through trade in intermediate goods. Second, I find that the substantial impact of trade is to improve allocation on the extensive margin by forcing out less productive firms and replacing those with more productive firms. Third, I prove that gains from trade are magnified due to endogenously directed technical change.

In the first chapter, I investigate whether the gains from trade are systematically related to the level of development. This chapter argues that we need to consider a multi-stage production process to answer the questions. I develop a Ricardian trade model which features two stages of production. At each stage, gains from trade can be measured by the home trade share, a measure of market integration. Looking at each stage's home trade shares across countries, I find different specialization patterns: rich countries are integrated at each stage whereas most poor countries are not integrated. Measured gains from trade are more than ten times larger for the 10 richest countries than for the 10 poorest countries. For the rich countries, two-thirds of the gains are accounted for by second

stage trade. Poor countries' small gains from trade are accounted entirely by first stage trade. I argue that difference in trade barriers between rich countries and poor countries, particularly in the second stage of production, limit trade gains for poor countries.

Second chapter studies the impact of international trade on sectoral total factor productivity (TFP). Misallocation of resources across heterogeneous firms impacts negatively on TFP. In this chapter, I study trade liberalization as a source of reducing misallocation across firms, thus leading to higher TFP. Misallocation is reduced on the extensive margin by forcing out less productive firms and replacing those with more productive firms. Using firm-level panel data on Chinese manufacturing, I measure distortions across firms and over time as in Hsieh and Klenow (2009). I find that the allocation of factors improves more in industries that experience a higher reduction in tariff rates. Less productive firms are more likely to exit in sectors that experience a higher tariff reduction. In addition, entrants in more liberalized sectors are more productive relative to entrants in less liberalized sectors. Reducing misallocation on the extensive margin has quantitatively large effect on TFP.

In the third chapter, I analyze how technical change is directed towards particular factors of production in international trade between the North and the South. Typical assumption in the literature is that either technologies are exogenously given or technical change is allowed only in the North. I present a model of international trade with endogenous growth by allowing the South to direct their technology. This chapter studies the implications of the technical change for the gains from trade and the skill premium. Main result shows that more R&D is directed towards skill-augmenting technology in the North than in the South in sectors with the same skill-intensity. Technical change induced by lowering trade costs can increase the skill premium in both the North and the South. Gains from trade are magnified due to endogenous directed technical change. This results in larger gains from trade compared with the model where technical change is either not allowed or allowed only in the North.

1. Chapter 1: Multi-Stage Production and Gains from Trade

1.1. Introduction

How large are the welfare gains from trade? Are they systematically related to the level of development? This paper argues that we need to consider a multi-stage production process to answer the questions. Arkolakis, Costinot, and Rodriguez-Clare (2012) demonstrate that, in a wide class of trade models, we can measure quantitative gains from trade for each country by the share of domestic expenditures and a common trade elasticity parameter. A country's share of expenditure on domestic goods, i.e., a home trade share, basically captures the level of integration of the economy with the global market. Lower home trade shares imply higher gains from trade. Thus, to study the relation between measured gains from trade and the level of development, we can simply compare home trade shares between rich and poor countries. The models, covered in Arkolakis, Costinot, and Rodriguez-Clare (2012), are based on an assumption that goods are produced in a single stage.

Normally goods are made in multiple stages. Different countries can specialize in different stages of production. This paper presents a different formula to measure the gains from trade, allowing different level of integration across stages. Using this formula, final goal of this paper is to quantify the effects of trade costs on the differences in the gains from trade between rich and poor countries.

In this paper, I try to capture the sequential production process by embedding one more stage of

production function into a multi-country international trade model of Eaton and Kortum (2002). By incorporating stages, I show that gains from trade are determined by the home trade share at each stage, not the aggregate share. Looking at each stage's home trade shares across countries in the year of 2004, I find different trade patterns across income groups.[1] For the first stage, home trade shares look similar across countries. But for the second stage, rich and poor countries look different. Rich countries have much lower home trade share in the second stage relative to the poor. If we did not distinguish the type of goods according to the stages, we would be using the formula with an aggregate share to measure gains from trade while missing these different trade patterns across countries.

I first calibrate the two stage model and simulate the economy into two extreme cases, autarky and free trade, to quantify the effects of trade costs on the gains from trade. I use global input-output table from GTAP 8 database to categorize goods into two stages. I adopt the following criterion from Yi (2003): a good is categorized into the first stage when its use in production of other goods more than doubles its final consumption. Bilateral trade shares for each stage are constructed using production and bilateral trade data of 100 countries, covering more than 95% of the production and trade in the world in the year of 2004. My model yields structural gravity type equations on the bilateral trade shares at each stage. Using the gravity equation implied by model, I recover jointly the technology and trade costs to match the trade shares in the data. Following arguments in Waugh (2010), I allow trade costs to vary contingent upon exporter. Estimated trade costs covary with income per worker. Poor countries' exporting costs are much higher than rich countries at both stages. Moreover, the covariance between the exporting cost and income per worker is much higher in the second stage than in the first stage.

I use this calibrated model to estimate gains from trade associated with changes in trade costs. The welfare costs or gains from trade, associated with the changes in trade costs, can be measured by

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[1] Tradable goods include all goods except service. I observe the same pattern of integration across countries for the year 2007. Moreover, when we restrict tradable goods to manufacturing goods, the home trade shares at each stage have same patterns while magnitude in difference in the second stage home trade shares are even larger between the rich and the poor.

the changes in home trade share at each stage. In one simulation, trade costs are raised to infinity while other technology parameters and endowments are fixed. Welfare costs of moving to autarky are much higher for rich countries than poor countries. Trade in the second stage goods account for more than two-thirds of difference in the welfare costs across countries. In another simulation, all trade barriers are removed. All countries gain from this liberalization, but poor countries gain much more than rich countries. Much of the gains for poor countries come from increased specialization in the second stage. These counterfactual exercises show that difference in trade barriers between rich countries and poor countries, particularly in the second stage of production, limit trade gains for poor countries.

Literature has studied relationship between the level of development and trade. Hall and Jones (1999) address variations in output per worker with "social infrastructure" measure, which includes Sachs and Warner (1995)'s openness index. Yanikkaya (2003) performed regression with various openness measures including tariffs. He showed that trade barriers can be positively related to growth while most openness measures do not have significant relation. Notable new approach comes from Eaton and Kortum (2002) and Waugh (2010). Rather than using simple regressions to capture the relation, trade frictions are presented as a functional form in aggregate TFP. I provide decomposition of this functional form in aggregate TFP, capturing vertical specialization across stages of production. Vertical specialization patterns are endogenously determined given production technologies, endowments, and trade costs.

In addition, I compute value added content of bilateral trade to compare intensity of production sharing across countries. Johnson and Noguera (2011) developed a method to compute value added content of bilateral trade using input-output structure and trade data. By applying their method in this model, we first analyze general equilibrium effect of trade costs on value added as well as gross exports. I change variable trade costs of country i to the U.S. and measure elasticity of relative value added and elasticity of relative gross exports associated with change in variable trade costs. Compared to elasticity of value added estimated by standard model, each country's elasticity of value added is larger which magnitude differ from 8 to 98 percent across countries. Elasticity

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of gross exports is smaller in my model around 35 percent than the elasticity of gross exports estimated by standard model. The difference in elasticity of gross exports is fairly constant. These trade elasticities depend on production linkage across countries as well as proximity in distance of other countries to country i. Finally, we use ratio of value added to gross exports (VAX ratio) to capture the intensity of production sharing. VAX ratios are low when intensity of production sharing is high. When we compare VAX ratios across countries at aggregate level, VAX ratios tend to decrease as income per worker increases. Intensity of production sharing is high for rich countries. We can compute VAX ratios for each stage of goods. Difference in VAX ratios across countries is large in stage 1. Rich countries have high intensity of production sharing at both stages of goods. By capturing linkages across countries through intermediate goods trade, the VAX ratios confirm that poor countries are much less vertically integrated compared to rich countries.

When applying model to the data, we defined service sector as non-tradable goods and included all other sectors as tradable goods. Results are consistent when I define tradable goods only for manufacturing or include service sector in tradable goods as well. Following Section 2 lays out model. Section 3 explains method to estimate the model. Section 4 reports estimation results and fit of the model to data on trade volume, aggregate prices, and cross-country income differences. Section 5 measures quantitative gains from trade and implications on cross-country income differences through the counterfactual experiments. Section 6 explores general equilibrium effect of trade costs on value added, gross exports, and welfare. Section 7 concludes.

1.2. Model

We closely follow the model of Eaton and Kortum (2002). There are N countries indexed by i. Each country is endowed with aggregate capital stock K_i, and stock of human capital $L_i h_i$ which is labor multiplied by average human capital. These are supplied by consumers inelastically. The consumers value only final non-tradable good, Y_i. There are two stages of tradable goods to be produced to make final non-tradable good. When we categorize sectors into two stages, we follow

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the method used in Yi (2003). Using Input-Output matrix, this artificial stage 1 sectors will include sectors whose output are used as inputs in other sectors more than twice as consumption. All other sectors are in stage 2. First section in estimation part contains details on categorization of sectors. We express variables in terms of per-worker. E.g. $k_i = K_i/L_i$.

1.2.1. Technologies

There is a continuum of tradable goods for each stage. Conveniently, we index each good by x at each stage.

First Stage Stage 1 good is produced with capital, labor and aggregate stage 1 good. Production function for Stage 1 good x is

$$q_{1,i}(x) = (z_{1,i}(x))^{-\theta} \left[Q^1_{1,i}(x)\right]^{1-\beta_1} \left[\left(k^1_i(x)\right)^{\alpha} \left(h^1_i(x)\right)^{1-\alpha}\right]^{\beta_1}$$

Productivity of producing good x in country i at the first stage is $(z_{1,i}(x))^{-\theta}$ where $z_{1,i}(x)$ follows exponential distribution with country specific parameter $A_{1,i}$. Higher $A_{1,i}$ means that the high efficiency draw for any good x is more likely. $A_{1,i} > A_{1,j} \Leftrightarrow \Pr(z_{1,i} > \bar{z}) > \Pr(z_{1,j} > \bar{z}) \ \forall \bar{z} \geq 0$. These productivity draws are independent across countries. For any tradable stage 1 good, $\mathbf{z}_1 = (z_{1,1}, ..., z_{1,N})$ is the vector of technology draws. Joint desity of $\mathbf{z}_1$ is

$\phi_1(\mathbf{z}_1) = \left(\prod_{i=1}^{N} A_{1,i}\right) \exp\left\{-\sum_{i=1}^{N} A_{1,i} z_{1,i}\right\}$.

First stage goods are aggregated through Spence–Dixit–Stiglitz (SDS) technology. Total output of stage 1 good is $Q_{1,i} = \left(\int q_1(x)^{\frac{\eta-1}{\eta}} \phi_1(x) dx\right)^{\frac{\eta}{\eta-1}}$ where $q_1(x)$ is country i's use of stage 1 good x. Elasticity of substitution between goods is η. I assume this value is the same for both stage goods. Producer of this SDS aggregate good finds minimum price for each good x. In closed economy, $q_1(x)$ corresponds to $q_{1,i}(x)$. Aggregate stage 1 good is either used as intermediate good for other stage 1 good producers, $Q^1_{1,i} \equiv \int Q^1_{1,i}(x) dx$, or used as intermediate good for stage 2 good

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producers, $Q_{1,i}^2$. Thus,

$$Q_{1,i}^1 + Q_{1,i}^2 \leq Q_{1,i} \tag{1.1}$$

Fist stage good producer maximizes its profit given prices. Stage 1 good producer in country i maximize:

$$p_{1,i}(x)q_{1,i}(x) - w_i h_i^1(x) - r_i k_i^1(x) - P_{1,i}Q_{1,i}^1(x) \tag{1.2}$$

where $p_{1,i}(x)$ is price of a good x in country i.

$P_{1,i} = \left(\int p_{1,i}(x)^{1-\eta} \phi_1(x) dx \right)^{\frac{1}{1-\eta}}$ is the price in i for a unit of aggregate stage 1 good.

Second Stage   Second stage good is produced with similar production structure to the first stage good. The difference comes from that second stage good production requires both stage 1 and stage 2 goods as intermediates. Stage 2 good x is produced by

$$q_{2,i}(x) = (z_{2,i}(x))^{-\theta} \left[\left(Q_{1,i}^2(x) \right)^{\kappa} \left(Q_{2,i}^2(x) \right)^{1-\kappa} \right]^{1-\beta_2} \left[\left(k_i^2(x) \right)^{\alpha} \left(h_i^2(x) \right)^{1-\alpha} \right]^{\beta_2}$$

where $z_{2,i}(x)$ follows exponential distribution with country specific parameter $A_{2,i}$. $\mathbf{z}_2 = (z_{2,1}, ..., z_{2,N})$ is the vector of technology draws. Joint density of $\mathbf{z}_2$ is

$$\phi_2(\mathbf{z}_2) = \left(\prod_{i=1}^N A_{2,i} \right) \exp \left\{ - \sum_{i=1}^N A_{2,i} z_{2,i} \right\}.$$

Similar to aggregation scheme in stage 1 good, $Q_{2,i} = \left(\int q_2(x)^{\frac{\eta-1}{\eta}} \phi_2(x) dx \right)^{\frac{\eta}{\eta-1}}$ is the aggregate stage 2 good where $q_2(x)$ is country i's consumption of stage 2 good $q_{2,i}(x)$. Aggregate stage 2 good is either used as intermediate good for other stage 2 good producers, $Q_{2,i}^2 \equiv \int Q_{2,i}^2(x) dx$, or used as intermediate good for final good production, $Q_{2,i}^f$. Thus,

$$Q_{2,i}^2 + Q_{2,i}^f \leq Q_{2,i} \tag{1.3}$$

Stage 2 good producer in country i maximize:

$$p_{2,i}(x)q_{2,i}(x) - w_i h_i^2(x) - r_i k_i^2(x) - P_{1,i}Q_{1,i}^2(x) - P_{2,i}Q_{2,i}^2(x) \tag{1.4}$$

where $p_{2,i}(x)$ is price of a good x in country i. $P_{2,i} = \left(\int p_{2,i}(x)^{1-\eta}\phi_2(x)dx\right)^{\frac{1}{1-\eta}}$ is the price in i for a unit of aggregate stage 2 good.

Whenever goods cross border from country j to country i, trade costs, τ_{ij}, is incurred. Trade barriers are expressed as "iceberg" physical term. τ_{ij} units of goods need to be shipped from j in order to deliver one unit of good to i. These barriers captures effective trade costs related to shipping goods from one destination to the other. These trade barriers can differ at each stage. These are denoted as $\tau_{1,ij}$ and $\tau_{2,ij}$ respectively. $\tau_{1,ii}$ and $\tau_{2,ii}$s are normalized to one for each country.

Final Goods Sector Representative firm produces a homogenous non-traded good. This non-traded final good is produced using capital and labor as well as aggregate tradable second stage good.

$$y_i = \left[Q_{2,i}^f\right]^{1-v}\left[\left(k_i^f\right)^\alpha \left(h_i^f\right)^{1-\alpha}\right]^v$$

Representative producer of non-traded good in country i maximize:

$$p_i y_i - w_i h_i^f - r_i k_i^f - P_{2,i}Q_{2,i}^f \tag{1.5}$$

where p_i is price of the final good. Consumers values only the produced final good, y_i, thus, this value represents welfare of economy i.

Parameters in production functions at each stage and final good α, β_1, β_2, β, θ, η, v are constant across countries.

1.2.2. Equilibrium

Equilibrium is characterized by set of prices, trade shares, and allocation of factors. Factors and goods markets are perfectly competitive. The set of prices are $\{p_{1,i}(x), p_{2,i}(x), P_{1,i}, P_{2,i}, w_i, r_i\}$ for each i. Given prices, all firms at each stage and final goods sector inputs satisfy the first order conditions to the firm's maximization problems (2), (4), and (5). Given prices, goods market clearing conditions (1), (3) hold in equality. Given prices, following factor market conditions are satisfied.

$$h_i = \int h_i^1(x)\phi_1(x)dx + \int h_i^2(x)\phi_2(x)dx + h_i^f$$

$$k_i = \int k_i^1(x)\phi_1(x)dx + \int k_i^2(x)\phi_2(x)dx + k_i^f$$

Finally, bilateral trade shares balances trade for each country.

Price Index and Trade Shares   Unit cost of producing stage 1 good x in country j is $c_{1,j} \equiv (P_{1,j})^{1-\beta_1}\left(w_j^{1-\alpha}r_j^\alpha\right)^{\beta_1}$. Cost of delivering a unit of first stage good x from country j to i is

$$p_{1,ij}(x) = \left[\frac{c_{1,j}}{(z_{1,j}(x))^{-\theta}}\right]\tau_{1,ij} = (P_{1,j})^{1-\beta_1}\left(w_j^{1-\alpha}r_j^\alpha\right)^{\beta_1}\tau_{1,ij}\left(z_{1,j}(x)\right)^\theta. \tag{1.6}$$

The good is bought from country which sells the good at the lowest price. The price of first stage good will be $p_{1,i}(x) = \min\{p_{1,ij}(x); j = 1,...,N\}$. Thus,

$$(p_{1,i}(x))^{1/\theta} = \min_j\left\{\left[\left(w_j^{1-\alpha}r_j^\alpha\right)^{\beta_1}(P_{1,j})^{1-\beta_1}\tau_{1,ij}\right]^{1/\theta}z_{1,j}(x)\right\}$$

Using characteristics of exponential distribution, $\left[\left(w_j^{1-\alpha}r_j^\alpha\right)^{\beta_1}(P_{1,j})^{1-\beta_1}\tau_{1,ij}\right]^{1/\theta}z_{1,j}(x)$ follows

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exponential distribution with parameter $\psi_{1,ij} \equiv \left[\left(w_j^{1-\alpha} r_j^{\alpha} \right)^{\beta_1} \left(P_{1,j} \right)^{1-\beta_1} \tau_{1,ij} \right]^{-1/\theta} A_{1,j}$. Using another characteristics, $(p_{1,i}(x))^{1/\theta}$ is also exponentially distributed with parameter $\psi_{1,i} \equiv \sum_{j=1}^{N} \psi_{1,ij}$.

Probability that producer in country j provides a first stage good to second stage producer in country i at the lowest price is

$$X_{1,ij} = \frac{\psi_{1,ij}}{\psi_{1,i}} = \frac{\left[\left(P_{1,j} \right)^{1-\beta_1} \left(w_j^{1-\alpha} r_j^{\alpha} \right)^{\beta_1} \tau_{1,ij} \right]^{-1/\theta} A_{1,j}}{\sum_{l=1}^{N} \left[\left(P_{1,l} \right)^{1-\beta_1} \left(w_l^{1-\alpha} r_l^{\alpha} \right)^{\beta_1} \tau_{1,il} \right]^{-1/\theta} A_{1,l}} \tag{1.7}$$

This probability is same as the fraction of the first stage goods that country i buys from country j since there are continuum of goods. As we can use property (b) of Eaton and Kortum (2002), this fraction of the first stage goods that country i buys from country j is also the country i's expenditure share on the first stage goods from country j.

Derivation of prices for second stage good is analogous to the first stage. Unit cost of producing stage 2 good x in country j is $c_{2,j} = \left[\left(P_{1,j} \right)^{\beta} \left(P_{2,j} \right)^{1-\beta} \right]^{1-\beta_2} \left(r_j^{\alpha} w_j^{1-\alpha} \right)^{\beta_2}$. Cost to deliver a unit of second stage good x from country j to i is

$$p_{2,ij}(x) = \left[\frac{c_{2,j}}{\left(z_{2,j}(x) \right)^{-\theta}} \right] \tau_{2,ij} = \left[\left(P_{1,j} \right)^{\kappa} \left(P_{2,j} \right)^{1-\kappa} \right]^{1-\beta_2} \left(r_j^{\alpha} w_j^{1-\alpha} \right)^{\beta_2} \tau_{2,ij} \left(z_{2,j}(x) \right)^{\theta} \tag{1.8}$$

The price of a second stage good x will be $p_{2,i}(x) = \min\{ p_{2,ij}(x); j = 1, ..., N \}$. Thus,

$$(p_{2,i}(x))^{1/\theta} = \min_{j} \left\{ \left[\left(P_{1,i} \right)^{\kappa(1-\beta_2)} \left(P_{2,i} \right)^{(1-\kappa)(1-\beta_2)} \left(r_j^{\alpha} w_j^{1-\alpha} \right)^{\beta_2} \tau_{2,ij} \right]^{1/\theta} z_{2,j}(x) \right\}$$

Define $\psi_{2,ij} \equiv \left[\left(P_{1,j} \right)^{\kappa(1-\beta_2)} \left(P_{2,j} \right)^{(1-\kappa)(1-\beta_2)} \left(r_j^{\alpha} w_j^{1-\alpha} \right)^{\beta_2} \tau_{2,ij} \right]^{-1/\theta} A_{2,j}$. $(p_{2,i}(x))^{1/\theta}$ follows exponential distribution with parameter $\psi_{2,i} \equiv \sum_{j=1}^{N} \psi_{2,ij}$.

Probability that producer in country j provides a second stage good at the lowest price in country

i is

$$X_{2,ij} = \frac{\psi_{2,ij}}{\psi_{2,i}} = \frac{\left[(P_{1,j})^{\kappa(1-\beta_2)} (P_{2,j})^{(1-\kappa)(1-\beta_2)} \left(r_j^\alpha w_j^{1-\alpha} \right)^{\beta_2} \tau_{2,ij} \right]^{-1/\theta} A_{2,j}}{\sum_{l=1}^{N} \left[(P_{1,l})^{\kappa(1-\beta_2)} (P_{2,l})^{(1-\kappa)(1-\beta_2)} \left(r_l^\alpha w_l^{1-\alpha} \right)^{\beta_2} \tau_{2,il} \right]^{-1/\theta} A_{2,l}} \tag{1.9}$$

Analogous to the $X_{1,ij}$, $X_{2,ij}$ is the country i's expenditure share on the second stage goods from country j. For country j, probability of providing second stage good to another country i not only depends on its technology level $A_{2,j}$ and trade costs $\tau_{2,ij}$ but also depends on both of those corresponding to the first stage production. Competitiveness of the second stage producer depends on the cost of aggregate first stage goods. The price of second stage good is likely to be low when trade costs of importing first stage good is low.

Aggregate price index of the first stage and the second stage goods in country i are, respectively,

$$P_{1,i} = \gamma_1 (\psi_{1,i})^{-\theta} = \gamma_1 \left\{ \sum_{l=1}^{N} \left[(P_{1,l})^{1-\beta_1} \left(w_l^{1-\alpha} r_l^\alpha \right)^{\beta_1} \tau_{1,il} \right]^{-1/\theta} A_{1,l} \right\}^{-\theta} \tag{1.10}$$

$$P_{2,i} = \gamma_2 (\psi_{2,i})^{-\theta} = \gamma_2 \left\{ \sum_{l=1}^{N} \left[(P_{1,l})^{\kappa(1-\beta_2)} (P_{2,l})^{(1-\kappa)(1-\beta_2)} \left(w_l^{1-\alpha} r_l^\alpha \right)^{\beta_2} \tau_{2,il} \right]^{-1/\theta} A_{2,l} \right\}^{-\theta} \tag{1.11}$$

Total expenditure on first stage tradable goods in country i is $L_i P_{1,i} Q_{1,i}$. Total expenditure on second stage tradable goods in country i is $L_i P_{2,i} Q_{2,i}$.

Wages   Gross exports from country j to i ,x_{ij}, is the sum of country j's exports of the first stage ($x_{1,ij}$) and the second stage ($x_{2,ij}$) goods to country i.

$$x_{ij} = x_{1,ij} + x_{2,ij} = X_{1,ij} L_i P_{1,i} Q_{1,i} + X_{2,ij} L_i P_{2,i} Q_{2,i}$$

Total imports of country i is $\sum_{j\neq i}^{N} x_{ij} = L_i P_{1,i} Q_{1,i} \sum_{j\neq i}^{N} X_{1,ij} + L_i P_{2,i} Q_{2,i} \sum_{j\neq i}^{N} X_{2,ij}$.

Total exports of country i is $\sum_{j\neq i}^{N} x_{ji} = \sum_{j\neq i}^{N} X_{1,ji} L_j P_{1,j} Q_{1,j} + \sum_{j\neq i}^{N} X_{2,ji} L_j P_{2,j} Q_{2,j}$.

Balanced trade requires that total imports of county i is equal to its total exports. Note that balanced trade at each stage is not required. Using balanced trade and including country i's own consumption lead to

$$L_i P_{1,i} Q_{1,i} + L_i P_{2,i} Q_{2,i} = \sum_{j=1}^{N} X_{1,ji} L_j P_{1,j} Q_{1,j} + \sum_{j=1}^{N} X_{2,ji} L_j P_{2,j} Q_{2,j}$$

Total spending on first stage goods, $L_i P_{1,i} Q_{1,i}$, is the derived demand from its corresponding second stage good production. Thus,

$$L_i P_{1,i} Q_{1,i} = \frac{(1-\beta_2)\kappa}{\beta_1} L_i P_{2,i} Q_{2,i}$$

Equation derived from balanced trade becomes

$$L_i P_{2,i} Q_{2,i} = \left[\frac{\beta_1}{\beta_1 + (1-\beta_2)\kappa}\right] \sum_{j=1}^{N} \left[\frac{(1-\beta_2)\kappa}{\beta_1} X_{1,ji} + X_{2,ji}\right] L_j P_{2,j} Q_{2,j} \tag{1.12}$$

GDP equals national income and constant fraction is used in production of tradable goods. As in Alvarez and Lucas (2007), equilibrium wage rate for each country is derived from the following equation.

$$L_i w_i = \left[\frac{\beta_1}{\beta_1 + (1-\beta_2)\kappa}\right] \sum_{j=1}^{N} \left[\frac{(1-\beta_2)\kappa}{\beta_1} X_{1,ji} + X_{2,ji}\right] L_j w_j, \quad i = 1,...,N \tag{1.13}$$

1.3. Estimation

In this section, I introduce the criterion to categorize goods into two stages firstly. Then, I construct bilateral trade shares at each stage using gross bilateral exports at each stage. Once I explain measurement of basic elements used in the estimation such as distance and endowments, I describe a scheme to estimate technology levels and trade barriers at each stage.

1.3.1. Categorization

We use a global input-output table along with bilateral trade data with reference year 2004 from GTAP 8 Data Base.[2]

I follow the criterion used in Yi (2003) to categorize goods into two stages. Goods belong to either stage 1 sector or stage 2 sector. This artificial stage 1 sector will include sectors whose output are used as inputs in other sectors more than twice as consumption.

In national output accounting, each sectors output in a country is expressed as

> Industry Output = Intermediate good consumption + Final consumption (Household final consumption + Government final consumption + Investment) + Export - Import

Final consumption includes household final consumption, government final consumption and investment. We aggregate over all countries for each industry. By balanced trade, industry's output is either used as inputs in other sectors or consumed. Sector is categorized as stage 1 when sum of intermediate use of other industries more than doubles the sum of final consumption. All other sectors are in stage 2. We define service as non-tradable goods for baseline results. We obtained similar results when we restrict tradable goods only to manufacturing goods which do not include agricultural goods and resources. I report the baseline results in this paper.

Stage 1 sectors are 'Paddy rice', 'Wheat' , 'Cereal grains nec', 'Oil seeds', 'Sugar cane, sugar beet', 'Plant-based fibers', 'Crops nec', 'Bovine cattle, sheep and goats, horses', 'Forestry', 'Coal', 'Oil', 'Gas', 'Minerals nec', 'Textiles', 'Wood products', 'Paper products, publishing', 'Petroleum, coal products', 'Chemical, rubber, plastic products', 'Mineral products nec ', 'Ferrous metals', 'Metals nec', 'Metal products'.

Stage 2 sectors are 'Vegetables, fruit, nuts', 'Animal products nec', 'Raw milk', 'Wool, silkworm cocoons', 'Fishing', 'Bovine meat products', 'Meat products nec', 'Vegetable oils and fats',

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[2]Specific information about the data base can be found in the following link. https://www.gtap.agecon.purdue.edu/default.asp. I also performed analysis with data from 2007 and all the results are quantitatively consistent with ones presented in this paper.

'Dairy products', 'Processed rice', 'Sugar', 'Food products nec', 'Beverages and tobacco products', 'Wearing apparel', 'Leather products', 'Motor vehicles and parts', 'Transport equipment nec', 'Electronic equipment', 'Machinery and equipment nec', 'Manufactures nec'.

