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Essays on the relative price of tradables and the composition of trade

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ESSAYS ON THE RELATIVE PRICE OF TRADABLES AND THE COMPOSITION OF TRADE

by

Michael Sposi

An Abstract

Of a thesis submitted in partial fulfillment of the
requirements for the Doctor of Philosophy
degree in Economics
in the Graduate College of
The University of Iowa

July 2012

Thesis Supervisor: Professor B. Ravikumar

ABSTRACT

This dissertation consists of two chapters. The first chapter addresses the role of trade barriers in explaining differences in the relative prices of tradables across countries. The second chapter assesses the quantitative importance of changes in comparative advantage in explaining the changes in the compositions of exports and output in South Korea during its growth miracle.

In the first chapter I quantitatively address the role of trade barriers in explaining the cross-country distribution of the price of nontradables relative to tradables. Relative prices of nontradables are higher in rich countries than in poor countries. The standard explanation for this is due to Balassa (1964) and Samuelson (1964), where, in each country, the relative price of nontradables is equal to the inverse of relative productivity, and relative productivity is higher in poor countries. I construct a multi-country model of trade in which countries face asymmetric trade barriers. There are many tradable goods and trade barriers determine the cross-country pattern of specialization across tradable goods. The realized pattern of specialization determines measured productivity in the tradables sector, which determines relative prices. Existing trade barriers account for half of the difference in relative prices between rich and poor countries.

In the second chapter, I explore how the evolution of comparative advantage can explain the changes in the compositions of exports and output that occurred in South Korea during its growth miracle. From 1960 to 1995 manufacture's share in both exports and output increased. I embed a dynamic, multi-country model of trade into a three-sector model of structural change where agriculture, manufactures, and services are complementary in both consumption and production. I measure productivity growth, in each sector for each country, using a growth accounting procedure. I feed the productivity growth rates into the model and find that the increase in manufacture's share in exports and output are explained by a shift in comparative advantage. The model also matches other aspects of the compositions: the declines in both agriculture's and service's share in exports, and the decline in agriculture's share in output. Finally, the model tracks the composition of output for other countries.

Abstract Approved: ______________________________

Thesis Supervisor

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CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

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has been approved by the Examining Committee for the thesis requirement for the Doctor of Philosophy degree in Economics at the July 2012 graduation.

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I dedicate this work to my parents: Philip and Karen Sposi, and to my grandparents: Vito and Teresa Colaninno.

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TABLE OF CONTENTS

LIST OF TABLES

Table

LIST OF FIGURES

Figure

CHAPTER 1
TRADE BARRIERS AND THE RELATIVE PRICE OF TRADABLES

1.1 Introduction

In this chapter I investigate the role that trade barriers play in accounting for the positive correlation between the price of nontradables relative to tradables and income per worker. Figure 1.1 plots the relative price of nontradables against income per worker for the year 2005. In my sample of 84 countries, the elasticity of the relative price of nontradables with respect to income per worker is 0.35.[1] Some references for further empirical documentation of relative prices can be found in Kravis and Lipsey (1988), Heston, Nuxoll, and Summers (1994), and more recently by Bergin, Glick, and Taylor (2006).

My main message is that trade barriers are a crucial ingredient in understanding the pattern of relative prices across countries. Cross-country differences in relative prices are the result of differences in productivity in the tradables sector. I take a novel view that productivity in the tradables sector depends critically on the pattern of specialization across multiple, heterogeneous, tradable goods. In turn, the pattern of specialization is largely driven by the pattern of trade barriers.

Relative prices lie at the heart of understanding real exchange rates (see Burstein, Eichenbaum, and Rebelo, 2005). Moreover, relative prices have been shown

[1] Both the price of nontradables, as well as the price of tradables, vary positively with income per worker; the price elasticity of nontradables with respect to income per worker is 0.59, while the price elasticity of tradables is 0.23.

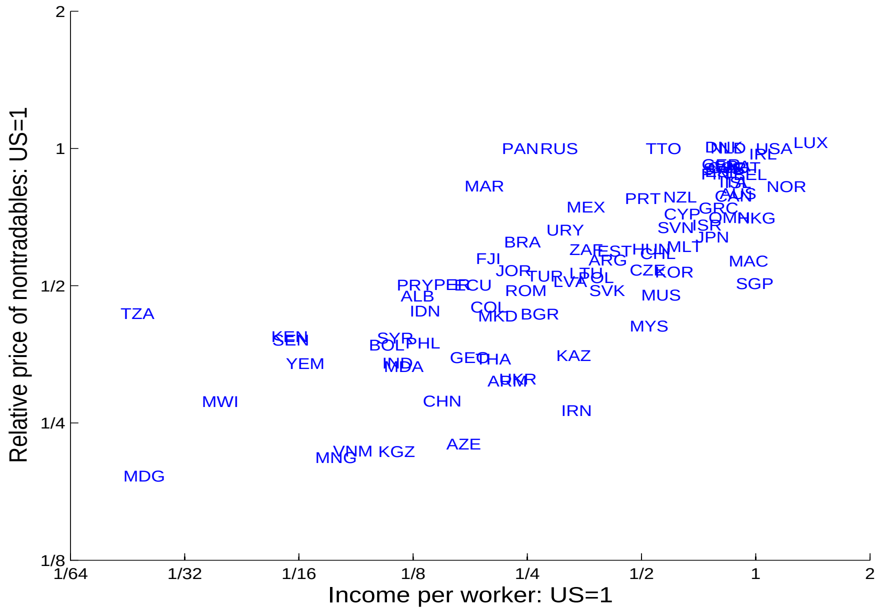

Figure 1.1: Price of nontradables relative to tradables.

to play a crucial role in explaining income differences across countries (Restuccia and Urrutia, 2001; Eaton and Kortum, 2002; Hsieh and Klenow, 2007). As such, it is important to understand the fundamental sources of what causes differences in relative prices across countries. An early explanation as to why relative prices vary positively with development is due to Balassa (1964) and Samuelson (1964), commonly known as the Balassa-Samuelson effect. The theory is as follows. There are larger cross-country productivity differences in tradables than in nontradables. Free trade and no arbitrage force the price of tradables to be equal across countries. Productivity in tradables in rich countries is higher than in poor countries, implying higher wages in rich countries, and therefore, higher production costs. Mobility of homogeneous labor across sectors generates higher production costs in rich countries' nontradables sector. This, coupled with small cross-country productivity differences in nontradables, results in a higher price of nontradables in rich countries than in poor countries. In particular, in each country, the relative price of nontradables is equal to the inverse of its relative productivity.

Herrendorf and Valentinyi (2010) find empirical evidence in support of the Balassa-Samuelson effect: measured cross-country productivity differences are larger in tradables than in nontradables. Bergin, Glick, and Taylor (2006) argue that the Balassa-Samuelson effect holds in the time series as well: as an economy develops, the price of nontradables relative to tradables declines. Theories for why cross-country productivity differences vary across sectors include Buera, Kaboski, and Shin (2011), where financial frictions result in a misallocation of productive resources across sectors. None of these papers, however, quantitatively address the role that trade barriers may have in accounting for relative price differences.

I argue that measured productivity in the tradables sector is the result of the pattern of specialization, which depends crucially on trade barriers. To make this point I construct a multi-country model of trade with many tradable goods. Each country's level of efficiency for each good is a random draw from a Fréchet distribution. Countries differ in their average efficiency across tradable goods and also face asymmetric bilateral trade barriers. In equilibrium, each country produces only a subset of the tradable goods. Therefore, measured productivity in the tradables sector depends on the subset of goods produced, and the subset depends on the pattern of trade barriers.

I apply the model to a set of 84 countries. I discipline the bilateral trade barriers to be consistent with the observed pattern of bilateral trade, and I calibrate the distribution of efficiency levels to match the cross-country distribution of income per worker. These parameters together determine the pattern of specialization, and in turn determine productivity in tradables which determines relative prices.

Through counterfactuals I find that barriers to trade account for half of the difference in relative prices between rich and poor countries. Elimination of trade barriers has two effects. First, it equalizes the price index of tradables across countries (PPP holds). Second, it allows all countries to reallocate resources towards the production of goods for which they have a comparative advantage, thereby changing the pattern of specialization and increasing measured productivity in the tradables sector. This effect is more pronounced in poor countries since they face larger export costs, and increases their wage relative to rich countries. Cross-sector labor mobility raises the price of nontradables in poor countries relative to rich countries. These two effects unambiguously result in convergence of the price of nontradables, relative to tradables, between rich and poor countries.

1.2 Model

My model builds on the framework of Eaton and Kortum (2002), Alvarez and Lucas (2007), and Waugh (2010). There are I countries indexed by $i = 1, \dots, I$. There are two sectors: tradables and nontradables. The tradables sector is denoted by m while the nontradables sector denoted by s.[2] Within the tradables sector there is a continuum of individual goods that are tradable. Individual tradable goods are aggregated into a composite intermediate good, and the composite intermediate good is used as an input in the production of tradables and nontradables. There is a single nontradable good that is used for final consumption.

Each country i admits a representative household that is endowed with a measure N_i of workers. Each worker has a human capital level of h_i. Effective labor is denoted by $L_i = N_i h_i$. The representative household owns its country's capital stock, denoted by K_i. Both capital and labor are immobile across countries but perfectly mobile across sectors. Earnings from capital and labor are spent on consumption of nontradables. From now on, where it is understood, country subscripts are omitted.

1.2.1 Technologies

There is a continuum of individual goods indexed by $x \in [0,1]$, and each individual good is potentially tradable. All technologies exhibit constant returns to scale.

Composite intermediate good All individual tradable goods along the continuum are aggregated into a composite intermediate good M according to

$$M = \left[\int q_m(x)^{\frac{\eta-1}{\eta}} dx \right]^{\frac{\eta}{\eta-1}}.$$

where $q_m(x)$ denotes the quantity of good x.

[2] My quantitative exercise will map tradables into manufactures, and nontradables into services, hence the notation m and s.

Individual tradable goods Each country has access to technologies for producing each individual tradable good as follows

$$m_i(x) = z_i(x)^{-\theta} \left[K_{mi}(x)^{\alpha} L_{mi}(x)^{1-\alpha}\right]^{\nu_m} M_{mi}(x)^{1-\nu_m}.$$

For each factor used in production, the subscript denotes the sector that uses the factor, and the argument in the parentheses denotes the index of the good along the continuum. For example, $K_m(x)$ is the amount of capital used to produce tradable good x. The parameter $\nu_m \in (0,1)$ determines the share of value added in gross production, while $\alpha \in (0,1)$ determines capital's share in value added.

As in Alvarez and Lucas (2007), $z_i(x)$ represents country i's *cost* of producing good x, which is modeled as an independent random draw from an exponential distribution with parameter $\lambda_i > 0$ in country i. This implies that $z_i(x)^{-\theta}$ has a Fréchet distribution. The expected value of $z_i(x)^{-\theta}$ is λ_i^{θ}, so average efficiency across the continuum of goods is λ_i^{θ}.[3] If $\lambda_i > \lambda_j$, then on average, country i is more efficient than country j. The parameter $\theta > 0$ governs the coefficient of variation in efficiency across the continuum. A larger θ implies more variation in efficiency levels, and hence, more room more specialization.

Since the index of the good x is irrelevant, from now on I follow Alvarez and Lucas (2007) and identify each individual good x by its vector of cost draws: $z = (z_1(x), z_2(x), \ldots z_I(x))$.

[3]In equilibrium, each country produces only a subset of these goods and imports the rest. Therefore, average *measured* productivity depends on the set of goods produced and is thus endogenous.

Final nontradable good There is a single non-tradable good. The non-tradable good is produced using capital, labor, and the composite intermediate good according to

$$S = \left(K_s^{\alpha} L_s^{1-\alpha}\right)^{\nu_s} M_s^{1-\nu_s}.$$

1.2.2 International Trade

Country i purchases each individual tradable good from its least cost supplier. The purchase price depends on the unit cost of the producer, as well as trade barriers.

Barriers to trade are denoted by τ_{ij}, where $\tau_{ij} > 1$ is the amount of goods that country j must export in order for one unit to arrive in country i. As a normalization I assume that there are no barriers to ship goods domestically; that is, $\tau_{ii} = 1$ for all i. I also assume that the triangle inequality holds: $\tau_{ij}\tau_{jl} \geq \tau_{il}$.

I focus on a competitive equilibrium. Informally, a competitive equilibrium is a set of prices and allocations which satisfy the following conditions: 1) The representative household exhausts its factor income on nontradables 2) firms maximize profits, taking factor prices as given, 3) domestic factor markets clear and 4) trade is balanced in each country. In the remainder of this section I describe each condition from country i's point of view.

1.2.3 Household optimization

At the beginning of the time period, the capital stock is rented to domestic firms in each sector at the competitive rental rate r_i and labor is supplied domestically at the wage rate w_i. Factor income is spent on consumption of nontradables which has price P_{si}.

1.2.4 Firm optimization

Denote the price for an individual tradable good z that was produced in country j and purchased by country i by $p_{mij}(z)$. Then, $p_{mij}(z) = p_{mjj}(z)\tau_{ij}$, where $p_{mjj}(z)$ is the marginal cost of producing good z in country j. Since each country purchases each individual good from its least cost supplier, the actual price in country i of good z is $p_{mi}(z) = \min_{j=1,\ldots,I}[p_{mjj}(z)\tau_{ij}]$.

The price of the composite intermediate good is

$$P_{mi} = \left[\int p_{mi}(z)^{1-\eta}\varphi(z)dz\right]^{\frac{1}{1-\eta}},$$

where $\varphi(z)$ is the joint density of cost draws across countries.

I explain how to derive the price indices for each country in appendix A.1. Given the assumption on the country-specific densities, φ_{mi}, the model implies that

$$P_{mi} = AB_m\left[\sum_{j=1}^{I}\left(u_{mj}\tau_{ij}\right)^{-1/\theta}\lambda_j\right]^{-\theta},$$

where the unit cost for input bundles u_{mi} is given by $u_{mi} = \left(r_i^{\alpha}w_i^{1-\alpha}\right)^{\nu_m}P_{mi}^{1-\nu_m}$. The terms B_b for $b \in \{m, s\}$, are constant across countries and are given by $B_b = (\alpha\nu_b)^{-\alpha\nu_b}((1-\alpha)\nu_b)^{(\alpha-1)\nu_b}(1-\nu_b)^{\nu_b-1}$. Finally, the term A is constant across countries and is given by $A = \Gamma\left(1+\theta(1-\eta)\right)^{\frac{1}{1-\eta}}$, where $\Gamma(\cdot)$ is the Gamma function. I restrict parameters such that $A > 0$.

The price of the final nontradable good is simply its marginal cost, which is given by

$$P_{si} = B_s u_{si}.$$

The fraction of country i's expenditures on tradable goods from country j is given by:

$$\pi_{ij} = \frac{\left(u_{mj}\tau_{ij}\right)^{-1/\theta}\lambda_j}{\sum\limits_l \left(u_{ml}\tau_{il}\right)^{-1/\theta}\lambda_l}. \tag{1.1}$$

An alternative interpretation of π_{ij} is that it is the fraction of tradable goods that j supplies to i. I describe how to derive trade shares in appendix A.1.

1.2.5 Equilibrium

I first define total factor usage in the tradables sector in country i as follows:

$$L_{mi} = \int L_{mi}(z)\varphi(z)dz,$$

$$K_{mi} = \int K_{mi}(z)\varphi(z)dz,$$

$$M_{mi} = \int M_{mi}(z)\varphi(z)dz,$$

where $L_{mi}(z)$, $K_{mi}(z)$, and $M_{mi}(z)$ refer to the amount of labor, capital, and composite intermediate good used in country i to produce the individual tradable good z. Note that each of $L_{mi}(z)$, $K_{mi}(z)$, and $M_{mi}(z)$ will be zero if country i imports good z.

The factor market clearing conditions are:

$$L_{mi} + L_{si} = L_i,$$

$$K_{mi} + K_{si} = K_i,$$

$$M_{mi} + M_{si} = M_i.$$

The left-hand side of each of the previous equations is simply the factor usage by each sector, while the right-hand side is the factor availability.

The next condition requires that expenditures on nontradables in country i must equal the value of nontradables produced by country i.

$$w_i L_i + r_i K_i = P_{si} S_i.$$

Aggregating over all producers of individual goods in each sector $b \in \{m, s\}$ of country i, and using the fact that each producer minimizes costs, the factor demands at the sectoral level are described by

$$w_i \text{Ł}_{bi} = (1 - \alpha)\nu_b Y_{bi},$$

$$r_{ei} K_{bi} = \alpha \nu_b Y_{bi},$$

$$P_{mi} M_{bi} = (1 - \nu_b) Y_{bi},$$

where Y_{bi} is the value of output in sector b. The goods market clearing condition for each sector implies that

$$Y_{mi} = \sum_{j=1}^{I} P_{mj} M_j \pi_{ji},$$

$$Y_{si} = P_{si} S_i.$$

Country j's total spending on tradables is given by $P_{mj} M_j$, while π_{ji} denotes the fraction that is spent on goods from country i. Thus, $P_{mj} M_j \pi_{ji}$ is the total value of trade flows from country i to country j.

To close the model I impose balanced trade country by country.

$$P_{mi} M_i \sum_{j \neq i} \pi_{ij} = \sum_{j \neq i} P_{mj} M_j \pi_{ji},$$

where the left-hand side denotes country i's imports, and the right-hand side denotes country i's exports.

This completes the description of a competitive equilibrium in the model. Next I turn to the calibration of the model.

1.3 Calibration

I calibrate my model using data for a set of 84 countries for the year 2005. This set includes both developed and developing countries and accounts for about 80 percent of the world GDP as computed from version 6.3 of the Penn World Tables (see Heston, Summers, and Aten, 2009, PWT63).

With respect to the trade and production data used, the tradables sector corresponds to four-digit ISIC revision 2 categories $15^{\star\star}$–$37^{\star\star}$ (manufactures). Trade data is reported at the four-digit SITC revision 2 level. I use a correspondence between production data (ISIC) and trade data (SITC) created by Affendy, Sim Yee, and Satoru (2010). This division excludes trade in primary goods, (both agriculture and mining activities) since production data for these activities is not readily available for a large set of countries. However, trade in primaries is trivial compared to trade in manufactures. What's more is that any processing of primary goods gets accounted for as manufactures anyway; for example, fruit juice shows up under manufactures.

I construct prices using data from the International Comparisons Program (ICP). For this data there is no one-to-one link with ISIC categories, so I take a stand on which categories are closest to tradables (manufactures), and which are closest to nontradables (services). I apply a split in accordance with Hsieh and Klenow (2007) and Herrendorf and Valentinyi (2010), and the details are given in appendix A.2.

The mapping between trade data and price data is not perfect. Prices are constructed from expenditures on value added, while trade and production data are measured from the producer side. In particular, the tradable expenditure category called "Clothing and footware" includes expenditures on all of the components that go into producing, say, a shirt. These components include the processing of polyester (tradable, manufactured component) and the retail services that delivered the shirt to the consumer (nontradable, service component). However, the trade and production data separate these two. I discuss the implications of this at the end of section 1.4.

1.3.1 Common parameters

I begin by describing the parameters which are common across countries and given in Table 1.1. Following Alvarez and Lucas (2007), I have set η equal to 2. This parameter is not quantitatively important for the question addressed in this chapter, however, it must satisfy $1 + \theta(1 - \eta) > 0$.

Capital's share α is set at 1/3 as in Gollin (2002). This parameter is set so that labor's share in GDP is 2/3.

The parameters ν_m and ν_s, respectively, control the share of value added in tradable and nontradable goods production. To calibrate ν_m I employ the data on value added and total output available in the INDSTAT4 database. The parameter ν_s also determines the share of labor in the nontradables sector. Due to the multiple interpretations, there is a range of values that can be applied. Alvarez and Lucas (2007) argue that anywhere between 0.70-0.80 is a reasonable range for OECD countries. However, since the share of labor in services tends to be lower in poor countries than in rich countries, I use a value at the lower end by setting $\nu_s = 0.70$.

The parameter θ controls the dispersion in efficiency levels. I follow Alvarez and Lucas (2007) and set this parameter at 0.15. This value lies in the middle of the estimates in Eaton and Kortum (2002).

Table 1.1: Common parameters.

Parameter	Description	Value
α	K's share in GDP	0.33
ν_m	K and L's share in production of tradables	0.31
ν_s	K and L's share in production of nontradables	0.70
θ	variation in efficiency levels	0.15
η	elasticity of substitution in aggregator	2

1.3.2 Country-specific parameters

I take the labor force N from PWT63. To construct measures of human capital h, I follow Caselli (2005) by converting data on years of schooling from Barro and Lee (2010) into measures of human capital using Mincer returns. Effective labor is then $L = Nh$; see appendix A.2 for details. I construct capital stocks K_i using the perpetual inventory method using investment data from PWT63; see appendix A.2 for details.

The remaining parameters include the bilateral trade barriers τ_{ij} and the average efficiency parameters λ_i. My strategy is to choose the bilateral trade barriers to be consistent with the pattern of bilateral trade, and to choose the average efficiency parameters to be consistent with levels of development. To calibrate the trade barriers I employ the methodology of Eaton and Kortum (2002) and Waugh (2010). In order to calibrate the average efficiency parameters I make use of a structural relationship that relates these parameters to income per worker and home trade shares.

Bilateral trade barriers From equation (1.1), the fraction of tradable goods that country i purchases from country j, relative to the fraction that i purchases domestically, is given by

$$\frac{\pi_{ij}}{\pi_{ii}} = \left(\frac{u_{mj}}{u_{mi}}\right)^{-1/\theta} \left(\frac{\lambda_j}{\lambda_i}\right) (\tau_{ij})^{-1/\theta}. \tag{1.2}$$

Since trade barriers are unobservable, I specify a parsimonious functional form that links trade barriers to observable data as follows

$$\log \tau_{ij} = \gamma_{ex} ex_j + \gamma_{dist,k} dist_{ij,k} + \gamma_{brdr} brdr_{ij} + \gamma_{lang} lang_{ij} + \varepsilon_{ij}. \tag{1.3}$$

Here, ex_j is an exporter fixed effect dummy. The variable $dist_{ij,k}$ is a dummy taking a value of one if two countries i and j are in the k'th distance interval. The six intervals, in miles, are [0,375); [375,750); [750,1500); [1500,3000); [3000,6000); and [6000,maximum). (The distance between two countries is measured in miles using the great circle method.) The variable $brdr$ is a dummy for common border and $lang$ is a dummy for common language. I assume that the residual, ε, is orthogonal to the previous variables and captures other factors which affect trade barriers. Each of these data, except for trade flows, are taken from the Gravity Data set available at http://www.cepii.fr.

Taking logs on both sides of (1.2) and substituting in the parsimonious specification (1.3), I obtain an estimable equation:

$$\begin{aligned} \log\left(\frac{\pi_{ij}}{\pi_{ii}}\right) &= \underbrace{\log\left(u_{mj}^{-1/\theta}\lambda_j\right)}_{F_j} - \underbrace{\log\left(u_{mi}^{-1/\theta}\lambda_i\right)}_{F_i} \\ &\quad -\frac{1}{\theta}\left[\gamma_{ex} ex_j + \gamma_{dist,k} dist_{ij} + \gamma_{brdr} brdr_{ij} + \gamma_{lang} lang_{ij} + \varepsilon_{ij}\right]. \end{aligned}$$

To compute the empirical counterpart to π_{ij}, I follow Bernard, Eaton, Jensen, and Kortum (2003); see appendix A.2. I estimate the coefficients for the parsimonious specification for trade barriers and recover the fixed effects F_i as country specific fixed effects using Ordinary Least Squares. Observations for which the recorded trade flows are zero are omitted from the regression. The bilateral trade barrier for such observations is set to the maximum estimated barrier in the sample. The estimation results in 6610 bilateral combinations with positive trade flows (out of 6972 bilateral country combinations) and produces a R^2 of 0.73.

Average efficiency levels My model implies a structural relationship that links home trade shares, average productivity, and factors of production, to levels of income. Following Waugh (2010), aggregate income in PPP in country i (defined as $Y = (wL + rK)/P_s$) can be shown to be $Y_i = \left(\frac{\lambda_i}{\pi_{ii}}\right)^{\theta(1-\nu_s)/\nu_m} K_i^{\alpha} L_i^{1-\alpha}$. Stated in terms of income per worker this becomes

$$y_i = \left(\frac{\lambda_i}{\pi_{ii}}\right)^{\theta(1-\nu_s)/\nu_m} k_i^{\alpha} h_i^{1-\alpha}, \tag{1.4}$$

where $k = K/N$ is the capital per worker. Data on income per worker and capital per worker are constructed using data from PWT63. Combining these data with home trade shares π_{ii}, I recover the terms λ_i as residuals to equation (1.4).

1.3.3 Model fit

The correlation between home trade shares in the model and home trade shares in the data is 0.71. Since capital per worker and average human capital are taken to be exogenous, the model-implied income per worker differs from the data only to the extent that home trade shares differ (see equation 1.4). Still, income per worker in the model is very close to the data, the correlation between the model and the data is 0.96.

Home trade shares do not vary systematically with income per worker (correlation -0.04). Therefore, the calibrated parameters controlling average efficiency, λ_i, vary positively with development. In particular, the 90-10 ratio for average efficiency, λ_i^{θ}, is 2.45.

Trade barriers implied by my model vary systematically with development. For country i, I compute the trade-weighted export barrier as $\frac{1}{EX_j} \sum_{i \neq j} \tau_{ij} EX_{ij}$, where EX_{ij} is exports from country j to country i and EX_j is country j's total exports. These are reported in Figure 1.2. The reason for the systematic variation in the trade-weighted export barriers is that the exporter-specific component of trade barriers is larger in poor countries than in rich countries. Hummels (2001), Djankov, Freund, and Pham (2006), and Li and Wilson (2009) provide empirical evidence that export costs are indeed larger in poor countries.

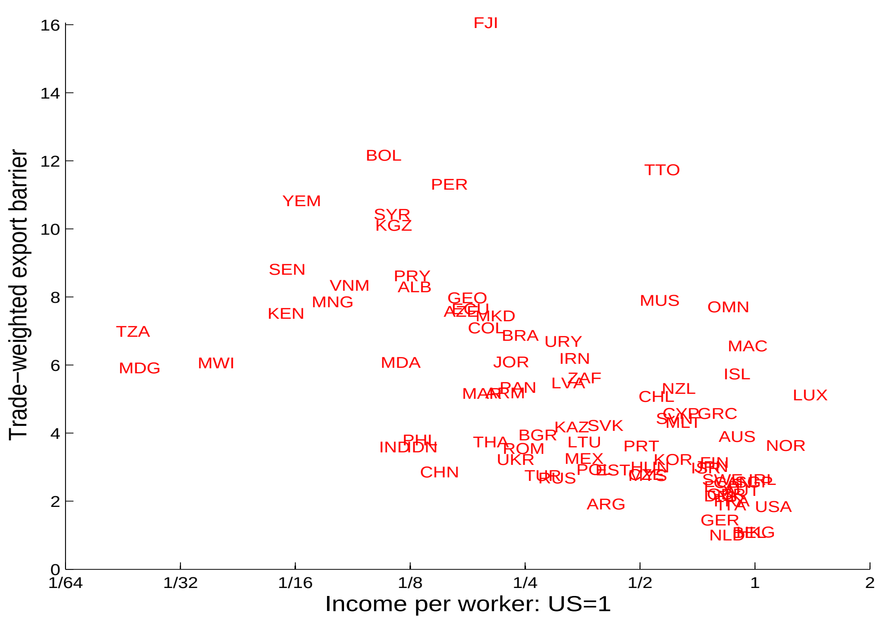

Figure 1.2: Trade-weighted export barriers.

My identification procedure separates the exporter fixed effect from productivity in following way. In the data, the share of poor countries in rich countries is small (Bolivian-produced goods account for less than one-tenth of a percent of US absorption), while the share of rich countries in poor countries is larger (US-produced goods account for over eight percent Bolivian absorption). This can be the result of either larger dispersion in export barrier, or large dispersion in average efficiency. However, large dispersion in efficiency combined with no dispersion in export barriers would also imply smaller home trade shares in poor countries than in rich countries. In the data, home trade shares do not vary systematically with development. Therefore, dispersion in export barriers is necessary to deliver the pattern of bilateral trade.

1.4 Results

Before discussing the quantitative implications of my model, I first discuss how relative prices are determined qualitatively. Note that the price of nontradables is (ignoring constant terms) $P_{si} = \left(r_i^{\alpha} w_i^{1-\alpha}\right)^{\nu_s} P_{mi}^{1-\nu_s}$. Therefore, the relative price of nontradables is given by $\frac{P_{si}}{P_{mi}} = \left(\frac{r_i}{w_i}\right)^{\alpha\nu_s} \left(\frac{w_i}{P_{mi}}\right)^{\nu_s}$ (†). It is also straightforward to show that (ignoring constant terms) $\left(\frac{\pi_{ii}}{\lambda_i}\right)^{-\theta} = \left(\frac{r_i}{w_i}\right)^{\alpha\nu_m} \left(\frac{w_i}{P_{mi}}\right)^{\nu_m}$ (‡). Solving (‡) for $\frac{w_i}{P_{mi}}$ and substituting into (†) implies that the relative price of nontradables in country i is

$$\frac{P_{si}}{P_{mi}} = \left[\left(\frac{\lambda_i}{\pi_{ii}}\right)^{\theta}\right]^{\nu_s/\nu_m}. \tag{1.5}$$

In order to interpret (1.5) recall that country i's average efficiency across all individual tradable goods is λ_i^θ. However, country i will specialize in only a subset of the tradable goods. Therefore, its average *measured* productivity is its average efficiency, λ_i^θ, corrected by the share of goods that it actually produces, i.e., its home trade share, π_{ii}. Measured productivity in tradables is then $(\lambda_i/\pi_{ii})^\theta$. The exponent ν_s/ν_m adjusts for the share of value added in total production in each of the two sectors. Moreover, I assumed that factor productivity in nontradables is equal across countries. Therefore, the model produces the classic Balassa-Samuelson effect endogenously: the price of nontradables, relative to tradables, is equal to the measured productivity in tradables, relative to the measured productivity in nontradables. What is novel to my model is that the measured productivity in the tradables sector depends critically on the degree of specialization: the more specialized a country is, the smaller its home trade share is, and the higher measured productivity in tradables will be since it will specialize in goods for which it is highly productive. The degree of specialization depends on average efficiency, as well as the pattern of bilateral trade barriers.

In the model, almost all of the systematic variation in the relative price of nontradables is due to systematic variation in the absolute price of nontradables. In rich countries labor is more costly due to higher productivity in the tradables sector. Since there are no cross-country differences in productivity in the nontradables sector, prices of nontradables are higher in rich countries. Crucini, Telmer, and Zachariadis (2005) argue that this matters only to the extent that the share of value-added in output is sufficiently large; this is where the exponent, ν_s/ν_m, matters in equation 1.5. If value added in nontradables was small, then most of the cross-country variation in the price of nontradables would be due to variation in the price of tradables, which is approximately equal across countries. In my model, the share of value added in the production of nontradables is large, $\nu_s = 0.70$, compared to the share of value added in production of tradables, $\nu_m = 0.31$.

The cross-country distribution of the relative price of nontradables is plotted in Figure 1.3. The left panel shows the data, while the right panel displays the model's prediction. Table 1.2 reports summary statistics. The model over-predicts the elasticity of the relative price w.r.t. income per worker (0.75 in the model compared to 0.35 in the data). The reason for this is that the model over-predicts the price elasticity of nontradables (0.77 in the model compared to 0.59 in the data) as well as under-predicts the price elasticity of tradables (0.02 in the model compared to 0.23 in the data).

Table 1.2: Price elasticities w.r.t. income per worker.

Variable	Data	Model
Price of nontradables relative to tradables	0.35	0.75
Price of nontradables	0.59	0.77
Price of tradables	0.23	0.02

This is not necessarily a failure, though, for two reasons. First, the price mea-

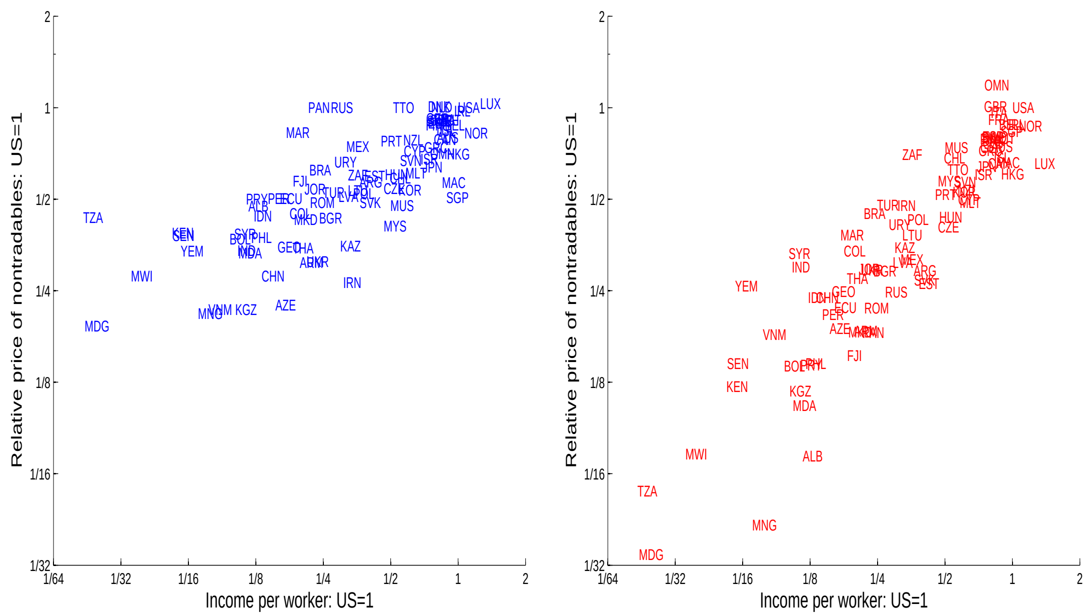

Figure 1.3: Price of nontradables relative to tradables: data (left) model (right).

surements in the data are constructed from expenditure data collected by the ICP. Therefore, goods classified as nontradables contain tradable components which understates the true price elasticity. For instance, in the nontradable category "Housing, water, electricity, gas and other fuels", fuels are highly traded. Second, the goods classified as tradables actually contain nontradable components, which tends to inflate the price elasticity of tradables with respect to development. The tradable category called "Furnishings, household equipment and household maintenance" contains household services which is a nontradable component. Ideally, in the data, one would like to strip away any additional value added that takes place after production. Consider the tradable category called "Machinery and equipment". This category contains the smallest retail component among all tradable goods (Burstein, Neves, and Rebelo, 2004). Therefore, the price of Machinery and equipment may be a better proxy for the price of tradables. In the data, the price elasticity of Machinery and equipment w.r.t. income per worker is 0.04 which is very close to what my model predicts.

Second, the question I address is: How important are trade barriers in explaining cross-country differences in relative prices? I did not use price data to impose any quantitative discipline on my model, only production and trade data. Thus, the prices generated by my model are a function of the observed trade and production data. Therefore, I am in a position to ask how relative prices would look under different distributions of trade barriers. This is what I do next.

1.4.1 Counterfactuals

In the remainder of this section I isolate the quantitative importance of trade barriers on relative prices by examining the implications of changes in the structure of bilateral trade barriers.

Free trade What happens if I remove all barriers to trade? To run this counterfactual experiment I set $\tau_{ij} = 1$ for all bilateral combinations. Moving to free trade increases measured productivity in the tradables sector in all countries by allowing countries to reallocate resources towards the goods for which they have a comparative advantage. This increases the wage rate, and thus increases the price of nontradables. Since poor countries face larger trade barriers, prices of nontradables increase more in poor countries than in rich countries. The price elasticity of nontradables w.r.t. income per worker decreases significantly (0.77 to 0.37). The price of tradables is equalized due to the Law of One Price so the price elasticity is almost unchanged (0.02 to 0.00). Taken together, the elasticity of the relative price of nontradables with respect to income per worker decreases substantially (0.75 to 0.37); see Table 1.2.