1.3.2. Bilateral Trade Shares at Each Stage

Once we categorize sectors into two stages, we get corresponding bilateral trade value at each stage. Note that assumptions on distribution of productivities at each stage imply that probability of a producer in country j provides a good at the lowest price in country i is same as country i's expenditure share on the goods from country j at each stage. We can construct trade shares X_{ij} from bilateral trade data following Eaton and Kortum (2002) and Waugh (2010). At each stage $s \in \{1,2\}$, trade shares are

$$X_{s,ij} = \frac{\text{Imports}_{s,ij}}{\text{Gross Production}_{s,i} - \text{Total Exports}_{s,i} + \text{Imports}_{s,i}},$$

$$X_{s,ii} = 1 - \sum_{j \neq i}^{N} X_{s,ij}$$

Fraction of total expenditures of country i from country j at each stage is captured by dividing value of inputs coming from j by total spending. Home trade shares, X_{ii}, are the country's share of expenditure on domestic goods. They basically capture openness of the economy. Figure 1.1 shows interesting features of the home trade shares $X_{s,ii}$ at each stage. First stage goods $X_{1,ii}$s are not systematically associated with the country's income per worker. (Data on the income per worker is purchasing power parity (PPP) adjusted GDP per worker in 2004, obtained from Penn World Table.) However, second stage good $X_{2,ii}$s are negatively correlated to the country's income per worker. I performed two regressions of the logarithm of $X_{s,ii}$ at each stage on the logarithm of PPP adjusted GDP per worker. Slope coefficient on the first stage home trade shares is close to zero, -0.018, and not significant statistically. Slope coefficient on the second stage home trade shares

(a) Relative Stage 1 home trade shares   (b) Relative Stage 2 home trade shares
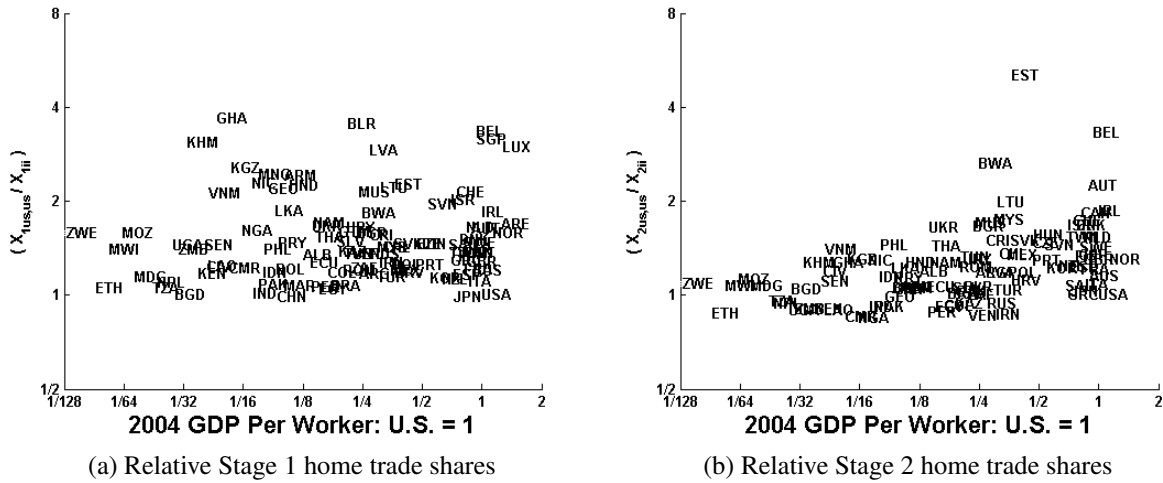
Figure 1.1.: Relative home trade shares at each stage over GDP per worker.

is -0.178 and is significantly different from zero. Most poor countries source second stage goods mostly from home. Since lower share of domestic expenditures implies larger gains from trade, the observed shares tell us that rich countries gained more from trade relative to poor countries, especially by trading of second stage goods.

1.3.3. Endowment and Distance Data

Endowments affect equilibrium prices and cross country income differences. I consider physical capital and human capital as observable endowments. We use capital stocks data from GTAP 8 data base. They construct capital stock measure using the database of the Development Economics Prospects Group of the World Bank.[3]

Average human capital in country i is constructed with the following equation:

$$h_i = \exp(\phi_s s_i)$$

where s_i is average years of schooling of people with age 25 and over. Barro-Lee educational

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[3]Following link has documentation on how they constructed capital stock. https://www.gtap.agecon.purdue.edu/resources/download/5666.pdf

Parameters			Target, Source
1- Labor share	$\alpha = \frac{1}{3}$		Gollin (2002)
Elasticity of substitution	$\eta = 2$		Alvarez and Lucas (2007) and Waugh (2010)
Mincerian return	$\phi_s = 0.1$		Psacharopoulos and Patrinos (2004)
Value added share of service	$v = 0.742$		Alvarez and Lucas (2007) and Waugh (2010)
Disperson of productivity	$\theta = 0.1818$		Waugh (2010)
Value added in 1st stage	$\beta_1 = 0.35$		Value added / Gross output
Value added in 2nd stage	$\beta_2 = 0.31$		Value added / Gross output
Share of 1st stage	$\kappa = 0.4$		Input (1st stage) / Input (1st + 2nd stage)

Table 1.1.: Parameters

attainment dataset provides educational attainment data for 146 countries in 5-year intervals from 1950 to 2010. (http://www.barrolee.com) We take data with reference year of 2005. ϕ_s is constant Mincerian return to the years of schooling. We set it at 10 percent which is the world average return as reported in Psacharopoulos and Patrinos (2004).

I used distance data from Centre d'Etudes Prospectives et d'Informations Internationales as in Waugh (2010). The distance data measures miles between capital cities in country i and j.

1.3.4. Common Parameter Values

Consistent with development accounting literature, we take labor share in total value added as 2/3. I use aggregated input-output matrix over all countries constructed with the two stage sectors to calibrate parameter values related to production at each stage. The aggregate input-output matrix is provided in the table A.1 at the appendix section A.1. The input-output matrix exposes that stage 1 good is mainly using stage 1 goods as intermediate inputs whereas its use of stage 2 goods is less than one-tenth of intermediate goods input. I abstract from using stage 2 good in stage 1 good production. β_1 is the value added in first stage goods over gross output of the first stage good. β_1 is 0.34. κ corresponds to the proportion of the first stage good used as an input in producing the second stage good. κ is 0.4. v is proportion of valued added in service out of total value added. v is 0.742.

1.3.5. Estimating Technologies and Trade Costs ($A_{1,i}$, $A_{2,i}$, $\tau_{1,ij}$, $\tau_{2,ij}$)

We estimate parameters related to each stage of production by performing Eaton and Kortum (2002) method at each stage.

$$\ln\left(\frac{X_{1,ij}}{X_{1,ii}}\right) = S_{1,j} - S_{1,i} - \frac{1}{\theta}\ln\left(\tau_{1,ij}\right) \tag{1.14}$$

where $S_{1,i} = \ln\left\{\left[(P_{1,i})^{1-\beta_1}\left(w_i^{1-\alpha}r_i^{\alpha}\right)^{\beta_1}\right]^{-1/\theta}A_{1,i}\right\}$.

I follow trade costs structure as in Waugh (2010). Waugh (2010) considers exporting country effect instead of importing country effect as in Eaton and Kortum (2002). This specification matches prices of tradable goods and income difference across countries more closely to the data than under importing country effect. We have

$$\log(\tau_{1,ij}) = d_k + b_{ij} + ex_{1,j} + \varepsilon_{1,ij}$$

d_k captures distance effect. d_k with $k = 1, 2, ..., 6$ is dummy variable when distance between capital cities of involved in trade falls into following intervals: [0, 375); [375, 750); [750, 1,500); [1,500, 3,000); [3,000, 6,000); [6,000, maximum) in miles. $b_{ij} = 1$ if countries share a border. $ex_{1,j}$ is exporting country effect. It captures trade costs of exporting 1st stage good specific to country j.

We need to jointly estimate $2 \times N$ technology parameters ($A_{1,i}$, $B_{1,i}$) and $2 \times (N+7)$ coefficients on trade costs function, fitting $2 \times N(N-1)$ bilateral trade shares $\frac{X_{ij}}{X_{ii}}$ at each stage. Given trade costs structure, $\hat{S}_{1,i}$s are estimated as a coefficient on country specific dummy variable. We can also estimate $\hat{\tau}_{1,ij}$s using OLS. Once we have estimated values of $\hat{S}_{1,i}$ and $\hat{\tau}_{1,ij}$, we recover estimated aggregate price of first stage good.

$$\hat{P}_{1,i} = \gamma_1 \left\{\sum_{j=1}^{N} e^{\hat{S}_{1,j}}\left(\hat{\tau}_{1,ij}\right)^{-1/\theta}\right\}^{-\theta} \tag{1.15}$$

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The log ratio of exports for the second stage is

$$\ln\left(\frac{X_{2,ij}}{X_{2,ii}}\right) = S_{2,j} - S_{2,i} - \frac{1}{\theta}\ln\left(\tau_{2,ij}\right) \tag{1.16}$$

where $S_{2,i} = \ln\left\{\left[(P_{1,i})^{\kappa(1-\beta_2)}(P_{2,i})^{(1-\kappa)(1-\beta_2)}\left(r_i^{\alpha}w_i^{1-\alpha}\right)^{\beta_2}\right]^{-1/\theta}A_{2,i}\right\}$.

Trade costs for the second stage has same structure to the first stage except that exporting country effect may have different cost at this stage compared to the first.

$$\ln(\tau_{2,ij}) = d_k + b_{ij} + ex_{2,j} + \varepsilon_{2,ij}$$

Similar to the first estimation, we can estimate values of $\hat{S}_{2,i}$ and $\hat{\tau}_{2,ij}$. Estimated aggregate price of the second stage goods is

$$\hat{P}_{2,i} = \gamma_2\left\{\sum_{j=1}^{N} e^{\hat{S}_{2,j}}\left(\hat{\tau}_{2,ij}\right)^{-1/\theta}\right\}^{-\theta} \tag{1.17}$$

Given the $\hat{P}_{1,i}$s from (1.15), we recover technology parameters $A_{1,i}$ for each country from the estimates of $\hat{S}_{1,i}$. Both $\hat{P}_{1,i}$s and $\hat{P}_{2,i}$ are used when we estimate $A_{2,i}$ from the estimates $\hat{S}_{2,i}$. Prices $P_{1,i}, P_{2,i}, w_i, r_i$ are functions of technology parameters and trade costs. Implied prices from estimated technology parameters and trade costs should be consistent with trade balance condition, (1.13). The step-by-step estimation scheme is detailed in appendix A.2.

1.4. Estimation Results

Model's fit on relative trade shares in terms of R^2 are 0.77 for stage 1 and 0.82 for stage 2. Country specific estimates are provided in the appendix A.3.
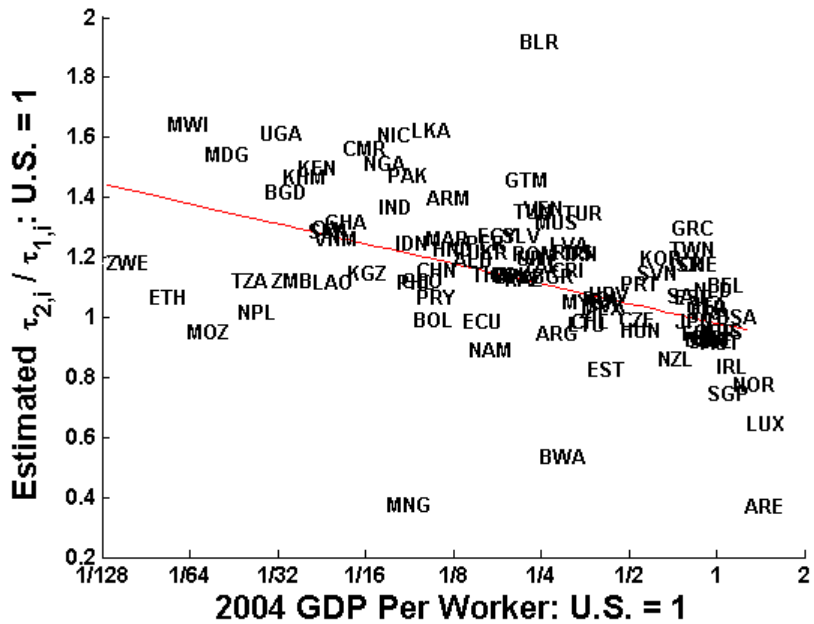
Figure 1.2.: Difference in median exporting cost between stage 1 and stage 2

1.4.1. Baseline Results

Poor countries are facing high cost for exporting goods compared to rich countries. Poor countries face even higher disadvantage in exporting stage 2 good than exporting stage 1 good. Correlation between exporter fixed effect and income per worker for stage 1 is -0.6. This negative correlation is stronger for stage 2, which is -0.74. Figure 1.2 illustrates the difference in median exporting cost between stage 1 and stage 2 for each country. Difference in exporting cost between stage 1 and 2 is narrow for rich countries. Rich countries have lower exporting cost in stage 2 good than stage 1 good. It is opposite case for the poor countries. The difference between the poor and the rich in estimated trade costs at each stage is even larger when we define tradable goods as manufactured goods.

Table 1.2 reports estimates on distance parameter d_k. The percentage effect on trade costs increases in geographic distance. Estimated trade costs are consistent with results with those in Waugh (2010). Note that trade costs effect on stage 1 good is more elastic to geographic barriers than the stage 2 good.

Geographic barriers	Stage 1		Stage 2	
Distance in miles	Parameter	% effect on trade costs	Parameter	% effect on trade costs
[0, 375)	-4.76 (0.13)	138	-5.21 (0.12)	158
[375, 750)	-5.72 (0.08)	183	-6.13 (0.07)	205
[750, 1,500)	-6.57 (0.05)	230	-6.70 (0.05)	238
[1,500 3,000)	-7.37(0.04)	282	-7.48 (0.04)	290
[3,000, 6,000)	-8.39 (0.02)	360	-8.44 (0.02)	364
[6,000, maximum)	-9.13 (0.03)	426	-9.02 (0.03)	415
Shared border	1.45 (0.11)	-23	1.39 (0.10)	-22

Table 1.2.: Estimation Results: Std. errors are reported in parenthesis.

1.4.2. Implications on Aggregate Trade Volume

Total imports relative to GDP in country i implied by the model is

$$\left[\frac{1-\nu}{1-(1-\beta_2)(1-\kappa)}\right]\left[\frac{(1-\beta_2)\kappa}{\beta_1}(1-X_{1,ii})+(1-X_{2,ii})\right].$$

Similar equation is derived in Alvarez and Lucas (2007). Figure 1.3 (a) plots trade share, in this case, $\frac{\text{imports+exports}}{2*GDP}$, over share of total income in the world. Trade shares have inverted U shape over share of total income. Alvarez and Lucas (2007) provide the same figure. In that figure, trade shares declines over share of total income since their data coverage is short of relatively poor and small economies. Fieler (2011) covers more countries and argues that standard Eaton and Kortum (2002) model under-estimates trade share, in this case, $\frac{\text{imports+exports}}{2*GDP}$ over share of total income in the world or over income per worker. Figure 1.3 (b) plots share of trade over share of total income, implied by model. Our model replicates pattern and volume of trade close to the data. Trade shares are much variant as in the data and show similar pattern while trade shares of many countries are over-estimated. Figure 1.4 plots the same trade shares over income per worker. Model clearly delivers increasing trade share over income per worker as in the data. Under given homothetic preference, these results are driven by having fixed effect of trade costs on exporters and allowing intermediate inputs. Estimated trade costs include not only trade costs incurred to deliver goods from i to j but also trade costs embodied in imported intermediate inputs to produce the goods.

(a) Data

(b) Model
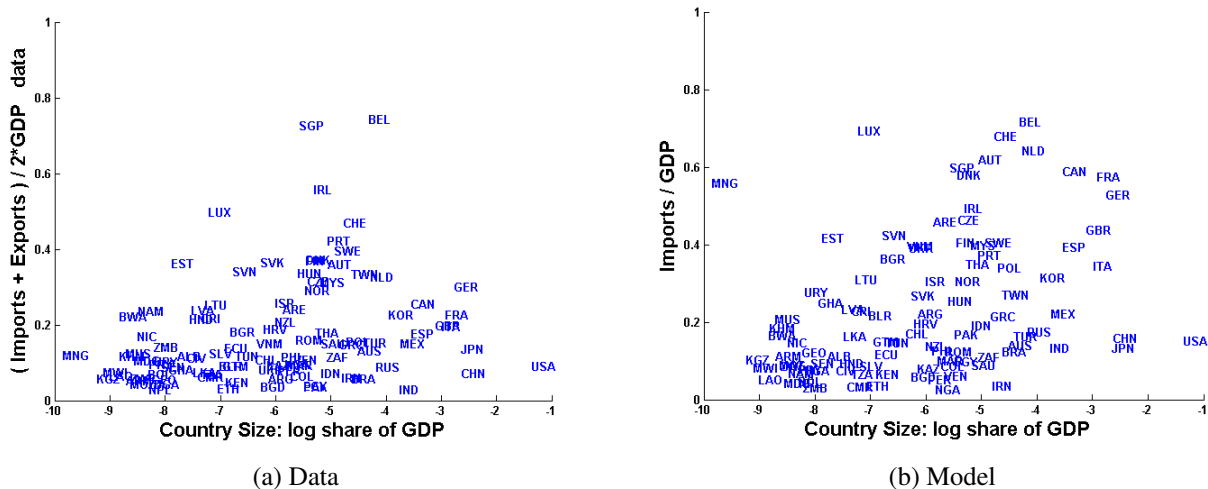
Figure 1.3.: Trade share over share of GDP

Thus, trade costs have amplified effects on trade volume through the use of intermediate inputs. Vertical specialization is hindered by high trade barriers that most poor countries face.

Figure 1.5 depicts each country's share of trade with the rich. Fraction of each country's trade with any 21 richest countries among its total trade is plotted over income per worker. Observation implied by model (hollow dot) and data (asterisks) expose increasing relation in this ratio. Rich countries choose other rich countries as their trade partners.

Besides of aggregate trade volume of all tradable goods, data on aggregate trade volume on stage 1 goods and stage 2 goods reveal a pattern. Rich countries import stage 2 goods more than stage 1 goods relative to poor countries. Correlation coefficient between (stage 1 imports / stage 2 imports) and relative income per worker is -0.49 in the data. My model implies that relative imports between stages is $\frac{(1-\beta_2)\kappa}{\beta_1} \cdot \frac{(1-X_{1,ii})}{(1-X_{2,ii})}$. Model yields the correlation coefficient between (stage 1 imports / stage 2 imports) and relative income per worker as -0.40. Standard trade models would predict this correlation to be at 0. Figure 1.6 shows model implied relative stage 1 imports to stage 2 imports over income per worker. Model correctly captures the pattern that poor countries' second stage import to first stage import is lower than the rich countries'. Admittedly, model predicts higher relative imports between stages for many poor countries than the data.

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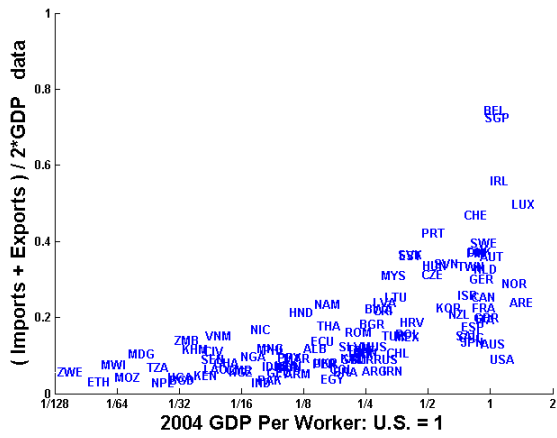
(a) Data
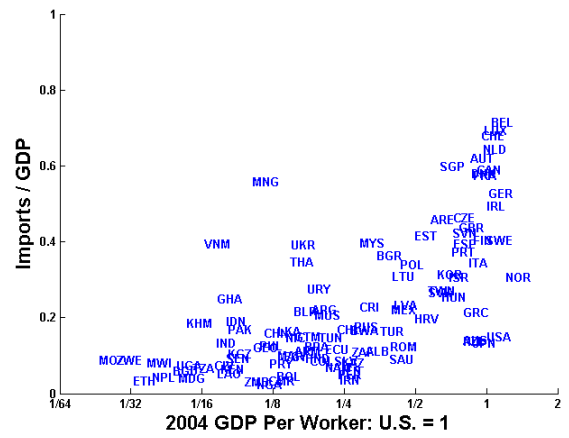
(b) Model

Figure 1.4.: Trade share over GDP per worker
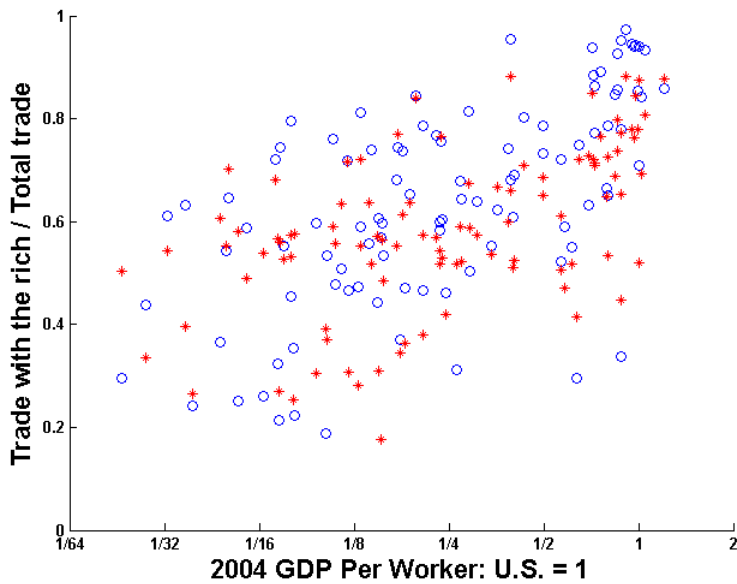
Figure 1.5.: Trade with the rich over total trade: * (Data), ○(Model)

21
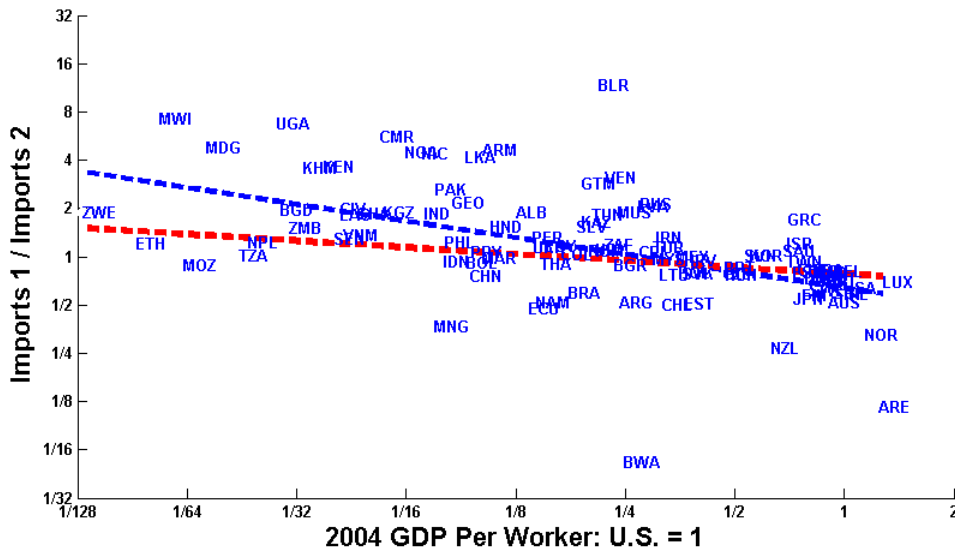
Figure 1.6.: Stage 1 imports over stage 2 imports: Red (Data), Blue (Model)

1.4.3. Implications on Prices and Income Differences

Equipped with estimated parameters on technology level and trade costs, I compute model implied
equilibrium on aggregate price of tradable goods at each stage as well as income per worker across
countries. These are non targeted moments. Data on price of tradable goods are from United Na-
tions International Comparison Program (ICP). We use benchmark year 2005 of price data which
is the closest to our data year 2004. Their targeted goods for collection of prices cover foods,
beverages, clothing, footwear, machinery and equipment. These goods are more relevant to final
consumption good which is second stage good in my model. I use same method as in Waugh
(2010) to construct price indices of tradable goods.[4] Figure 1.7 plots aggregate price of goods at
each stage against income per worker. Fitted line for price of tradable goods for 2005 data is up-
ward sloping and shown in red dotted line. In the data, price elasticity with respect to income level
is 0.174. Poor countries face lower price of tradable goods than rich countries. From the model,
aggregate price of stage 1 good has elasticity of -0.002. Price elasticity of stage 2 good is 0.071.
This model delivers better fit on the tradable goods as the elasticity is positive. Prices implied by

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[4]From ICP data source, Waugh (2010) uses prices of goods which fits to the bilateral trade data. There are countries
that are not included in the benchmark 2005 year price data. The prices for those countries are imputed using the
price of consumption and the price of investment in the Penn World Table.

model also show much variance as in the data. Model improves on matching aggregate price by taking account the effect of multiple stages of production. When we derive elasticity on aggregate tradable goods without distinguishing goods into stages as in Waugh (2010), the elasticity is 0.006.

On variation in income per worker, model performs well in replicating data. Data and model's income levels lie close to 45 degree line as shown in Figure 1.8. However, model underpredicts income per worker for many rich countries and overpredicts income per worker for some poor countries. Note that there is no technology difference in service sector across countries in our model. Log variance of income per worker is 1.57 in data and 1.07 implied by model. Difference income per worker between the 90th percentile and 10th percentile, captured by percentile ratio, is 27.1 in data and 14.9 implied by model.

1.5. Gains from Trade

Difference in technologies, endowments and trade costs determine integration patterns across countries at each stage. Trade costs prevent a country in specializing in its comparative advantage not only across tradable goods but also across stages of production. In this section, I study implied cross-country differences in gains from trade stemming from different levels of trade openness at each stage.

1.5.1. Gains from Trade in the Two Stage Model

Following Waugh (2010), real output per worker is represented as standard growth model functional form of physical and human capital with technology parameter A_i:

$$y_i = A_i (k_i)^\alpha (h_i)^{1-\alpha}$$

23
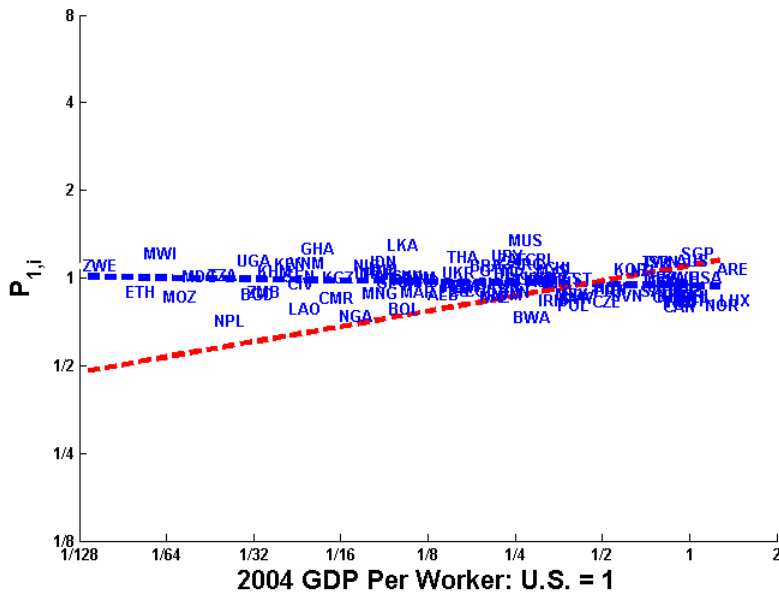
(a) Aggregate price of stage 1 good over GDP per worker.
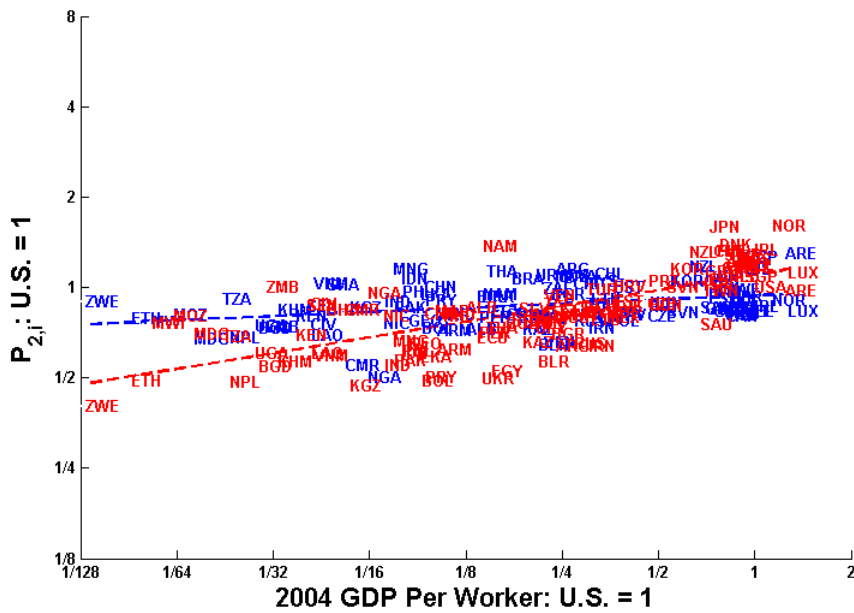
(b) Aggregate price of stage 2 good over GDP per worker.