Although a complete removal of trade barriers is not realistic, this exercise is meant to speak to the role that the mere presence of trade barriers plays in explaining differences in relative prices. According to the specification that I use to estimate trade barriers, all of the asymmetry is generated by the exporter-specific component ex_j. Next I discuss the implications of removing cross-country differences in the exporter-specific component only.

Table 1.3: Price elasticities w.r.t. income per worker.

Variable	Benchmark	CF1	CF2
Price of nontradables relative to tradables	0.75	0.37	0.42
Price of nontradables	0.77	0.37	0.40
Price of tradables	0.02	0.00	-0.02

Note: The column called Benchmark refers to the implications of the calibrated model. CF1 refers to the free trade counterfactual implications in which $\tau_{ij} = 1$ for all (i, j). Finally, CF2 refers to the counterfactual in which each countries' exporter-fixed effect component of trade barriers is set equal to the US value: $ex_j = ex_{USA}$ in equation (1.3).

Removal of exporter-specific component of trade barriers Recall the parsimonious specification for trade costs given by (1.3): $\log \tau_{ij} = \gamma_{ex} ex_j + \gamma_{dis,k} dis_{ij,k} + \gamma_{brd} brd_{ij} + \gamma_{lang} lang_{ij} + \varepsilon_{ij}$. The purpose of this exercise is to quantify the importance of the asymmetric component of the trade barrier that is generated by the exporter-specific fixed effect. That is, how would relative prices vary if differences in trade barriers were symmetric and due only due geography and language?

To run this counterfactual I set the exporter fixed effect in all countries equal to the US value, $ex_j = ex_{USA}$, and recompute trade barriers for all bilateral combinations. The elasticity of the relative price of nontradables w.r.t. income per worker decreases from 0.75 to 0.42; see Table 1.3. The mechanism which generates this result is the same as discussed in the free trade counterfactual above. In sum, asymmetry in export costs alone are responsible for almost half of the difference in relative prices between rich and poor countries.

1.5 Conclusion

I argue that trade barriers are a quantitatively important component in explaining the cross-country distribution of the relative price of nontradables. Trade barriers help determine the pattern of specialization across multiple, heterogeneous, tradable goods, which in turn determines measured productivity in the tradables sector.

To make this argument I construct a multi-country model of trade with multiple tradable goods. Each country's level of efficiency for each good is a random draw from a country-specific distribution. Countries differ in their average efficiency across the entire basket of goods and also face asymmetric bilateral trade barriers. The subset of goods that each country produces is a function of both average efficiency and trade barriers. Measured productivity in the tradables sector then depends on the set of goods produced.

My calibration implies that poor countries face larger export costs than rich countries do. This leads to large cross-country differences in measured productivity in the tradables sector, which translates into large cross-country differences in relative prices vis-à-vis the Balassa-Samuelson effect. Quantitatively, nearly half of the difference in relative prices between rich and poor countries can be attributed to trade barriers, particularly the fact that poor countries face larger costs to export than rich countries do.

CHAPTER 2
EVOLVING COMPARATIVE ADVANTAGE, STRUCTURAL CHANGE, AND THE COMPOSITION OF TRADE

2.1 Introduction

In this chapter I quantitatively explore the changes in the composition of exports, as well as the changes in the composition of output, that occurred in South Korea ("Korea" from now on) from 1960 to 1995. During this time Korea grew two and a half times as fast as the US and simultaneously underwent significant changes in its compositions of both exports and output, with respect to agriculture, manufactures, and services. In particular, manufacture's share in both compositions increased dramatically.

From 1960 to 1995 Korea experienced what is referred to as structural change. In early stages of development, the agricultural sector constitutes a substantial fraction of production. As the process of development begins, the manufactures sector starts growing. Eventually, the manufactures sector tapers off and services account for an increasing share of economic activity. The left panel of Figure 2.1 shows these features. From 1960 to 1995, agriculture's share in total output fell by over 25 percentage points. From 1960 to 1975, manufacture's share in total output rose by over 20 percentage points, remained steady for almost twenty years, and then slightly declined. These facts have been documented by, among others, Yi and Zhang (2011). Moreover, the process of structural change is not unique to Korea; Buera and Kaboski (2009) provide a useful reference for the United States.

In the right panel of Figure 2.1, I document the evolution of the composition of exports in Korea from 1960 to 1995. Manufacture's share in total exports increases by 25 percentage points in the first half of the sample, and then slowly rises another 13 percentage points for the remainder of the period. Agriculture's share in total exports displays a secular decline of about 20 percentage points over the entire period, while service's share declines by about 15 percentage points in the first 15 years, and then remains relatively flat for the next 25 years.

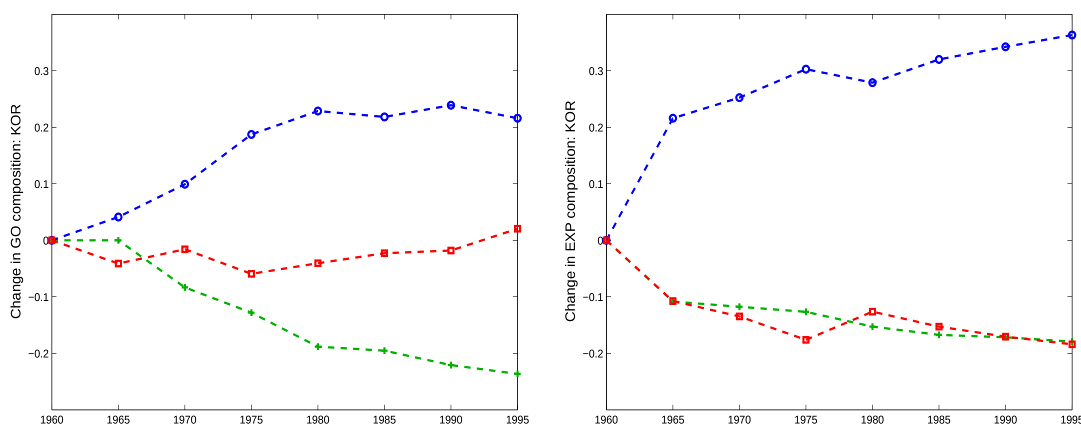

Figure 2.1: Composition of gross output (left) and exports (right) in Korea: 1960-1995. The green line with plus signs (+) represents agriculture, blue circles represent manufactures, and red squares represent services.

I ask the following question: How much of the changes in Korea's export and output compositions can be explained by changes in comparative advantage? This question is an important one since closed-economy models of structural change are, by definition, not suited to address the composition of exports. Moreover, while they do a fine job at explaining the composition of output in developed economies (Ngai and Pissarides, 2007; Dietrich and Krüger, 2010), they are not capable of simultaneously explaining the composition of output in emerging economies. To answer this question I employ a multi-country, dynamic, Ricardian model of trade, along the lines of Eaton and Kortum (2002), which includes three sectors: agriculture, manufactures, and services. I embed the trade framework into a model of structural change, in the spirit of Ngai and Pissarides (2007), in which output from the three sectors are complementary in both consumption and production.

My model includes several unique features. First, I explicitly incorporate dynamics by introducing capital accumulation. Capital accumulation is important since almost all of investment spending is on manufactured goods, particularly in the early part of the sample. In Korea, investment rates increase from 11 percent to over 40 percent over the period 1960-1995, so the increase in investment can play an important role in the rise in manufacture's share in output. Second, I incorporate borrowing and lending between countries. Korea runs a trade deficit until the mid 1980's which contributes to its expansion of manufactures output by allowing it to transfer production from early years, when productivity is low, to later years, when productivity is high. Third, I explicitly model trade in services which allows me to capture the link between service's share in trade and service's share in output. This is important since services constitute a larger share of exports than agriculture does in Korea over the period 1960-1995; on average, service's share in total exports is about 15 percentage points higher than agriculture's share.

I discipline the parameters of the model to be consistent with the observed compositions in 1960. Then I measure productivity growth over time, for each sector, using a Solow growth accounting technique, and feed the paths of productivity into the model. In all countries, the composition of exports shifts toward the sector of increasing comparative advantage. In smaller emerging economies, like Korea, the composition of output shifts towards the sector with the fastest growing productivity, a result of increasing comparative advantage. However, in larger developed economies, like the US, the composition of output shifts toward the sector with the slowest growing productivity since world prices are essentially driven by output of these countries, the same prediction as closed-economy models.

Increases in manufacturing productivity in Korea, relative to other countries, account for a substantial portion of the rise in manufacture's share in exports through changes in comparative advantage. Manufacture's share in exports rises by 53 percentage points in the model compared to 36 percentage points in the data. This in turn leads Korea to allocate more resources towards the production of manufactures which explains why manufacture's share in the composition of output increased during the same time: manufacture's share in output rises by 21 percentage points in the model compared to 22 percentage points in the data. In addition, my model generates a growth rate in real GDP per worker in Korea that is just over two times as high as it is in the US; in the data, growth in real GDP per worker in Korea is two and a half times as high as it is in the US. Finally, my model produces the observed changes in the composition of output for other countries that Korea trades with. This last result quantitatively supports the finding that Korea's reallocation of production across sectors is a result of a reallocation of production across countries within each sector; the link being the composition of trade. In particular, trade is crucial to explain structural change in Korea and in other emerging economies.

Through counterfactual exercises I show that if Korea was closed, then manufacture's share in output would have actually declined. This is because in a closed economy production shifts away from the sector with the slowest growing productivity; increasingly less resources are needed to produce a given level of output. Similarly, I show that shutting down trade in manufactures only, produces a similar result to autarky. This finding suggests that, not only is trade important for Korea's structural change, but the composition of trade is what matters. I also find that access to international finance, which allows Korea to run aggregate trade deficits/surpluses, plays an important role in structural change. This works by allowing Korea to transfer production from early years when it is relatively unproductive, to later years when it is relatively productive. Removing this channel leads to a smaller change in manufacture's share in outpu over the time period under consideration.

My model makes use of two popular mechanisms that are commonly used in the structural change literature: Engel's law and the Baumol effect. Engel's law operates purely on the demand side. Examples include Laitner (2000) and Kongsamut, Rebelo, and Xie (2001), who appeal to non-homothetic preferences in closed economies. Over time, as income grows, a smaller fraction of total expenditures is allocated towards sectors with a low income elasticity. Teignier (2011) shows a similar result in a two-sector small open economy. In my model I find that a low income elasticity for agricultural consumption is important in generating the decline in agriculture's share in Korean output, but, I also find that this mechanism alone cannot account for the changes in Korea's export composition.

The Baumol (1967) effect, recently made rigorous by Ngai and Pissarides (2007), works as follows. Productivity grows asymmetrically across sectors causing relative prices to change over time: sectors with the fastest growing productivity realize a decreasing relative price, and vice-versa. If goods are complements in, say, consumption, then over time, consumption expenditures are allocated more toward the good with the fastest growing price, or slowest growing productivity. In a closed economy changes in the composition of output follow since output in each sector equals expenditure in each sector. However, in an open economy sectoral output does not need to equal sectoral expenditure country-by-country.

As pointed out by Matsuyama (2009), asymmetric productivity growth across sectors, and across countries, leads to changes in comparative advantage which has opposite implications as the Baumol effect does. To see why, consider two countries, 1 and 2, and two sectors, a and b, which produce complementary goods. Suppose country 1 realizes an increase in productivity in sector a relative to sector b. In a closed economy this would lead to a reallocation of resources from sector a towards sector b. However, in an open economy, if nothing changes in country 2, then the change in relative productivity would imply a shift in comparative advantage in favor of producing good a in country 1, and lead country 1 to specialize in good a. This has the effect of country 1 allocating more resources toward the production of good a, opposite to the Baumol effect.

Two papers build on the ideas of Matsuyama (2009) in order to explain the structural change experience of Korea. Yi and Zhang (2011) show how the Baumol effect, together with changes in comparative advantage, can generate the hump-shape in manufacture's share in output. However, they show this by using numerical examples and leave the quantitative analysis for future work. Moreover, they do not discuss the implications for the composition of trade. Betts, Giri, and Verma (2011) quantitatively explore the role that trade liberalization played in Korea's structural transformation. They also do not address trade compositions. The two aforementioned papers utilize two-country models and consider structural change in only one country. My model includes six countries and disciplines the evolution of comparative advantage across the three sectors in each country, and quantitatively reproduces the output compositions for Canada, Europe, Latin America, South-east Asia, and the United States. Furthermore, my model also explains the compositions of output *and* exports in Korea.

Echevarria (2008) explores changes in the composition of trade at the world level in a theoretical framework. She documents a long run shift in the composition of world trade, from agriculture to manufactures, and argues that it is the result of increased world demand for manufactures relative to agriculture. My research quantitatively studies the experience of Korea, and finds that an increase in relative demand for manufactures is of second order importance. The shift in comparative advantage towards manufactures in Korea is the primary reason for the increase manufacture's share in Korean exports.

To my knowledge, my work is the first to simultaneously address changes in export compositions and structural change in a quantitative framework, as wells as simultaneously generating the observed pattern of structural change across multiple countries. Matsuyama (2009) provides a theoretical justification for why trade should be considered when studying structural change. I argue that empirically, structural change and export compositions should be studied simultaneously. Back of the envelope calculations below highlight the link between changes in the composition of exports and changes in the composition of output.

Denote gross exports in sector b at time t by EXP_{bt}, and denote gross output in sector b at time t by GO_{bt}. Out of sector b's gross output, some fraction is exported while some is retained for domestic use. Denote the fraction that is exported by Φ_{bt}, so that

$$EXP_{bt} = \Phi_{bt} \times GO_{bt}.$$

Similarly, define the fraction of aggregate output that gets exported, Ψ_t, as follows:

$$\sum_b EXP_{bt} = \Psi_t \times \sum_b GO_{bt}.$$

Therefore, sector $b's$ share in the composition of exports is related to sector b's share in the composition of output in the following way:

$$\underbrace{\frac{EXP_{bt}}{\sum_b EXP_{bt}}}_{b\text{'s share in exports}} = \underbrace{\left(\frac{\Phi_{bt}}{\Psi_t}\right)}_{\textit{trade component}} \times \underbrace{\left(\frac{GO_{bt}}{\sum_b GO_{bt}}\right)}_{b\text{'s share in output}} . \tag{2.1}$$

Suppose the fraction of goods that gets exported, Φ_{bt}, is constant across sectors but varying over time, i.e., $\Phi_{bt} = \Phi_t$ for each b. Then $\Phi_t = \Psi_t$ and the trade component will be constant over time. This would imply that the export composition would look identical to the output composition in Figure 2.1. However, this is not the case. Therefore, a theory of structural change alone will not be able to quantitatively explain the composition of exports.

Consider the other extreme, Φ_{bt} is constant over time but varies across sectors, i.e., $\Phi_{bt} = \Phi_b$ at each t.[1] Then, over time, the rate of change of the trade component in each sector depends only on the sequence $\{\Psi_t\}$. Recall that Ψ_t is the fraction of aggregate output that gets exported; Figure 2.2 displays the time series for Ψ_t. Feeding the sequence $\{\Psi_t\}$ and the composition of output into equation (2.1), agriculture's share in exports would have declined by less than one percentage point, whereas in the data it declined by almost 20 percentage points (see the right panel of Figure 2.1). Similar contradictions arise for manufacture's and service's share in exports. Therefore, a theory of structural change combined with a theory of *aggregate* trade is not enough to explain the composition of exports. Consequently, I construct a theory that produces changes in output and trade at the sectoral level.

[1]Both Φ_{bt} being constant across time and constant across sectors are factually incorrect. In 1960, $(\Phi_a, \Phi_m, \Phi_s) = (0.02, 0.04, 0.03)$, in 1980, $(\Phi_a, \Phi_m, \Phi_s) = (0.06, 0.16, 0.10)$, while in 1995, $(\Phi_a, \Phi_m, \Phi_s) = (0.03, 0.19, 0.06)$.

Figure 2.2: Fraction of aggregate output exported by Korea: 1960-1995.

The rest of the chapter is organized as follows. Section 2.2 develops a simple two-country, two-good framework to provide an understanding of the essential ingredients of the quantitative model that follows. Sections 2.3 and 2.4 describe the multi-country dynamic model and equilibrium. Section 2.5 discusses the calibration and fit of the model. Section 2.6 presents the results and counterfactual implications, while section 2.7 concludes.

2.2 A two-good example

Before diving into the full model it is useful to highlight the key features in a simple setup. Consider a world with two goods. The thought experiment will be to consider what happens when there is an increase in productivity for one good. I will consider two cases: a closed economy, and a small-open economy. Denote the two goods by a and b. There is a household that values consumption of the two goods. For simplicity I assume that the two goods are perfect complements so that consumption of good a is proportional to consumption of good m, i.e., $C_a = \psi C_m$.

Closed economy Consider first the case of a closed economy. If the country becomes more productive in producing good m then the Production Possibilities Frontier (PPF) shifts to the right; see the left panel of Figure 2.3. Because of perfect complementarity, the two goods are consumed in the same proportion, but the price of good m falls relative to the price of good a, therefore, expenditures on good m fall relative to expenditures on good a. In a closed economy, sectoral production equals sectoral consumption: $Y_m = C_m$ and, therefore, the value of output in sector m falls relative to the value of output in sector a. Thus, resources shift away from the sector with the fastest growing productivity, and into the sector with the slowest growing productivity (known as the Baumol effect).

Small-open economy Now consider a small-open economy. Suppose that world prices are initially the same as the autarky prices. Now consider the response to an increase in productivity for good m. The PPF shifts right, as in the closed economy, but the ratio of domestic prices now remains unchanged; see the right panel of Figure 2.3. Consumption will then take place at the intersection of the indifference curve and the price vector, while production will take place at the intersection of the PPF and the price vector. Production of good m increases unambiguously, while production of good a may increase or decrease, but if it increases, it does by a smaller

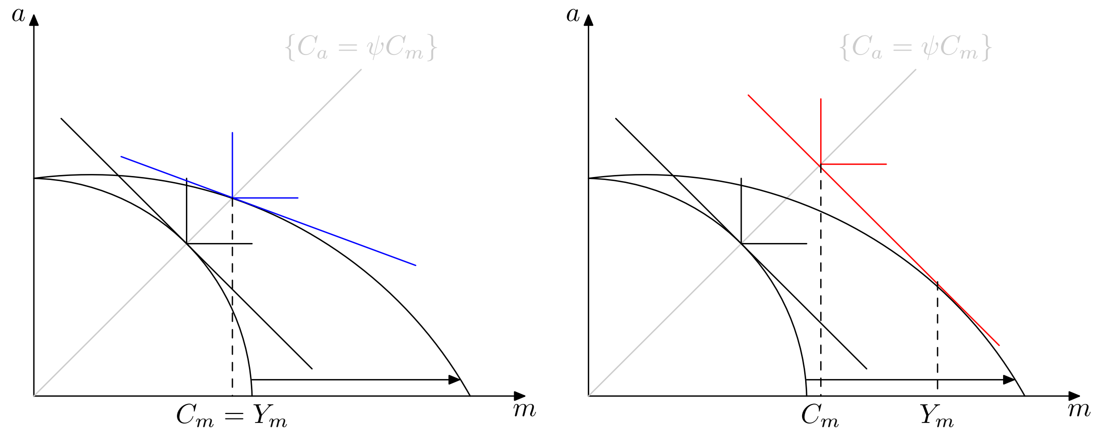

Figure 2.3: Response to an increase in productivity for good m: Closed economy (left) and small-open economy (right).

proportion than the increase in production of good m. Since the relative price is unaffected, the value of output in sector m increases relative to the value of output in sector a. On the other hand, the ratio of consumption expenditures remains the same. Therefore, exports in sector m rise relative to exports in sector a.[2] Hence, resources shift away from the sector with the slowest growing productivity, and into the sector with the fastest growing productivity.

Summary In practice, Korea is somewhere in between a closed economy and small open economy, so in the next section I will take a general equilibrium approach with multiple countries. Moreover, goods are not perfect complements, but there is empirical evidence that, for the sectors I consider, they are indeed gross complements which is all that matters for the intuition to follow through. Finally,

[2]By virtue of having only two goods in a static setup, it is not possible to have positive exports in both sectors.

this two-good example does not allow for intra-sectoral trade, i.e., there is perfect specialization. In practice, each sector has positive exports and positive imports. The quantitative model will allow for multiple goods within each sector to take care of this issue, but the key channel remains the same, exports in one sector will rise by more than exports in the other sector (the other sector may actually realize a decrease in exports). It is through this channel that the problem of reallocation of production across sectors depends on trade and the relative size of the economy matters.

2.3 Multi-country dynamic model

I embed a three-sector, multi-country model of Ricardian trade, in the spirit of Eaton and Kortum (2002) and Alvarez and Lucas (2007), into an exogenous growth framework. There are I countries indexed by $i = 1, \ldots, I$. Time is discrete and runs from $t = 1, 2, \ldots, T$. There are three sectors: agriculture, manufactures, and services, denoted by a, m, and s respectively. Within each sector there is a continuum of *individual* goods. Each individual good within each sector is potentially tradable. Production of each individual good is carried out by competitive firms using capital, labor, and intermediates from all three sectors. Each country's efficiency in producing each individual good is the realization of a random draw from country- and sector-specific distributions. Within each sector, each country purchases each individual good from its least cost supplier, and all of the individual goods are combined into sector-specific *composite* goods. Composite goods are consumed, invested, and used as intermediate inputs in production. Each country admits a representative household which owns the primary factors of production: capital and labor. The representative household supplies the factors of production to firms and spends factor income on consumption, investment, and assets. The representative household has access to borrowing and lending by trading assets on an international market.

2.3.1 Technology

There are three productive sectors: agriculture, manufactures and services, each with a continuum of individual goods. In each country and each sector competitive firms have access to technologies for producing each good. All technologies exhibit constant returns to scale. As in Dornbusch, Fischer, and Samuelson (1977), each individual good, within each sector $b \in \{a, m, s\}$, is potentially tradable and is indexed along the unit interval by $x_b \in [0, 1]$. Firms operate technologies that require capital, labor, and intermediate goods from all three sectors. Within each sector, all individual goods are combined to construct a sector-specific composite good.

Composite goods Within each sector, all of the individual goods are combined with constant elasticity in order to construct a sectoral composite good according to

$$A = \left[\int q_a(x_a)^{1-1/\eta} dx_a\right]^{\eta/(\eta-1)},$$
$$M = \left[\int q_m(x_m)^{1-1/\eta} dx_m\right]^{\eta/(\eta-1)},$$
$$S = \left[\int q_s(x_s)^{1-1/\eta} dx_s\right]^{\eta/(\eta-1)},$$

where η is the elasticity of substitution between any two goods.[3] The term $q_b(x_b)$ is the quantity of good x_b used to construct the sector b composite good.

Individual goods Each individual good is produced using capital, labor, and intermediate goods from each sector. The technologies for producing individual goods in each sector are given by

$$a_i(x_a) = z_{ai}(x_a)^{-\theta_a} \left[K^\alpha L^{1-\alpha}\right]^{\nu_a} \tilde{Q}_a^{1-\nu_a},$$
$$m_i(x_m) = z_{mi}(x_m)^{-\theta_m} \left[K^\alpha L^{1-\alpha}\right]^{\nu_m} \tilde{Q}_m^{1-\nu_m},$$
$$s_i(x_s) = z_{si}(x_s)^{-\theta_s} \left[K^\alpha L^{1-\alpha}\right]^{\nu_s} \tilde{Q}_s^{1-\nu_s}.$$

The parameters ν_b, for $b \in \{a, m, s\}$, control the share of value-added in production in each sector and are constant both across countries and over time. The term α determines capital's share in value-added and is constant both across countries and over time. The terms $\tilde{Q}_b$, for $b \in \{a, m, s\}$ denote aggregate intermediate inputs

[3]This value plays no quantitative role other than satisfying technical conditions which ensure convergence of the integrals.

which combine the three composite goods according to

$$\tilde{Q}_a = \left((1-\mu_a-\sigma_a)A^{1-1/\varepsilon_a} + \mu_a M^{1-1/\varepsilon_a} + \sigma_a S^{1-1/\varepsilon_a}\right)^{\varepsilon_a/(\varepsilon_a-1)}, \tag{2.4a}$$

$$\tilde{Q}_m = \left((1-\mu_m-\sigma_m)A^{1-1/\varepsilon_m} + \mu_m M^{1-1/\varepsilon_m} + \sigma_m S^{1-1/\varepsilon_m}\right)^{\varepsilon_m/(\varepsilon_m-1)}, \tag{2.4b}$$

$$\tilde{Q}_s = \left((1-\mu_s-\sigma_s)A^{1-1/\varepsilon_s} + \mu_s M^{1-1/\varepsilon_s} + \sigma_s S^{1-1/\varepsilon_s}\right)^{\varepsilon_s/(\varepsilon_s-1)}. \tag{2.4c}$$

The parameters $\mu_b \in [0,1]$ and $\sigma_b \in [0,1]$ control the shares of the composite manufactures and composite services goods, respectively, in the aggregate intermediate good for sector b, while $1-\mu_b-\sigma_b \in [0,1]$ controls the share of the composite agriculture good in the aggregate intermediate input. The terms ε_b govern the elasticity of substitution between the three composite goods within each aggregate intermediate. Each one of these parameters is constant both across countries and over time, but are allowed to vary across sectors.

Following Alvarez and Lucas (2007) the terms $z_{bi}(x_b)$ are random variables that determine the *cost* of production for each individual good x_b. The *cost* draws come from country-, sector-, and time-specific exponential distributions with parameters λ_{bit}, for $b \in \{a, m, s\}$, $i = 1, 2, \ldots, I$, and $t = 1, 2, \ldots, T$. Once the vector of cost draws is known, the country-specific index for the good becomes irrelevant. So from now on each individual good in sector b is denoted by its vector of cost draws z_b.

Efficiency, or factor productivity, in production of each good is $z_{bi}^{-\theta_b}$, which has a Fréchet distribution, implying an average level of efficiency across the continuum of goods of $\lambda_{bi}^{\theta_b}$. If $\lambda_{ai} > \lambda_{aj}$, then on average, country i is more efficient than country j

at producing agricultural goods. Average efficiency at the sectoral level determines specialization across sectors. A country that has a large value of λ_a, relative to the other sectors, will tend to be a net exporter of agriculture. The parameter $\theta_b > 0$, which is constant across countries and over time, governs the coefficient of variation of the efficiency draws within sector b. A larger θ implies more variation in efficiency levels, and hence, more room for specialization within each sector; i.e., more intra-sectoral trade.

Capital accumulation Aggregate investment, denoted by X, augments the stock of capital, denoted by K, according to

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

where δ is the rate at which capital depreciates each period. Aggregate investment combines composite goods from the three sectors according to

$$X = \left((1-\mu_x-\sigma_x)X_a^{1-1/\varepsilon_x} + \mu_x X_m^{1-1/\varepsilon_x} + \sigma_x X_s^{1-1/\varepsilon_x}\right)^{\varepsilon_x/(\varepsilon_x-1)}, \qquad (2.5)$$

where $\mu_x \in [0,1]$ and $\sigma_x \in [0,1]$ determine the relative importance of the composite manufactures and composite services goods, respectively, in aggregate investment, while the term $1-\mu_x-\sigma_x \in [0,1]$ determines the relative importance of the composite agriculture good. The term $\varepsilon_x > 0$ is the elasticity of substitution between the three composite goods. Each parameter is constant across countries and over time.

2.3.2 Endowments

At time $t = 1$ the representative household in country i is endowed with K_{i1} units of capital. At each point in time, $t = 1, 2, \ldots$, country i is endowed with a measure L_{it} of homogeneous labor.

2.3.3 Preferences

The representative household values the stream of consumption per worker according to

$$\sum_{t=1}^{T} \beta^t L_t \frac{(C_t/L_t)^{1-1/\gamma}}{1-1/\gamma},$$

where β is the period discount factor and γ is the inter-temporal elasticity of substitution. C_t denotes aggregate *discretionary* consumption at time t. I use the modifier *discretionary* since it measures the level of consumption above a minimum requirement. Aggregate consumption combines composite goods from each sector according to:

$$C_t = \left((1-\mu_c-\sigma_c)(C_{at}-L_t\bar{a})^{1-1/\varepsilon_c} + \mu_c C_{mt}^{1-1/\varepsilon_c} + \sigma_c C_{st}^{1-1/\varepsilon_c}\right)^{\varepsilon_c/(\varepsilon_c-1)},$$

where $\bar{a}$ denotes the minimum required level of consumption, per worker, of the agricultural good, which is constant over time and across countries. The parameters $\mu_c \in [0,1]$ and $\sigma_c \in [0,1]$ determine the relative importance of the composite manufactures and composite services goods, respectively, in aggregate consumption, while the term $1-\mu_c-\sigma_c \in [0,1]$ determines the relative importance of the composite agriculture good. The term $\varepsilon_c > 0$ is the elasticity of substitution between the three goods. Each parameter is constant across countries and over time.

2.3.4 Borrowing and lending

There is an international asset market. Each country i enters period t with an asset position of $\mathcal{A}_{it}$. During period t new purchases of assets, denoted by B_{it}, augment the existing asset position according to

$$\mathcal{A}_{it+1} = \mathcal{A}_{it} + B_{it}.$$

All prices are quoted in terms of time 1 prices so I abstract from explicitly including the rate of return on assets. If $B_{it} > 0$, then country i is a net lender at time t, and is a net borrower otherwise. If $\mathcal{A}_{it} > 0$, then country i has a positive existing asset position at time t, and has a negative asset position otherwise. Each country begins with an initial asset position of $\mathcal{A}_{i1} = 0$, and must resolve any remaining debt by the end of period T so that $\mathcal{A}_{iT+1} \geq 0$.

2.3.5 Budget constraint

At time t the representative household in country i rents capital to domestic firms at the rental rate r_{it}, and supplies labor at the wage rate w_{it}. Composite goods from each sector are purchased for consumption and investment purposes at the country- and sector-specific prices P_{ait}, P_{mit}, and P_{sit}. Finally, the representative household purchases or sells assets and respects the following budget constraint each period:

$$P_{ait}C_{ait} + P_{mit}C_{mit} + P_{sit}C_{sit} \text{ (aggregate consumption spending)}$$

$$+ P_{ait}X_{ait} + P_{mit}X_{mit} + P_{sit}X_{sit} \text{ (aggregate investment spending)}$$

$$+ B_t \text{ (net asset purchases)}$$

$$= w_{it}L_{it} + r_{it}K_{it}. \text{ (income)} \tag{2.6}$$

2.3.6 Investment rate

The investment rate in current domestic prices, in country i at time t, is denoted by $\rho_{it} \in (0, 1)$, so that

$$P_{ait}X_{ait} + P_{mit}X_{mit} + P_{sit}X_{sit} = \rho_{it}(w_{it}L_{it} + r_{it}K_{it}). \tag{2.7}$$

2.3.7 Trade

Country i purchases each individual good from its least cost supplier. The purchase price depends on the unit cost of the producer, as well as barriers to trade.

Barriers to trade take the form of iceberg costs. That is, at time t, in each sector $b \in \{a, m, s\}$, country j must ship $\tau_{bijt} > 1$ units in order for one unit to arrive in country i. As a normalization I assume that there are no barriers to ship goods domestically so that $\tau_{biit} = 1$.

2.4 Equilibrium

A competitive equilibrium is of a set of prices and allocations that satisfy the following conditions: 1) The representative household maximizes lifetime utility taking prices as given, 2) firms maximize profits taking factor prices as given, and 3) markets clear. In the remainder of this section I carefully describe each condition. Country and time subscripts are omitted where it is clear.

2.4.1 Household optimization

The representative household maximizes lifetime utility by choosing paths for discretionary consumption, investment, and asset holdings, subject to its budget constraint, taking prices as given. Since there are no frictions in the asset market, I find it easier to work with the lifetime budget constraint which is

$$\sum_{t=1}^{T} P_{at}C_{at} + P_{mt}C_{mt} + P_{st}C_{st} + P_{at}X_{at} + P_{mt}X_{mt} + P_{st}X_{st} = \sum_{t=1}^{T} w_t L_t + r_t K_t.$$

I assume that minimum consumption requirements are always met so that the optimal solution is always interior. I define price indices for aggregate discretionary consumption, C, and aggregate investment, X, as follows:[4]

$$P_c = \left((1-\mu_c-\sigma_c)^{\varepsilon_c} P_a^{1-\varepsilon_c} + \mu_c^{\varepsilon_c} P_m^{1-\varepsilon_c} + \sigma_c^{\varepsilon_c} P_s^{1-\varepsilon_c}\right)^{1/(1-\varepsilon_c)},$$

$$P_x = \left((1-\mu_x-\sigma_x)^{\varepsilon_x} P_a^{1-\varepsilon_x} + \mu_x^{\varepsilon_x} P_m^{1-\varepsilon_x} + \sigma_x^{\varepsilon_x} P_s^{1-\varepsilon_x}\right)^{1/(1-\varepsilon_x)}.$$

Using the aggregate price indices for consumption and investment, the lifetime budget constraint can be written as

$$\sum_{t=1}^{T} P_{ct}C_t + P_{xt}X_t = \sum_{t=1}^{T} w_t L_t + r_t K_t - L_t P_{at}\bar{a},$$

where the right hand side is lifetime income remaining after satisfying minimum consumption requirements.

[4]The aggregate price indices are defined so that $P_cC = P_a(C_a - L\bar{a}) + P_mC_m + P_sC_s$, and $P_xX = P_aX_a + P_mX_m + P_sX_s$, where C_b and X_b, for $b \in \{a, m, s\}$, are the optimal levels of sectoral consumption and investment.

The representative household's problem can be broken down into two parts. The first part is intertemporal; the household decides how to allocate aggregate discretionary consumption expenditures and aggregate investment expenditures across time. The second part is intratemporal; within each time period the household decides how to allocate aggregate discretionary consumption and aggregate investment expenditures across the three types of sectoral composite goods.

Intertemporal optimization First I describe the trade-off between consumption and saving. Given exogenous investment rates and the entire sequence of prices, the representative household chooses the sequence of aggregate investment spending according to equation (2.7). Let $W = \sum_t (1-\rho_t)(w_t L_t + r_t K_t) - P_{at} L_t \bar{a}$ denote lifetime income, less lifetime investment spending, less lifetime spending on minimum consumption. The household is left to determine how to allocate W on discretionary consumption spending across time. The optimal decision is to allocate a fraction ξ_t to aggregate discretionary consumption spending at each time t so that

$$P_{ct} C_t = \underbrace{\frac{L_t \beta^{\gamma t} P_{ct}^{1-\gamma}}{\sum_{n=1}^{T} L_n \beta^{\gamma n} P_{cn}^{1-\gamma}}}_{\xi_t} W. \tag{2.9}$$

Once aggregate consumption spending and aggregate investment spending are chosen at each point in time, net purchases of assets at t is given by:

$$B_t = (1-\rho_t)(w_t L_t + r_t K_t) - P_{at} L_t \bar{a} - \xi_t W. \tag{2.10}$$

Intratemporal optimization Now I describe how households optimize within a time period, taking aggregate discretionary consumption spending and aggregate investment spending at that point in time as given. $P_c C$ denotes aggregate discretionary consumption expenditures. Then total consumption expenditures on each of the three sectoral composite goods are given by

$$P_a C_a = (1-\mu_c-\sigma_c)^{\varepsilon_c}\left(\frac{P_a}{P_c}\right)^{1-\varepsilon_c} P_c C + P_a L\bar{a}, \tag{2.11a}$$

$$P_m C_m = \mu_c^{\varepsilon_c}\left(\frac{P_m}{P_c}\right)^{1-\varepsilon_c} P_c C, \tag{2.11b}$$

$$P_s C_s = \sigma_c^{\varepsilon_c}\left(\frac{P_s}{P_c}\right)^{1-\varepsilon_c} P_c C. \tag{2.11c}$$

Similarly, $P_x X$ denotes aggregate investment expenditures. Investment expenditures on each of the three sectoral composite goods are given by

$$P_a X_a = (1-\mu_x-\sigma_x)^{\varepsilon_x}\left(\frac{P_a}{P_x}\right)^{1-\varepsilon_c} P_x X, \tag{2.12a}$$

$$P_m X_m = \mu_x^{\varepsilon_x}\left(\frac{P_m}{P_x}\right)^{1-\varepsilon_x} P_x X, \tag{2.12b}$$

$$P_s X_s = \sigma_x^{\varepsilon_x}\left(\frac{P_s}{P_x}\right)^{1-\varepsilon_x} P_x X. \tag{2.12c}$$

2.4.2 Firm optimization

In each country, producers of individual goods set price equal to their marginal cost taking factor prices as given. Denote the price for an individual good z_b, of sector $b \in \{a, m, s\}$, that was produced in country j and purchased by country i, by $p_{bij}(z_b)$. Then $p_{bij}(z_b) = p_{bjj}(z_b)\tau_{bij}$, where $p_{bjj}(z_b)$ is the marginal cost of good z_b in country j. Since each country purchases each individual good from its least cost supplier, the actual price in country i for the individual good z_b is $p_{bi}(z_b) = \min_{j=1,\ldots,I}[p_{bjj}(z_b)\tau_{bij}]$.