Figure 1.7.: Aggregate price at each stage: Red (Data), Blue (Model)

24
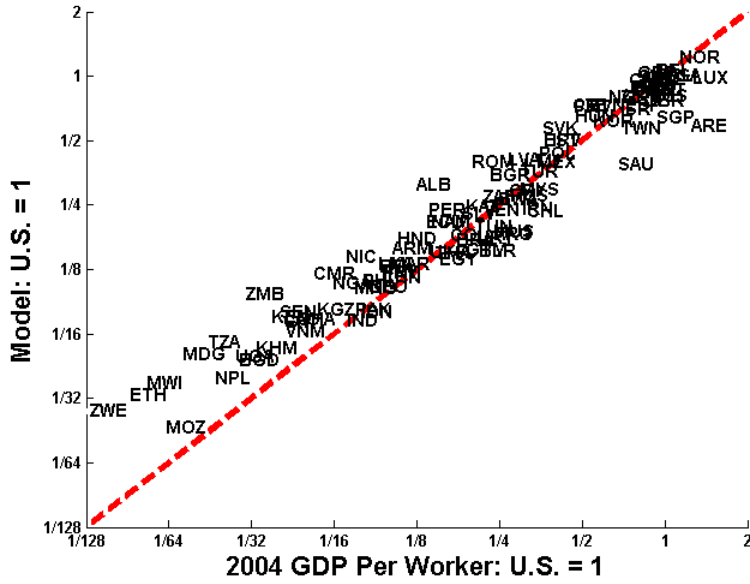
Figure 1.8.: GDP per worker implied by model over Data

with aggregate TFP

$$A_i = \kappa \left(\frac{A_{1,i}}{X_{1,ii}}\right)^{\frac{\kappa\theta(1-\beta_2)(1-\nu)}{\beta_1\{1-(1-\kappa)(1-\beta_2)\}}} \left(\frac{A_{2,i}}{X_{2,ii}}\right)^{\frac{\theta(1-\nu)}{\{1-(1-\kappa)(1-\beta_2)\}}}$$

Home trade shares as well as technology level at both first and second stages affect the TFP term A_i. Power terms on technology and home trade shares reflect input-output structure relevant to the two stage production. Gains from trade is captured in the home trade shares with associated power terms. When there is any change in trade costs from $\tau \equiv \{\tau_{ij}\}$ to $\tau' \equiv \{\tau'_{ij}\}$, home trade shares at each stage will move from $X_{1,ii}$ (and $X_{2,ii}$) to $X'_{1,ii}$ (and $X'_{2,ii}$) endogenously. Welfare costs or gains are measured by the change in the real income, y'_i/y_i. Thus, welfare costs or gains associated with any change in trade costs are measured by

$$\left(\frac{X_{1,ii}}{X'_{1,ii}}\right)^{\frac{\kappa\theta(1-\beta_2)(1-\nu)}{\beta_1\{1-(1-\kappa)(1-\beta_2)\}}} \left(\frac{X_{2,ii}}{X'_{2,ii}}\right)^{\frac{\theta(1-\nu)}{\{1-(1-\kappa)(1-\beta_2)\}}} \tag{1.18}$$

Specialization in each stage contributes to the gains from trade.

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When there is no distinction between the two stages of production, the model is nested into Waugh (2010).[5] Production function in one stage model is given by

$$q_i(x) = (z_i(x))^{-\theta} [Q_i(x)]^{1-\beta} \left[(k_i(x))^{\alpha} (h_i(x))^{1-\alpha} \right]^{\beta}$$

where $Q_i = \left(\int_0^1 q(x)^{\frac{\eta-1}{\eta}} \phi(x) dx \right)^{\frac{\eta}{\eta-1}}$ is the aggregate good where $q(x)$ is country i's consumption of good $q_i(x)$. Final good production technology is $y_i = \left[Q_i^f \right]^{1-v} \left[\left(k_i^f \right)^{\alpha} \left(h_i^f \right)^{1-\alpha} \right]^{v}$. Implied aggregate TFP in this model becomes

$$\bar{A}_i = \kappa \left(\frac{A_i}{X_{ii}} \right)^{\theta(1-v)/\beta}$$

where X_{ii} is home trade share of total tradable goods. β is the value added in aggregate goods (both first stage and second stage goods) over gross output. β is 0.33.

In a model without stages, welfare costs or gains associated with any change in trade costs are measured by $\left(\frac{X_{ii}}{X_{ii}'} \right)^{\frac{\theta(1-v)}{\beta}}$. Even though we allow additional margin of specialization in stages, multi-stage production per se does not necessarily imply larger gains from trade, i.e., when countries are endowed with identical technology level and trade costs in both stages, implied gains from trade associated with change in trade costs are identical to implied gains obtained from a standard model with tradable intermediate goods but without stages. Thus, multi-stage nature of production per se does not deliver higher magnification effect of trade costs than one stage models.

To quantify effects of trade costs on differences in gains from trade across countries, we turn to counterfactual experiments in the following section.

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[5]From my model, set technology parameters at each stage,$A_{1,i} = A_{2,i}$, bilateral trade costs, $\tau_{1,ij} = \tau_{2,ij}$, the same across stages. Set value added shares across stages $\beta_1 = \beta_2$ the same. Additionally, only first stage goods are used as intermediate input for production of stage 2 goods, $\kappa = 1$. Then, model is nested into the model of Waugh (2010).

1.5.2. Quantitative Effects of Trade Costs on Gains from Trade

Trade barriers affect pattern of specialization and allocation of factors. When one country's economy is closed due to high trade barriers, the country can not benefit from specialization across countries. We perform counterfactual exercises to illustrate the effects of trade costs on gains from trade across countries. In one extreme, economies move to autarky where all countries produce and consume by themselves. The other extreme is to move to free trade where all goods are traded without any trade costs. Estimated technologies at each stage are used for all the counterfactual exercises.

When any country is in autarky, its home trade shares, $X_{1,ii}$, and $X_{2,ii}$, at each stage will be equal to 1. Welfare costs of a country, expressed as percentage change in real income, moving from the observed economy to the autarky state is

$$(X_{1,ii})^{\frac{\kappa\theta(1-\beta_2)(1-v)}{\beta_1\{1-(1-\kappa)(1-\beta_2)\}}} (X_{2,ii})^{\frac{\theta(1-v)}{\{1-(1-\kappa)(1-\beta_2)\}}} - 1$$

Each country's welfare costs of autarky range from 1 to 50. The welfare costs of autarky are larger for the rich countries than the poor countries. The results are reported in table 1.3. Median welfare costs for the 10 richest countries are 17.1 percent. The welfare costs are 5.7 times larger than the welfare costs of the U.S. For the 10 poorest countries, welfare costs account just 40 percent of the U.S. welfare costs. The welfare costs of autarky is small for the 25 poorest countries as well. Welfare costs are more variant across countries than the welfare costs measured with one stage model. The log variance of welfare costs across countries is 32 percent larger than the log variance of welfare costs implied by one stage model.

I perform other exercises by moving economies to autarky state at each stage to disentangle the effects of trade costs at each stage on the welfare costs. When trade is prevented in specific stage, the other stage good is traded with estimated trade costs. For example, third column of table 1.3 reports median welfare costs for income groups when the first stage goods trade costs are raised to

Income per worker	Complete autarky $\tau_{1,ij} = +\infty,$ $\tau_{2,ij} = +\infty$	1st stage autarky $\tau_{1,ij} = +\infty,$ $\tau_{2,ij} = \hat{\tau}_{2,ij}$	2nd stage autarky $\tau_{1,ij} = \hat{\tau}_{1,ij},$ $\tau_{2,ij} = +\infty$
First decile	-17.1 (5.7)	-7.0 (5.2)	-11.0 (5.9)
First quartile	-10.8 (3.6)	-4.7 (3.5)	-6.9 (3.7)
Last quartile	-1.7 (0.6)	-1.0 (0.7)	-0.8 (0.4)
Last decile	-1.3 (0.4)	-0.7 (0.5)	-0.6 (0.3)

Note: Each column reports median change in real income, *y*, (percent) of countries in the 90th, 75th, 25th and 10th percentile of real income per worker for each counterfactual trade costs scenario. Numbers in the parentheses reports the median change in real income, *y*, of countries in each percentile relative to the change in real income of the U.S.

Table 1.3.: Welfare costs of autarky

infinite. In this case, second stage goods are traded with the estimated costs, For the rich countries, two-thirds of the welfare costs are accounted for by second stage trade. Poor countries' small gains from trade are accounted almost entirely by first stage trade. From these exercises, we learn that rich countries have benefitted from trade in intermediate goods, particularly in the second stage. Welfare costs of autarky are high for these countries since they have low trade barriers.

In the second scenario, we study how much gains from trade change when we eliminate any trade costs. We can measure gains from trade by equation (1.18). Table 1.4 provides the results. Estimated gains from trade are much larger for the poor countries than the rich countries. Poor countries face high trade barriers in any stages. By removing these trade barriers, their gains from trade is relatively larger than the rich countries' gains. In complete free trade scenario, income differences shrink up to 21 percentage in log variance in income per worker and to 25 percentage in 90/10th percentile income ratio.

Second and third column of table 1.4 report gains from trade when specific stage goods are freely traded while the other stage goods are traded at the estimated trade costs. Trade at each stage goods is quantatively important to account for difference in gains from trade. The effect of second stage good trade on gains from trade is around 1.5 times larger than the effect of first stage good trade for the 10 or 25 poorest countries. Trade in stage 2 goods are quantatively more important since trade in stage 2 brings more demand of goods from both stages. Moreover, poor countries face

Income per worker	Complete free trade $\tau_{1,ij} = 1,$ $\tau_{2,ij} = 1$	1st stage free trade $\tau_{1,ij} = 1,$ $\tau_{2,ij} = \hat{\tau}_{2,ij}$	2nd stage free trade $\tau_{1,ij} = \hat{\tau}_{1,ij},$ $\tau_{2,ij} = 1$
First decile	43.3 (1.5)	17.5 (1.0)	24.2 (1.2)
First quartile	65.4 (2.2)	28.4 (1.7)	28.3 (1.4)
Last quartile	133.0 (4.5)	53.1 (3.1)	81.8 (3.9)
Last decile	139.7 (4.7)	59.8 (3.5)	87.0 (4.2)

Note: Each column reports median change in *y* (percent) of countries in the 90th, 75th, 25th and 10th percentile of real income per worker for each counterfactual trade costs scenario. Numbers in the parentheses reports the median change in real income, *y*, of countries in each percentile relative to the change in real income of the U.S.

Table 1.4.: Welfare gains of free trade

higher disadvantage in exporting and importing 2nd stage goods. By removing this disadvantage, poor countries benefit more from trading stage 2 goods than trading stage 1 goods.

Through these exercises, we decomposed the gains from trade. Both scenarios remove asymmetry in trade costs across countries. We found that current asymmetry in trade costs benefitted the rich more than the poor. Gains from trade is measured by negative exponential term over home trade share X_{ii} at each stage. The smaller home trade share, the bigger gains from trade. Removing asymmetries in trade costs allows poor countries' home trade shares change relatively more than rich countries. Trade in the second stage goods plays bigger role in both scenarios since existent asymmetry in trade costs is larger for trade of the second stage goods.

1.6. Value Added Trade and Gains from Trade

In the previous section, we analyzed effects of trade costs in income across countries by changing trade costs in all countries simultaneously. In this section, we study the change in real income of a country associated with any change in trade costs of this country with any other countries. Implications on gross trade, valued added trade, and welfare under stages of production process are different from ones implied by a model without stages.

Trade in intermediate goods creates vertical linkages across countries. For example, Chinese ex-

ports to the U.S. contain value of intermediate goods originated from Korea. When trade costs between China and the U.S. is lowered, it may benefit specific countries, e.g. Korea and Japan, more compared to other countries. The difference comes from the degree in which country is more tied to China in vertical linkages of production process at each stage. Johnson and Noguera (2011) compute value added (domestic) content of bilateral trade using input-output and bilateral trade data from same data source as in this paper. They provide a framework to track value added via multi-country production chain. We can apply the framework to Eaton and Kortum (2002) type of models to decompose aggregate value added into bilateral value added flows. Benefit of applying this method to general equilibrium models is that we can study changes in bilateral value added content and gross exports in response to any change in trade barriers. Moreover, we can compare degree of production sharing across countries by using the ratio of value added content over gross trade.

1.6.1. Value Added Trade versus Gross Exports

Value added content from country j to i at each stage is denoted by $va_{s,ij}$ for $s = \{1,2\}$. Total value added produced in j and absorbed in i is $va_{ij} = va_{1,ij} + va_{2,ij}$. When we sum up all value added content in the tradable goods originated from country i to all countries, it should be equal to tradable goods share of GDP. Thus, $\sum_j va_{ji}/L_i p_i y_i = 1 - v$. The method to compute bilateral value added content is explained in the appendix A.4.

Johnson and Noguera (2011) defines bilateral value added to gross export ratio as "VAX" ratio to capture degree of vertical specialization. Bilateral VAX ratio is defined as va_{ij}/x_{ij}. VAX ratio at each stage is $va_{s,ij}/x_{s,ij}$ for $s = \{1,2\}$. Aggregate VAX ratio in country i is $\sum_{j \neq i} va_{ji}/\sum_{j \neq i} x_{ji}$. Johnson and Noguera (2011) reports this ratio over 94 countries. They use more detailed input-output table for 57 sectors which include service. Thus, my model to capture value added content is parsimonious compared to their method. When I regressed aggregate VAX ratios for matched 88 countries with the ratios reported in Johnson and Noguera (2011), the slope coefficient was 0.6
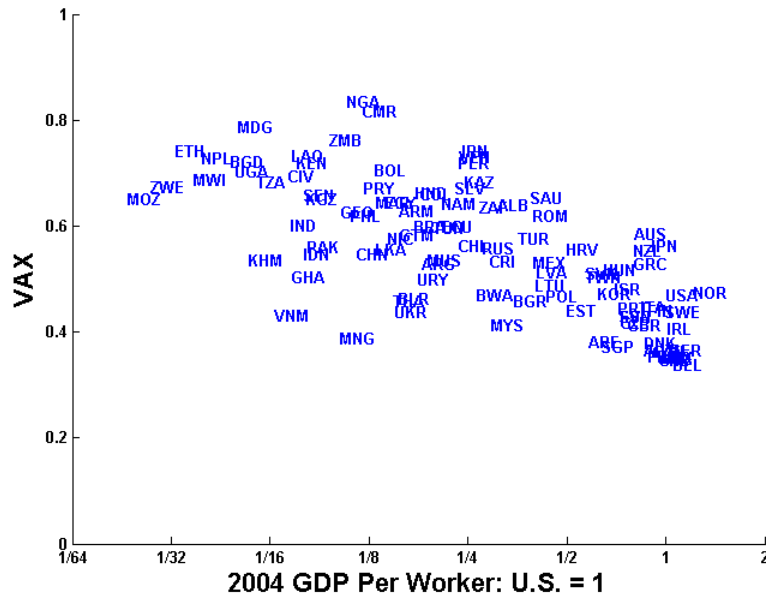
Figure 1.9.: VAX ratios

and significant. R-square was 0.32. Analysis based on this model is limited in the sense that model captures vertical production linkages across countries with simple two stages. Figure 1.9 plots aggregate VAX ratio for each country over GDP per worker. We can find decreasing relationship in the VAX ratios (increasing in degree of vertical specialization) with GDP per worker. This relation is much stronger at the first stage. Aggregate VAX ratios at each stage are shown in Figure 1.10. Rich countries have high degree of vertical specialization at both stages.

We inspect difference in vertical specialization pattern between the rich and the poor by plotting bilateral VAX ratios of selected countries. Figure 1.11 and 1.12 plots bilateral VAX ratios, va_{ji}/x_{ji} for all $j \neq i$, for country i. Selected countries represent general pattern of specialization of other countries with similar income per worker.

Bilateral VAX ratios for each country to all other trade partners show different patterns in production sharing and trade for the rich and the poor. Figure 1.11 (a) and (b) plots bilateral VAX ratios at stage 1. For rich countries, bilateral VAX ratios across countries are slightly decreasing in income per worker. Bilateral VAX ratio, va_{ji}/x_{ji}, tends to be low when goods made in j using inputs from country i are exported back to country i or other third countries and made into final goods. Rich

(a) Stage 1   (b) Stage 2
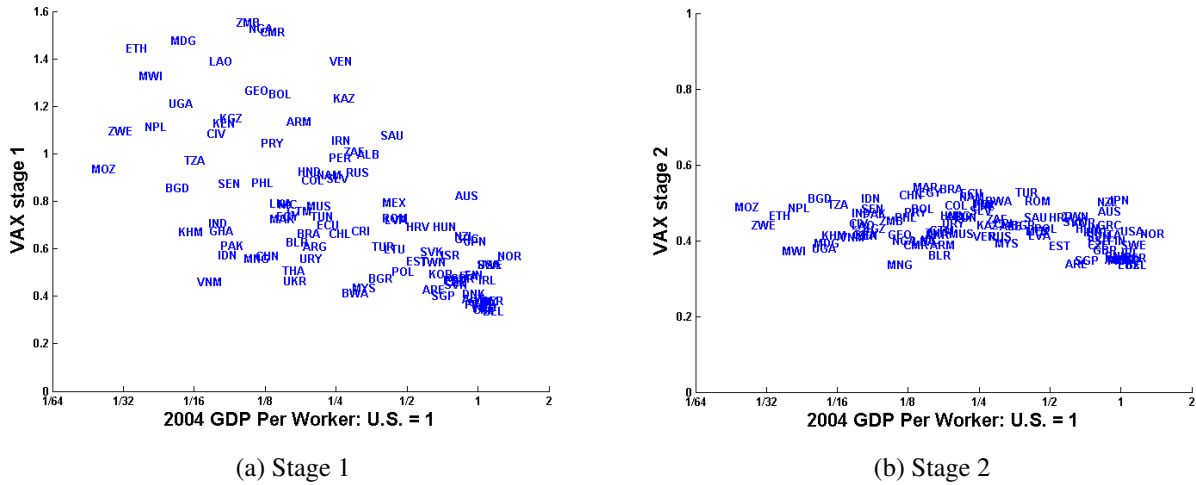
Figure 1.10.: VAX ratios at each stage

countries engage in this type of trade with the other rich, leading to have low VAX ratios. For poor countries, bilateral VAX ratios across countries are increasing in income per worker. Bilateral VAX ratio tends to be high when country j uses third country good which embeds value of inputs from country i to make final consumption good in j. Poor countries' goods are consumed indirectly in rich countries as its value is embedded in rich countries' consumption of goods from the third countries.

Bilateral VAX ratios at stage 2 are shown in Figure 1.12 (a) and (b). The VAX ratios are decreasing in income per worker with higher degree for the rich than the poor. Rich countries goods are consumed in the poor indirectly.

Low bilateral VAX ratios at both stages among rich countries demonstrate that rich countries are more tightly linked in vertical specialization production process.

1.6.2. Effects of Trade Costs on Value Added, Gross Exports, and Welfare

We quantify effects of trade costs in two different cases. We lower bilateral trade costs for country pairs with the U.S. while costs for all other pairs remain fixed in the first case. This case is meant

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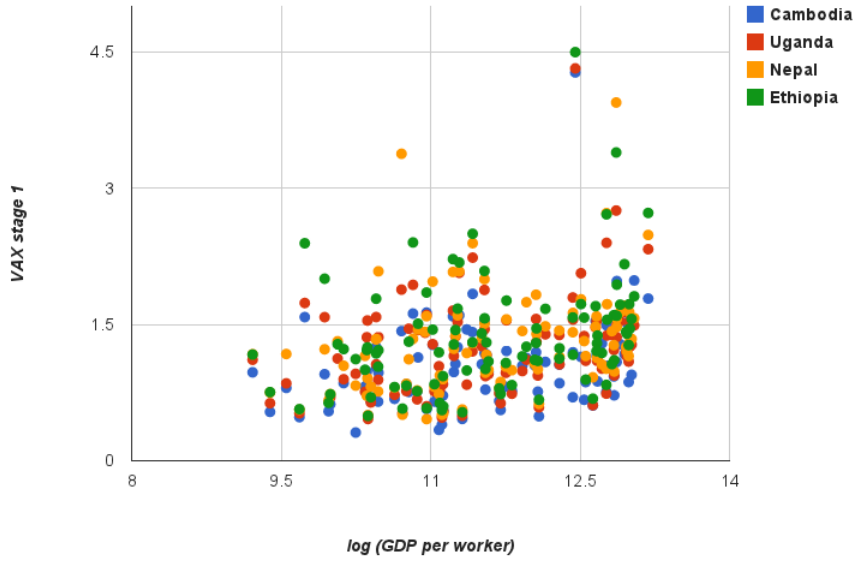
(a) Stage 1 VAX Ratios for selected poor countries
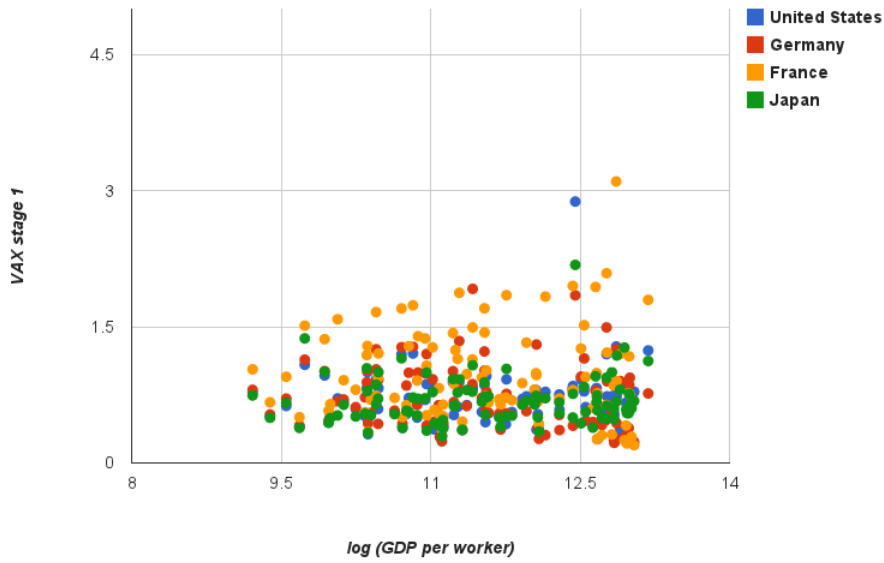
(b) Stage 1 VAX Ratios for selected rich countries

Figure 1.11.: Stage 1 Bilateral VAX ratios for selected countries
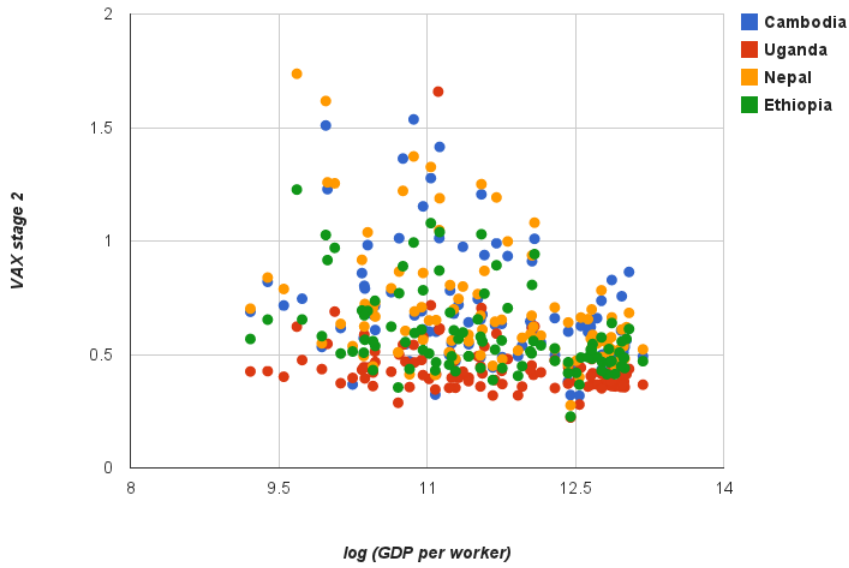
(a) Stage 2 VAX Ratios for selected poor countries
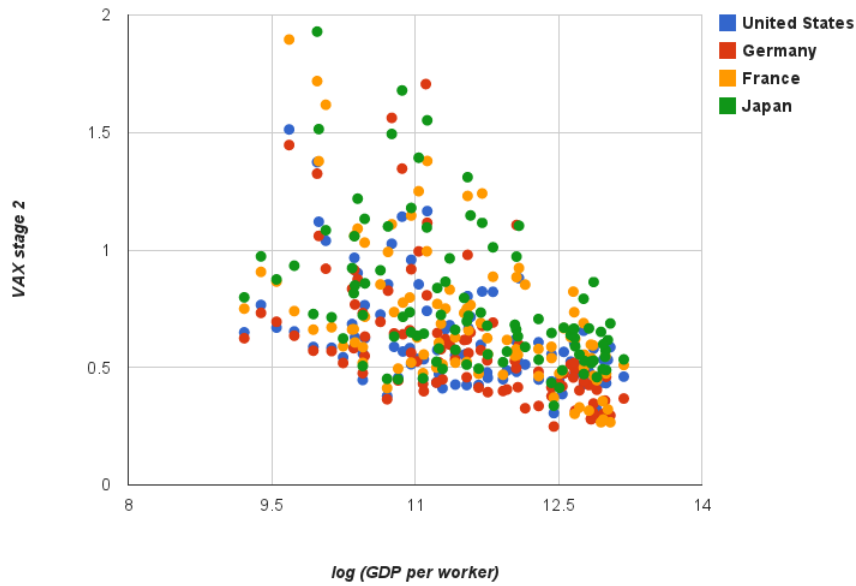
(b) Stage 2 VAX Ratios for selected rich countries

Figure 1.12.: Stage 2 Bilateral VAX ratios for selected countries

to capture effect of bilateral trade agreement. In the other case, we decrease trade costs of each country when trade costs of all other country do not change except the trade costs to the country. Lowering tariff in general, getting into WTO, or improving infrastructures are related to this scenario.

Lowering in Bilateral Trade Costs

We lower exporting cost of country i to the U.S. by 20 percent. Elasticity of value added and gross exports are measured as $\varepsilon_{us,i}^{va} \equiv \partial \ln(va_{us,i}/va_{us,us})/\partial \ln(\tau_{us,i})$ and $\varepsilon_{us,i}^{x} \equiv \partial \ln(x_{us,i}/x_{us,us})/\partial \ln(\tau_{us,i})$ respectively. Elasticity of a variable is percentage change in the relative value from country i to the U.S. related to 20 percent drop in i's exporting cost to the U.S. These elasticities are reported in the first and second columns of appendix table A.5. Elasticity of value added is smaller than elasticity of gross exports. $\varepsilon_{us,i}^{va}/\varepsilon_{us,i}^{x}$ varies much across countries which number ranges from 0.3 to 0.8. Change in value added content of trade between country i and the U.S. can not be measured simply by calculating change in gross export value. When we measure same elasticities in a model without stages, elasticity of gross exports is around 35 percent larger for each countries. Moreover, elasticity of value added are lower in the model without stages. Difference varies from 8 to 98 percent across countries. Compared to the model without stages, our model implies more increase in value added and less increase in gross exports to the U.S. when trade costs to the U.S. is lowered. Changes in value added for each country are much more variant in our model than what standard model predicts.

Cross elasticity of value added and gross exports are $\varepsilon_{us,j}^{va} \equiv \partial \ln(va_{us,j}/va_{us,us})/\partial \ln(\tau_{us,i})$ and $\varepsilon_{us,j}^{x} \equiv \partial \ln(x_{us,j}/x_{us,us})/\partial \ln(\tau_{us,i})$ for any $j \neq i$. $\varepsilon_{us,j}^{x} < 0$ while $\varepsilon_{us,j}^{va}$ can be positive for some j. Gross exports of all countries to the U.S. increases when trade costs of country i decreases. Value added content of trade to the U.S. may decrease for some countries. Changes in these values depend on production linkage across countries as well as proximity in distance of other countries to country i.