Prices The prices of each sectoral composite good, $b \in \{a, m, s\}$, are

$$P_{bi} = \left[\int p_{bi}(z_b)^{1-\eta} \varphi_b(z_b) dz_b \right]^{\frac{1}{1-\eta}},$$

where $\varphi_b = \prod_i \varphi_{bi}$ is the joint density across countries for cost draws. Since each individual good is purchased from the least cost supplier, given the assumptions on the country-specific densities, φ_{bi}, the model has a tractable implication for the prices of the composite goods:

$$P_{bi} = \Gamma_b B_b \left[\sum_l (u_{bl} \tau_{bil})^{-1/\theta} \lambda_{bl} \right]^{-\theta},$$

where the unit costs for input bundles u_{bi}, for each sector $b \in \{a, m, s\}$, are given by

$$u_{bi} = \left(r_i^{\alpha} w_i^{1-\alpha} \right)^{\nu_b} \tilde{P}_{bi}^{1-\nu_b},$$

and $\tilde{P}_b$ is the ideal price index for the aggregate intermediate used by sector b, $\tilde{Q}_b$, which is given by

$$\tilde{P}_b = \left((1 - \mu_b - \sigma_b)^{\varepsilon_b} P_a^{1-\varepsilon_b} + \mu_b^{\varepsilon_b} P_m^{1-\varepsilon_b} + \sigma_b^{\varepsilon_b} P_s^{1-\varepsilon_b} \right)^{1/(1-\varepsilon_b)}.$$

The terms B_b for $b \in \{a, m, s\}$ are constant both across countries and over time and are given by $B_b = (\alpha\nu_b)^{-\alpha\nu_b}((1-\alpha)\nu_b)^{(\alpha-1)\nu_b}(1-\nu_b)^{\nu_b - 1}$. Finally, the term $\Gamma_b = \Gamma(1 + \theta_b(1-\eta))^{\frac{1}{1-\eta}}$ is constant both across countries and over time, where $\Gamma(\cdot)$ is the Gamma function; I impose parameter restrictions so that Γ_b is positive.

Trade shares There is a tractable implication for bilateral trade flows. For each sector b, the fraction of country i's expenditure on imports from country j is given by

$$\pi_{bij} = \frac{\left(u_{bj}\tau_{bij}\right)^{-1/\theta}\lambda_{bj}}{\sum_{l}\left(u_{bl}\tau_{bil}\right)^{-1/\theta}\lambda_{bl}}.$$

Another interpretation of π_{bij} is the following: π_{bij} the probability that for any individual good z_b in sector b, country j is the least cost supplier to country i. Equivalently, by the law of large numbers, it is the fraction of the unit interval for which j supplies i.

Factor demands I first define total factor usage in sector b as follows:

$$K_{bi} = \int K_{bi}(z_b)\varphi_b(z_b)dz_b,$$

$$L_{bi} = \int L_{bi}(z_b)\varphi_b(z_b)dz_b,$$

$$A_{bi} = \int A_{bi}(z_b)\varphi_b(z_b)dz_b,$$

$$M_{bi} = \int M_{bi}(z_b)\varphi_b(z_b)dz_b,$$

$$S_{bi} = \int S_{bi}(z_b)\varphi_b(z_b)dz_b.$$

The notation on the right-hand side, $L_{bi}(u)$ for example, refers to the amount of labor used in country i to produce the individual good z_b, and similarly, $M_{bi}(z_b)$ refers to the quantity of the composite manufactured good used by sector b. Note that each of $L_{bi}(z_b), K_{bi}(z_b), A_{bi}(z_b), M_{bi}(z_b)$, and $S_{bi}(z_b)$ will take the value zero if country i imports good z_b. On the left-hand side, the notation L_{bi} denotes the total labor allocated to sector b in country i, while M_{bi} denotes the quantity of manufactures used by sector b firms in production.

Denote the value of gross output in sector b of country i by Y_{bi}. Spending by firms on each factor of production is given by

$$r_i K_{bi} = \alpha \nu_b Y_{bi}, \tag{2.13a}$$

$$w_i L_{bi} = (1-\alpha)\nu_b Y_{bi}, \tag{2.13b}$$

$$P_{ai} A_{bi} = (1-\mu_b-\sigma_b)^{\varepsilon_b} \left(\frac{P_{ai}}{\tilde{P}_{bi}}\right)^{1-\varepsilon_b} (1-\nu_b) Y_{bi}, \tag{2.13c}$$

$$P_{mi} M_{bi} = \mu_b^{\varepsilon_b} \left(\frac{P_{mi}}{\tilde{P}_{bi}}\right)^{1-\varepsilon_b} (1-\nu_b) Y_{bi}, \tag{2.13d}$$

$$P_{si} S_{bi} = \sigma_b^{\varepsilon_b} \left(\frac{P_{si}}{\tilde{P}_{bi}}\right)^{1-\varepsilon_b} (1-\nu_b) Y_{bi}. \tag{2.13e}$$

2.4.3 Market clearing

Goods and factor market clearing I begin by describing market clearing conditions for capital, labor, and each of the sectoral composite goods

$$K_{ai} + K_{mi} + K_{si} = K_i, \tag{2.14a}$$

$$L_{ai} + L_{mi} + L_{si} = L_i, \tag{2.14b}$$

$$A_{ai} + A_{mi} + A_{si} + C_{ai} + X_{ai} = A_i, \tag{2.14c}$$

$$M_{ai} + M_{mi} + M_{si} + C_{mi} + X_{mi} = M_i, \tag{2.14d}$$

$$S_{ai} + S_{mi} + S_{si} + C_{si} + X_{si} = S_i. \tag{2.14e}$$

The left-hand side of each of the previous equations is simply the factor usage by country i while the right-hand side is the factor availability in country i.

Cross-country flows of goods In order for flows of funds to match up, it is necessary that the following conditions are met:

$$Y_{ai} = \sum_{j=1}^{I} P_{aj} A_j \pi_{aji}, \tag{2.15a}$$

$$Y_{mi} = \sum_{j=1}^{I} P_{mj} M_j \pi_{mji}, \tag{2.15b}$$

$$Y_{si} = \sum_{j=1}^{I} P_{sj} S_j \pi_{sji}. \tag{2.15c}$$

The left-hand side is country i's gross output in each sector, while the right hand side is world gross expenditure on goods that were produced in country i. That is, each term inside of the summation denotes the value of trade flows from country i to country j.

Country-specific resource constraints Lastly, I impose country-specific resource constraints. These conditions require that GDP be equal to total consumption expenditures, plus investment expenditures, plus net exports, at each point in time. This is equivalent to imposing the condition that net purchases of assets be equal to the trade surplus at each point in time:[5]

$$B_i = \underbrace{Y_{ai} - P_{ai}A_i}_{\text{surplus in } a} + \underbrace{Y_{mi} - P_{mi}M_i}_{\text{surplus in } m} + \underbrace{Y_{si} - P_{si}S_i}_{\text{surplus in } s}.$$

[5] An equivalent way to view this is as follows. Using the period budget constraint the left-hand side, net purchases of assets, is equal to $wL + rK - P_c(C + L\bar{a}) - P_x X$. Moreover, by definition, the right-hand side, the aggregate trade surplus, is equal to net exports. With some abuse of notation this is equivalent to the familiar condition $Y - C - I = NX$, i.e., $Y = C + I + NX$. Also note that if borrowing/lending were not allowed, i.e., we imposed the constraint that $B = 0$, then this condition would be equivalent to balanced trade country-by-country so that $Y = C + I$.

2.5 Calibration

In this section I describe how I choose parameter values. I use data over the time period 1960-2000. This interval covers the period of Korea's growth miracle which began in the 1960's and ended in the 1990's. I report results for 1960 through 1995 and discard the last five years (1996-2000) in order to diminish endpoint effects.

The model consists of six economies: Canada, Europe, South Korea, Latin America, South-east Asia, and the United States, denoted by CAN, EUR ,KOR, LAM, SEA, and USA respectively. The European economy is treated as a group, in particular the EU-15, which consists of 15 countries: Austria, Belgium, Denmark, France, Germany, Great Britain, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and Sweden. Latin America consists of 7 countries: Argentina, Bolivia, Chile, Colombia, Costa Rica, Mexico, and Venezuela. Finally, South-east Asia consists of 9 countries: Hong Kong, India, Indonesia, Japan, Malaysia, the Philippines, Singapore, Taiwan, and Thailand.

The choice of grouping countries was made to facilitate computation, while still covering a sufficient amount of world trade, particularly Korea's trade. For the year 2000, this specification covers 67 percent of Korean merchandise exports and 63 percent of Korean merchandise imports.

The production side of the economy is split into three sectors using two-digit ISIC categories. The agricultural sector corresponds to *Agriculture, Forestry and Fishing* (ISIC categories 01-05). The manufactures sector corresponds to industrial related activity which includes: *Mining and Quarrying* (ISIC categories 10-14), *Man-*

ufacturing (ISIC categories 15-37), and *Construction* (ISIC category 45). Finally, the services sector accounts for remaining activity which includes: *Public Utilities* (ISIC categories 40-41), *Wholesale and Retail Trade, Hotels and Restaurants* (ISIC categories 50-55), *Transport, Storage, and Communication* (ISIC categories 60-64), *Finance, Insurance, and Real Estate* (ISIC categories 65-74), *Community, Social, and Personal Services* (ISIC categories 75-99), and *Government Services* (ISIC categories 75-99).

2.5.1 Common parameters

In this section I describe how I select values for parameters that are constant across countries and over time.

Preference parameters I calibrate the level of minimum consumption $\bar{a}$ to match key aspects of agricultural output in Korea. This is done jointly with other parameters and I postpone the discussion until section 2.5.3.

The elasticity of substitution between the three composite goods is set to $\varepsilon_c = 0.67$ in line with Betts, Giri, and Verma (2011). They chose this value to be the average across two specifications estimated by Herrendorf, Rogerson, and Valentinyi (2009). I follow the same source and set the weights on agriculture and manufactures to be $\mu_c = 0.17$ and $\sigma_c = 0.78$. These parameters are given in Table 2.2.

I set the intertemporal elasticity of substitution to be $\gamma = 0.5$ as in Backus, Kehoe, and Kydland (1992). The annual discount factor is set to $\beta = 0.96$ so that, in the long run, when all exogenous variables are constant over time, the real rate of return is about 4 percent. These parameters are summarized in Table 2.1.

Capital's share, depreciation, and η I define aggregate investment in the model to be consistent with the measure of aggregate investment in the Penn World Tables. Accordingly, I set the annual rate of depreciation of capital in the model to be $\delta = 0.06$, a standard value used in the literature. I set capital's share in value added to be $\alpha = 1/3$ in accordance with estimates by Gollin (2002); he argues that payments to labor account for about 2/3 of total GDP in a large cross section of countries. Valentinyi and Herrendorf (2008) argue that capital's share is roughly constant across sectors as well. Finally, I set the parameter which governs the elasticity of substitution across individual goods, in each composite good, to be $\eta = 2$. This value plays no quantitative role other than satisfying technical conditions in order to insure convergence of the integrals.

Table 2.1: Common parameters.

Parameter	Description	Value
β	Discount factor	0.96
γ	Intertemporal elasticity of substitution	0.50
δ	Depreciation rate of capital	0.06
α	Capital's share in GDP	0.33
η	Elasticity of substitution between individual goods	2

Sector-specific weights and elasticities for investment and intermediate inputs Intermediate spending by firms in the three productive sectors, and investment spending, are allocated across the three sectoral composite goods. The composition of spending across the three goods depends on the elasticity of substitution as well as each goods weight in its aggregator. To recover these parameters I use time series data from input-output tables for both Korea and the US.

There are 4 elasticities which need to be recovered: ε_b for $b \in \{a, m, s, x\}$ and 8 weights: μ_b and σ_b for $b \in \{a, m, s, x\}$. Next I describe how I estimate the elasticity and weights for aggregate investment in equation (2.5). I estimate the analogous parameters for aggregate intermediate inputs (from equations 2.4a) – (2.4c) similarly.

The model implies that, in country i at period t, the share of total investment spending allocated to each composite good is given by

$$\begin{aligned}
\frac{P_{ait}X_{ait}}{P_{xit}X_{it}} &= \frac{(1-\mu_x-\sigma_x)^{\varepsilon_x} P_{ait}^{1-\varepsilon_x}}{(1-\mu_x-\sigma_x)^{\varepsilon_x} P_{ait}^{1-\varepsilon_x} + \mu_x^{\varepsilon_x} P_{mit}^{1-\varepsilon_x} + \sigma_c^{\varepsilon_x} P_{sit}^{1-\varepsilon_x}}, \\
\frac{P_{mit}X_{mit}}{P_{xit}X_{it}} &= \frac{\mu_x^{\varepsilon_x} P_{mit}^{1-\varepsilon_x}}{(1-\mu_x-\sigma_x)^{\varepsilon_x} P_{ait}^{1-\varepsilon_x} + \mu_x^{\varepsilon_x} P_{mit}^{1-\varepsilon_x} + \sigma_x^{\varepsilon_x} P_{sit}^{1-\varepsilon_x}}, \\
\frac{P_{sit}X_{sit}}{P_{xit}X_{it}} &= \frac{\sigma_x^{\varepsilon_x} P_{sit}^{1-\varepsilon_x}}{(1-\mu_x-\sigma_x)^{\varepsilon_x} P_{ait}^{1-\varepsilon_x} + \mu_x^{\varepsilon_x} P_{mit}^{1-\varepsilon_x} + \sigma_x^{\varepsilon_x} P_{sit}^{1-\varepsilon_x}},
\end{aligned}$$

where $P_{xit}X_{it}$ is aggregate investment spending. On the left-hand side I compute expenditure shares directly from input-output tables for Korea and the US. On the right-hand I take a stand on which data correspond to purchase prices. The EU Klems database provides prices of intermediate inputs dating back to 1970. These prices are provided at a more disaggregate level than three sectors, so I use corresponding data on total intermediate spending on each disaggregate good as weights in order to arrive at expenditure-weighted intermediate goods prices for the three sectors.[6] In the model, composite goods prices are the same regardless of their use; that is, one unit of the composite services good has the same price whether it is used for investment or intermediate use. Since I do not have access to prices of investment at the sectoral level, I use the same price series to identify the parameters in aggregate investment.

To recover the parameters I use Nonlinear Least Squares. I do this jointly for Korea and the US by feeding in the time series of prices and expenditure shares for both countries. I apply the same parameter value for all other countries in the model, and all parameters are reported in Table 2.2.

The estimated weights are fairly intuitive. Manufactures carry the largest weight in intermediate usage by producers of manufactures; manufacturing a computer requires mainly processors, chips, cases, and hard drives (all manufactures). Manufactures also carries a substantial weight in agriculture; for example, fertilizer (manufactures) is a very large input in corn production (agriculture). Agriculture has very little, if any, weight in the other sectors, while its weight in its own sector is 0.15; animal feed is an important input that goes into raising livestock. With respect to final final demand, manufactures carry almost all of the weight in aggregate investment and services carry 2/3 of the weight in consumption.

My elasticity estimates imply that the three goods are indeed complemen-

[6]Total intermediate spending on a particular good is the sum of all expenditures made by all firms in all sectors on that good.

tary in all sectors, but with different elasticities of substitution. Producers of services substitute across intermediate inputs much more easily than do producers of manufactures. For example, restaurants (services) substitute ambiance/entertainment (services) for merchandise/portions (manufactures/agriculture) and vice-versa. On the other hand, production of automobiles (manufactures) requires manufactured inputs such as engines, paint, etc., which can not be replaced by agricultural or services goods. With respect to aggregate investment, the elasticity of substitution is very low, 0.18, while it is much higher with respect to consumption, 0.67.

Shares of value added in sectoral gross output For each productive sector $b \in \{a, m, s\}$, the share of value added in gross output is given by ν_b. For Canada, the EU-15, Korea, and the US I take the ratio of value added output to gross output for each year for which data is available, then take the average across time. In the data these ratios are quite stable over time. For Korea the source of data are input-output tables which are published by the Bank of Korea. These data are available for benchmark years which occur approximately every 5 years going back to 1960. For the US the source is also input-output tables which are published by the BEA. These data are available for benchmark years, approximately every 5 years, beginning in 1947. For Canada and the EU-15 the source is EU Klems, in which value added output and gross output have already been aggregated into the group EU-15 for all member countries. EU Klems provides annual data as far back as 1970. For these four economies (CAN, EUR, KOR, USA) I obtain the following: $\nu_a =$

$(0.48, 0.51, 0.70, 0.40)$, $\nu_m = (0.38, 0.36, 0.30, 0.40)$, and $\nu_s = (0.67, 0.61, 0.68, 0.62)$. In the model, I take the average of these and apply them to each country so that $\nu_a = 0.53, \nu_m = 0.36$, and $\nu_s = 0.65$.

Variation in efficiency draws The terms θ_a, θ_m, and θ_s govern the variation of efficiency levels within each sector and each country. A larger value of θ_b implies more variation in efficiency levels for each country in sector b, and hence, more room for specialization within that sector. These parameters also determine how sensitive trade shares are to changes in trade costs. For the manufactures sector I set $\theta_m = 0.15$, the preferred value of Alvarez and Lucas (2007), which lies in the range of estimates in Eaton and Kortum (2002). In order to isolate any effects that can stem from different values of θ_b across sectors, I set $\theta_a = \theta_s = 0.15$ as well.

2.5.2 Country-specific parameters

In this section I describe the selection of parameter values which vary across countries and over time. These consist of the initial capital stocks K_{i1}, the sequence of labor endowments $\{L_{it}\}$, the sequence of investment rates $\{\rho_{it}\}$, the sequences of sector specific productivity terms $\{\lambda_{ait}, \lambda_{mit}, \lambda_{sit}\}$, and the sequences of trade barriers $\{\tau_{aijt}, \tau_{mijt}, \tau_{sijt}\}$.

Initial capital stocks For each country I set the initial capital stock to its 1960 level, which I compute using the perpetual inventory method as in Caselli

Table 2.2: Sector-specific parameters.

Sector:	Agriculture	Manufacturing	Services	Consumption	Investment
Elasticity of substitution between composite goods in aggregators					
	$\varepsilon_a = 0.61$	$\varepsilon_m = 0.44$	$\varepsilon_s = 0.77$	$\varepsilon_c = 0.67$	$\varepsilon_x = 0.18$
Weight of the composite manufactured good in aggregators					
	$\mu_a = 0.51$	$\mu_m = 0.92$	$\mu_s = 0.38$	$\mu_c = 0.17$	$\mu_x = 0.985$
Weight of the composite services good in aggregators					
	$\sigma_a = 0.15$	$\sigma_m = 0.07$	$\sigma_s = 0.61$	$\sigma_c = 0.78$	$\sigma_x = 0.01$
Share of value added in sectoral gross output					
	$\nu_a = 0.53$	$\nu_m = 0.36$	$\nu_s = 0.65$		
Variation in efficiency draws					
	$\theta_a = 0.15$	$\theta_m = 0.15$	$\theta_s = 0.15$		

(2005). The perpetual inventory equation is

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

where I_t is aggregate investment in PPP and δ is the depreciation rate. I_t is computed from the Penn World Tables according to the formula: `rgdpl*pop*ki`. I begin by setting $K_0 = I_0/(g + \delta)$, where I_0 is the value of the investment series for the first year in which it is available, and g is the average geometric growth rate for the investment series between the first year with available data and 1970. I set $\delta = 0.06$ in line with the existing literature.

Aggregate investment for the groups EUR, LAM, and SEA are the sum of aggregate investment over each of their members. The first year in which data is available for all countries in EUR is 1951 with the exception of Germany for which the series for `rgdpl` and ki does not begin until 1970. To handle this I compute the ratio of the value in Germany, to the cumulative value for that variable for the rest of EUR, for years in which data is available: 1970-2000.[7] I then take the average of this ratio over the period 1970-2000 and use this ratio to impute missing values for Germany from 1951-1969. The first year in which data are available for CAN is 1950, the first year in which data are available for KOR is 1953, the first year in which data are available for all countries in LAM is 1952, the first year in which data are available for all countries in SEA is 1960, and the first year in which data are available for USA is 1950.

Labor endowments I set the endowment of labor, in each country at each point in time, to be the value of the number of workers computed from the Penn World Tables version 6.3. I apply the following formula: number of workers equals 1000*`pop`*`rgdpl/rgdpwok`.

Investment rates Investment rates in nominal terms are constructed using data from version 6.3 of the Penn World Tables. I apply the following formula: nominal investment rate equals `ki`*`pi/p`. To compute the nominal investment rate for a group such as EUR I first compute the sum of nominal investment over all

[7]These ratios did not vary by more than 1 percentage point over the period 1970-2000.

members in EUR ($\sum$ `rgdpl*pop*ki*pi`), and divide it by the sum of nominal GDP over all members in EUR ($\sum$ `rgdpl*pop*p`).

Productivity Average efficiency in sector b of country i is $\lambda_{bi}^{\theta_b}$. I break the identification of average efficiency into two parts. One part is to identify initial average efficiency, in 1960, for each country in each sector. The second part is to compute growth rates in order to recover the entire time series.

I normalize initial agricultural productivity in the United States to one, i.e., $\lambda_{a,USA,1}^{\theta_a} = 1$, which leaves 17 initial productivity terms to be identified. I calibrate these jointly with other objects and discuss the details in section 2.5.3.

I recover growth in average efficiency from observed growth in sector-specific TFP. I compute sector- specific TFP using a Solow accounting procedure:

$$RVA_{bit} = Z_{bit} K_{bit}^{\alpha} L_{bit}^{1-\alpha}.$$

where RVA_{bit} and L_{bit} are real value added and labor employment, respectively, in country i, sector b, at time t. K_{it} and L_{it} denote the aggregate capital stock and labor in country i at time t. Rewriting in terms of output per worker, and using the fact that, according to the model, capital-labor ratios are constant across sectors within each country I recover the TFP, Z_{bit}, as a residual to

$$\frac{RVA_{bit}}{L_{bit}} = Z_{bit} \left(\frac{K_{it}}{L_{it}} \right)^{\alpha}.$$

I assume that country- and sector-specific productivities grow at rates that are constant over time. Bernard and Jones (1996) measure productivity growth for the

United States and find that, on average, TFP growth is on 0.03 for agriculture, 0.02 for manufactures, and 0.01 for services. This is in line with Ngai and Pissarides (2004) who find that agricultural productivity growth is 1 percent higher than manufactures productivity growth, and manufactures productivity growth is 1 percent higher than services productivity growth. Therefore, I set growth rates for USA, to $g_a = 0.03, g_m = 0.02$, and $g_s = 0.01$. For the remaining countries I treat sector-specific average productivity as a Solow residual and take the average growth over the period 1960-2000, relative to the United States:

$$(1 + g_{bi}) = \frac{\sum_{t=1}^{T-1} Z_{bit+1}/Z_{bit}}{\sum_{t=1}^{T-1} Z_{bUSAt+1}/Z_{bUSAt}}(1 + g_{bUSA}),$$

The GGDC provides data on value added in constant dollars as well as employment, both at the sectoral level for Korea, Latin America, South-east Asia, and the United States. I convert all real value added series into 1995 US dollars to make them comparable. For Canada and Europe I use data from EU Klems. I use nominal value added data and construct sector-specific producer price indices from disaggregate price data from the same source in order to produce real value added figures. I also construct sectoral employment figures by summing over the more disaggregate sectors. I report the sector- and country-specific growth rates in Table 2.3.

To map measured TFP growth rates into the model, I assume that growth in measured TFP, Z, is the same as growth in average productivity, λ^{θ}. This is an imperfect measure since productivity should be measured using gross output data. However, I do not have access to intermediate inputs so such a calculation is not feasible. Therefore, I recover the time series of average productivities as

$$\lambda_{bit+1}^{\theta_b} = (1 + g_{bi})\lambda_{bit}^{\theta_b},\ t = 1, \ldots, T - 1.$$

Table 2.3: Annual growth in productivity.

	Agriculture	Manufacturing	Services
CAN	0.027	0.040	0.020
EUR	0.049	0.030	0.016
KOR	0.023	0.054	0.009
LAM	0.009	0.021	0.001
SEA	0.000	0.051	0.038
USA	0.030	0.020	0.010

Trade barriers In order to quantify trade barriers, I treat them as the sum of a policy related component and a non-policy related component. That is, $\tau_{bit} = 1 + trf_{bit} + d_b$, where trf_{bit} is the effective tariff rate, or policy component, applied by country i on sector b goods at time t. The non-policy component, d_b, captures trade costs associated with geography, and other frictions that are non-policy related, as well as policy-related components that are not readily measured. The non-policy related components are common to all countries and constant over time.

I measure the policy component directly using data from GATT. From 1960 to 2000 there have been four rounds of tariff reductions implemented by GATT which were applied to member countries: the Dillon rounds (1960-1962), the Kennedy rounds (1964-1967), the Tokyo rounds (1973-1979), and the Uruguay rounds (1986-1994). Membership was not uniform over this time, but by the Kennedy rounds, all countries in my sample were members. I compute tariff levels from Finger, Ingco, and Reincke (1996) (FIR), who document the tariff levels both before and after the Uruguay rounds. Then I compute the remaining tariffs for the remaining time periods by using changes in tariffs from the other rounds of negotiations.

The average tariff cuts made during the Dillon rounds were 35%, but were made on an item-by-item basis. Not all countries in my sample were GATT members at this point, including Korea. However, I assume that all countries reduced tariffs linearly by 35%. By 1964, Korea had become a member of GATT and participated in the Kennedy rounds. During the Kennedy and Tokyo rounds most cuts were made on a linear basis, and average cuts were 35% in each round.[8] For the Kennedy, Tokyo, and Uruguay rounds there was a 5 year phase-in period for mandated cuts to be applied. Therefore, I assume that cuts were phased in in equal portions over the five years after the last year of negotiations.

I choose tariff levels by beginning with data on agricultural tariffs as well as tariffs on industrial goods, both before and after the Uruguay Round. This

[8]See the World Trade Organization http://www.adb.org/documents/others/ogc-toolkits/wto/wto0200b.asp.

data is available in FIR. Tables G.1 and G.2 in FIR provide concessions given for each importer economy or group by product category. For each importer, the tariff weight is computed as an import-weighted average across all countries from which it imports.

A major accomplishment of the Uruguay Round was the conversion of non-tariff restrictions on imports of agricultural goods into their tariff equivalent. Therefore, direct tariffs are available in addition to the ad valorem equivalent on non-tariff barriers. I assume that this ratio is the same for industrial goods and construct the tariff equivalent for the manufactures sector accordingly.

FIR provide country groupings, such as the European Union, and take care of aggregation by weighting tariffs by imports. There is no one-to-one correspondence between my country groupings, and the data available in FIR so I use an approximation. For my grouping called EUR, I use Tables G.1 for the European Union from FIR which is a strict superset of my group that includes 27 countries (my group is only 15). For my grouping LAM I use Tables G.2 for Latin America from FIR which includes Argentina, Brazil, Chile, Colombia, El Salvador, Jamaica, Mexico, Peru, Uruguay, and Venezuela. Finally, for the grouping SEA I take averages across multiple Tables from FIR including Tables G.2 (*East Asia and Pacific* which consists of Indonesia, Korea, Macao, Malaysia, Philippines, and Thailand), Tables G.2 (*South Asia* which consists of India and Sri Lanka), Tables G.1 (Hong Kong), Tables G.1 (Japan), and Tables G.1 (Singapore). The advantage of using groupings already provided by FIR is that they have weighted each member country's tariff by their share of imports within the group.

I report the values in ten year intervals for all tariffs used in the model in Table 2.4. The tariff levels are consistent with Connolly and Yi (2009): the tariff level for manufactures in Korea in the early 1960's is about three times as large as the tariff level for manufactures in developed countries such as the US.

I calibrate the non-policy related components, d_a, d_m, and d_s jointly with other parameters; I describe the procedure next.

2.5.3 Remaining parameters

The remaining parameters that need to be calibrated are: the minimum level of agricultural consumption per worker, $\bar{a}$, initial average productivity in all countries in each sector, $\lambda_{bi1}^{\theta_b}$, and the non-policy related components of trade barriers, d_a, d_m, and d_s. I calibrate these parameters jointly to match key aspects of the data in 1960. I normalize initial agricultural productivity in the US to 1, leaving 21 parameters.

I want the model to deliver the initial composition of output across all countries in the year 1960 so I target the compositions of gross output in each of the six countries: Canada, Europe, Korea, Latin America, South-east Asia, and the United States (12 moments). In addition, I want to make sure the model matches the composition of exports in Korea in 1960 (2 moments). Referring back to equation (2.1), once I have matched the composition of output and the composition of exports in 1960, there is one more degree of freedom: the fraction of aggregate output that gets exported in 1960 (1 moment). Matching this value will discipline the weight of

Table 2.4: Policy component of trade barriers (ad valorem tariff equivalent values).

Country	Sector	1960	1970	1980	1990	2000
CAN	Agr	0.25	0.14	0.10	0.07	0.05
	Mfg	0.47	0.26	0.19	0.13	0.10
	Srv	0.36	0.20	0.14	0.10	0.08
EUR	Agr	0.75	0.65	0.45	0.32	0.16
	Mfg	0.54	0.46	0.33	0.23	0.08
	Srv	0.65	0.55	0.39	0.28	0.12
KOR	Agr	1.96	0.48	0.34	0.24	0.22
	Mfg	1.93	1.50	1.06	0.75	0.69
	Srv	1.95	0.99	0.70	0.50	0.46
LAM	Agr	1.06	0.75	0.53	0.37	0.23
	Mfg	0.34	0.24	0.17	0.12	0.06
	Srv	0.70	0.50	0.35	0.25	0.14
SEA	Agr	1.16	0.65	0.46	0.32	0.30
	Mfg	0.71	0.40	0.28	0.20	0.17
	Srv	0.94	0.52	0.37	0.26	0.23
USA	Agr	0.43	0.24	0.17	0.12	0.12
	Mfg	0.65	0.36	0.26	0.18	0.17
	Srv	0.54	0.30	0.21	0.15	0.14

exports in output, and in turn discipline the role of trade in structural change.

Output in Korea is determined by spending patterns in Korea as well as spending patterns in countries that Korea trades with. I have access to spending compositions for both Korea and the US so I target the composition of gross spending in Korea and the United States in 1960 (4 moments). To impose quantitative discipline on the dependence between spending in the US and output in Korea I also target the fraction of aggregate gross spending in the US on imports (1 moment). Finally, I target the fraction of aggregate gross spending that is imported by Korea (1 moment).

In total there are 21 moments and 21 parameters. I choose the parameter values by minimizing the distance between the data and the model under the Euclidean norm: $\min \sum(\text{model} - \text{data})^2$, and constrain each each parameter to be non-negative. Table 2.5 reports the calibrated parameter values.

The values for initial average productivity across the three sectors are consistent with the values used by Dietrich and Krüger (2010); productivity is highest in agriculture, and lowest in services.

Barriers are substantially larger in agriculture than in the other sectors. The reason for this is because there is very little trade in agriculture relative to production. The barrier in manufactures is somewhat smaller than those found in the literature. For instance, Mutreja, Ravikumar, Riezman, and Sposi (2012) obtain an average barrier in manufactures of around 4. The reason the value is smaller is because the barrier reflects the cost of shipping across countries relative to shipping

Table 2.5: Calibrated parameter values.

	Agriculture	Manufacturing	Services
Initial average productivity relative to the US: $\lambda_{bi1}^{\theta_b}$			
CAN	0.97	0.50	1.25
EUR	0.96	0.27	1.19
KOR	0.28	0.13	0.14
LAM	0.14	0.20	0.47
SEA	0.30	0.18	0.35
USA	1.00	1.00	1.00
Non-policy component of trade barriers: d_b			
	6.07	2.24	5.03

Note: All productivity levels are relative to the US. $\lambda_{aUSA1}^{\theta_a} = 1$ is a normalization, while $\lambda_{mUSA1}^{\theta_m}/\lambda_{aUSA1}^{\theta_a} = 0.05$ and $\lambda_{sUSA1}^{\theta_s}/\lambda_{aUSA1}^{\theta_a} = 0.01$. The calibrated value for the minimum level of agricultural consumption, $\bar{a}$, implies that in 1960, 45 percent of total Korean consumption is for subsistence, while in 1995, 26 percent is for subsistence.

domestically. In this chapter countries are grouped together so the relative barrier will appear smaller.

Table 2.6 shows how close the model comes to matching the targets. Since the parameters are exactly identified, it is no surprise that the model is close to the data. This is important since the initial levels of each compositions can affect how much the composition can change. For instance, suppose that the calibration implied that manufacture's share in Korean output was close to 1 in 1960. Then it would be impossible to generate the observed increase in manufacture's share in Korean output after 1960 since the share can not be larger than 1.

Table 2.6: Fit of calibration to 1960 data.

		CAN	EUR	KOR	LAM	SEA	USA
Output composition							
Agriculture	Model	0.03	0.03	0.30	0.21	0.34	0.02
	Data	*0.05*	*0.08*	*0.27*	*0.23*	*0.38*	*0.06*
Manufactures	Model	0.56	0.49	0.39	0.44	0.42	0.54
	Data	*0.57*	*0.52*	*0.38*	*0.45*	*0.38*	*0.53*
Export composition							
Agriculture	Model			0.19			
	Data			*0.19*			
Manufactures	Model			0.47			
	Data			*0.47*			
Fraction of gross output exported							
Aggregate	Model			0.02			
	Data			*0.03*			
Gross spending composition							
Agriculture	Model			0.28			0.02

Table 2.6 – Continued

		CAN	EUR	KOR	LAM	SEA	USA
	Data			*0.26*			*0.04*
Manufactures	Model			0.43			0.54
	Data			*0.43*			*0.53*
Fraction of gross spending on imports							
Aggregate	Model			0.04			0.02
	Data			*0.07*			*0.02*

2.6 Results

In appendix B.1 I discuss qualitative the implications of a two-country, two-sector static model. In this section I present quantitative results from the multi-country dynamic model for the years 1960 through 1995. Since the model has a finite-horizon, I discard the last five years (1996-2000) in order to diminish end point effects.

2.6.1 Korean compositions

The left panel of Figure 2.4 presents the model's performance with respect to the composition of output in Korea. The model generates the increase in manufacture's share almost exactly. It also generates about 87 percent of the decline in agriculture's share.

Crucial to the decline in agriculture's share is the minimum consumption requirement. Trade costs are high in agriculture, so Korea is forced to produce agricultural goods on its own. Over time, as Korea grows richer, and experiences productivity advances in manufactures, it is able to shift resources away from agriculture and into manufactures, and import agricultural goods.