Gains from lowered trade costs is measured by change in real income. Estimated changes in real income of each country are reported in the third column of appendix table A.5. The fourth column reports results from a model without stages for comparison. Each country benefits from lowering exporting cost to the U.S. However, when country i's exporting cost to the U.S. is lowered, real income of other countries $j \neq i$ may increase or decrease depending on production linkages. My model captures these linkages better than the model without stages. For instance, when exporting cost of China to the U.S. is lowered, real income increases in Japan according to our model while model without stages predicts decrease in real income.

Lowering in Multilateral Trade Costs

We focus on the welfare effects of lowering multilateral trade costs of each country. When we lower both importing and exporting trade costs of a country by 20 percent while all other trade costs remain unchanged, every country benefits with different magnitude of gains. Equation (1.18) is used to measure gains from trade. The fifth column of appendix table A.5. reports welfare gains from trade as the percentage change in real income. Results from one stage model are reported in the sixth column. Welfare gains in the one stage model is measured by $(X_{ii}/X'_{ii})^{\frac{\kappa\theta(1-\beta_2)(1-\nu)}{\beta_1\{1-(1-\kappa)(1-\beta_2)\}} + \frac{\theta(1-\nu)}{\{1-(1-\kappa)(1-\beta_2)\}}}$. One stage model predicts larger gains from lowering trade costs for most countries than our model.

The difference of gains from trade between the two models comes from different pattern of changes in home trade shares at each stage. Gains from trade is calculated as product of gains from trading first stage good $\left(X_{1,ii}/X'_{1,ii}\right)^{\frac{\kappa\theta(1-\beta_2)(1-\nu)}{\beta_1\{1-(1-\kappa)(1-\beta_2)\}}}$ and second stage good $\left(X_{2,ii}/X'_{2,ii}\right)^{\frac{\theta(1-\nu)}{\{1-(1-\kappa)(1-\beta_2)\}}}$. Change in home trade share associated with lowering trade costs is higher when initial trade costs is lower. Estimated trade costs of stage 2 goods are higher than the trade costs of stage 1 goods for most poor countries. When trade costs at each stage are lowered, home trade share of the second stage goods drops less than the home trade share of the first stage goods. These deviation of the changes in home trade shares lessens effect on aggregate gains from trade compared to standard models.

In contrast to this scenario, when we raise trade costs of a country by 20 percent, estimated loss due to closing its economy is larger for many developed countries compared to loss estimated from standard models. These countries have lower trade costs in stage 2 goods than stage 1 goods. [6]

1.7. Conclusion

To conclude, when we distinguish goods following its main end use to capture vertical production linkages across countries, we find poor countries have high barriers on goods used in producing final consumption goods. Poor countries are much less vertically integrated compared to rich countries. The results imply that trade barriers not only reduce trade flows but hinder countries from integrating in the production linkages created through intermediate goods trade. Measured gains from trade is positively correlated to the level of income per labor. Rich countries benefited more from intermediate goods trade. When we estimate gains from trade of a country lowering its trade barriers, our model predicts lower gains from trade for many countries than gains implied by standard models. This implies that considering production linkages are important when we evaluate trade policy implications. Even though trade costs are not directly obtained from data but estimated from trade and production data, we find quantitatively important role of trade friction on welfare through linkages created by trade of intermediate goods.

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[6]I omit results on estimated loss for each country associated with increased trade costs due to space limit but available upon request.

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2. Chapter 2: Trade, Misallocation, and Sectoral Productivity: Evidence from China

2.1. Introduction

Recent literature find that misallocation of factors across heterogeneous firms impacts negatively on total factor productivity (TFP). They find that extent of misallocation is much larger for many developing countries compared to the U.S. Aggregate TFP in those countries are low in large part due to the misallocation. Thus, reducing misallocation of resources can result in large TFP gains. Various market-oriented reforms such as opening to international market, allowing foreign investment, reforming financial market, privatizing state-owned firms among others can lead to more efficient allocation of resources across firms. Such reforms can benefit developing countries where the TFP loss from distortions are relatively severe. In this paper, I study trade liberalization as a source of reducing misallocation across firms, thus leading to TFP growth. Important role of trade comes from inducing better market selection. Misallocation is reduced on the extensive margin by forcing out less competitive and more distorted firms and replacing those with more competitive firms. Individual firms face more competitive market condition when import tariffs are lowered. Marginal firms with relatively low productivity or high distortion are likely to exit when they face tighter demand.

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Studies have shown that firm's entry and exit process has substantial quantitative effect on TFP growth for countries including the U.S.. Brandt, Van Biesebroeck and Zhang (2012) find that net entry accounts for over two thirds of total TFP growth for manufacturing in China between 1998 and 2007. They estimate that the TFP growth is of 13.4% per annum during the period. Given that the entry and exit of firms accounts for large part of TFP growth, my paper focuses on the link between the firms' entry and exit and misallocation across firms. For example, inefficient firms may survive in the market when the firms have access to subsidized credit. Absent these subsidies, they do not make positive profits, hence are forced to exit. When the market becomes more competitive due to trade liberalization, many of these inefficient firms can no longer exist. Trade liberalization brings more tight bounds for market selection. Firms need to be more efficient to enter more competitive market. Reducing misallocation on the extensive margin can have quantitatively large effect on TFP growth.

Goal of this paper is to measure the impact of trade on sectoral TFP through improvement on allocative efficiency within sectors. Using firm-level panel data on Chinese manufacturing, spanning 1998 to 2007, I measure distortions across firms within each sector and over time as in Hsieh and Klenow (2009). During the time of our analysis, China joined the WTO at the end of 2001. Major reduction in industrial tariffs happened right after the time of accession. The degree of trade liberalization is captured by the change in the average tariff rates for four-digit ISIC manufacturing industries. I utilize sectoral variation in the tariff reduction across sectors. I control for the endogeneity of the tariff reduction by using the 2001 tariff rates, pre-WTO tariff levels, as an instrumental variable. I find that the allocation of factors improves over time significantly more in the industries that experience a higher drop in tariff rates. I argue that an important role of trade is to improve misallocation on the extensive margin by forcing out less competitive and more distorted firms and replacing these with more competitive firms. I find that highly distorted firms are more likely to exit in sectors which experience a higher tariff reduction. In addition, entrants in more liberalized sectors are more productive as well as less distorted relative to the sectoral average level.

I present two-country, multi-sector model which features endogenous entry and exit of firms. The model framework is based on Ghironi and Melitz (2005), Atkeson and Burstein (2008), and Edmond, Midrigan and Xu (2012). I embed exogenous distortions at firm level as exemplified in Restuccia and Rogerson (2008) and Hsieh and Klenow (2009).[1] These distortions can be thought as firm-specific taxes or subsidies which create wedges between marginal product of capital and labor across firms within a sector. For each sector, there exists a threshold line which determines survival of firms with different levels of efficiency and distortion. Changes in the market selection effect come from the movement of the threshold line. In my model, the degree of trade liberalization can differ across sectors. Sectors which experience high drop in import tariffs can become more competitive due to reduced sectoral aggregate price. Reduction in the sectoral aggregate price increases the threshold line, inducing better market selection within the sector.

There are two strands of empirical studies which are related to this paper. One line of research focuses on quantifying the impact of allocational efficiency on TFP (e.g. Neumeyer and Sandleris (2010), Mark and Sandleris (2011), Camacho and Conover (2010), and Oberfield (2013)). The extent of misallocation across firms is measured over a given period utilizing firm-level data. They find that there are potential gains in TFP by improving allocational efficiency in many developing countries. Mark and Sandleris (2011) and Oberfield (2013) find that worsening allocational efficiency during crises can explain 25-50 percent of decline in measured TFP. My paper contributes to the literature by studying impact of trade as a specific source of the changes in the allocational efficiency.

Another line of research studies the impact of trade on firm productivity and exit. The most closely related paper is Brandt, Van Biesebroeck, Wang and Zhang (2013) since they study the impact of trade on sectoral productivity of Chinese economy as in this paper. They find that the impact of trade on extensive margin accounts much of the effects on sectoral productivity. Eslava, Haltiwanger, Kugler and Kugler (2013) find that trade strengthen the link between plant productivity

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[1]The aggregate effects of misallocation on the extensive margin by allowing firms' entry and exit are studied in recent papers, for example, by Yang (2011), Jaef (2012), and Bartelsman, Haltiwanger, and Scarpetta (2013).

and plant exit. They show that aggregate productivity increases substantially due to enhanced market selection. My paper focuses on the wedges that create misallocation across firms within a sector. These wedges affect decision on firms' entry and exit along with firms' productivity. I use the model to quantify impact of trade on sectoral TFP especially by reducing misallocation along the extensive margin.

The rest of the paper is organized as follows. Section 2 explains relevant event of China's WTO accession and change in the import tariffs. Section 3 lays out model to explain mechanism how trade can affect extent of misallocation. Section 4 describes data, measurement of distortions, and empirical evidence that trade affected the extent of misallocation. Section 5 shows results on the impact of trade on the firms' entry and exit. Section 6 concludes.

2.2. WTO Accession and Tariffs

China has lowered tariffs on imports since early 1990s. There was a major reduction in tariffs between 1992 to 1997. Simple average MFN Applied tariff rates was 41.4 percent in 1992, subsequently lowered to 16.3 percent in 1997. Another major reduction in tariffs occurred when China joined the WTO in 2001. Figure B.1 plots the simple and weighted average MFN Applied tariff rates from 1997 to 2007.[2] Average tariff rate on imports of manufacturing goods decreased over the period 1998 to 2007. There is a particular drop of average tariff rates in 2002 which reflects China's accession to the WTO in December 2001.

Upon China's accession to the WTO, tariff rates were adjusted or planned to comply to the general rules of the WTO. This resulted in bigger reduction of tariffs for goods with initially high tariff rates. We can find that this is true for 4-digit ISIC manufacturing industry level. Figure B.2 shows the changes in average import tariffs from 2001 to 2006 with the initial average level of import tariffs in 2001 at 4-digit ISIC manufacturing industry level. First, we can observe that there

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[2]Data is from WITS tariff profile option which aggregates MFN Applied tariff rates from UNCTAD TRAINS database.

is significant variance in the average tariff rates in 2001 across industries. Second, reduction in import tariffs was larger for industries with high level of average tariff rate in 2001. However, there is much variation in the change of average tariff rates with similar average tariff rates in 2001. This may reflect political factors come in the process of negotiation. China's concessions on tariff rates across industries can be endogenous. In this paper, I measure the degree of trade liberalization by the change in the average tariff rates for four-digit ISIC manufacturing industries. Endogeneity issue with the change in tariff rates arises since the change is related to other industrial characteristics. I control for the endogeneity of the tariff reduction by using the 2001 tariff rates, pre-WTO tariff levels, as an instrumental variable. I will discuss how I address this endogeneity issue in detail in section 4 and 5.

2.3. Model

Economy has two countries: home and foreign. Variables of the foreign country are denoted with an asterisk. I describe problems of agents in home country.

2.3.1. Consumers

There is a continuum of identical consumers. They supply labor L_t inelastically to the market. A homogeneous final good is produced by firms in the perfectly competitive market. This final good is used for either consumption C_t or investment X_t. Consumers has preference over stream of aggregate consumption good. They choose consumption C_t and investment X_t to maximize

$$\sum_{t=0}^{\infty} \beta^t U(C_t)$$

subject to

$$P_t(C_t + X_t) \leq R_t K_t + W_t L_t + \Pi_t$$

where P_t is price of aggregate consumption good, R_t is rental rate of capital, W_t is wage rate, and Π_t is aggregate profits.

Aggregate law of motion for capital is

$$K_{t+1} = (1-\delta)K_t + X_t$$

The return on capital is related to the intertemporal decision on consumption through standard first-order condition of the consumer's problem.

$$\frac{\beta U_{c,t+1}}{U_{c,t}}\left(\frac{R_{t+1}}{P_{t+1}} + (1-\delta)\right) = 1$$

In the steady-state competitive equilibrium, the return on capital becomes $R = \frac{1}{\beta} - (1-\delta)$.

I assume that identical initial capital stocks and technologies as well as distortions in both home and foreign countries. Trade is balanced each period since there is no aggregate uncertainty in this model.

For the remainder of model, time subscript is suppressed for simplicity unless timing can be an issue.

2.3.2. Final Good Production

A homogeneous non-tradable final good is produced using aggregate sectoral output in the perfectly competitive market. It combines sectoral output from total S number of manufacturing industries with Cobb-Douglas production technology.

$$Y = \prod_{s=1}^{S} Y_s^{\theta_s} \qquad \text{where } \sum_{s=1}^{S} \theta_s = 1 \tag{2.1}$$

Given the sectoral shares $\{\theta_s\}$, cost minimization implies $P_s Y_s = \theta_s PY$, where P_s is the price of sectoral aggregate output Y_s.

2.3.3. Sectoral Output

Sectoral output is aggregated with C.E.S. production technology using intermediate goods produced from home country and sold to home $y^H(\omega)$ and intermediate goods produced from foreign country and sold to home $y^F(\omega)$. ω denotes particular type of good.

$$Y_s = \left[\int x^H(\omega) y^H(\omega)^{1-1/\sigma} d\mu(\omega) + \int x^F(\omega) y^F(\omega)^{1-1/\sigma} d\mu^*(\omega) \right]^{\sigma/(\sigma-1)} \tag{2.2}$$

where $x^H(\omega)$ indicates whether domestic firm produces in domestic market. $x^F(\omega)$ is an indicator of foreign firm's export status which takes 1 when the firm exports and 0 otherwise. σ is the elasticity of substitution across goods ω within a sector s. Goods are gross substitutes, $1 < \sigma$. I assume that this elasticity is the same across sectors.

Intermediate good producer ω in sector s produces with the following technology.

$$y_s(\omega) = z_s(\omega) \left[k_s(\omega) \right]^{\alpha_s} \left[l_s(\omega) \right]^{1-\alpha_s} \tag{2.3}$$

Produced output are sold either home or abroad. When the good is sold abroad, physical trade costs is incurred. They are iceberg shipping cost δ_s and import tariff κ_s^* of sector s in foreign country. They need to export $(1+\delta_s)(1+\kappa_s^*)y^{*H}(\omega)$ of goods to meet the foreign demand $y^{*H}(\omega)$. Define physical trade costs term as $d_s \equiv (1+\delta_s)(1+\kappa_s^*)$. Feasibility constraint for intermediate good z is

$$y_s(\omega) = x^H(\omega) y_s^H(\omega) + x^{*H}(\omega) d_s y_s^{*H}(\omega) \tag{2.4}$$

where $y^H(\omega)$ is domestic demand and $y^{*H}(\omega)$ is foreign demand.

2.3.4. Demand

Sectoral good producer purchases intermediate inputs $y_s^H(\omega)$ and $y_s^F(\omega)$ to maximize its profit given production technology equation 2.2. This makes intermediate good producers from home and abroad face the inverse demand functions as follows.

$$\frac{y_s^H(\omega)}{Y_s} = \left(\frac{p_s^H(\omega)}{P_s}\right)^{-\sigma}, \quad \frac{y_s^{*H}(\omega)}{Y_s^*} = \left(\frac{p_s^{*H}(\omega)}{P_s^*}\right)^{-\sigma} \tag{2.5}$$

where the price index of sectoral aggregate good is given by

$$P_s = \left[\int x^H(\omega) p_s^H(\omega)^{1-\sigma} d\mu(\omega) + \int x^{*F}(\omega) p_s^F(\omega)^{1-\sigma} d\mu^*(\omega)\right]^{1/(1-\sigma)} \tag{2.6}$$

Using the relation between sectoral output and the aggregate output, equation 2.5 can be expressed as

$$y_s^H(\omega) = \left(\frac{p_s^H(\omega)}{P_s}\right)^{-\sigma} \left(\frac{\theta_s P}{P_s}\right) Y, \quad y_s^{*H}(\omega) = \left(\frac{p_s^{*H}(\omega)}{P_s^*}\right)^{-\sigma} \left(\frac{\theta_s P^*}{P_s^*}\right) Y^*,$$

Intermediate good firms pay fixed cost f_s to operate in domestic market. They pay fx_s in order to export. Each sectoral market is monopolistically competitive.

Each firm face output distortion $\tau_y(\omega)$ which affects marginal product of labor and capital in same proportion. It can be interpreted as either tax or subsidy on output. There is capital distortion $\tau_k(\omega)$ which change marginal product of capital relative to labor. These firm-specific distortions will appear in the firm's profit maximization problems in domestic market as well as in export market. In the following two sections, 3.5 and 3.6, I explain incumbent firms' problem in domestic market and foreign market, respectively.

2.3.5. Incumbent Firms in the Domestic Market

Due to constant return to scale production, we can separate the problem into domestic and foreign market. Firms' problem to operate in any market is static since firm's productivity and distortion

level do not change over time. If their current profit is non-negative, they will operate in the market and hire labor and capital to maximize current period profits.

Firm's profit maximization problem in home market is

$$\pi_s^H(\omega) \equiv \max_{y_s^H(\omega), l_s^H(\omega), k_s^H(\omega)} (1 - \tau_y(\omega)) p_s^H(\omega) y_s^H(\omega) - W l_s^H(\omega) - (1 + \tau_k(\omega)) R k_s^H(\omega) - f_s$$

subject to 2.3, 2.4, and 2.5, and where $f_s = \alpha_s^{-\alpha_s}(1 - \alpha_s)^{-(1-\alpha_s)}[(1 + \tau_k(z))R]^{\alpha_s}W^{1-\alpha_s}F_s$. Fixed cost f_s can be considered as fixed payments to F_s unit of capital and labor.

Firm's output price is a fixed markup over its marginal cost.

$$p_s^H(\omega) = \frac{\sigma}{\sigma - 1} c_s \frac{\tau_s(\omega)}{z_s(\omega)}$$

where $c_s \equiv \left(\frac{R}{\alpha_s}\right)^{\alpha_s} \left(\frac{W}{1-\alpha_s}\right)^{1-\alpha_s}$ and $\tau_s(\omega) \equiv \frac{(1+\tau_k(\omega))^{\alpha_s}}{(1-\tau_y(\omega))}$.

The firm produces in domestic market when it earns non-negative profit, $\pi_s^H(z) \geq 0$. The condition to produce at home is

$$\frac{(\sigma - 1)^{\sigma - 1}}{\sigma^\sigma} \theta_s PY P_s^{\sigma - 1} c_s^{-\sigma} [z_s(\omega)]^{\sigma - 1} [\tau_s(\omega)]^{-\sigma} > F_s \tag{2.7}$$

Any firm that does not satisfy this condition exits. Firm is likely to exit from home market when it has lower productivity or faces higher distortion, $\tau_s(z)$. Given its productivity and distortion level, firm exits when price of sectoral aggregate goods is low.

2.3.6. Incumbent Firms in the Export Market

Firm maximizes profit in the export market. It exports when the exporting revenue can cover exporting cost.

$$\pi_s^{*H}(\omega) \equiv \max_{y_s^{*H}(\omega), l_s^{*H}(\omega), k_s^{*H}(\omega)} (1 - \tau_y(\omega)) p_s^{*H}(\omega) y_s^{*H}(\omega) - W l_s^{*H}(\omega) - (1 + \tau_k(\omega)) R k_s^{*H}(\omega) - f x_s$$

subject to 2.3, 2.4, and 2.5, and where $fx_s = \alpha_s^{-\alpha_s}(1-\alpha_s)^{-(1-\alpha_s)}[(1+\tau_k(\omega))R]^{\alpha_s}W^{1-\alpha_s}FX_s$. FX_s unit of capital and labor should be paid as fixed cost in order to export.

Price of exporting good is a fixed markup over its marginal cost.

$$p_s^{*H}(\omega) = \frac{\sigma}{\sigma-1}c_s\frac{\tau_s(\omega)}{z_s(\omega)}d_s$$

Firm exports when the following condition is satisfied.

$$\frac{(\sigma-1)^{\sigma-1}}{\sigma^{\sigma}}\theta_s P^*Y^*\left(\frac{P_s^*}{d_s}\right)^{\sigma-1}c_s^{-\sigma}[z_s(\omega)]^{\sigma-1}[\tau_s(\omega)]^{-\sigma} > FX_s$$

In steady state equilibrium, the discounted present value of an incumbent firm is given by

$$V_s(\omega) = \frac{\pi_s^H(\omega)+\pi_s^{*H}(\omega)}{1-\beta}$$

2.3.7. Entering Firms

Potential firms need to pay entry cost fe_s to know their productivity, $z_s(\omega)$, and distortion level, $\tau_s(\omega)$, over a distribution $\mu(\omega)$. Once they learn the levels, they decide whether to operate or exit immediately. In an equilibrium with positive number of entering firms, following free entry condition should hold.

$$fe_s = \int \max_{exit,operate}\{0,V_s(\omega)\}d\mu(\omega)$$

where $fe_s = \alpha_s^{-\alpha_s}(1-\alpha_s)^{-(1-\alpha_s)}R^{\alpha_s}W^{1-\alpha_s}FE$.

2.3.8. Allocation

Define total $l_s(\omega) \equiv l_s^H(\omega) + l_s^{*H}(\omega)$, $k_s(\omega) \equiv k_s^H(\omega) + k_s^{*H}(\omega)$. From profit maximization problem, we have capital-labor ratio, labor allocation, and output as

$$\frac{k_s(\omega)}{l_s(\omega)} = \frac{\alpha_s}{1 - \alpha_s} \cdot \frac{w}{R} \cdot \frac{1}{1 + \tau_{k,s}(\omega)},$$

$$l_s(\omega) \propto \frac{(z_s(\omega))^{\sigma-1} (1 - \tau_{y,s}(\omega))^{\sigma}}{(1 + \tau_{k,s}(\omega))^{\alpha_s(\sigma-1)}},$$

$$y_s(\omega) \propto \frac{(z_s(\omega))^{\sigma-1} (1 - \tau_{y,s}(\omega))^{\sigma}}{(1 + \tau_{k,s}(\omega))^{\alpha_s \sigma}}.$$

We can find the distortions in output and capital affect resource allocations across firms. These distortions affect marginal revenue product of labor and capital as following

$$MRPL_s(\omega) = w \frac{1}{1 - \tau_{y,s}(\omega)}$$

$$MRPK_s(\omega) = R \frac{1 + \tau_k(\omega)}{1 - \tau_{y,s}(\omega)}$$

Foster, Haltiwanger, and Syverson (2008) point out important distinction between "physical productivity (TFPQ)" and "revenue productivity (TFPR)." I follow the same definition made in Hsieh and Klenow (2009) to distinguish these objects. $TFPQ_s(\omega) \equiv z_s(\omega) = y_s(\omega) / [k_s(\omega)]^{\alpha_s} [wl_s(\omega)]^{1-\alpha_s}$ and $TFPR_s(\omega) = p_s(\omega)y_s(\omega) / [k_s(\omega)]^{\alpha_s} [wl_s(\omega)]^{1-\alpha_s}$. Firm's $TFPR_s(\omega)$ is a geometric average of the firm's marginal revenue product of labor and capital.

$$
\begin{aligned}
TFPR_s(\omega) &= \frac{\sigma}{\sigma - 1} \left(\frac{MRPK_s(\omega)}{\alpha_s} \right)^{\alpha_s} \left(\frac{MRPL_s(\omega)}{1 - \alpha_s} \right)^{1-\alpha_s} \\
&= \frac{\sigma}{\sigma - 1} \left(\frac{R}{\alpha_s} \right)^{\alpha_s} \left(\frac{w}{1 - \alpha_s} \right)^{1-\alpha_s} \frac{(1 + \tau_k(\omega))^{\alpha_s}}{(1 - \tau_y(\omega))}
\end{aligned}
$$

$TFPR_s(\omega)$ is proportional to the term $\tau_s(\omega)$. Industry level $TFPR$ is calculated as

$$\bar{\tau}_s \equiv \left[\frac{\alpha_s}{R}\left(\int\left(\frac{1+\tau_k(\omega)}{1-\tau_{y,s}(\omega)}\right)\frac{p_s(\omega)y_s(\omega)}{P_sY_s}d\mu(\omega)\right)\right]^{-\alpha_s}$$
$$\cdot\left[\frac{1-\alpha_s}{w}\left(\int(1-\tau_{y,s}(\omega))\frac{p_s(\omega)y_s(\omega)}{P_sY_s}d\mu(\omega)\right)\right]^{\alpha_s-1}$$

2.3.9. Equilibrium

Consumer and final good firms and intermediate good firms optimize. Labor and physical capital markets clear.

$$L = \sum_{s=1}^{S} L_s = \sum_{s=1}^{S}\int\left\{x^H(\omega)\left[l_s^H(\omega)+F_s+FE\right]+x^{*H}(\omega)\left[l_s^{*H}(\omega)+FX_s+FE\right]\right\}d\mu(\omega)$$

$$K = \sum_{s=1}^{S} K_s = \sum_{s=1}^{S}\int\left\{x^H(\omega)\left[k_s^H(\omega)+F_s+FE\right]+x^{*H}(\omega)\left[k_s^{*H}(\omega)+FX_s+FE\right]\right\}d\mu(\omega)$$

Goods market clear and trade is balanced with symmetry assumption.

$$Y = C + X$$

2.3.10. Aggregation

Aggregate output can be expressed with sectoral TFP and inputs used net of fixed cost in each sector.

$$Y = \prod_{s=1}^{S}\left[A_s\left(\tilde{K}_s\right)^{\alpha_s}\left(\tilde{L}_s\right)^{1-\alpha_s}\right]^{\theta_s}$$

where $\tilde{K}_s$ is the aggregate capital used in sector s net of fixed cost. $\tilde{L}_s$ is the aggregate labor used in sector s net of fixed cost.

Following expression on sectoral productivity is derived from firm's optimal choice for labor and capital as well as market clearing conditions for capital and labor.[3]

$$
\begin{aligned}
A_s &= \left[\int \left\{ x^H(\omega) \frac{(1+\tau_k(\omega))^{\alpha_s-1}}{z_s(\omega)} \frac{y_s^H(\omega)}{Y_s} + x^{*H}(\omega) \frac{(1+\tau_k(\omega))^{\alpha_s-1}}{z_s(\omega)} \frac{y_s^{*H}(\omega)}{Y_s} \right\} d\mu(\omega) \right]^{-\alpha_s} \\
&\quad \cdot \left[\int \left\{ x^H(\omega) \frac{(1+\tau_k(\omega))^{\alpha_s}}{z_s(\omega)} \frac{y_s^H(\omega)}{Y_s} + x^{*H}(\omega) \frac{(1+\tau_k(\omega))^{\alpha_s}}{z_s(\omega)} \frac{y_s^{*H}(\omega)}{Y_s} \right\} d\mu(\omega) \right]^{\alpha_s-1}
\end{aligned}
$$

Sectoral productivity A_s is an average of firm level productivity and distortion weighted by quantity.

2.3.11. Symmetric Equilibrium

I present the simplest setup of the model to show impact of trade on sectoral TFP analytically. I assume that countries are completely symmetric such that distribution of productivity and distortions are the same as well as aggregate input endowments: $z(\omega) = z^*(\omega)$, $\tau(\omega) = \tau^*(\omega)$, $L = L^*$, $K = K^*$.

In this symmetric case, sectoral productivity is expressed by

$$
A_s = \left\{ J_s \left[1 - \Phi(\bar{\omega}_D)\right] \mathbf{E}\left[\left(\frac{z_s(\omega)}{\tau_s(\omega)} \bar{\tau}_s \right)^{\sigma-1} \mid \Omega_D \right] + J_s \left[1 - \Phi(\bar{\omega}_X)\right] \mathbf{E}\left[\left(\frac{z_s(\omega)}{\tau_s(\omega)} \frac{\bar{\tau}_s}{d_s} \right)^{\sigma-1} \mid \Omega_X \right] \right\}^{1/(\sigma-1)}
$$

The set of operating firms are given by

$$
\Omega_D = \left\{ \omega : \frac{z_s(\omega)}{(\tau_s(\omega))^{\frac{\sigma}{\sigma-1}}} \geq \bar{\omega}_D \right\}
$$

Equation 2.7 defines the threshold line, $\bar{\omega}_D$, for any firm to operate in sector s,

$$
\bar{\omega}_D \equiv \left(\frac{\sigma^\sigma}{(\sigma-1)^{\sigma-1}} \frac{F_s}{\theta_s} \frac{1}{PY} \right)^{\frac{1}{\sigma-1}} \frac{1}{P_s} (c_s)^{\frac{\sigma}{\sigma-1}} .
$$

---

[3]Edmond, Midrigan and Xu (2012) provide similar expression for aggregate productivity. I applied their method to derive the function for sectoral productivity.

The set of exporting firms are given by

$$\Omega_X = \left\{ \omega : \frac{z_s(\omega)}{(\tau_s(\omega))^{\frac{\sigma}{\sigma-1}}} \geq \bar{\omega}_X \right\}$$

The threshold line, $\bar{\omega}_X$, for any firm to export given by $\bar{\omega}_X \equiv \left(\frac{\sigma^\sigma}{(\sigma-1)^{\sigma-1}} \frac{FX_s}{\theta_s} \frac{1}{PY} \right)^{\frac{1}{\sigma-1}} \frac{1}{P_s} (c_s)^{\frac{\sigma}{\sigma-1}} d_s$.
The threshold line is higher for exporters than domestic firms when $(FX_s)^{\frac{1}{\sigma-1}} d_s > (F_s)^{\frac{1}{\sigma-1}}$.