The right panel of Figure 2.4 presents results for changes in the composition of exports. The model predicts the initial increase in manufacture's share as well as the eventual flattening. However, the model over-predicts manufacture's increase as well as over-predicts the decrease in service's share. The model comes very close to reproducing agriculture's share in exports.

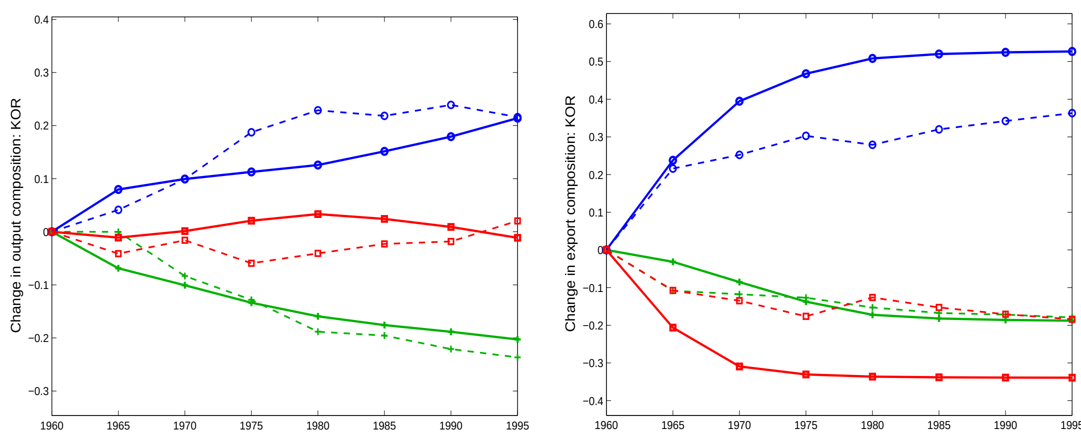

Figure 2.4: Composition of output (left) and exports (right) in Korea: 1960-1995. The green line with plus signs (+) represents agriculture, the blue line with circles represents manufactures, and the red line with squares represents services. The dashed lines correspond to the data and the solid lines correspond to the model.

The increase in manufacture's share in exports is driven primarily by the shift in Korea's comparative advantage towards the manufactures sector. This in turn causes the increase in manufacture's share in output through specialization.

2.6.2 Trade deficit and growth miracle

From 1960 to the 1980's Korea ran an aggregate trade deficit. During the 80's they ran a surplus which eventually returned to a deficit. The model does a decent job in tracking the trend of net export-to-GDP ratio. The model predicts a decreasing deficit, which turns into a surplus, and a peak in the surplus in the 1980's; see the left panel of Figure 2.5.

During this time Korea grew at an annualized rate of 3.3 percentage points higher than the United States. This sustained growth is often referred to as a miracle. The model generates the Korean growth miracle, but under-states it by generating an annualized Korean growth rate of 3.0 percentage points higher than the United States. I plot the time series for real GDP per worker, relative to the United States, in the right panel of Figure 2.5.

2.6.3 Structural change in the rest of the world

Changes in comparative advantage in Korea depend not only on the productivity growth across each sector in Korea, but also on the productivity growth across sectors in other countries. In this section I argue that the paths of productivity that I used indeed are consistent with changes in compositions for the other countries in the model as well.

I begin by presenting the output composition in the US. The model predicts

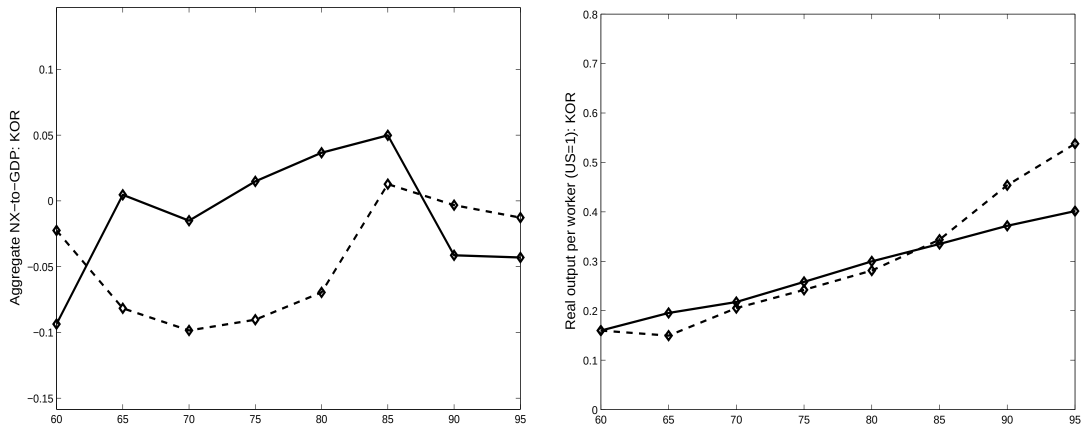

Figure 2.5: Net export-to-GDP ratio (left) and real GDP per worker relative to the US (right) in Korea: 1960-1995. The dashed lines correspond to the data and the solid lines correspond to the model. Real GDP per worker relative to the US in 1960 is normalized so that it has the same value in 1960 as in the data.

the secular increase in services as well as the secular decline in manufactures from 1960 to 1995; see Figure 2.6. Form 1960 to 1995, agriculture's share in US output declined by a few percentage points, but the model does not generate this decline and therefore captures about 75 percent of the rise in service's share in output. However, the model picks up the entire decline in manufacture's share in output.

Figure 2.7 presents results for changes in output compositions for the remaining countries: Canada, Europe, Latin America, and South-east Asia.

For Canada the model understates the increase in service's share and understates the decline in manufacture's share, but tracks agriculture's share closely.

For Europe, the model generates an increase in agriculture's share in output which is not observed in the data. The reason is because productivity in agriculture grows faster than productivity in its other sector, and also faster than in other coun-

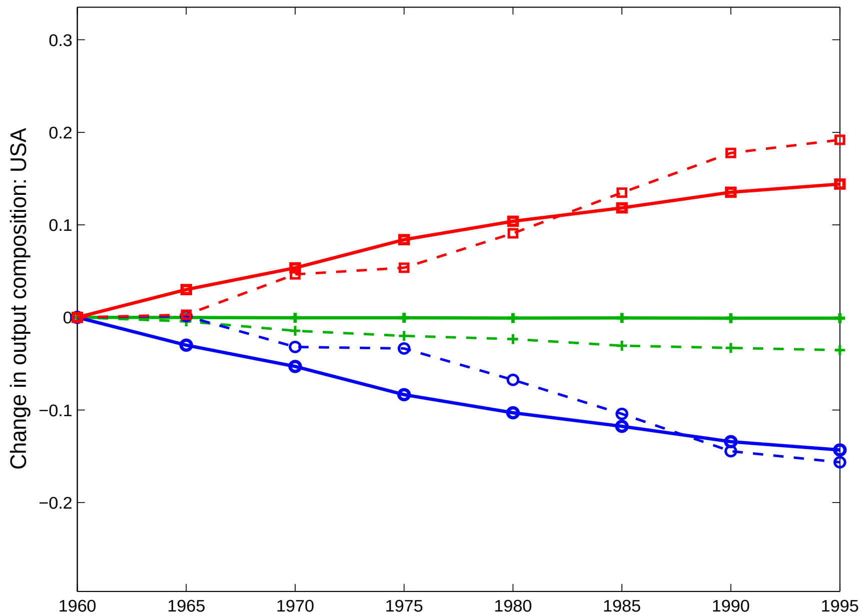

Figure 2.6: Composition of output (left) and exports (right) in the United States: 1960-1995. The green line with plus signs (+) represents agriculture, the blue line with circles represents manufactures, and the red line with squares represents services. The dashed lines correspond to the data and the solid lines correspond to the model.

tries. This shifts Europe's comparative advantage toward agriculture. At the same time, the model does produce an increase in service's share along with a decrease in manufacture's share.

For both Latin America and South-east Asia, the model delivers the secular decline in agriculture's share. In both countries, minimum consumption accounts for a sizable chunk of consumption levels. For these countries, productivity growth in agriculture is very low relative to manufactures. However, over time they increasingly export other goods and import agriculture which generates the decline in agriculture's share in output.

For the case of South-east Asia, the model tracks the increase in manufacture's share very closely. South-east Asia, like Korea, experiences its fastest productivity growth in manufactures. This shifts their comparative advantage towards manufactures generating the sharp increase in manufacture's share in the early part of the sample. However, the growth in manufactures productivity in South-east Asia is not as high as it is in Korea. Eventually, as the relative price of services rises, gross spending shifts towards services and manufactures exports from South-east Asia slow down generating an increase in service's share in output.

In sum, Canada, Europe and the US are very large and account for anywhere between 70 and 90 percent of output in the model depending on the year. Therefore, they display similar patterns as a closed-economy model would predict. In each of these countries, services productivity grows slower than productivity in the other sectors so service's share in output increases (Baumol effect). Meanwhile, minimum consumption requirements are quite trivial relative to actual consumption since they are relatively developed in 1960, so agriculture's share stays close to zero throughout time. On the other hand, emerging economies such as Korea and South-east Asia account for a small share in world output. Therefore, increases in manufactures output has little effect on domestic prices and the Baumol effect is negligible. However, manufacture's share in output increases due to increased specialization stemming from the fact that comparative advantage shifts towards manufactures. This is backed by the fact that manufactures share in exports increased, and that exports account for a substantial share of manufactures output.

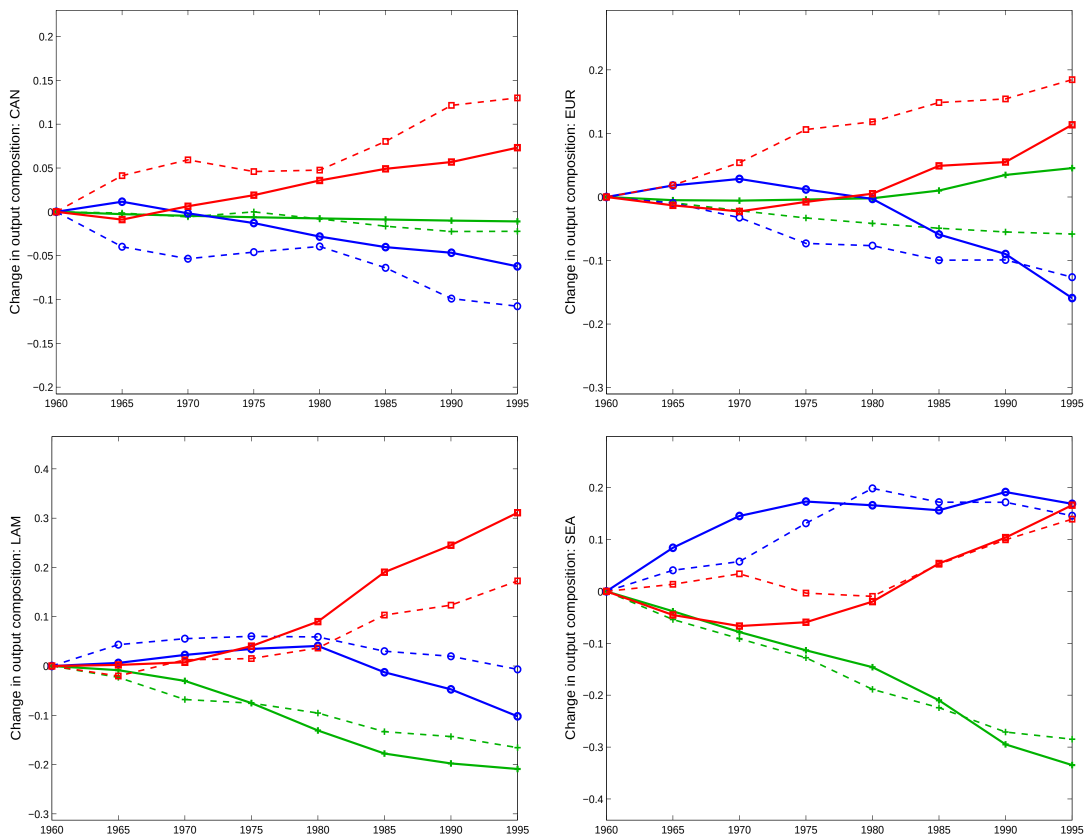

Figure 2.7: Composition of output (left) and exports (right) in the other countries: 1960-1995. The green line with plus signs (+) represents agriculture, the blue line with circles represents manufactures, and the red line with squares represents services. The dashed lines correspond to the data and the solid lines correspond to the model. The upper left panel in Canada, the upper right panel is Europe, the lower left panel is Latin America, and the lower right panel is South-east Asia.

2.6.4 Counterfactuals

In this section I run a series of counterfactual exercises to assess the quantitative importance of various mechanisms in generating the observed export and output compositions in Korea. For each counterfactual experiment I summarize the overall change, from 1960 to 1995, in each component of of Korea's export and output composition in Table 2.7.

Counterfactual 1: Autarky The purpose of this counterfactual exercise is to quantitatively evaluate the role that trade played in the evolution of the compositions in Korea. To execute this experiment I shut down trade in all sectors and all countries by setting the trade barriers sufficiently high. No trade flows across countries implies that there is also no borrowing/lending either. Other than the trade barriers, I feed in the same parameter values as in the baseline model, i.e., the same paths of productivity.

Figure 1 compares the counterfactual implications for structural change in Korea to the baseline results. What happens is that manufacture's share in output actually declines, and services share increases. The reason is that, in a closed economy, resources shift away from the sector with the fastest growing productivity. This also explains why service's share increases.

Counterfactual 2: No borrowing/lending In counterfactual 1, I imposed no trade by setting the trade barriers sufficiently high. That resulted in two outcomes. First, there was no trade. Second, was no borrowing/lending. To isolate these two separate channels I run a separate counterfactual where I remove access to international finance, but do allow trade. In this experiment countries are allowed to trade, but trade must be balanced at the aggregate level at each point in time. That is, if Korea runs a trade deficit in agriculture, then it must be offset by a combined surplus in manufactures and services. I feed in the same paths of productivity and the same trade barriers as in the baseline model.

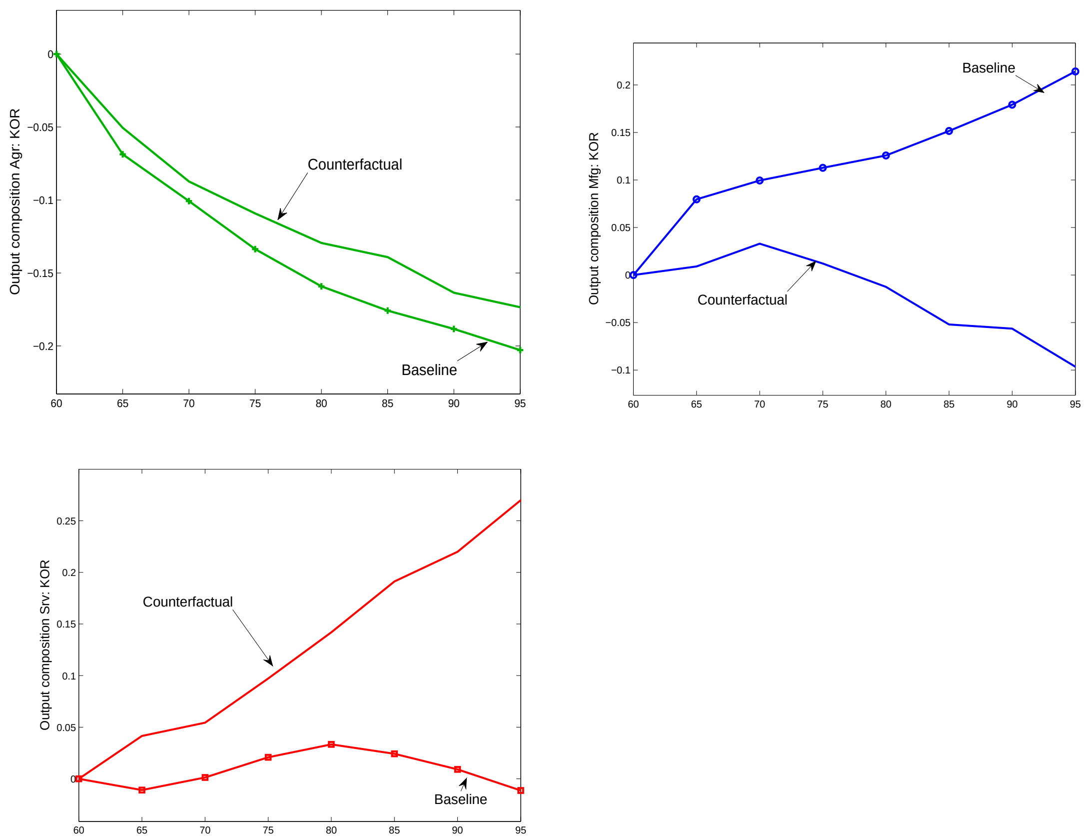

Figure 2.8: Counterfactual 1: Composition of output in Korea under autarky: 1960-1995. The solid line with markings corresponds to the baseline result while the solid line with no markings corresponds to the counterfactual result. The green lines in the upper left panel denote agriculture's share, the blue in the upper right panel denote manufacture's share, and the red lines in the bottom left panel denote service's share.