Impact of trade liberalization on sectoral TFP can be expressed in a functional form of the extensive margin when we assume that joint distribution of firm-level productivity and distortions follows a specific form. Following case is based on an analysis provided in Yang (2011). Suppose $\log z_s(\omega)$ and $\log \tau_s(\omega)$ follow joint normal distribution. Let $m \equiv \frac{\sigma}{\sigma-1}$. Then truncated mean of $\log \frac{z_s(\omega)}{\tau_s(\omega)}$ is given by

$$\mathbf{E}\left[\log z_s(\omega) - \log \tau_s(\omega) \mid \Omega_D\right] = \mu_z - \mu_\tau + \frac{Var(z) - (m+1)COV(z,\tau) + mVar(\tau)}{Var(z) + Var(\tau) - 2COV(z,\tau)} \lambda(\bar{\omega}_D)$$

where $\lambda(.)$ is the Inverse Mill's Ratio.

We can show that $\frac{\partial \lambda(\bar{\omega}_D)}{\partial \bar{\omega}_D} > 0$. If more trade liberalization raises the threshold line that firms can survive, average productivity net of distortion will increase. However, the direction of change in the threshold line due to trade liberalization depends on the general equilibrium effects on wage and sectoral price. We need full calibrated model to study the direction as wells as magnitude of the change in the threshold line. Jaef (2012) studies general equilibrium effects of entry and exit on aggregate implications from resource allocation. He points out that entry and exit can offset misallocation effect. When the threshold line, $\bar{\omega}_D$, increases, fraction of firms operating in the domestic market decreases. This decrease in number of operating firms can negatively affect the overall TFP. However, in an open economy setup as in this paper, overall TFP can increase by using more variety of goods from abroad when the threshold line for exports, $\bar{\omega}_D$, decreases due to lower tariff.

2.4. Gains from Reallocation

2.4.1. Data

Data for Chinese firms are from the Annual Surveys of Industrial Production conducted by the China's National Bureau of Statistics. The data spans 1998 through 2007. Hsieh and Klenow (2009) use the same data set between years 1998 and 2005. This Annual Surveys of Industrial Production covers nonstate firms with more than 5 million yuan in revenue (about $600,000) as well as all state-owned firms. The firms included in the data represent around 90% of gross output in manufacturing sector. The unbalanced panel data includes over 140,000 firms in 1998 and increases to over 300,000 firms in 2007. From this data set, I use information on the firms' industry, ownership type, age, value added, wage payments, employment, capital stocks, and export revenues. Related to labor compensation, non-wage compensation such as insurance payments are reported only after 2004. Hsieh and Klenow (2009) point out that the median labor share in plant-level data is significantly lower than the aggregate labor share reported in the national accounts. They assume that nonwage benefits are constant fraction of a plant's wage payment to close the discrepancy. I assume that the constant fraction is 1. This is an arbitrary number applied to firms' wage payment universally. [4]

2.4.2. Calibration

I apply the methodology used in Hsieh and Klenow (2009) to measure distortions across firms within each sectors. We need to calibrate other parameters related to sectoral output shares, sectoral capital shares, firm specific distortions and productivities. Sectors are defined at 4-digit ISIC (revision 3) manufacturing industry level. The Chinese Annual Surveys data classify firms according to Chinese Industrial Classification (CIC) which is at 4-digit level. I use concordance

---

[4]By using this constant number, the share of sectoral aggregate labor compensation in sectoral aggregate value added in each sector remains between 0 and 1.

from Brandt, Van Biesebroeck, and Zhang (2012) to match CIC industries with ISIC revision 3 industries.

I set the rental price of capital, R, to 0.1. The rental price of capital for individual firm ω is $(1 + \tau_k(\omega))R$ which depends on its capital distortion level. The elasticity of substitution between plant value added is set at $\sigma = 3$, following Hsieh and Klenow (2009).

Capital shares in each industry (α_s) are obtained as 1 minus the labor share in each industry. I use 2005 year data from the Chinese Annual Survey to calculate labor shares in each industry. Labor shares are calculated as total labor compensation over total value added at sectoral level. I use the labor shares directly obtained by the Chinese Annual Survey since changes in misallocation over time within each industry of China is the issue that we focus on this paper. We can not identify average capital distortions separately from the capital shares. Capital shares in each Chinese industry changes over time, which may reflect changes in average capital distortions. Changes in the capital shares are small since year 2005. Since magnitude of distortions within each industry is reduced over time, I use comparatively less distorted 2005 year data to compute capital shares.

Firm specific productivity, capital and output distortions in each year are derived from the following equations.[5]

Productivity, $TFPQ_s(\omega)$,

$$z_s(\omega) = \kappa_s \frac{(p_s(\omega)y_s(\omega))^{\frac{\sigma}{\sigma-1}}}{[k_s(\omega)]^{\alpha_s}[l_s(\omega)]^{1-\alpha_s}}$$

Capital distortion

$$1 + \tau_{k,s}(\omega) = \frac{\alpha_s}{1-\alpha_s} \cdot \frac{wl_s(\omega)}{Rk_s(\omega)}$$

Output distortion

$$1 - \tau_{y,s}(\omega) = \frac{\sigma}{\sigma-1} \cdot \frac{wl_s(\omega)}{(1-\alpha_s)p_s(\omega)y_s(\omega)}$$

$TFPR_s(\omega)$ is a geometric average of the firm's marginal revenue products of capital and labor. It

---

[5]These equations correspond to equation (17), (18), and (19) in Hsieh and Klenow (2009).

is expressed as a function of capital and output distortion.

$$\tau_s(\omega) = \frac{\left(1 + \tau_{k,s}(\omega)\right)^{\alpha_s}}{\left(1 - \tau_{y,s}(\omega)\right)}$$

2.4.3. Misallocation and Sectoral TFP

Goal of this paper is to quantify impact of trade on sectoral TFP through improvement on allocative efficiency within sectors. When we calibrate model, we need to match initial level of misallocation since they determine size of gains. Other than joining the WTO, market oriented reform in China has been ongoing during the sample period of our analysis. We want to separate out impact from trade by considering observable sectoral characteristics such as capital intensity and ownership as well as unobservable characteristics such as particular reform at sectoral level. Before calibrating full model, this section considers a case where it allows us to observe gains on sectoral TFP through reducing level of distortions. Hsieh and Klenow (2009) calculate gains in TFP by comparing actual TFP with hypothetical case where TFPRs are equalized across firms within sectors. They show that Chinese allocative efficiency improved 2% per year on average between 1998 and 2005. I focus on the change in the allocative efficiency over time within each sector. Allocative efficiency depends on the variation in TFPR. High dispersion of TFPR within a sector will lower sectoral TFP. This point is clearly illustrated in the equation (16) of Hsieh and Klenow (2009). Assume $\left(\log z_s(\omega), \log(1 - \tau_{y,s}(\omega)), \log(1 + \tau_{k,s}(\omega))\right)$ follow multivariate normal distribution. When we consider symmetric equilibrium introduced in section 3.10. and shut down endogenous selection by setting $F_s = 0$ and $FX_s = 0$, sectoral TFP is expressed as

$$\begin{aligned}
\log A_s &= \frac{1}{\sigma - 1}\left[\log M_s + \log \mathbf{E}\left((z_s(\omega))^{\sigma-1}\right)\right] - \frac{\sigma}{2} Var\left(\log TFPR_s(\omega)\right) \\
&\quad - \frac{\alpha_s(1 - \alpha_s)}{2} Var\left(\log(1 + \tau_{k,s}(\omega))\right)
\end{aligned} \tag{2.8}$$

Sectoral TFP is lower when the variance of log TFPR or the variance of log $1 + \tau_{k,s}(\omega)$ are larger.

56

When allocative effiency improves, dispersion of distortions will be lowered, increasing sectoral TFP. Using equation 2.8, percentage change in sectoral TFP can be calculated by taking difference in $\ln A_s$ over time, $\ln A_{s,t'} - \ln A_{s,t}$.

$$
\begin{aligned}
\log A_{s,t'} - \log A_{s,t} &= \frac{1}{\sigma-1}\left[\log\frac{M_{s,t'}}{M_{s,t}} + \log\frac{\mathbf{E}\left(\left(z_{s,t'}(\omega)\right)^{\sigma-1}\right)}{\mathbf{E}\left(\left(z_{s,t}(\omega)\right)^{\sigma-1}\right)}\right] \\
&\quad - \frac{\sigma}{2}\left[Var\left(\log TFPR_{s,t'}(\omega)\right) - Var\left(\log TFPR_{s,t}(\omega)\right)\right] \\
&\quad - \frac{\alpha_s(1-\alpha_s)}{2}\left[Var\left(\log(1+\tau_{k,s,t'}(\omega))\right) - Var\left(\log(1+\tau_{k,s,t}(\omega))\right)\right] (2.9)
\end{aligned}
$$

Change in the dispersion of distortions contributes to the change in sectoral TFP. When variance of log TFPR or the variance of log $1+\tau_{k,s}(\omega)$ decreases from time t to time t', sectoral TFP increases proportionally. Second and third line 2.9 measures the changes in the dispersion of distortions.

I next calculate observed variance of log TFPR across sectors over time. Related to the impact of trade on the dispersion of distortions, I want to study whether the dispersion has lowered more for sectors which face higher drop in import tariffs. As I pointed out in section 2, upon joining the WTO, reduction in import tariffs was larger for industries with high level of average tariff rate in 2001. Figure B.3 plots change in the variance of log TFPR between 2002 and 2005 over average tariff rate in 2001 in each sector.[6] We can observe that variance of log TFPR decrease more in sectors with higher drop in import tariffs. This change in the variance of log TFPR can be driven by sectoral characteristics as well.

I perform regression on following equation to capture linear relationship between percentage change in the variance of log TFPR and percentage change in the average import tariff rate.

$$
\begin{aligned}
\frac{Var\left(\log TFPR_{s,2005}\right) - Var\left(\log TFPR_{s,2002}\right)}{Var\left(\log TFPR_{s,2002}\right)} &= \beta_0 + \beta_1\left(\frac{tariff_{2005} - tariff_{2001}}{tariff_{2001}}\right) \\
&\quad + \beta_2\alpha_s + \beta_3 emp_s + \beta_4 ex_s + \varepsilon_s
\end{aligned}
$$

---

[6]For figure B.3 and B.4, I chose the specific years to compare the change over same time period, 4 years, before and after the WTO.

where emp_s is an employment share of sector s over total employment in 2001, ex_s is an export intensity (export value in sector s over value added in sector s) in 2001. α_s is capital intensity in 2005.

Endogeneity can be an issue in this regression since error term can be correlated with the change in tariff rate. I proceed with two-stage least-squares (2SLS) method, using average import tariff rate in 2001 as an instrument variable for the percentage change in the average import tariff rate. Pre-reform tariff level is often used as an instrument variable in the trade literature as in Goldberg and Pavcnik (2005). Average import tariff rate in 2001 is highly correlated with the percentage change in the average import tariffs between 2001 and 2005. The estimate will be consistent if the instrumental variable is not correlated with the error term. Error term may include other economic and political factors other than the tariffs. I control for observable sectoral characteristics such as sectoral employment share, export share in value added, and capital intensity. These variables were not correlated with average tariff rate in 2001. Thus, we use these variables as valid instruments together with average tariff rate in 2001. Additional evidence that error term may not be correlated with initial tariff level in 2001 comes from performing the same regression applied for year 1998 and 2001. I look at changes in the variance of log TFPR for the years before China joined the WTO. Change in the variance of log TFPR is not systematically related to the level of average tariff rate in 1998 as well as the change in the average tariff rate between 1998 and 2001. Figure B.4 plots change in the variance of log TFPR between 1998 and 2001 over average tariff rate in 1998 across sectors.

Table B.1 in the appendix B reports the (2SLS) regression result. It also reports simple OLS regression results. Baseline result in the first column of table B.1 shows that only the change in the average tariff is a statistically significant explanatory variable for the change of variance of log TFPR. When the average tariff rate drops 1 percentage, variance of log TFPR drops around 1 percentage. This result shows that the allocation of factors improves significantly more in industries that experience a higher drop in tariff rates. The analysis in this section was to demonstrate that trade can impact the extent of misallocation within each sector. In the next section, I study effects

of lowering import tariffs as a source of the reduction in misallocation through extensive margin by firm's exit and entry.

2.5. Identifying Impacts of Trade on Extensive Margin

Important role of trade is to improve misallocation on the extensive margin by forcing out less competitive and more distorted firms and replacing those with more competitive firms. Individual firms face more competitive market condition when import tariffs are lowered. Marginal firms with relatively low productivity or high distortion are likely to exit when they face tighter demand. In our setup, tighter demand comes through lower sectoral aggregate price since firms are in monopolistically competitive market. Utilizing firm level data, this section verifies empirically that lowering tariffs induce highly distorted firms to exit. In order to identify entry and exit of firms, I need to link individual firms over time. Brandt, Van Biesebroeck, and Zhang (2012) provide a code, which utilizes information on firm id, phone number and location, to link firms over time.

2.5.1. Effects of Tariffs on Firm Exit

I want to find empirical evidence whether firms with relatively high distortion are more likely to exit in sectors which experience a higher tariff reduction. Firm's distortion level, $TFPR$, is the primary variable of interest. Firm's physical productivity level, $TFPQ$, is another predictor for firm's exit. We can expect that firms with higher $TFPR$ value or lower $TFPQ$ value are more likely to exit. Other variables such as firm employment size, firm age, ownership type and sectoral capital intensity are included as additional determinants of exit. I only consider firms in 2001, a year before large drop in tariffs occurred due to the China's accession to the WTO. Characteristics of firms that entered market after 2001 can be different from others due to trade liberalization. Thus, taking snapshot of characteristics of firms in 2001, we estimate how these characteristics affected firms' decision on exit on the years coming after. The following equation is used for

estimation.

$$
\begin{aligned}
\text{Exit}_{s,t'}(\omega) \;=\; & \beta_0 + \beta_1 \left(-\frac{tariff_{s,2003} - tariff_{s,2001}}{tariff_{s,2001}} \right) \\
& + \beta_2 \log TFPQ_{s,2001}(\omega) \times \left(-\frac{tariff_{s,2003} - tariff_{s,2001}}{tariff_{s,2001}} \right) \\
& + \beta_3 \log TFPR_{s,2001}(\omega) \times \left(-\frac{tariff_{s,2003} - tariff_{s,2001}}{tariff_{s,2001}} \right) \\
& + \beta_4 \log \left(TFPQ_{s,2001}(\omega)/\bar{z}_s \right) + \beta_5 \log \left(TFPR_{s,2001}(\omega)/\bar{\tau}_s \right) \\
& + \beta_6 \alpha_{s,2005} + \beta_7 \log emp(\omega) + \beta_8 age(\omega) + \beta_9 age^2(\omega) \\
& + \beta_{10} D_{\text{SOE}}(\omega) + \beta_{11} D_{\text{Collective}}(\omega) + \beta_{12} D_{\text{Private}}(\omega) \\
& + \beta_{13} D_{\text{HMT}}(\omega) + \beta_{14} D_{\text{Foreign}}(\omega) \\
& + \beta_{15} D_{s,\text{tariff2001}>3} + \beta_{16} D_{s,2.75<\text{tariff2001}\leq 3} + \beta_{17} D_{s,2.5<\text{tariff2001}\leq 2.75} + \varepsilon(\omega)
\end{aligned}
$$

Dependent variable is a dummy variable which takes value 1 when the firm ω in sector s exits between year t and t'. $(tariff_{s,2003} - tariff_{s,2001})/tariff_{s,2001}$ is percentage change of average import tariffs of sector s. $\log TFPQ_{s,2001}(\omega)$ ($\log TFPR_{s,2001}(\omega)$) is log of year 2001 $TFPQ$ ($TFPR$) level of firm ω in sector s. Sector level productivity absent distortions is captured by $\bar{z}_s = \left[\sum (z_s(\omega))^{\sigma-1} \right]^{\frac{1}{\sigma-1}}$. $\log (TFPQ_{s,2001}(\omega)/\bar{z}_s)$ and $\log (TFPR_{s,2001}(\omega)/\bar{\tau}_s)$ are the difference in level in productivity and distortion of firm ω relative to its sectoral level, respectively. $\alpha_{s,2005}$ is capital intensity in 2005. $\log emp(\omega)$ is log value of number of employee of firm ω. $age(\omega)$ is the years since reported firm's year of establishment. There are 5 dummy variables for ownership type of firms: state-owned firms (SOE), collective firms, private domestic firms, HMT (Hong Kong, Macao, Taiwan based) firms, and foreign firms. Last three dummy variables take value 1 if average import tariff rate of sector s in 2001 falls into the relevant domain.

There are several things to note about the equation for estimation. When we want to estimate binary choice, firm's exit in this estimation, where explanatory variables are endogenous, natural model to use is a linear probability model. In this estimation, I use 2SLS method by using average tariff rate of each sector in 2001 as an instrument variable for the percentage change in the aver-

age import tariff rate between 2001 and 2003. It is because endogeneity issue on the change in the average tariff rates still arises in this estimation. The estimated coefficient of an explanatory variable is a direct estimate of marginal effect on the probability of firms' exit as the explanatory variable change. Interaction terms of the change in the average tariff with two key variables, $\log TFPQ_{s,2001}(\omega)$ and $\log TFPR_{s,2001}(\omega)$, are used to assess impact of trade liberalization on firm exit. The average import tariff rates in the interaction terms are instrumented with the average tariff rate in 2001. Presence of interaction terms in the estimation makes the linear probability model more desirable to use. Ai and Norton (2003) pointed out that magnitude and statistical significance on the interaction effect, in the non-linear models such as logit or probit, are not equal the marginal effect of the interaction term.

Inclusion of dummy variables for firm types is important since exit of firms can be driven by other reforms associated with firm types. Industry dummies are perfectly correlated with the change in average tariff rate variable, thus are omitted. Different level of average tariff rate in sector s can affect impact of trade liberalization on firms exit. Market selection has been going through before China joined the WTO. Less productive firms may have already exited in a sector with low level of tariff rate. Dummy variables for the level of average tariff rate in 2001 are included to control for the difference across sectors in the impact of trade liberalization on firms exit.

Table B.2 reports estimation results. Coefficients in the first row tell us that firms are more likely to exit in sectors which experienced higher drop in tariff rates. This effect is the largest in the first year after China's accession to the WTO and decreases over time. Impact of trade liberalization on firms' exit can be seen in the second and third row. Less productive firms are much more likely to exit in the following 3 years after 2001 in more liberalized sectors. Moreover, highly distorted firms are more likely to exit in sectors that experience a higher tariff reduction.

2.5.2. Effects of Tariffs on Firm Entry

In this section, I perform estimation to study whether productivities or distortions levels of entrants in more liberalized sectors are different from those levels of entrants in less liberalized sectors. I use the following equation for estimation.

$$
\begin{aligned}
\log\left(TFPQ_{s,t}(\omega)/\bar{z}_s\right) \;=\; & \beta_0 + \beta_1\left(-\frac{tariff_{s,2003} - tariff_{s,2001}}{tariff_{s,2001}}\right) \\
\text{or } \log\left(TFPR_{s,t}(\omega)/\bar{\tau}_s\right) \quad & +\beta_2 D_{\text{Entry}_{s,t}}(\omega) \times \left(-\frac{tariff_{s,2003} - tariff_{s,2001}}{tariff_{s,2001}}\right) \\
& +\beta_3 D_{\text{Exit}_{s,t+1}}(\omega) \times \left(-\frac{tariff_{s,2003} - tariff_{s,2001}}{tariff_{s,2001}}\right) \\
& +\beta_4 D_{\text{Incumbent}_{s,t}}(\omega) \times \left(-\frac{tariff_{s,2003} - tariff_{s,2001}}{tariff_{s,2001}}\right) \\
& +\beta_5 D_{\text{Entry}_{s,t}}(\omega) + \beta_6 D_{\text{Exit}_{s,t+1}}(\omega) \\
& +\beta_7 \alpha_{s,2005} + \beta_8 \log emp(\omega) \\
& +\beta_9 D_{\text{SOE}}(\omega) + \beta_{10} D_{\text{Collective}}(\omega) + \beta_{11} D_{\text{Private}}(\omega) \\
& +\beta_{12} D_{\text{HMT}}(\omega) + \beta_{13} D_{\text{Foreign}}(\omega) \\
& +\beta_{14} D_{s,\log(\text{tariff2001})>3} + \beta_{15} D_{s,2.75<\log(\text{tariff2001})\leq 3} \\
& +\beta_{16} D_{s,2.5<\log(\text{tariff2001})\leq 2.75} + \varepsilon(\omega)
\end{aligned}
$$

Dependent variable is relative productivity (distortion) level of firm ω to its sectoral productivity (distortion) level. $D_{\text{Entry}_{s,t}}(\omega)$ is a dummy variable which is 1 when firm ω enters sector s in year t. $D_{\text{Exit}_{s,t+1}}(\omega)$ is a dummy variable for firm ω's exit in year $t+1$. Other explanatory variables are introduced in section 5.1. I consider interaction term of entry and exit dummies with the change in average import tariff rates. This allows us to compare productivity levels of entering firms and exiting firms in more liberalized sectors with those in less liberalized sectors.

Table B.3 reports estimation results on relative productivity level of firms across sectors with different degree of trade liberalization. For year 2002 and 2003, entrants in more liberalized sectors are more productive relative to entrants in less liberalized sectors. Coefficients on the interaction

terms with entrants and trade liberalization are positive and significant. When we look at the productivity levels of entrants compared to other firms, they are less productive than other firms. As pointed out in Brandt, Van Biesebroeck and Zhang (2012), entrant firms have lower productivity compared to the incumbents. However, there is a significant difference in productivity levels of entrants across sectors. Trade liberalization impacts market selection of firms.

Estimation results on relative distortion level of firms across sectors are reported in Table B.4. For year 2002, entering firms and exiting firms' level of productivity and distortion show not significant difference across sectors. However, from 2003, entrants in more liberalized sectors had less distortion level relative to entrants in less liberalized sectors. Notice that entrants typically had high distortion level as confirmed by the coefficients on the entry term. This may be due to the higher financial friction that they may face at the initial periods of establishment. Still, entrants in more liberalized sectors may need to have better access to the financial market in order to operate in the sectors. State-owned firms have significantly lower distortion compared to other types of firms over all periods, which confirms the perception that they have better access to credit.

2.6. Conclusion

To conclude, I show in this paper that trade liberalization is an important source of reducing misallocation across firms, thus leading to higher TFP. I provided evidence that reduction in misallocation comes from the extensive margin. Highly distorted firms are more likely to exit in sectors that experience a higher tariff reduction. In addition, entrants in more liberalized sectors are much more productive relative to entrants in less liberalized sectors. Through these forces in the extensive margin, allocation of factors improves more in industries that experience a higher drop in tariff rates. Under restrictive assumptions, I showed that reducing misallocation on the extensive margin has quantitatively large effect on TFP. I plan to calibrate the model to the economy in China. This will allow me to estimate quantitative impacts of trade liberalization on the sectoral TFP in China.

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3. Chapter 3: Schumpeterian Growth, Trade, and Directed Technical Change

3.1. Introduction

Technical change towards particular factors has been studied rigorously in recent decade. Acemoglu (2002) provides analysis on conditions that shape the direction of technical change. It is common in the literature that technical change is performed by the skilled labor in the North, where skilled labor is relatively more abundant than the South. The South adopts the technology developed in the North. The technology may not fit to them since it is developed to fit the endowments of factors in the North.

In this paper, I argue that the South can engage in technical change and utilize their best fitted technology to produce goods rather than adopting the technology developed in the North. This view may be more appropriate for many developing countries where economy is not stagnant. These countries steadily increase its trade with other countries, specifically with the North. Direction of technical change can be different for these countries. The same price effect and market size effect which shaped the technical change in the North affect the South but with different direction. Thus, we need to analyze how these forces have different effects on the economy.

I present a simple model of international trade with endogenous growth. In general equilibrium set up, we analyze how technology advancement is directed towards particular factor of production in international trade between the North and the South. The North has endowed with relatively higher skilled labor to unskilled labor than the South. Cross-country differences in factor endowments and sectoral productivities affect incentive to invest in R&D toward each factor. Main result shows that more R&D is directed towards skill-augmenting technology in the North than in the South in the sector with same skill-intensity. Trade allows the North to focus on more skill-intensive sectors not only in production but also in technology advancement. Moreover, innovation is tilted toward skill-augmenting technology as the skill intensity of sector increases. Results find that the direction of technology change is different in the South. We analyze impact of trade on the skill premium. As trade costs changes, there is a reallocation of resources in both production and innovation, which leads the change in the skill premium. There exist gains from trade not only due to specialization but also from endogenous directed technical change.

Caselli and Coleman (2006) perform cross-country analysis and find that lower-income countries use unskilled labor more efficiently than the higher-income countries. Romalis (2004) uses detailed trade data between US and several other countries to analyze how factor proportions determine the structure of commodity trade. The sectors are ranked by skill intensivity, which is approximated by ratio of nonproduction workers to total employment in each industry. Alternatively, average wages can be used to measure skill-intensivity. He finds that northern country has larger shares of more skill-intensive industries. Bloom, Draca, and Van Reenen (2009) have done empirical work which can be related to directed technical change. Technical change in their paper is measured by IT, patent counts and citations, TFP and R&D. Using a panel of over to 200,000 European firms, they find positive impact of the growth of Chinese import competition on technical change. They analyzed the technical change only in the North. This paper gives a theoretical background on the cross-country difference in the direction of technical change toward the factors of production.

3.2. Model

There exist 2 countries, North and South. Each country shares same production technology and utility function. Difference is in their endowment in skilled labor, h, and unskilled labor, l. These two are the factors of production and they are supplied inelastically. There can be initial sectoral differences in technology. There exists continuum of sectors j on $[0,1]$. Sector j is arranged to rank sectors by skilled labor intensiveness. I focus on country N in analysis. Time subscript t is muted in following section

3.2.1. Technologies

Production of a good in sector j is

$$y(j) = A_i \left[\alpha_j^{\frac{1}{\rho}} (z_{h,j} h_j)^{\frac{\rho-1}{\rho}} + (1-\alpha_j)^{\frac{1}{\rho}} (z_{l,j} l_j)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}} \tag{3.1}$$

where A_i is general technology for country i. h_j and l_j is the skilled labor and unskilled labor hired in sector j respectively. z_h (z_l) is a technology augmented to the factor h (l). Innovation is s-augmenting if there is improvement on z_h and l-augmenting if z_l improves. And $\rho > 0$ is the elasticity of substitution between skilled and unskilled labor.

α_j shows relative importance of skilled labor. E.g. if $\alpha_j = 1$, the firm in sector j hires only skilled labor.

Produced good will be consumed domestically and (or) be exported. And trade costs are expressed as iceberg cost where $D (\geq 1)$ units should be produced in order to export 1 unit of a good. Thus, $y(j) = a(j) + x_j D a^*(j)$. $a^*(j)$ is the quantity of goods exported to the country S. Certain goods are not produced but imported from country S. Goods are imported when the price of the imported good is cheaper than the domestically produced good.

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Profit of a firm is

$$\pi(j) = \max_{y(j),p_a(j),p_a^*(j),a_j,a_j^*,x_j} p_a(j)a_j + x_j p_a^*(j)a_j^* - sh_j - wl_j$$

where $p_a(j)$ is the price of good j in domestic market and $p_a^*(j)$ is the price of good j in foreign market. s denotes wage paid for skilled labor while w is wage for unskilled labor.

Resource constraints output to be used either in the North or the South, $y(j) = a_j + x_j D a_j^*$.

Producers maximize their profits subject to resource constraints and technology given by equation (3.1).

3.2.2. Final Consumption Good

Non-tradable final consumption good is produced from home and foreign intermediate goods with the form

$$Y = \left(\int_0^1 q(j)^{\frac{\sigma-1}{\sigma}} dj \right)^{\frac{\sigma}{\sigma-1}} \tag{3.2}$$

Final consumption good producer purchase $q(j)$ quantity of goods j, which is $q(j) = a(j) + x_j^* b(j)$. $a(j)$ is the quantity of good produced and consumed within the country. $b(j)$ is the quantity of good produced and imported from country S. $\sigma > 1$ is the elasticity of substitution between sectors. $x_j \in \{0, 1\}$ indicates whether the country exports or not for good j. x_j^* is the export decision of a firm j in foreign country. The value is 1 when the firm exports. This set up is similar to Atkeson and Burstein (2009), where each firm produces differentiated good in a measure of operating firms. In their analysis, when new firm enters market, it will create new differentiated good. Here, new firm replaces existing operating firm. Also, in this model, both skilled labor and unskilled labor are factors of production. Innovation is directed toward specific factor of production. Directed technology change is analyzed in Acemoglu (2002). Here, we allow the south to develop their technology rather than importing the technology deloped by the North. Also, sectors differ in skill-intensity. Each sector has different incentive in directing R&D to specific technology. We

can analyze how factor proportion and endowment can affect the structure of trade. The main goal would be to analyze how this trade structure interact with innovation.

3.2.3. Demand for Intermediate Goods

Final consumption good producers buy intermediate goods from home producers at prices $p_a(j)$ and from foreign producers at prices $p_b(j)$. They will purchase cheaper good j between the two goods. Thus, price of a good j will be $p(j) = \min\{p_a(j), p_b(j)\}$. Consumption of intermediate goods j is $q(j) = a(j) + x_j^* b(j)$. Solution to final consumption good producer's problem leads to following demand functions:

Price of final consumption goods is

$$
P_t = \left[\int_0^1 p(j)^{1-\sigma} dj \right]^{\frac{1}{1-\sigma}}
\tag{3.3}
$$

Demand for intermediate good j is

$$
\frac{a_j}{Y_t} = \left(\frac{p_a(j)}{P_t} \right)^{-\sigma}, \quad \frac{b_j}{Y_t} = \left(\frac{p_b(j)}{P_t} \right)^{-\sigma}
\tag{3.4}
$$

Demand for intermediate good j in the South is

$$
\frac{a_j^*}{Y_t^*} = \left(\frac{p_a^*(j)}{P_t^*} \right)^{-\sigma}, \quad \frac{b_j^*}{Y_t^*} = \left(\frac{p_b^*(j)}{P_t^*} \right)^{-\sigma}
$$

Intermediate good producers face this demand curve with elasticity σ. They charge constant markup over their marginal costs. Price of good j is

$$
p_a(j) = \frac{\sigma}{\sigma - 1} c_j
\tag{3.5}
$$

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where unit cost is defined as

$$c_j \equiv \frac{1}{A_i} \left(\alpha_j \left(\frac{s}{z_{h,j}} \right)^{1-\rho} + (1 - \alpha_j) \left(\frac{w}{z_{l,j}} \right)^{1-\rho} \right)^{\frac{1}{1-\rho}} \tag{3.6}$$

Export price of good j reflects trade costs:

$$p_a^*(j) = \frac{\sigma}{\sigma - 1} Dc_j \tag{3.7}$$

Prices of goods in the South are

$$p_b(j) = \frac{\sigma}{\sigma - 1} Dc_j^*, \quad p_b^*(j) = \frac{\sigma}{\sigma - 1} c_j^*$$

Good j will be exported when $p_a^*(j) < p_b^*(j)$, which is $\frac{\sigma}{\sigma-1} Dc_j < \frac{\sigma}{\sigma-1} c_j^*$. Using unit costs in the North and the South, this condition corresponds to

$$D\frac{1}{A_i} \left(\alpha_j \left(\frac{s}{z_{h,j}} \right)^{1-\rho} + (1-\alpha_j) \left(\frac{w}{z_{l,j}} \right)^{1-\rho} \right)^{\frac{1}{1-\rho}} < \frac{1}{A_i^*} \left(\alpha_j \left(\frac{s^*}{z_{h,j}^*} \right)^{1-\rho} + (1-\alpha_j) \left(\frac{w^*}{z_{l,j}^*} \right)^{1-\rho} \right)^{\frac{1}{1-\rho}} \tag{3.8}$$

Firm produces when $p_a(j) < p_b(j)$, which is

$$\frac{1}{A_i} \left(\alpha_j \left(\frac{s}{z_{h,j}} \right)^{1-\rho} + (1-\alpha_j) \left(\frac{w}{z_{l,j}} \right)^{1-\rho} \right)^{\frac{1}{1-\rho}} < D\frac{1}{A_i^*} \left(\alpha_j \left(\frac{s^*}{z_{h,j}^*} \right)^{1-\rho} + (1-\alpha_j) \left(\frac{w^*}{z_{l,j}^*} \right)^{1-\rho} \right)^{\frac{1}{1-\rho}} \tag{3.9}$$

Exporting firm also produce for domestic good since condition (3.9) is satisfied whenever condition (3.8) holds. We define $\bar{\alpha}_j$ and $\underline{\alpha}_j$ as threshold values which make inequality (3.8) and (3.9) hold in equality respectively.

First, in the presence of trade costs, when factor price equalization fails, we can show that $\frac{s}{w} \frac{z_{l,j}}{z_{h,j}} < \frac{s^*}{w^*} \frac{z_{l,j}^*}{z_{h,j}^*}$. In this case, sectors requiring more skilled labor, $\alpha_j > \bar{\alpha}_j$, will export to country S. This corresponds to the region C in Figure 3.1. And sectors requiring more unskilled labor, $\alpha_j < \underline{\alpha}_j$
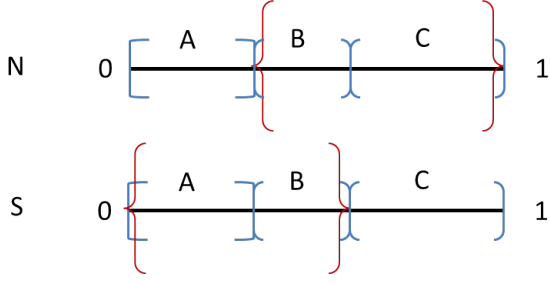
Note: For country N, region A denotes sectors where goods are imported. Sectors in region B produce goods but the goods are consumed within the country N. Region C sectors produce and they export to country S.

Figure 3.1.: Specialization patterns

will import from country S (region A). In the middle range sectors (region B), $\alpha_j \in [\underline{\alpha}_j, \bar{\alpha}_j]$, goods will be produced and consumed within their own country. The range will be broader when trade costs, D, is higher or when relative price of skilled labor to unskilled labor is not much different in two countries.

Second, export is more likely when the relative productivity $A_i/A_i{}^*$ is high. Difference in technology and relative factor endowments determine specialization.

3.3. Research (R&D) : Directed Technical Change

Research is done by hiring skilled labor. Research can be directed toward improving on either z_h or z_l (or both). Profit is a function of $z_{h,j}$ and $z_{l,j}$.

$$\pi_j = \frac{1}{(\sigma-1)^{1-\sigma}\sigma^\sigma} \left(Y_t P_t^\sigma + x_j D^{1-\sigma} Y_t^* P_t^{*\sigma}\right) A_i^{\sigma-1} \left(\alpha_j \left(\frac{s}{z_{h,j}}\right)^{1-\rho} + (1-\alpha_j)\left(\frac{w}{z_{l,j}}\right)^{1-\rho}\right)^{\frac{1-\sigma}{1-\rho}}$$

Innovator choose $z_{h,t+1}$ and $z_{l,t+1}$. However, research cost is increasing in the distance $z_{h,t+1} - z_{h,t}$. Following specification from Acemoglu (2002), productivity in creating new technology is dependent on the current state of both s-augmenting and l-augmenting technology.

$$\frac{z_{h,j,t+1} - z_{h,j.,t}}{\left(z_{h,j,t}\right)^{\frac{1+\delta}{2}} \left(z_{l,j,t}\right)^{\frac{1-\delta}{2}}} = Bh_{h,j,t}^{\theta}, \qquad \frac{z_{l,j,t+1} - z_{l,j,t}}{\left(z_{h,j,t}\right)^{\frac{1-\delta}{2}} \left(z_{l,j,t}\right)^{\frac{1+\delta}{2}}} = h_{l,j,t}^{\theta} \qquad (3.10)$$

where $0 \leq \theta \leq 1$, $0 \leq \delta \leq 1$ and $B \leq 1$. δ is the degree of state dependence. When $\delta = 1$, technology advancements depends only on their own state of technology and do not affect cost of developing the other.

When $B < 1$, it costs more to innovate on s-augmenting technology. There is an advantage in innovating s-augmenting technology in the North. s-augmenting technology in the North is $\frac{z_{h,j,t+1} - z_{h,j.,t}}{\left(z_{h,j,t}\right)^{\frac{1+\delta}{2}} \left(z_{l,j,t}\right)^{\frac{1-\delta}{2}}} = B\zeta h_t^{\theta}$ where $\zeta \geq 1$. Parameter ζ is needed to match with empirical data which shows higher relative wage for the skilled to the unskilled in the North compared to the South. All analysis goes through when we set this parameter ζ equal to 1.

Entrant needs to pay fixed cost, f_e, to initiate research. The fixed cost can be interpreted as wages paid to specialized labor which exists only for R&D as in Aghion and Howitt (1992). Specialized labor has to be hired proportional to skilled labor hired in R&D. Entry cost makes the ex ante profit of the entrant be equal to zero. The number of entrant is indeterminate but there is always one entrant who succeeds in innovation. Thus, entrant is indifferent in which sector to innovate on. Entrant decides how many skilled labor to hire in innovating each technology. The entrant reaps every profit from monopolist selling the innovated good for next period.

Entrant's problem is

$$\max_{h_{h,j,t}^{E}, h_{l,j,t}^{E}} \pi_{j,t+1}\left(z_{h,j,t+1}, z_{l,j,t+1} | z_{h,j,t}, z_{l,j,t}\right) - s_t\left(h_{h,j,t}^{E} + h_{l,j,t}^{E}\right) - f_e$$

subject to

$$\frac{z_{h,j,t+1} - z_{h,j.,t}}{\left(z_{h,j,t}\right)^{\frac{1+\delta}{2}} \left(z_{l,j,t}\right)^{\frac{1-\delta}{2}}} = B\zeta h_{h,j,t}^{\theta}, \qquad \frac{z_{l,j,t+1} - z_{l,j,t}}{\left(z_{h,j,t}\right)^{\frac{1-\delta}{2}} \left(z_{l,j,t}\right)^{\frac{1+\delta}{2}}} = h_{l,j,t}^{\theta}.$$

First order conditions are

$$\frac{1}{\theta}(B\zeta)^{-\frac{1}{\theta}}\left(\frac{z_{h,j,t+1}-z_{h,j,t}}{(z_{h,j,t})^{\frac{1+\delta}{2}}(z_{l,j,t})^{\frac{1-\delta}{2}}}\right)^{\frac{1}{\theta}-1}\frac{s_t}{(z_{h,j,t})^{\frac{1+\delta}{2}}(z_{l,j,t})^{\frac{1-\delta}{2}}}=$$

$$\frac{1}{(\sigma-1)^{-\sigma}\sigma^{\sigma}}\left(Y_{t+1}P_{t+1}^{\sigma}+x_jD^{1-\sigma}Y_{t+1}^{*}P_{t+1}^{*\sigma}\right)A_i^{\sigma-1}\alpha_j s_{t+1}^{1-\rho}z_{h,j,t+1}^{\rho-2}$$

$$\cdot\left(\alpha_j\left(\frac{s_{t+1}}{z_{h,j,t+1}}\right)^{1-\rho}+(1-\alpha_j)\left(\frac{w_{t+1}}{z_{l,j,t+1}}\right)^{1-\rho}\right)^{\frac{\rho-\sigma}{1-\rho}} \tag{3.11}$$

and

$$\frac{1}{\theta}\left(\frac{z_{l,j,t+1}-z_{l,j,t}}{(z_{h,j,t})^{\frac{1-\delta}{2}}(z_{l,j,t})^{\frac{1+\delta}{2}}}\right)^{\frac{1}{\theta}-1}\frac{s_t}{(z_{h,j,t})^{\frac{1-\delta}{2}}(z_{l,j,t})^{\frac{1+\delta}{2}}}=$$

$$\frac{1}{(\sigma-1)^{-\sigma}\sigma^{\sigma}}\left(Y_{t+1}P_{t+1}^{\sigma}+x_jD^{1-\sigma}Y_{t+1}^{*}P_{t+1}^{*\sigma}\right)A_i^{\sigma-1}(1-\alpha_j)w_{t+1}^{1-\rho}z_{l,j,t+1}^{\rho-2}$$

$$\left(\alpha_j\left(\frac{s_{t+1}}{z_{h,j,t+1}}\right)^{1-\rho}+(1-\alpha_j)\left(\frac{w_{t+1}}{z_{l,j,t+1}}\right)^{1-\rho}\right)^{\frac{\rho-\sigma}{1-\rho}} \tag{3.12}$$

We can solve for optimal technology in the next period, $z_{h,j,t+1}$ and $z_{l,j,t+1}$, from these equations. Then, the number of employee for innovation on s-augmenting and l-augmenting technology ($h_{h,j,t}$ and $h_{l,j,t}$) is easily traced with innovation technology constraint (3.10).

From conditions(3.11) and (3.12) , we have

$$\left(\frac{1}{B\zeta}\right)\left(\frac{h_{h,j,t}}{h_{l,j,t}}\right)^{1-\theta}\left(\frac{s_{t+1}}{w_{t+1}}\right)^{\rho-1}\left(\frac{z_{h,j,t}}{z_{l,j,t}}\right)^{2-\delta-\rho}\left\{\frac{B\zeta\left(h_{h,j,t}\right)^{\theta}\left(\frac{z_{h,j,t}}{z_{l,j,t}}\right)^{\frac{\delta-1}{2}}+1}{\left(h_{l,j,t}\right)^{\theta}\left(\frac{z_{h,j,t}}{z_{l,j,t}}\right)^{\frac{1-\delta}{2}}+1}\right\}^{2-\rho}=\frac{\alpha_j}{1-\alpha_j} \tag{3.13}$$

Free entry condition is

$$\frac{1}{(\sigma-1)^{1-\sigma}\sigma^{\sigma}}\left(Y_{t+1}P_{t+1}^{\sigma}+x_{j}D^{1-\sigma}Y_{t+1}^{*}P_{t+1}^{*\sigma}\right)A_{i}^{\sigma-1}$$

$$\cdot\left(\alpha_{j}\left(\frac{s_{t+1}}{z_{h,j,t+1}}\right)^{1-\rho}+(1-\alpha_{j})\left(\frac{w_{t+1}}{z_{l,j,t+1}}\right)^{1-\rho}\right)^{\frac{1-\sigma}{1-\rho}}=$$

$$s_{t}(h_{h,j,t}^{E}+h_{l,j,t}^{E})+f_{e} \tag{3.14}$$

Constant fraction φ of profit is paid to skilled labor hired in research. Thus,

$$\varphi\frac{1}{(\sigma-1)^{1-\sigma}\sigma^{\sigma}}\left(Y_{t+1}P_{t+1}^{\sigma}+x_{j}D^{1-\sigma}Y_{t+1}^{*}P_{t+1}^{*\sigma}\right)A_{i}^{\sigma-1}$$

$$\cdot\left(\alpha_{j}\left(\frac{s_{t+1}}{z_{h,j,t+1}}\right)^{1-\rho}+(1-\alpha_{j})\left(\frac{w_{t+1}}{z_{l,j,t+1}}\right)^{1-\rho}\right)^{\frac{1-\sigma}{1-\rho}}=$$

$$s_{t}(h_{h,j,t}^{E}+h_{l,j,t}^{E})$$

3.4. Equilibrium

Definition 1 : Equilibrium of the economy is composed of a sequence of aggregate prices $\{P_{t}, P_{t}^{*}, s_{t}, s_{t}^{*}, w_{t}, w_{t}^{*}\}$, aggregate quantity $\{Y_{t}, Y_{t}^{*}, H_{t}, H_{t}^{*}, L_{t}, L_{t}^{*}\}$, sector prices for domestic good and export good $\{p_{a,t}(j), p_{a,t}^{*}(j), p_{b,t}(j), p_{b,t}^{*}(j)\}_{j\in[0,1]}$, sector quantities demanded and produced $\{q(j), q^{*}(j), a_{t}(j), a_{t}^{*}(j), b_{t}(j), b_{t}^{*}(j)\}$, firm's profit, export decisions $\{\pi_{j,t}, \pi_{j,t+1}^{*}, x_{j,t}, x_{j,t}^{*}\}$, factor demands for production $\{h_{j,t}, h_{j,t}^{*}, l_{j,t}, l_{j,t}^{*}\}$ and for research $\{h_{h,j,t}^{E}, h_{h,j,t}^{E*}, h_{l,j,t}^{E}, h_{l,j,t}^{E*}\}$ satisfying (intermediate and final good) producers' and innovators' optimality conditions, while those equilibrium clear factors and goods markets and balance trade in the North and the South.

Using demand functions, firm profit can be expressed as

$$
\begin{aligned}
\pi(j) &= \frac{1}{\sigma-1} y_j c_j \\
&= \frac{1}{(\sigma-1)^{1-\sigma}\sigma^\sigma} c_j^{1-\sigma} \left(Y_t P_t^\sigma + x_j D^{1-\sigma} Y_t^* P_t^{*\sigma} \right) \\
&= \frac{A_i^{\sigma-1}}{(\sigma-1)^{1-\sigma}\sigma^\sigma} \left(Y_t P_t^\sigma + x_j D^{1-\sigma} Y_t^* P_t^{*\sigma} \right) \left(\alpha_j \left(\frac{s}{z_{h,j}} \right)^{1-\rho} + (1-\alpha_j) \left(\frac{w}{z_{l,j}} \right)^{1-\rho} \right)^{\frac{1-\sigma}{1-\rho}} (3.15)
\end{aligned}
$$

Profit is increasing as the unit cost is decreasing. Thus, profit increases when the technology advances.

Domestic demand is

$$
a_j = Y_t \left(\frac{p_a(j)}{P_t} \right)^{-\sigma} = Y_t P_t^\sigma p_a(j)^{-\sigma} = Y_t P_t^\sigma \left(\frac{\sigma}{\sigma-1} c_j \right)^{-\sigma}
$$

Foreign demand is

$$
a_j^* = Y_t^* \left(\frac{p_a^*(j)}{P_t^*} \right)^{-\sigma} = Y_t^* P_t^{*\sigma} p_a^*(j)^{-\sigma} = Y_t^* P_t^{*\sigma} \left(\frac{\sigma}{\sigma-1} D c_j \right)^{-\sigma} \tag{3.16}
$$

Output produced in sector j is

$$
\begin{aligned}
y(j) &= a_j + x_j D a_j^* \\
&= Y_t P_t^\sigma \left(\frac{\sigma}{\sigma-1} c_j \right)^{-\sigma} + x_j D Y_t^* P_t^{*\sigma} \left(\frac{\sigma}{\sigma-1} D c_j \right)^{-\sigma} \\
&= \left(\frac{\sigma}{\sigma-1} \right)^{-\sigma} \left(Y_t P_t^\sigma + x_j Y_t^* P_t^{*\sigma} D^{1-\sigma} \right) c_j^{-\sigma} \tag{3.17}
\end{aligned}
$$

Skilled labor and unskilled labor hired in production are, respectively,

$$
h(j) = \frac{y(j)}{A_i^{1-\rho}} \alpha_j z_h^{\rho-1} \left(\frac{c_j}{s} \right)^\rho = \left(\frac{\sigma}{\sigma-1} \right)^{-\sigma} \left(Y_t P_t^\sigma + x_j Y_t^* P_t^{*\sigma} D^{1-\sigma} \right) \frac{1}{A_i^{1-\rho}} \alpha_j z_{h,j}^{\rho-1} s^{-\rho} c_j^{\rho-\sigma} \tag{3.18}
$$

and

$$l(j) = \frac{y(j)}{A_i^{1-\rho}}(1-\alpha_j)z_l^{\rho-1}\left(\frac{c_j}{w}\right)^{\rho} = \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma}(Y_t P_t^{\sigma} + x_j Y_t^* P_t^{*\sigma} D^{1-\sigma})\frac{1}{A_i^{1-\rho}}(1-\alpha_j)z_{l,j}^{\rho-1}w^{-\rho}c_j^{\rho-\sigma}$$

$$(3.19)$$

Relative ratio of the skilled to the unskilled is

$$\frac{h(j)}{l(j)} = \frac{\alpha_j}{1-\alpha_j}\left(\frac{w}{s}\right)^{\rho}\left(\frac{z_{h,j}}{z_{l,j}}\right)^{\rho-1}$$

Skill-premium is expressed as

$$\frac{s}{w} = \left\{\frac{\alpha_j}{1-\alpha_j}\left(\frac{z_{h,j}}{z_{l,j}}\right)^{\rho-1}\frac{l(j)}{h(j)}\right\}^{1/\rho}$$

$$(3.20)$$

Labor market clearing conditions for each factors are

$$\begin{aligned}
H &= \int\{h(j) + h_{h,j}^E + h_{l,j}^E\}dj \\
&= \int\left(\frac{\sigma}{\sigma-1}\right)^{-\sigma}(Y_t P_t^{\sigma} + x_j Y_t^* P_t^{*\sigma} D^{1-\sigma})\frac{1}{A_i^{1-\rho}}\alpha_j z_{h,j}^{\rho-1}s_t^{-\rho}c_{j,t}^{\rho-\sigma} \\
&\quad + \varphi\frac{1}{(\sigma-1)^{1-\sigma}\sigma^{\sigma}}(Y_{t+1}P_{t+1}^{\sigma} + x_j Y_{t+1}^* P_{t+1}^{*\sigma} D^{1-\sigma})s_t^{-1}c_{j,t+1}^{1-\sigma}dj \\
&= \int\left(\frac{\sigma}{\sigma-1}\right)^{-\sigma}(Y_t P_t^{\sigma} + x_j Y_t^* P_t^{*\sigma} D^{1-\sigma})\frac{1}{s_t}\cdot \\
&\quad \left(\left(\frac{A_i z_{h,j}}{s_t}\right)^{\rho-1}\alpha_j c_{j,t}^{\rho-\sigma} + \frac{(Y_{t+1}P_{t+1}^{\sigma} + x_j Y_{t+1}^* P_{t+1}^{*\sigma} D^{1-\sigma})}{(Y_t P_t^{\sigma} + x_j Y_t^* P_t^{*\sigma} D^{1-\sigma})}\frac{\varphi}{\sigma-1}c_{j,t+1}^{1-\sigma}\right)dj \quad (3.21)
\end{aligned}$$

and

$$\begin{aligned}
L &= \int l(j)dj \\
&= \int\left(\frac{\sigma}{\sigma-1}\right)^{-\sigma}(Y_t P_t^{\sigma} + x_j Y_t^* P_t^{*\sigma} D^{1-\sigma})w^{-\rho}(A_i z_{l,j})^{\rho-1}(1-\alpha_j)c_j^{\rho-\sigma}dj \quad (3.22)
\end{aligned}$$

Trade balance requires that all income is spent on the final non-traded good.

$$PY = sH + wL$$

General equilibrium of this model is described as following:

Given factor prices $\{s, s^*, w, w^*\}$, unit cost (c_j, c_j^*) is derived from equation (3.6). Prices for intermediate goods are determined from equation (3.5) and (3.7) which are proportional to the unit cost. Export decision is made based on condition (3.8). Once production decision is made from (3.9), unskilled and skilled labor are hired following equation (3.18) and (3.19). In this step, we use normalized final output. They produce a_j, a_j^*, b_j, b_j^* according to equation (3.16). From (3.3), aggregate price and quantity is retrieved using labor market clearing condition for unskilled labor, (3.19). Profit is given from (3.15). Next, equation (3.11) and (3.12) give how many researchers are hired on both s-augmenting and l-augmenting R&D in each sector. Equilibrium factor prices should satisfy labor market clearing conditions and balance trade between the North and the South.

3.5. Balanced Growth Path

> Definition 2 : Balanced growth path (BGP) is an equilibrium sequence where variables (research labor for each sector and each technology, skilled labor and unskilled labor for each sector) stay constant. Skill-premium and the threshold values $\underline{\alpha}_j, \bar{\alpha}_j$ also stays constant. And output and consumption grows at constant rate.

Under complete specialization where the North produces goods over $\underline{\alpha}_j$ and exports goods over $\bar{\alpha}_j$, aggregate prices are

$$P_t = \left\{ \int_0^{\underline{\alpha}_j} \left(\frac{\sigma}{\sigma - 1} D c_{j,t}^* \right)^{1-\sigma} dj + \int_{\underline{\alpha}_j}^1 \left(\frac{\sigma}{\sigma - 1} c_{j,t} \right)^{1-\sigma} dj \right\}^{\frac{1}{1-\sigma}}$$

$$P_t^* = \left\{ \int_0^{\bar{\alpha}_j} \left(\frac{\sigma}{\sigma-1} c_{j,t}^* \right)^{1-\sigma} dj + \int_{\bar{\alpha}_j}^1 \left(\frac{\sigma}{\sigma-1} Dc_{j,t} \right)^{1-\sigma} dj \right\}^{\frac{1}{1-\sigma}}$$

Trade balance in the North is

$$
\begin{aligned}
P_t Y_t &= s_t H + w_t L \\
&= \int_{\underline{\alpha}_j}^1 \left(\frac{\sigma}{\sigma-1} \right)^{-\sigma} Y_t P_t^\sigma \left\{ \left(1 + \frac{Y_{t+1} P_{t+1}^\sigma}{Y_t P_t^\sigma} \frac{c_{j,t+1}^{1-\sigma}}{c_{j,t}^{1-\sigma}} \frac{\varphi}{\sigma-1} \right) c_{j,t}^{1-\sigma} \right\} dj \\
&\quad + \int_{\bar{\alpha}_j}^1 \left(\frac{\sigma}{\sigma-1} \right)^{-\sigma} Y_t^* P_t^{*\sigma} D^{1-\sigma} \left\{ \left(1 + \frac{c_{j,t+1}^{1-\sigma}}{c_{j,t}^{1-\sigma}} \frac{\varphi}{\sigma-1} \right) c_{j,t}^{1-\sigma} \right\} dj \qquad (3.23)
\end{aligned}
$$

Trade balance in the South is

$$
\begin{aligned}
P_t^* Y_t^* &= s_t^* H^* + w_t^* L^* \\
&= \int_0^{\bar{\alpha}_j} \left(\frac{\sigma}{\sigma-1} \right)^{-\sigma} Y_t^* P_t^{*\sigma} \left\{ \left(1 + \frac{Y_{t+1}^* P_{t+1}^{*\sigma}}{Y_t^* P_t^{*\sigma}} \frac{c_{j,t+1}^{*1-\sigma}}{c_{j,t}^{*1-\sigma}} \frac{\varphi}{\sigma-1} \right) c_{j,t}^{*1-\sigma} \right\} dj \\
&\quad + \int_0^{\underline{\alpha}_j} \left(\frac{\sigma}{\sigma-1} \right)^{-\sigma} Y_t P_t^\sigma D^{1-\sigma} \left\{ \left(1 + \frac{c_{j,t+1}^{*1-\sigma}}{c_{j,t}^{*1-\sigma}} \frac{\varphi}{\sigma-1} \right) c_{j,t}^{*1-\sigma} \right\} dj \qquad (3.24)
\end{aligned}
$$

In essence, what we solve in general equilibrium are $\{s, s^*, w, w^*, Y, Y^*\}$ with equations (3.21)and (3.22) and the trade balance for the North and the South, (3.23) and (3.24).

Share of expenditure on foreign goods is $\frac{\int_0^{\alpha_j} p_b(j)b(j)dj}{PY} = P_t^{\sigma-1} \int_0^{\alpha_j} \left(\frac{\sigma}{\sigma-1} Dc_{j,t}^* \right)^{1-\sigma} dj$

On the balanced growth path, $\frac{z_{h,j,t+1} - z_{h,j,t}}{z_{h,j,t}} = \frac{z_{l,j,t+1} - z_{l,j,t}}{z_{l,j,t}} \equiv \lambda_j \Leftrightarrow$

$$\frac{B\zeta h_{h,j,t}^\theta}{h_{l,j,t}^\theta} = \left(\frac{z_{h,j,t}}{z_{l,j,t}} \right)^{1-\delta} \qquad (3.25)$$

Using this on equation (3.13), we have

$$(B\zeta)^{-\frac{1}{\theta}} \left(\frac{z_{h,j,t}}{z_{l,j,t}} \right)^{\frac{1}{\theta}(1-\delta)+1-\rho} \left(\frac{s_{t+1}}{w_{t+1}} \right)^{\rho-1} = \frac{\alpha_j}{1-\alpha_j} \tag{3.26}$$

Combining with equation (3.20), skill premium is

$$\frac{s}{w} = (B\zeta)^{-\frac{1}{\theta}} \left(\frac{z_{h,j,t}}{z_{l,j,t}} \right)^{\frac{1}{\theta}(1-\delta)} \frac{l(j)}{h(j)} \tag{3.27}$$

3.6. Main Results

Assumption 1. Parameter values satisfy $\frac{1}{\theta}(1-\delta)+1-\rho > 0$

Parameters δ and θ governs R&D technology. ρ is the elasticity of substitution between skilled labor and unskilled labor. Estimated value on ρ in the literature ranges from 1.2 to 1.4. Following results come under this assumption. When $\frac{1}{\theta}(1-\delta)+1-\rho < 1$, then we can not pin down relative technology in each sector since $\frac{z_{h,j,t}}{z_{l,j,t}}$ is a convex function of α_j.

Proposition 1. $\frac{z_{h,j,t}}{z_{l,j,t}}$ is increasing in α_j. Moreover, when $\delta < 1$, $\frac{h_{h,j,t}}{h_{l,j,t}}$ is increasing in α_j.

The result is derived from equation (3.26). When $\delta < 1$, equation (3.25) proves the second result. As skill intensity is increasing, ratio of innovation on s-augmenting technology to innovation on l-augmenting technology is increasing. As skill intensity grows, more skilled labor is employed in the s-augmenting R&D sector to the l-augmenting R&D sector.

Lemma 1. $\frac{\partial \frac{z_{h,j}}{z_{l,j}}}{\partial \alpha_j} > \frac{\partial \frac{z_{h,j}^*}{z_{l,j}^*}}{\partial \alpha_j}$ if and only if $\frac{s}{w} < \zeta^{\frac{1}{\theta(\rho-1)}} \frac{s^*}{w^*}$ for $\forall j, t$.

From equation (3.26), we have

$\frac{\partial \frac{z_{h,j,t}}{z_{l,j,t}}}{\partial \alpha_j} = \frac{1}{\frac{1}{\theta}(1-\delta)+1-\rho} \left(\frac{\alpha_j}{1-\alpha_j} \right)^{\frac{1}{\frac{1}{\theta}(1-\delta)+1-\rho}-1} \frac{1}{(1-\alpha_j)^2} (B\zeta)^{\frac{1}{(1-\delta)+(1-\rho)\theta}} \left(\frac{s_{t+1}}{w_{t+1}} \right)^{\frac{1-\rho}{\frac{1}{\theta}(1-\delta)+1-\rho}}$. Comparing same

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equation for $\dfrac{\partial \frac{z^*_{h,j}}{z^*_{l,j}}}{\partial \alpha_j}$ proves the result.

Lemma 2. In equilibrium, $\frac{s}{w} < \zeta^{\frac{1}{\theta(\rho-1)}} \frac{s^*}{w^*}$ should be satisfied.

Suppose not. Then we have $\dfrac{\partial \frac{z_{h,j}}{z_{l,j}}}{\partial \alpha_j} \leq \dfrac{\partial \frac{z^*_{h,j}}{z^*_{l,j}}}{\partial \alpha_j}$. This implies that $\frac{z^*_{h,j}}{z^*_{l,j}} \geq \frac{z_{h,j}}{z_{l,j}}$ for all sectors. This is not

compatible with the assumption that $H/L > H^*/L^*$. There should exist some sectors in the North

where they hire more skilled labor to unskilled labor than in the South.

Using lemma 2, $\zeta^{\frac{1}{\theta}} \left(\frac{s^*_{t+1}/z^*_{h,j,t}}{w^*_{t+1}/z^*_{l,j,t}} \right)^{\rho-1} > \left(\frac{s_{t+1}/z_{h,j,t}}{w_{t+1}/z_{l,j,t}} \right)^{\rho-1}$. Define $\zeta^{\frac{1}{\theta}} \left(\dfrac{\frac{s^*_{t+1}/z^*_{h,j,t}}{w^*_{t+1}/z^*_{l,j,t}}}{\frac{s_{t+1}/z_{h,j,t}}{w_{t+1}/z_{l,j,t}}} \right)^{\rho-1} \equiv \Delta_j > 1$.

Proposition 2. $\zeta^{\frac{1}{\theta}} \frac{h_{h,j}}{h_{l,j}} \geq \frac{h^*_{h,j}}{h^*_{l,j}}$ for $\forall j \in [0,1]$.

Skilled labor hired in each R&D is $h^E_{h,j} = \left\{ \frac{1}{B\zeta} \lambda_j \left(\frac{z_{h,j,t}}{z_{l,j,t}} \right)^{\frac{1-\delta}{2}} \right\}^{\frac{1}{\theta}}$ and $h^E_{l,j} = \left\{ \lambda_j \left(\frac{z_{h,j,t}}{z_{l,j,t}} \right)^{\frac{\delta-1}{2}} \right\}^{\frac{1}{\theta}}$. On

the balanced growth path, free entry condition becomes $\varphi \pi_{j,t+1} = s_t(h^E_{h,j} + h^E_{l,j})$. Hence,

$$\frac{\pi_{j,t+1}}{\pi_{j,t}} = \frac{\left(Y_{t+1}P^\sigma_{t+1} + x_j D^{1-\sigma} Y^*_{t+1} P^{*\sigma}_{t+1} \right)}{\left(Y_t P^\sigma_t + x_j D^{1-\sigma} Y^*_t P^{*\sigma}_t \right)} \lambda_j^{\sigma-1} = \frac{s_t}{s_{t-1}}$$

This holds for all sectors, thus λ_j is constant, λ, across sectors. Thus, $\frac{\partial h^E_{h,j}}{\partial \alpha_j} > 0$ and $\frac{\partial h^E_{l,j}}{\partial \alpha_j} < 0$.

Furthermore, $\frac{\partial \pi_{j,t+1}}{\partial \alpha_j} = \frac{\partial (s_t(h^E_{h,j}+h^E_{l,j}))}{\partial \alpha_j} = s_t \frac{\partial (h^E_{h,j}+h^E_{l,j})}{\partial \frac{z_{h,j,t}}{z_{l,j,t}}} \frac{\partial \frac{z_{h,j,t}}{z_{l,j,t}}}{\partial \alpha_j}$. $\frac{\partial \pi_{j,t+1}}{\partial \alpha_j} > 0 \Leftrightarrow \frac{z_{h,j,t}}{z_{l,j,t}} > (B\zeta)^{\frac{1}{1-\delta}}$

As $\frac{z_{h,j,t}}{z_{l,j,t}}$ is increasing in α_j, profit is U-shaped as we move along α_j. We can find a turn-around

value $\tilde{\alpha}_j$ where $\frac{z_{h,\tilde{j},t}}{z_{l,\tilde{j},t}} = (B\zeta)^{\frac{1}{1-\delta}}$. R&D investment in sectors above (below) this value increases

and the increase is mainly driven by investment in s-augmenting (l-augmenting) technology. Thus,

proportion of s-augmenting technology investment in R&D is increasing as sectors are more skill-

intensive. Same argument holds for the South and the turn-around value for the South is $\tilde{\alpha}^*_j$. Same

turn around value applies for the inverse-U-shaped unit cost function. Price of a good is a linear

function of the unit cost. Thus, for sectors over this turn-around value, price of a good decreases

as the sectors become more skill-intensive.

Proposition 3. If$\Delta_j > \zeta^{\frac{1}{\theta}}$, $\tilde{\alpha}^*_j > \tilde{\alpha}_j$

At $\tilde{\alpha}_j$, $\frac{z_{h,\tilde{j},t}}{z_{l,\tilde{j},t}} = (B\zeta)^{\frac{1}{1-\delta}}$. If $\Delta_j > \zeta^{\frac{1}{\theta}}$, then $\frac{s_{t+1}/z_{h,\tilde{j},t}}{w_{t+1}/z_{l,\tilde{j},t}} < \frac{s^*_{t+1}/z^*_{h,\tilde{j},t}}{w^*_{t+1}/z^*_{l,\tilde{j},t}}$. Equation (3.26) leads to $\frac{z_{h,\tilde{j},t}}{z_{l,\tilde{j},t}} > $

$\zeta^{\frac{1}{1-\delta}}\frac{z^*_{h,\tilde{j},t}}{z^*_{l,\tilde{j},t}}$. Therefore, $B^{\frac{1}{1-\delta}} > \frac{z^*_{h,\tilde{j},t}}{z^*_{l,\tilde{j},t}}$. And $\frac{z^*_{h,\tilde{j}*,t}}{z^*_{l,\tilde{j}*,t}} = B^{\frac{1}{1-\delta}}$ at $\tilde{\alpha}^*_j$. Thus, $\frac{z^*_{h,\tilde{j}*,t}}{z^*_{l,\tilde{j}*,t}} > \frac{z^*_{h,\tilde{j},t}}{z^*_{l,\tilde{j},t}}$.

In this proposition, we need the condition $\Delta_j > \zeta^{\frac{1}{\theta}}$. This is more likely to be held when difference in the endowment ratio of skilled and unskilled labor is large while advantage of the North in s-augmenting technology is small. Note that when there is no specific advantage in the North in developing s-augmenting technology, $\zeta = 1$, the condition always hold.

> **Proposition 4.** Threshold values for domestic production $\underline{\alpha}_j$ and for export $\bar{\alpha}_j$ is a function of trade costs and other parameters.

$\frac{\partial \underline{\alpha}_j}{\partial D} < 0$, $\frac{\partial \bar{\alpha}_j}{\partial D} > 0$.

$\frac{\partial \underline{\alpha}_j}{\partial (A_i/A^*_i)} < 0$, $\frac{\partial \bar{\alpha}_j}{\partial (A_i/A^*_i)} < 0$.

The range of $[\underline{\alpha}_j, \bar{\alpha}_j]$ shrinks as trade costs decreases. Thus, larger variety of goods is traded when trade costs decreases. As the relative productivity of the North to the South increases, the ranges that the North produces and exports get wider.

> **Proposition 5.** $\frac{\partial (s/w)}{\partial D} < 0$, $\frac{\partial (s^*/w^*)}{\partial D}?0$, $\frac{\partial (s/w)}{\partial D} < \frac{\partial (s^*/w^*)}{\partial D}$

$\frac{\partial (s/w)}{\partial (H/L)}?0$, $\frac{\partial (s*/w*)}{\partial (H*/L*)}?0$,

$\frac{\partial (\lambda_{h,j}/\lambda_{l,j})}{\partial (H/L)}?0$, $\frac{\partial (\lambda^*_{h,j}/\lambda^*_{l,j})}{\partial (H^*/L^*)}?0$

The skill-premium increases as trade costs decreases. When trade costs drops, threshold value for domestic production, $\underline{\alpha}_j$, increases. This allows the North to focus its resources in more skill-intensive sectors where they hire more skilled labor. Thus, skill-premium increases in the North. Moreover, less trade costs brings a decrease in threshold value of domestic production for the South, $\bar{\alpha}_j$. The South will put more resources in the labor-intensive sectors. However, the change in the skill-premium in the South can be positive or negative. Even though they require more unskilled labor in production which will raise wage for the unskilled, they need to hire skilled labor in developing l-augmenting technology and that drives up wages for the skilled. Thus, the answer depends on the magnitude of each effect on the skill-premium.

Proposition 6. Gains from trade are magnified due to endogenous directed technical change.

Gains from trade come from specialization based on Heckscher-Ohlin effect. Trade allows countries to specialize in sectors that intensively use their relatively abundant factors. The gains are magnified by directed technical change. Thus, gains from trade is larger in this model compared to the case where there is no directed technical change or to the case where the technical change is only allowed in the North. Endogenous technical change in the South lowers unit costs in the South. This lowers price of intermediate goods as well as aggregate price in both the North and the South. Real output increases due to directed technical change spurred by trade.

3.7. Conclusion

We analyze how technology advancement is directed towards particular factor of production in international trade between the North and the South. Cross-country differences in factor endowments and sectoral productivities affect incentive to invest in R&D toward each factor. Main result shows that more R&D is directed towards skill-augmenting technology in the North than in the South in the sector with same skill-intensity. Trade allows the North to focus on more skill-intensive sectors not only in production but also in technology advancement. Result finds that the direction of technology change is different in the South. In both countries, innovation is tilted toward skill-augmenting technology as the skill intensity of sector increases. Growth of the economy is affected by these forces. Countries specialize in sectors that use their abundant factors more intensively. As a result, they have larger shares of production and trade of commodities in those sectors. As trade costs changes, there is a reallocation of resources in both production and innovation, which leads the change in the skill premium. As trade costs decreases, skill premium in the North increases. Change of the skill premium in the South can be either positive or negative. In data, the skill premium has increased for both developed and undeveloped countries. There exists gains from trade not only due to specialization but also from endogenous directed technical change. Lowering

trade costs allows countries to trade more various set of goods and higher level of technology development in those added sectors. Interesting further work can be done by allowing endowments of skilled and unskilled labor to be endogenous. Quantitative analysis is desired. Quantitative work will help me to verify whether this technical change is directed to skill-intensive sectors or unskilled-intensive sectors in both the North and the South.

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A. Appendix for Chapter 1

A.1. Two Stage Input-Output Matrix

Input\Output	Stage 1	Stage 2	Service	Consumption	Export
Stage 1	6,059,723	2,988,430	4,309,906	2,656,440	3,688,840
Stage 2	532,533	4,509,671	2,245,967	9,027,211	4,619,429
Service	2,702,294	2,732,990	14,218,944	30,540,579	1,801,192
Value added	5,079,023	4,715,457	28,202,172		

Table A.1.: Input-Output Structure (Aggregated over all countries) Year : 2004, Unit : Million $, Source : GTAP 8

A.2. Scheme of Estimation

1. Guess wage for each country, $w_i = \tilde{w}_i$. Rental rate is decided from wage and aggregate capital-labor ratio, $\tilde{r}_i = \frac{\alpha}{1-\alpha} \tilde{w}_i h_i k_i^{-1}$.

2. With $\hat{P}_{1,i}$ (equation (1.15)), get $\hat{A}_{1,i}$ from $\hat{S}_{1,i} = \ln \left\{ \left[\left(\hat{P}_{1,i} \right)^{1-\beta_1} \left(\tilde{w}_i^{1-\alpha} \tilde{r}_i^{\alpha} \right)^{\beta_1} \right]^{-1/\theta} A_{1,i} \right\}$.

3. Guess aggregate price of first stage good, $P_{1,i} = \tilde{P}_{1,i}$.

4. With $\tilde{w}_i$ and $\hat{A}_{1,i}$, get new $P_{1,i}$ from equation (1.10).

$$P_{1,i} = \gamma_1 \left\{ \sum_{l=1}^{N} \left[\left(\tilde{w}_l^{1-\alpha} \tilde{r}_l^{\alpha} \right)^{\beta_1} \left(\tilde{P}_{1,l} \right)^{1-\beta_1} \hat{\tau}_{1,il} \right]^{-1/\theta} \hat{A}_{1,l} \right\}^{-\theta}$$

5. Go back to step 3 using this new $P_{1,i}$ as a guess until we get to a fixed point $P_{1,i}$.

6. With $\hat{P}_{2,i}$ (equation (1.17)) and $P_{1,i}$ from step 5, get $\hat{A}_{2,i}$ from

$$\hat{S}_{2,i} = \ln \left\{ \left[(P_{1,i})^{\beta(1-\beta_2)} \left(\hat{P}_{2,i} \right)^{(1-\beta)(1-\beta_2)} \left(\tilde{w}_i^{1-\alpha} \tilde{r}_i^{\alpha} \right)^{\beta_2} \right]^{-1/\theta} A_{2,i} \right\}.$$

7. Guess aggregate price of second stage good, $P_{2,i} = \tilde{P}_{2,i}$.

8. With $\hat{A}_{2,i}$ and $P_{1,i}$ from step 5, get new $P_{2,i}$ from equation (1.11).

$$P_{2,i} = \gamma_2 \left\{ \sum_{l=1}^{N} \left[(P_{1,l})^{\kappa(1-\beta_2)} \left(\tilde{P}_{2,l} \right)^{(1-\kappa)(1-\beta_2)} \left(\tilde{w}_l^{1-\alpha} \tilde{r}_l^{\alpha} \right)^{\beta_2} \hat{\tau}_{2,il} \right]^{-1/\theta} \hat{A}_{2,l} \right\}^{-\theta}$$

9. Go back to step 7 using this new $P_{2,i}$ as a guess until we get to a fixed point $P_{2,i}$.

10. Equipped with $P_{1,i}$, $P_{2,i}$, $\hat{A}_{1,i}$, $\hat{A}_{2,i}$, $\hat{\tau}_{1,ij}$, $\hat{\tau}_{2,ij}$s, equations (1.7) and (1.9) give trade shares. We get new wage, w_i, which satisfies trade balance condition, (1.13). Go back to step 1 using this new wage as a guess until we get to a fixed point w_i.

A.3. Country-Specific Estimates

Country	$ex_{1,i}$	$ex_{2,i}$	$cost_1$ (%)	$cost_2$(%)	$\hat{S}_{1,i}$	$\hat{S}_{2,i}$	$\left(\frac{A_{1,us}}{A_{1,i}}\right)^{\theta}$	$\left(\frac{A_{2,us}}{A_{2,i}}\right)^{\theta}$
United States	5.58	6.16	-63.7	-67.4	0.02	-0.56	1.00	1.00
Albania	-3.48	-3.79	88.2	99.3	0.79	1.49	1.19	1.01
United Arab Emirates	1.75	7.83	-27.2	-75.9	-0.26	-6.13	0.98	2.38
Argentina	1.32	2.07	-21.3	-31.3	-0.50	-1.45	1.89	1.99
Armenia	-3.24	-4.43	80.2	123.7	-0.04	1.60	1.84	1.41
Australia	3.15	3.86	-43.6	-50.4	-0.54	-1.19	1.12	1.14
Austria	1.64	2.72	-25.7	-39.0	-0.34	-1.24	1.18	1.26
Belgium	4.84	4.89	-58.6	-58.9	-1.91	-2.05	1.32	1.23
Bangladesh	-1.18	-2.50	23.9	57.6	1.00	1.52	2.09	1.84
Bulgaria	0.07	0.00	-1.3	0.1	-0.39	-0.57	1.45	1.37
Belarus	-0.55	-3.55	10.6	90.6	-0.99	2.19	1.83	1.11
Bolivia	-4.23	-3.75	115.6	97.6	1.69	1.52	1.67	1.59
Republic of Brazil	2.40	2.28	-35.4	-33.9	-0.37	-0.83	1.74	1.72
Botswana	-5.38	-1.32	165.9	27.1	2.07	-1.27	1.27	1.79
Canada	2.95	3.93	-41.5	-51.1	0.11	-0.96	1.16	1.26
Switzerland	3.23	2.92	-44.4	-41.2	-1.19	-1.25	1.36	1.25
Chile	1.10	1.60	-18.1	-25.3	-0.27	-1.07	1.55	1.59
China	3.82	3.62	-50.1	-48.2	0.02	-0.49	1.66	1.64
Cote d'Ivoire	-1.73	-2.58	37.0	59.9	0.49	1.37	1.79	1.51
Cameroon	-2.93	-4.80	70.3	139.4	1.22	3.11	1.61	1.22
Colombia	-0.53	-0.83	10.0	16.2	0.82	0.92	1.28	1.18
Costa Rica	0.31	-0.06	-5.5	1.0	-1.04	-0.78	1.32	1.18
Czech Republic	0.34	0.99	-6.0	-16.4	0.20	-0.18	1.25	1.21
Germany	4.13	4.56	-52.8	-56.4	-0.20	-0.52	1.19	1.15
Denmark	1.39	2.39	-22.4	-35.3	-0.48	-1.19	1.18	1.22

Country	$ex_{1,i}$	$ex_{2,i}$	$cost_1$ (%)	$cost_2$(%)	$\hat{S}_{1,i}$	$\hat{S}_{2,i}$	$\left(\frac{A_{1,us}}{A_{1,i}}\right)^{\theta}$	$\left(\frac{A_{2,us}}{A_{2,i}}\right)^{\theta}$
Ecuador	-1.29	-0.77	26.4	15.0	0.81	0.05	1.35	1.38
Egypt	-0.36	-1.04	6.7	20.7	0.52	0.68	1.27	1.16
Spain	3.45	3.68	-46.6	-48.8	-0.21	-0.48	1.05	1.01
Estonia	-1.25	0.40	25.5	-7.0	-0.27	-1.37	1.28	1.40
Ethiopia	-3.13	-2.89	76.6	69.2	0.91	1.11	1.84	1.68
Finland	1.17	2.06	-19.2	-31.3	-0.23	-1.07	1.02	1.07
France	3.55	4.05	-47.5	-52.1	-0.12	-0.45	1.09	1.05
United Kingdom	3.79	4.68	-49.8	-57.3	-0.17	-0.75	1.03	1.04
Georgia	-3.20	-3.19	78.9	78.6	0.29	1.15	1.62	1.36
Ghana	0.80	-0.13	-13.5	2.4	-1.67	-0.58	2.57	2.06
Greece	1.44	0.67	-23.1	-11.4	-0.25	0.44	0.95	0.80
Guatemala	-0.36	-2.01	6.7	44.1	-0.47	0.90	1.23	0.96
Honduras	-1.97	-2.68	43.1	62.7	0.28	0.84	1.23	1.07
Croatia	-1.39	-1.17	28.8	23.6	0.72	0.63	0.94	0.88
Hungary	-0.34	0.50	6.5	-8.7	0.27	-0.07	1.09	1.06
Indonesia	2.66	1.88	-38.4	-29.0	-0.67	-0.82	2.04	1.93
India	2.72	1.60	-39.0	-25.2	-0.16	0.30	1.79	1.57
Ireland	0.69	2.27	-11.7	-33.9	0.13	-1.09	0.93	1.05
Iran	-1.32	-1.73	27.0	37.0	1.29	1.52	1.03	0.94
Israel	1.77	1.53	-27.5	-24.2	-1.19	-0.82	1.25	1.10
Italy	3.27	3.63	-44.8	-48.3	0.23	-0.20	0.90	0.89
Japan	3.49	4.14	-46.9	-52.9	0.59	-0.41	1.09	1.14
Kazakhstan	-1.95	-2.00	42.5	43.9	1.08	1.55	1.35	1.19
Kenya	-0.55	-2.18	10.5	48.7	-0.45	1.00	1.82	1.43
Kyrgyzstan	-3.97	-4.14	105.8	112.3	0.08	0.58	2.20	1.92

Country	$ex_{1,i}$	$ex_{2,i}$	$cost_1$ (%)	$cost_2$(%)	$\hat{S}_{1,i}$	$\hat{S}_{2,i}$	$\left(\frac{A_{1,us}}{A_{1,i}}\right)^{\theta}$	$\left(\frac{A_{2,us}}{A_{2,i}}\right)^{\theta}$
Cambodia	-2.44	-3.96	55.7	105.6	-0.62	0.64	2.62	2.05
Republic of Korea	3.75	3.35	-49.4	-45.6	-0.65	-0.91	1.22	1.16
Lao	-6.68	-6.41	236.9	220.7	1.58	1.81	1.57	1.42
Sri Lanka	0.99	-1.08	-16.5	21.7	-1.77	-0.01	2.42	1.79
Lithuania	-1.21	-0.49	24.6	9.3	-0.07	-0.33	1.32	1.27
Luxembourg	-0.30	2.70	5.6	-38.7	-0.90	-3.43	1.17	1.67
Latvia	-1.49	-2.09	31.1	46.2	-0.43	0.71	1.26	1.00
Morocco	-0.58	-1.28	11.1	26.1	0.80	0.87	1.22	1.13
Madagascar	-2.85	-4.65	67.9	132.9	0.20	2.01	2.01	1.53
Mexico	1.43	1.70	-22.8	-26.6	0.74	0.82	1.11	1.03
Mongolia	-3.93	2.06	104.4	-31.3	0.70	-4.55	2.16	4.53
Mozambique	-4.15	-3.29	112.7	81.8	1.09	0.93	2.44	2.32
Mauritius	0.39	-0.53	-6.8	10.2	-1.90	-0.87	1.76	1.43
Malawi	-2.06	-4.21	45.5	115.1	-1.00	1.26	2.50	1.78
Malaysia	2.46	2.77	-36.1	-39.6	-0.94	-1.39	1.39	1.36
Namibia	-3.86	-2.61	101.6	60.9	0.65	0.01	1.22	1.23
Nigeria	-2.20	-3.89	49.3	102.9	1.99	3.66	1.57	1.22
Nicaragua	-1.32	-3.51	27.0	89.3	-0.61	1.30	1.66	1.22
Netherlands	3.26	3.37	-44.7	-45.8	-0.48	-0.85	1.28	1.25
Norway	-0.50	1.49	9.6	-23.7	1.35	-0.35	0.98	1.15
Nepal	-5.74	-5.24	184.1	159.2	2.18	1.92	1.90	1.83
New Zealand	1.07	2.33	-17.7	-34.6	-0.05	-1.38	1.02	1.12
Pakistan	0.97	-0.57	-16.2	11.0	-0.25	0.55	1.69	1.41
Peru	-0.46	-1.24	8.7	25.2	0.70	1.03	1.30	1.17
Philippines	0.63	0.46	-10.9	-7.9	-0.23	-0.15	1.97	1.81

Country	$ex_{1,i}$	$ex_{2,i}$	cost$_1$ (%)	cost$_2$(%)	$\hat{S}_{1,i}$	$\hat{S}_{2,i}$	$\left(\frac{A_{1,us}}{A_{1,i}}\right)^{\theta}$	$\left(\frac{A_{2,us}}{A_{2,i}}\right)^{\theta}$
Poland	0.45	0.70	-7.8	-11.9	0.80	0.52	1.19	1.14
Portugal	1.23	1.23	-20.0	-20.1	0.16	-0.03	0.86	0.81
Paraguay	-2.83	-2.76	67.2	65.1	0.32	0.29	1.63	1.53
Romania	-0.66	-1.13	12.7	22.9	0.82	0.96	1.29	1.19
Russian Federation	1.62	1.12	-25.5	-18.4	0.07	1.10	1.44	1.18
Saudi Arabia	-0.02	0.25	0.3	-4.5	0.79	0.58	1.07	1.02
Senegal	-1.71	-2.50	36.5	57.5	0.09	0.53	1.72	1.52
Singapore	4.01	6.23	-51.8	-67.8	-1.91	-3.96	1.06	1.36
El Salvador	-1.60	-2.49	33.7	57.3	0.45	1.01	1.09	0.95
Slovakia	-1.24	-0.87	25.3	17.1	0.73	0.40	1.09	1.05
Slovenia	-0.95	-1.08	18.9	21.6	-0.08	0.03	1.15	1.04
Sweden	1.85	2.91	-28.6	-41.1	-0.40	-1.17	1.06	1.10
Thailand	3.29	3.14	-45.0	-43.5	-1.27	-1.45	1.76	1.67
Tunisia	-1.28	-2.34	26.2	53.1	0.33	1.06	1.30	1.10
Turkey	1.93	0.94	-29.6	-15.7	0.05	0.29	1.05	0.95
Taiwan	3.48	2.95	-46.9	-41.5	-0.88	-1.08	1.08	1.02
Tanzania	-1.55	-1.58	32.5	33.2	0.10	0.22	1.63	1.50
Uganda	-1.63	-3.66	34.4	94.5	-0.67	1.42	2.14	1.56
Ukraine	1.25	0.75	-20.3	-12.8	-0.98	-0.43	2.32	1.98
Uruguay	0.16	-0.39	-2.9	7.3	-1.19	-1.09	1.71	1.57
Venezuela	-0.98	-2.08	19.4	46.0	0.88	2.16	1.24	1.00
Viet Nam	1.89	1.19	-29.1	-19.5	-1.37	-0.83	2.36	1.99
South Africa	2.32	2.04	-34.4	-30.9	-0.66	-0.28	1.41	1.25
Zambia	-4.02	-4.07	107.8	109.7	0.92	1.48	1.61	1.41
Zimbabwe	-2.70	-3.04	63.4	73.7	-0.41	0.34	3.36	2.86

A.4. Value Added Trade

Market clearing for the first stage goods states that

$$
\begin{aligned}
L_i P_{1,i} Q_{1,i} &= \sum_j^N X_{1,ji} L_j P_{1,j} Q_{1,j} \\
&= \sum_j^N X_{1,ji} L_j P_{1,j} Q_{1,j}^1 + \sum_j^N X_{1,ji} L_j P_{1,j} Q_{1,j}^2
\end{aligned}
$$

Total expenditure on first stage tradable goods in country i equals total demand from the world. Its total demand can be decomposed into input consumption in the first stage production and input consumption in the second stage production. Market clearing for the second stage goods implies

$$
\begin{aligned}
L_i P_{2,i} Q_{2,i} &= \sum_j^N X_{2,ji} L_j P_{2,j} Q_{2,j} \\
&= \sum_j^N X_{2,ji} L_j P_{2,j} Q_{2,j}^2 + \sum_j^N X_{2,ji} L_j P_{2,j} Q_{2,j}^f
\end{aligned}
$$

Total expenditure on second stage tradable goods in country i equals total demand coming from input consumption in the second stage production and input consumption in the final good production.

Market clearing requires that the value of goods produced equals value of goods used in production at each stage. Thus, we have

$$
(1 - \beta_1) L_i P_{1,i} Q_{1,i} = L_i P_{1,i} Q_{1,i}^1
$$

$$
(1 - \kappa)(1 - \beta_2) L_i P_{2,i} Q_{2,i} = L_i P_{2,i} Q_{2,i}^2
$$

Let

$$
\mathbf{LP}_s\mathbf{Q}_s \equiv \begin{pmatrix} L_1 P_{s,1} Q_{s,1} \\ \vdots \\ L_i P_{s,i} Q_{s,i} \\ \vdots \\ L_N P_{s,N} Q_{s,N} \end{pmatrix}, \qquad \mathbf{LP}_s\mathbf{Q}_{s,i}^{s'} \equiv \begin{pmatrix} X_{s,1i} L_1 P_{s,1} Q_{s,1}^{s'} \\ \vdots \\ X_{s,ji} L_j P_{s,j} Q_{s,j}^{s'} \\ \vdots \\ X_{s,Ni} L_1 P_{s,N} Q_{s,N}^{s'} \end{pmatrix},
$$

$$
\mathbf{X}_s \equiv \begin{pmatrix} X_{s,11} & X_{s,21} & & X_{s,N1} \\ X_{s,12} & X_{s,22} & \cdots & X_{s,N2} \\ \vdots & & \ddots & \vdots \\ X_{s,1N} & \cdots & \cdots & X_{s,NN} \end{pmatrix}
$$

where $s' = 2$ for $s = 1$ and $s' = f$ for $s = 2$.

$$
\begin{aligned}
\mathbf{LP}_1\mathbf{Q}_1 &= \sum_i \mathbf{LP}_1\mathbf{Q}_{1,i}^2 + (1-\beta_1)\mathbf{X}_1\mathbf{LP}_1\mathbf{Q}_1 \\
&= \sum_i (\mathbf{I} - (1-\beta_1)\mathbf{X}_1)^{-1} \mathbf{LP}_1\mathbf{Q}_{1,i}^2 \\
\mathbf{LP}_2\mathbf{Q}_2 &= \sum_i \mathbf{LP}_2\mathbf{Q}_{2,i}^f + (1-\kappa)(1-\beta_2)X_2\mathbf{LP}_2\mathbf{Q}_2 \\
&= \sum_i (\mathbf{I} - (1-\kappa)(1-\beta_2)\mathbf{X}_2)^{-1} \mathbf{LP}_2\mathbf{Q}_{2,i}^f
\end{aligned}
$$

Terms $(\mathbf{I} - (1-\beta_1)\mathbf{X}_1)^{-1}$ and $(\mathbf{I} - (1-\kappa)(1-\beta_2)\mathbf{X}_2)^{-1}$ are the "Leontief inverse" of the input-output matrix. $N \times 1$ vector $(\mathbf{I} - (1-\beta_1)\mathbf{X}_1)^{-1}\mathbf{LP}_1\mathbf{Q}_{1,i}^2$ and $(\mathbf{I} - (1-\kappa)(1-\beta_2)\mathbf{X}_2)^{-1}\mathbf{LP}_2\mathbf{Q}_{2,i}^f$ is the output from each country used to produce final goods consumed in i. These output include direct intermediate good used to produce the final good as well as additional intermediate good used to produce the intermediate good and on and on. Value added embodied in output transfer

from each country to i at each stage is defined as

$$
\begin{aligned}
va_{1,i} &\equiv \beta_1 \left(\mathbf{I} - (1-\beta_1)\mathbf{X}_1\right)^{-1} \mathbf{LP}_1 \mathbf{Q}_{1,i}^2 \\
va_{2,i} &\equiv \beta_2 \left(\mathbf{I} - (1-\kappa)(1-\beta_2)\mathbf{X}_2\right)^{-1} \mathbf{LP}_2 \mathbf{Q}_{2,i}^f
\end{aligned}
$$

Value added content from country j to i at each stage is the jth element of $va_{1,i}$ and $va_{2,i}$ respectively. Total value added produced in j and absorbed in i is $va_{ij} = va_{1,ij} + va_{2,ij}$. When we sum up all value added content in the tradable goods originated from country i to all countries, it should be equal to tradable goods share of GDP. Thus, $\sum_j va_{ji}/L_i p_i y_i = 1 - v$.

A.5. Effects of Trade Costs

Country	$\partial \tau_{us,j} = -.2$				$\partial \tau_{ij}, \partial \tau_{ji} = -.2 \forall j \neq i$	
	$\varepsilon_{us,j}^{va}$	$\varepsilon_{us,j}^{x}$	$\partial y_j(\%)$	$\partial y_j^*(\%)$	$\partial y_j(\%)$	$\partial y_j^*(\%)$
United States					1.29	1.30
Albania	-4.0	-10.3	0.22	0.19	2.13	1.97
United Arab Emirates	-6.2	-8.6	1.70	0.80	6.47	5.18
Argentina	-4.4	-7.9	1.13	1.15	3.66	3.77
Armenia	-4.3	-9.4	0.34	0.24	2.30	1.80
Australia	-4.5	-8.1	0.70	0.61	2.52	2.39
Austria	-4.3	-11.2	0.50	0.51	5.05	5.15
Belgium	-5.6	-10.4	0.94	0.95	2.75	2.89
Bangladesh	-3.8	-10.3	0.12	0.15	1.17	1.45
Bulgaria	-4.8	-10.4	0.66	0.75	5.96	6.40
Belarus	-4.9	-10.2	0.38	0.35	3.49	3.52
Bolivia	-4.1	-8.4	0.22	0.23	0.97	1.05
Brazil	-4.1	-7.6	0.72	0.77	2.18	2.33
Botswana	-5.2	-10.1	0.37	0.14	3.00	1.35
Canada	-2.7	-3.4	8.43	7.91	2.23	2.33
Switzerland	-4.2	-11.2	0.54	0.59	3.86	4.05
Chile	-4.2	-7.4	1.06	1.08	3.09	3.20
China	-4.2	-9.5	0.29	0.31	2.05	2.16
Cote d'Ivoire	-3.9	-8.2	0.37	0.46	1.57	1.99
Cameroon	-3.7	-8.1	0.16	0.21	0.73	0.92
Colombia	-3.9	-6.6	0.71	0.82	1.54	1.78
Costa Rica	-3.6	-5.9	2.13	2.22	3.96	4.18
Czech Republic	-3.9	-11.2	0.38	0.39	4.89	4.94
Germany	-4.8	-9.5	0.62	0.62	3.13	3.25
Denmark	-4.6	-11.1	0.58	0.58	5.13	5.23

Country	$\partial \tau_{us,j} = -.2$				$\partial \tau_{ij}, \partial \tau_{ji} = -.2 \forall j \neq i$	
	$\varepsilon_{us,j}^{va}$	$\varepsilon_{us,j}^{x}$	$\partial y_j(\%)$	$\partial y_j^*(\%)$	$\partial y_j(\%)$	$\partial y_j^*(\%)$
Ecuador	-4.0	-6.1	1.09	1.31	2.12	2.56
Egypt	-3.8	-9.8	0.26	0.30	1.77	1.97
Spain	-5.0	-9.7	0.71	0.71	3.54	3.63
Estonia	-5.4	-10.0	0.98	0.94	7.36	7.31
Ethiopia	-4.1	-9.4	0.11	0.12	0.79	0.89
Finland	-4.9	-10.3	0.75	0.78	5.37	5.44
France	-4.2	-10.3	0.48	0.47	2.68	2.84
United Kingdom	-5.1	-9.3	0.80	0.75	3.65	3.71
Georgia	-4.4	-9.5	0.36	0.36	2.46	2.71
Ghana	-4.6	-7.8	1.33	1.56	4.93	5.86
Greece	-4.5	-10.0	0.45	0.48	3.31	3.50
Guatemala	-3.3	-6.9	1.04	0.91	2.52	2.23
Honduras	-3.6	-6.5	0.77	0.75	1.74	1.70
Croatia	-4.1	-10.7	0.30	0.31	3.24	3.34
Hungary	-4.6	-10.5	0.44	0.45	3.98	4.18
Indonesia	-4.3	-9.7	0.48	0.51	2.74	2.89
India	-4.3	-10.1	0.25	0.26	1.97	2.15
Ireland	-4.1	-11.0	0.52	0.53	4.42	4.47
Iran	-3.6	-10.3	0.07	0.12	0.73	1.25
Israel	-5.2	-9.2	1.01	1.04	5.27	5.52
Italy	-4.6	-9.7	0.53	0.54	3.10	3.17
Japan	-4.4	-9.1	0.32	0.34	1.79	1.92
Kazakhstan	-4.3	-9.7	0.22	0.32	1.53	2.29
Kenya	-3.9	-9.2	0.22	0.22	1.45	1.45
Kyrgyzstan	-4.4	-10.4	0.20	0.24	2.17	2.93

	$\partial \tau_{us,j} = -.2$				$\partial \tau_{ij}, \partial \tau_{ji} = -.2 \forall j \neq i$	
Country	$\varepsilon^{va}_{us,j}$	$\varepsilon^{x}_{us,j}$	$\partial y_j(\%)$	$\partial y^*_j(\%)$	$\partial y_j(\%)$	$\partial y^*_j(\%)$
Cambodia	-3.9	-10.8	0.24	0.17	2.79	2.28
Republic of Korea	-5.0	-10.2	0.49	0.54	3.72	4.00
Lao	-3.2	-11.1	0.06	0.05	0.88	0.91
Sri Lanka	-4.6	-9.1	0.55	0.51	3.33	3.28
Lithuania	-4.9	-10.3	0.61	0.65	5.46	5.82
Luxembourg	-4.8	-11.3	0.60	0.60	5.73	6.54
Latvia	-4.7	-10.2	0.46	0.52	4.15	4.81
Morocco	-3.9	-9.8	0.27	0.32	1.82	2.08
Madagascar	-3.8	-8.8	0.17	0.20	0.99	1.21
Mexico	-3.2	-4.6	2.78	2.81	1.94	2.00
Mongolia	-6.1	-10.9	0.71	0.52	7.47	7.82
Mozambique	-4.1	-10.2	0.19	0.21	1.59	1.95
Mauritius	-4.7	-8.5	0.92	1.00	4.53	5.23
Malawi	-4.0	-8.7	0.32	0.46	1.88	2.80
Malaysia	-3.9	-10.7	0.50	0.53	3.92	4.16
Namibia	-4.4	-9.5	0.21	0.23	1.45	1.69
Nigeria	-3.6	-8.5	0.11	0.19	0.53	0.91
Nicaragua	-3.4	-6.1	1.22	1.05	2.69	2.38
Netherlands	-4.0	-11.1	0.50	0.53	3.41	3.62
Norway	-4.7	-10.4	0.54	0.46	4.28	3.97
Nepal	-3.9	-10.7	0.06	0.06	0.84	0.85
New Zealand	-4.6	-8.4	0.65	0.67	2.69	2.90
Pakistan	-4.3	-10.7	0.23	0.27	2.53	3.01
Peru	-3.9	-7.8	0.29	0.36	1.05	1.30
Philippines	-4.5	-9.8	0.33	0.36	2.34	2.63

Country	$\partial \tau_{us,j} = -.2$				$\partial \tau_{ij}, \partial \tau_{ji} = -.2 \forall j \neq i$	
	$\varepsilon_{us,j}^{va}$	$\varepsilon_{us,j}^{x}$	$\partial y_j(\%)$	$\partial y_j^*(\%)$	$\partial y_j(\%)$	$\partial y_j^*(\%)$
Poland	-3.4	-11.2	0.27	0.30	3.64	3.72
Portugal	-4.2	-10.7	0.50	0.54	3.43	3.56
Paraguay	-4.1	-8.4	0.38	0.48	1.59	2.02
Romania	-4.0	-10.2	0.26	0.32	2.25	2.60
Russian Federation	-4.6	-9.7	0.41	0.57	2.76	3.79
Saudi Arabia	-3.9	-10.2	0.19	0.23	1.66	2.02
Senegal	-4.0	-8.4	0.45	0.53	2.02	2.36
Singapore	-6.3	-8.9	1.85	1.75	6.41	6.75
El Salvador	-3.6	-6.4	0.73	0.77	1.60	1.68
Slovakia	-4.1	-10.9	0.33	0.35	3.99	4.22
Slovenia	-4.1	-11.2	0.38	0.40	5.08	5.27
Sweden	-5.2	-10.0	0.86	0.85	5.24	5.38
Thailand	-5.1	-9.9	0.78	0.79	5.01	5.20
Tunisia	-4.0	-10.3	0.29	0.32	2.51	2.77
Turkey	-4.2	-9.7	0.42	0.49	2.69	2.95
Taiwan	-5.0	-9.9	0.59	0.64	4.03	4.37
Tanzania	-4.2	-9.2	0.24	0.25	1.49	1.61
Uganda	-4.0	-9.1	0.25	0.29	1.66	2.01
Ukraine	-5.3	-10.2	0.80	0.97	6.25	7.13
Uruguay	-4.6	-8.6	1.21	1.44	4.64	5.41
Venezuela	-3.7	-6.4	0.49	0.74	1.09	1.62
Viet Nam	-5.4	-10.7	0.57	0.59	5.41	5.80
South Africa	-4.3	-8.6	0.47	0.49	2.17	2.35
Zambia	-4.0	-9.0	0.12	0.16	0.73	1.06
Zimbabwe	-4.1	-9.5	0.26	0.33	1.80	2.44

Note: ∂y_j^* is the change in real income predicted by a model without stages.
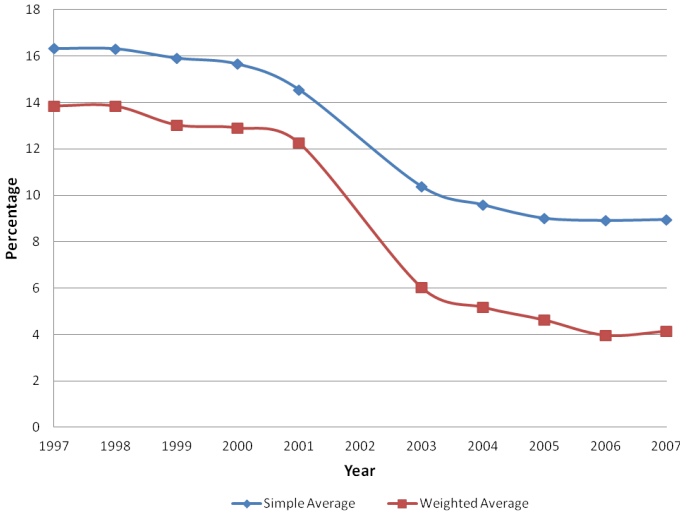
B. Appendix for Chapter 2

B.1. Figures

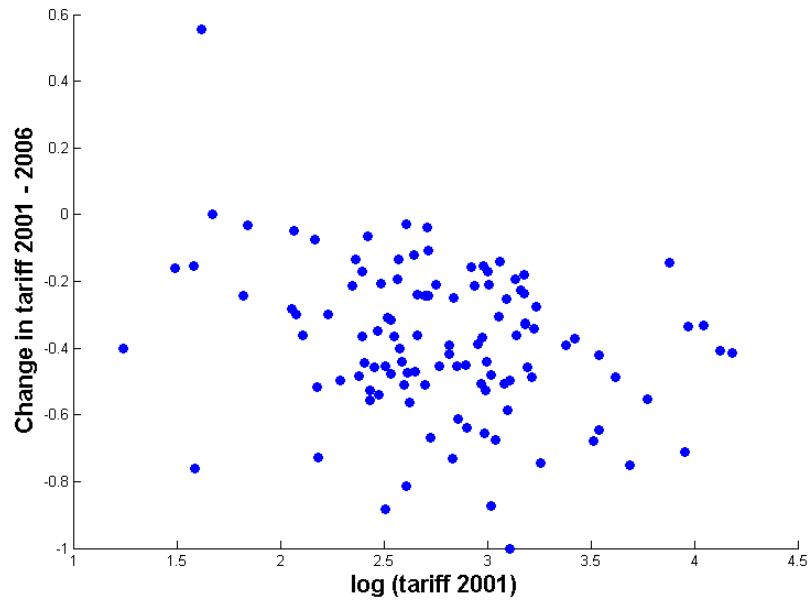Figure B.1.: Average MFN applied import tariffs

Figure B.2.: Change in tariffs 2001 - 2006 relative to average tariff levels in 2001
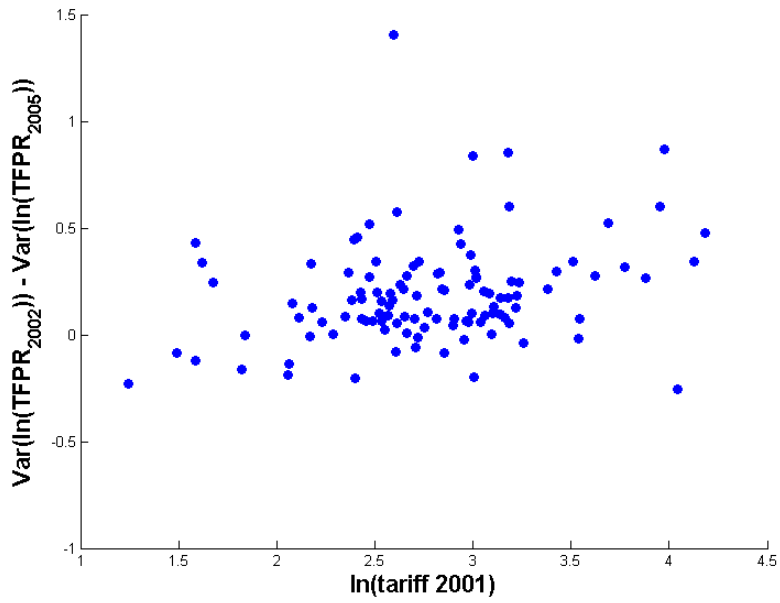
Figure B.3.: Change in S.D.(TFPR) 2002 - 2005 relative to average tariff levels in 2001
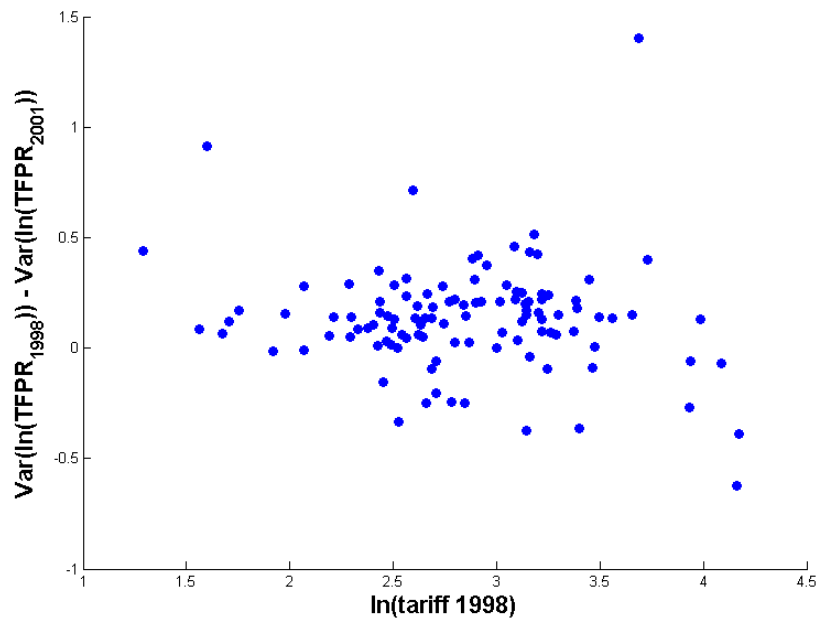
Figure B.4.: Change in S.D.(TFPR) 1998 - 2001 relative to average tariff levels in 1998

B.2. Tables

	2SLS (1)	2SLS (2)	2SLS (3)	OLS (4)
% Change in tariff	0.955**	0.895**	0.928**	0.142*
	(0.432)	(0.436)	(0.377)	(0.075)
Capital intensity	0.133	-0.000		
	(0.219)	(0.13)		
Employment share	1.331	1.283		
	(2.179)	(2.11)		
Export intensity	-0.015	-0.026		
	(0.033)	(0.028)		
Constant	0.133	0.204	0.206	-0.079**
	(0.148)	(0.142)	(0.138)	(0.032)
Observations	111	111	111	111

Note: Dependant variable is the percentage change in the variance of log TFPR between 2002 and 2005. For 2SLS method, Change in average tariff rate between 2001 and 2005 is instrumented with average tariff rate in 2001 as well as other variables that represent sectoral characteristics. For second regression (2), I use capital intensity calculated for year 2001. Significance levels: ** $p < 0.05$, * $p < 0.1$.

Table B.1.: Impact of trade on variance of log TFPR

	Exit 2002	Exit 2003	Exit 2004	Exit 2005	Exit 2006
% Change in tariff	1.100***	0.837***	0.749***	0.066*	-0.063**
	(0.052)	(0.049)	(0.061)	(0.037)	(0.032)
$TFPQ_s(\omega)$	-0.247***	-0.182***	-0.158***	-0.015*	0.013*
* % Change in tariff	(0.012)	(0.011)	(0.014)	(0.009)	(0.007)
$TFPR_s(\omega)$	0.046***	0.039***	0.076***	-0.018*	-0.008
* % Change in tariff	(0.014)	(0.013)	(0.016)	(0.010)	(0.009)
$TFPQ_s(\omega)/\bar{z}_s$	-0.003	-0.001	0.001	-0.006***	-0.005***
	(0.002)	(0.002)	(0.003)	(0.002)	(0.001)
$TFPR_s(\omega)/\bar{\tau}_s$	0.069***	0.054***	0.051***	0.016***	0.005*
	(0.005)	(0.004)	(0.006)	(0.003)	(0.003)
Capital intensity	-0.056***	-0.024***	-0.015	-0.007	-0.004
	(0.008)	(0.008)	(0.010)	(0.006)	(0.005)
Employment	-0.012***	-0.003**	0.005***	0.002**	-0.001
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Age	0.000	0.000**	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Age^2	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
SOE	-0.004	0.028***	0.026***	0.058***	0.013***
	(0.003)	(0.003)	(0.004)	(0.002)	(0.002)
Collective	0.021***	0.019***	0.058***	-0.006***	0.001
	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)
Private	-0.014***	-0.014***	0.021***	-0.008***	-0.006***
	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)
HMT	-0.029***	-0.034***	-0.042***	0.001	0.007***
	(0.003)	(0.003)	(0.004)	(0.003)	(0.002)
Foreign	-0.035***	-0.034***	-0.069***	-0.007**	-0.004
	(0.004)	(0.004)	(0.005)	(0.003)	(0.002)
tariff2001 > 3	0.079***	0.064***	0.071***	0.007**	-0.002
	(0.004)	(0.004)	(0.005)	(0.003)	(0.002)
2.75 < tariff2001 ≤ 3	0.044***	0.025***	0.019***	0.005**	0.000
	(0.003)	(0.003)	(0.004)	(0.002)	(0.002)
2.5 < tariff2001 ≤ 2.75	0.036***	0.016***	0.008**	0.003	-0.001
	(0.003)	(0.003)	(0.004)	(0.002)	(0.002)
Constant	0.022	0.008	0.015	0.005	0.030***
	(0.015)	(0.014)	(0.017)	(0.011)	(0.009)
Observations	135343	135343	135343	135343	135343

Note: Regressions are performed following 2SLS procedure. Dependant variable is exit dummy which takes value 1 when firm exits in that year. Change in average tariff rate between 2001 and 2003 is instrumented with average tariff rate in 2001 as well as other variables that represent individual firm or sectoral characteristics. All variables except dummy variables are expressed in log. Significance levels: *** $p < 0.01$ ** $p < 0.05$, * $p < 0.1$.

Table B.2.: Impact of trade on extensive margin (Exit)

	$TFPQ_{s,t=2002}(\omega)/\bar{z}_s$	$TFPQ_{s,t=2003}(\omega)/\bar{z}_s$	$TFPQ_{s,t=2005}(\omega)/\bar{z}_s$
% Change in tariff	0.203	1.218***	1.416***
	(0.169)	(0.164)	(0.167)
Entry t	2.367***	2.241***	-0.150
* % Change in tariff	(0.739)	(0.703)	(0.671)
Exit $t+1$	0.399	-0.079	2.163***
* % Change in tariff	(0.430)	(0.318)	(0.816)
Incumbent t	1.051***	0.307***	1.333***
* % Change in tariff	(0.115)	(0.077)	(0.116)
Entry t	-0.591***	-0.768***	-0.029
	(0.211)	(0.205)	(0.199)
Exit $t+1$	-0.335***	-0.081	-0.612**
	(0.120)	(0.090)	(0.244)
Capital intensity 2005	-0.702***	-0.982***	-1.172***
	(0.032)	(0.031)	(0.027)
Employment t	0.220***	0.239***	0.214***
	(0.003)	(0.003)	(0.003)
SOE t	-0.948***	-0.898***	-0.723***
	(0.014)	(0.015)	(0.018)
Collective t	0.232***	0.176***	0.118***
	(0.012)	(0.012)	(0.013)
Private t	0.233***	0.213***	0.034***
	(0.012)	(0.010)	(0.008)
HMT t	0.009	-0.113***	-0.295***
	(0.014)	(0.014)	(0.012)
Foreign t	0.102***	0.041***	-0.095***
	(0.015)	(0.014)	(0.012)
tariff2001 > 3	-0.132***	-0.120***	-0.044***
	(0.011)	(0.010)	(0.008)
2.75 < tariff2001 ≤ 3	-0.269***	-0.255***	-0.284***
	(0.013)	(0.012)	(0.010)
2.5 < tariff2001 ≤ 2.75	0.058***	0.060***	0.063***
	(0.012)	(0.011)	(0.010)
Constant	-6.116***	-6.169***	-6.398***
	(0.042)	(0.046)	(0.038)
Observations	144498	161501	227051

Note: Regressions are performed following 2SLS procedure. Dependant variable is $\log(TFPQ_{s,t}(\omega)/\bar{z}_s)$ for $t = \{2002, 2003, 2005\}$. Change in average tariff rate between 2001 and 2003 is instrumented with average tariff rate in 2001 as well as other variables that represent individual firm or sectoral characteristics. All variables except dummy variables are expressed in log. Significance levels: *** $p < 0.01$ ** $p < 0.05$, * $p < 0.1$.

Table B.3.: Impact of trade on extensive margin (Entry)

	$TFPR_{s,t=2002}(\omega)/\bar{\tau}_s$	$TFPR_{s,t=2003}(\omega)/\bar{\tau}_s$	$TFPR_{s,t=2005}(\omega)/\bar{\tau}_s$
% Change in tariff	-1.645***	-0.844***	-2.038***
	(0.122)	(0.116)	(0.115)
Entry t	-0.283	-1.046**	-1.134**
* % Change in tariff	(0.534)	(0.495)	(0.463)
Exit $t+1$	-0.213	-0.009	-0.019
* % Change in tariff	(0.311)	(0.224)	(0.563)
Incumbent t	0.614***	0.068	0.863***
* % Change in tariff	(0.083)	(0.055)	(0.080)
Entry t	0.192	0.282**	0.322**
	(0.152)	(0.144)	(0.138)
Exit $t+1$	-0.047***	-0.036	0.106
	(0.087)	(0.063)	(0.168)
Capital intensity 2005	0.346***	0.181***	0.157***
	(0.023)	(0.022)	(0.018)
Employment t	-0.142***	-0.128***	-0.147***
	(0.003)	(0.002)	(0.002)
SOE t	-0.666***	-0.634***	-0.565***
	(0.010)	(0.011)	(0.012)
Collective t	0.267***	0.229***	0.165***
	(0.009)	(0.009)	(0.009)
Private t	0.259***	0.228***	0.103***
	(0.008)	(0.007)	(0.006)
HMT t	0.021**	-0.027***	-0.074***
	(0.010)	(0.010)	(0.008)
Foreign t	-0.007	-0.016	-0.033***
	(0.011)	(0.010)	(0.008)
tariff2001 > 3	-0.253***	-0.225***	-0.244***
	(0.008)	(0.007)	(0.006)
2.75 < tariff2001 ≤ 3	-0.121***	-0.097***	-0.116***
	(0.009)	(0.008)	(0.007)
2.5 < tariff2001 ≤ 2.75	-0.145***	-0.157***	-0.174***
	(0.009)	(0.008)	(0.007)
Constant	1.142***	1.067***	1.345***
	(0.030)	(0.032)	(0.026)
Observations	144498	161501	227051

Note: Regressions are performed following 2SLS procedure. Dependant variable is $\log\left(TFPR_{s,t=2002}(\omega)/\bar{\tau}_s\right)$ for $t=\{2002,2003,2005\}$. Change in average tariff rate between 2001 and 2003 is instrumented with average tariff rate in 2001 as well as other variables that represent individual firm or sectoral characteristics. All variables except dummy variables are expressed in log. Significance levels: *** $p < 0.01$ ** $p < 0.05$, * $p < 0.1$.

Table B.4.: Impact of trade on extensive margin (Entry)