In the baseline model Korea ran an aggregate trade deficit in early years and repaid the deficit in later years when it was more productive relative to other countries. Since manufactures was the sector of increasing comparative advantage for Korea, without this channel, Korea ends up producing more manufactures in early years and less in later years than it otherwise would have. Therefore, eliminating access to international finance results in manufacture's share in output being flatter

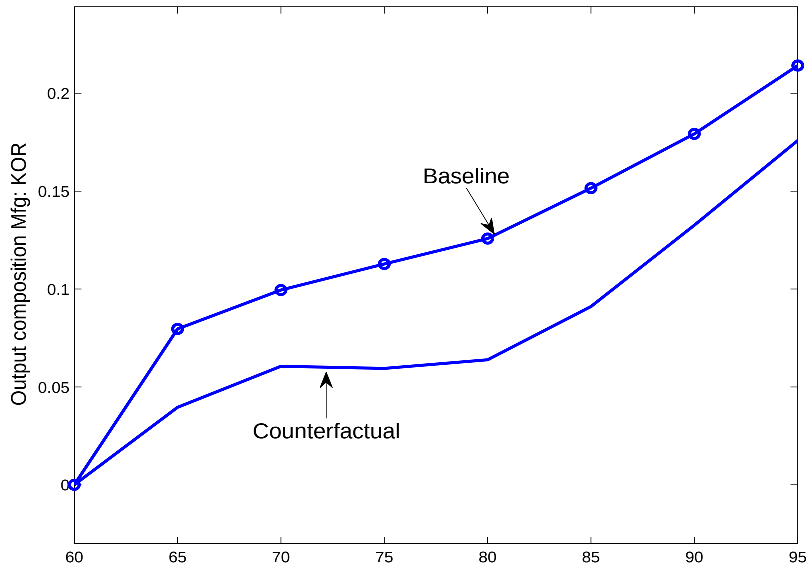

Figure 2.9: Counterfactual 2: Manufacture's share in the composition of output in Korea with no borrowing/lending: 1960-1995. The solid line with markings corresponds to the baseline result while the solid line with no markings corresponds to the counterfactual result.

than in otherwise would have been; see Figure 2.9.

Counterfactual 3: Close manufactures sector in Korea Given that comparative advantage in Korea shifted towards manufactures, it is important to address the role of trade in manufactures alone in generating the compositions of exports and output. To address this I shut down trade in the manufactures sector in Korea only by setting the barriers sufficiently high. However, I maintain the baseline values for barriers in the other sectors. That is, I use the following trade barrier matrix

$$\tau_m = \begin{bmatrix} 1 & \# & \infty & \# & \# & \# \\ \# & 1 & \infty & \# & \# & \# \\ \infty & \infty & 1 & \infty & \infty & \infty \\ \# & \# & \infty & 1 & \# & \# \\ \# & \# & \infty & \# & 1 & \# \\ \# & \# & \infty & \# & \# & 1 \end{bmatrix}$$

The symbol # means that the barrier takes on the baseline value. In the matrix τ_m, entry (i, j) denotes the barrier to ship goods from country j (column) to country i (row). The third row implies that the trade cost for Korea to import manufactures in infinite, while the third column implies that the cost for other countries to import manufactures from Korea is infinite.

I find that the composition of output looks almost identical to the case of complete autarky. The reason is that the main driver behind the composition of output in Korea is the shift in comparative advantage. Once trade in manufactures is shut down, there is no channel in which Korea can become increasingly specialized in manufactures. At the same time, since Korean productivity grows faster in manufactures relative to the other sectors, its share in aggregate output diminishes (Baumol effect). Figure 2.10 demonstrates that manufacture's share in exports is in fact flat since it accounts for 0 percent of exports. On the other hand, since agriculture productivity growth is higher than services productivity growth in Korea, agriculture's share in exports increases while services share declines.

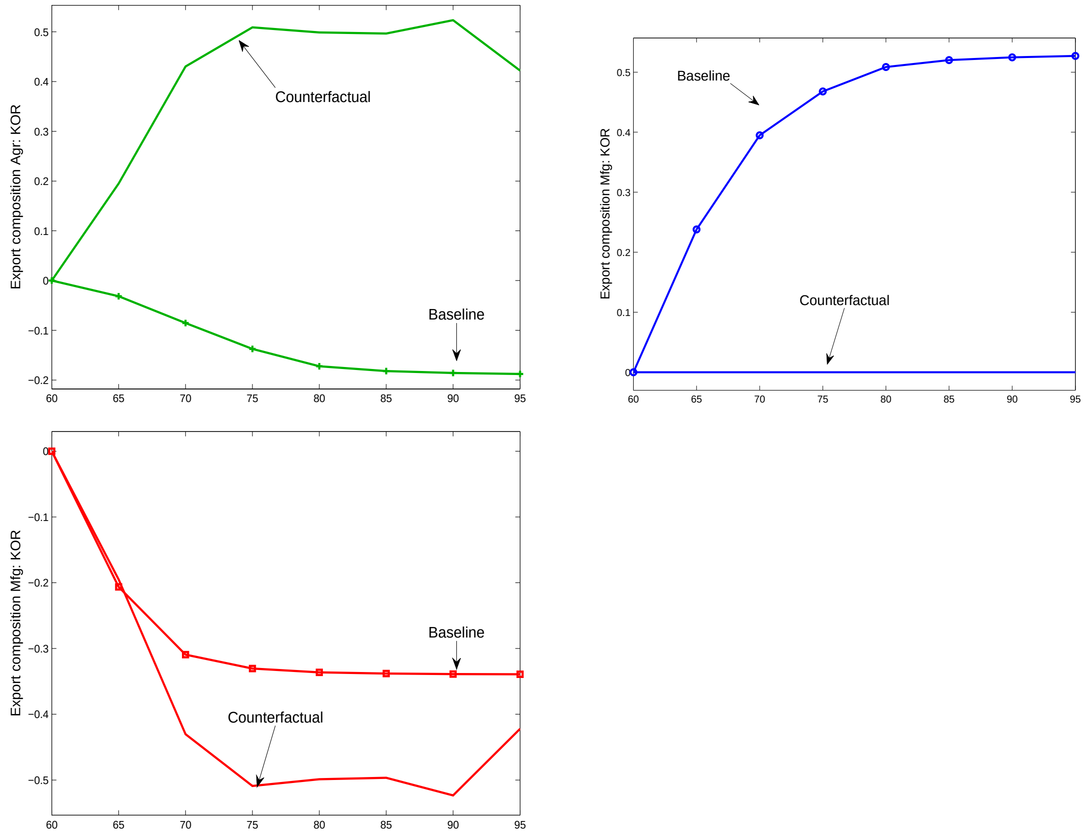

Figure 2.10: Counterfactual 3: Composition of exports in Korea when Korea's manufactures sector is closed: 1960-1995. The solid line with markings corresponds to the baseline result while the solid line with no markings corresponds to the counterfactual result. The green lines in the upper left panel denote agriculture's share, the blue in the upper right panel denote manufacture's share, and the red lines in the bottom left panel denote service's share.

Counterfactual 4: Free trade To emphasize the quantitative importance of changes in comparative advantage in explaining compositions, I remove trade costs and examine how compositions would have evolved. In particular I set $\tau_{bit} = 1$ for each sector, each country, and each point in time. Table 2.7 shows that manufacture's share in both Korean exports and Korean output would have increased even more. In fact, they increase to the point where they account for close to 100 percent of their respective composition. The reason is that, under free trade, Korea capitalizes on its comparative advantage in manufactures and becomes almost completely specialized.

Counterfactual 5: Eliminate GATT In the model I assumed that trade costs, in sector b in country i at time t, take the form $\tau_{bit} = trf_{bit} + d_b$, where trf_{bit} is the ad valorem tariff equivalent component measured from GATT. To assess the implications of tariff reductions implemented by GATT I examine what would have happened if tariffs had never been reduced. That is, for each sector b and each country i I set $trf_{bit} = trf_{bi1}$, its value in 1960, for all time periods.

I find that the compositions are quantitatively unaffected; see Table 2.7. The reason is that tariffs account for a very small portion of the overall trade cost. If I instead remove only Korea from GATT and keep all other countries in, the results are essentially identical.

2.7 Conclusion

I assess the quantitative importance of changes in comparative advantage in generating changes in the composition of exports and output that occurred in Korea during its growth miracle. I argue that changes in comparative advantage lead to changes in specialization, which quantitatively explains the changes in the composition of exports and changes in the composition of output. In small emerging economies, like Korea, the composition of output shifts towards the sector with the fastest growing productivity, a result of increasing comparative advantage. However, in large developed economies, like the US, the composition of output shifts toward

Table 2.7: Change in Korean compositions from 1960 to 1995.

	Baseline	CF1	CF2	CF3	CF4	CF5
Output composition						
Agriculture	-0.20	-0.17	-0.20	-0.17	-0.79	-0.19
Manufacturing	0.21	-0.13	0.18	-0.10	0.90	0.09
Services	-0.01	0.31	0.02	0.27	-0.10	0.10
Export composition						
Agriculture	-0.19	—	-0.24	-0.42	-0.79	-0.19
Manufacturing	0.53	—	-0.73	0.00	0.90	0.53
Services	-0.34	—	-0.49	0.42	-0.10	-0.34

Note: This table reports the percentage point change between the periods 1960 and 1995. For instance, manufacture's share in Korean output in the baseline model went from 0.39 in 1960 to 0.60 in 1995 so its change is 0.21. The counterfactual abbreviations are as follows: CF1 – Autarky, CF2 – No borrowing/lending, CF3 – Manufacturing closed in Korea, CF4 – Free trade, CF5 – No tariff reductions by GATT.

the sector with the slowest growing productivity since world prices are essentially driven by output of these countries, the same prediction as closed-economy models. Without trade, it is not possible to simultaneously explain the output compositions for both emerging and developed economies.

From 1960 to 2000, the increase in manufacture's share in exports and output was large. Using a Solow-type accounting procedure to measure productivity, I find three key features: 1) Korea experiences its largest productivity gains in manufactures, 2) productivity growth in manufactures is higher in Korea than in other countries and, 3) productivity in services grows relatively slower than in the other sectors. In order to map these paths of productivity into comparative advantage, I embed a dynamic, multi-country model of trade into a three-sector model of structural change where agriculture, manufactures, and services are complementary in both consumption and production.

I calibrate initial productivity levels to match key aspects of the data in 1960. I feed in the measured productivity changes from the data and find that changes in productivity, both across sectors and across countries, are able to quantitatively explain the output compositions for Korea as well as the following countries simultaneously: Canada, Europe, Korea, Latin America, South-east Asia, and the United States. The model also quantitatively generates changes in export compositions for Korea. Non-homothetic preferences are crucial in generating the decline in agriculture's share in both exports and output in all countries.

Through counterfactual exercises I argue that, not only is trade crucial for explaining Korea's structural change, but the composition of trade itself is important. That is, trade in manufactures is, quantitatively, the most important channel for Korea's structural change experience. Furthermore, I find that access to international finance allows Korea to transfer production from early years when productivity is relatively low to later years when productivity is relatively high, generating an additional increase in manufacture's share in output.

APPENDIX A
MATERIAL FOR CHAPTER 1

A.1 Derivations

In this section I show how to derive analytical expressions for price indices and trade shares. The following derivations rely on three properties of the exponential distribution.

1) $u \sim \exp(\mu)$ and $k > 0 \Rightarrow ku \sim \exp(\mu/k)$.

2) $u_1 \sim \exp(\mu_1)$ and $u_2 \sim \exp(\mu_2) \Rightarrow \min\{u_1, u_2\} \sim \exp(\mu_1 + \mu_2)$.

3) $u_1 \sim \exp(\mu_1)$ and $u_2 \sim \exp(\mu_2) \Rightarrow \Pr(u_1 \leq u_2) = \frac{\mu_1}{\mu_1+\mu_2}$.

Price indices Here I derive the price index for the composite intermediate good, P_{mi}. Cost minimization by producers of tradable good u implies a unit cost of an input bundle used in sector m, which is denoted by u_{mi}.

Perfect competition implies that the price in country i of the individual intermediate good z, when purchased from country j, equals unit cost in country j times the trade barrier

$$p_{mij}(z) = B_m u_{mj} \tau_{ij} z_j^{\theta},$$

where B_m is a collection of constant terms. The trade structure implies that country i purchases each intermediate good z from the least cost supplier, so the price of good z, in country i, is

$$p_{mi}(z)^{1/\theta} = (B_m)^{1/\theta} \min_j \left[(u_{mj}\tau_{ij})^{1/\theta} z_j \right].$$

Since $z_j \sim \exp(\lambda_j)$, it follows from property 1 that

$$(u_{mj}\tau_{ij})^{1/\theta} z_j \sim \exp\left((u_{mj}\tau_{ij})^{-1/\theta}\lambda_j\right).$$

Then, property 2 implies that

$$\min_j \left[(u_{mj}\tau_{ij})^{1/\theta} z_j\right] \sim \exp\left(\sum_j (u_{mj}\tau_{ij})^{-1/\theta}\lambda_j\right).$$

Lastly, appealing to property 1 again,

$$p_{mi}(z)^{1/\theta} \sim \exp\left(B_m^{-1/\theta}\sum_j (u_{mj}\tau_{ij})^{-1/\theta}\lambda_j\right). \tag{A.1}$$

Now let $\mu_{mi} = (B_m)^{-1/\theta}\sum_j (u_{mj}\tau_{ij})^{-1/\theta}\lambda_j$. Then

$$P_{mi}^{1-\eta} = \mu_{mi}\int t^{\theta(1-\eta)}\exp(-\mu_{mi}t)\,dt.$$

Apply a change of variables so that $\omega_i = \mu_{mi}t$ and obtain

$$P_{mi}^{1-\eta} = (\mu_{mi})^{\theta(\eta-1)}\int \omega_i^{\theta(1-\eta)}\exp(-\omega_i)d\omega_i.$$

Let $A = \Gamma(1+\theta(1-\eta))^{1/(1-\eta)}$, where $\Gamma(\cdot)$ is the Gamma function. Therefore,

$$\begin{aligned} P_{mi} &= A(\mu_{mi})^{-\theta} \\ &= AB_m\left[\sum_j (u_{mj}\tau_{ij})^{-1/\theta}\lambda_j\right]^{-\theta}. \end{aligned} \tag{A.2}$$

Trade shares Now I derive the trade shares π_{ij}, the fraction of i's total spending on tradable goods that is obtained from country j. Due to the law of large numbers, the fraction of goods that i obtains from j is also the probability, that for any good z, country j is the least cost supplier. Mathematically,

$$\begin{aligned} \pi_{ij} &= \Pr\left\{p_{mij}(z) \le \min_l [p_{mil}(z)]\right\} \\ &= \frac{(u_{mj}\tau_{ij})^{-1/\theta}\lambda_j}{\sum_l (u_{ml}\tau_{il})^{-1/\theta}\lambda_l}, \end{aligned} \tag{A.3}$$

where I have used equation (A.1) along with properties 2 and 3.

Using equations (A.2) and (A.3), the relationship between prices and home trade shares is given by

$$P_{mi} = AB_m u_{mi} \left(\frac{\lambda_i}{\pi_{ii}} \right)^{-\theta}.$$

A.2 Data

This section describes my data sources as well as how I map my model to the data.

Categories Tradables in my model correspond to manufactures. I identify tradables with categories 15**-37** according to the four-digit ISIC revision 3 classification (see http://unstats.un.org/unsd/cr/registry/regcst.asp?cl=2).

Prices and expenditures Prices are constructed using ICP data from the 2005 benchmark studies of the Penn World Tables. The ICP provides expenditures in current US dollars as well as in international dollars. The goods that I classify as tradable are: "Food and non-alcoholic beverages", "Alcoholic beverages and tobacco", "Clothing and footwear", "Furnishings, household equipment and household maintenance", and "Machinery and equipment". The goods which I classify as nontradable are: "Housing, water, electricity, gas and other fuels", "Health", "Transport", "Communication", "Recreation and culture", "Education", "Restaurants and hotels", and "Construction". The remaining categories are split equally between tradables and nontradables. To construct prices for tradables and nontradables, I divide total expenditures on all goods in the category in current US dollars, by total expenditures on all goods in the category in international dollars.

Human Capital I use data on years of schooling from Barro and Lee (2010) to construct human capital measures. I take average years of schooling for the population age 25 and up and convert into measures of human capital using $h = \exp(\phi(s))$, where ϕ is piecewise linear in average years of schooling s. This method is identical to the one used by Hall and Jones (1999) and Caselli (2005).

National Accounts Real income per worker is taken directly from PWT63 as the variable `rgdpwok`. The size of the workforce is constructed using PWT63 data as follows: number of workers equals 1000*`pop`*`rgdpl`/`rgdpwok`. In constructing aggregate stocks of capital, I follow the method employed by Caselli (2005). He used the perpetual inventory equation:

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

where I_t is aggregate investment in PPP and δ is the depreciation rate. I_t computed from PWT63 as `rgdpl`*`pop`*`ki`. The initial capital stock K_0 is computed as $I_0/(g + \delta)$, where I_0 is the value of the investment series in the first year it is available, and g is the average geometric growth rate for the investment series between the first year with available data and 1975 (for some countries the first year with available data is after 1975, In which case, the geometric growth rate for first 5 years with available data is calculated). Following the literature, δ is set to 0.06.

Production Data on manufacturing production is taken from INDSTAT4, a database maintained by UNIDO (2010) at the four-digit ISIC revision 3 level. I compute gross production as the sum of gross output over all manufacturing categories.

Trade barriers Trade barriers are assumed to be a function of distance, common language, and shared border; each of which are taken from Centre D'Etudes Prospectives Et D'Informations Internationales (http://www.cepii.fr/welcome.htm).

Trade Flows Data on bilateral trade flows are obtained from UN Comtrade for the year 2005 (http://comtrade.un.org/). All trade flow data is at the four-digit SITC revision 2 level, and then aggregated into total manufacturing trade flows. In order to link trade data to production data I employ the correspondence provided by Affendy, Sim Yee, and Satoru (2010) which links ISIC revision 3 to SITC revision 2 at the 4 digit level.

Construction of Trade Shares The empirical counterpart to the model variable π_{ij} is constructed following Bernard, Eaton, Jensen, and Kortum (2003) (recall that this is the fraction of country i's spending on intermediates that was purchased from country j). I divide the value of country i's imports of tradables from country j, by i's gross production of tradables minus i's total exports of tradables (for the whole world) plus i's total imports of tradables (for only the sample) to arrive at the bilateral trade share.

Table A.1: List of Countries

Country	**Isocode**
Albania	ALB
Argentina	ARG
Armenia	ARM
Australia	AUS
Austria	AUT
Azerbaijan	AZE
Belgium	BEL
Bolivia	BOL
Brazil	BRA
Bulgaria	BGR
Canada	CAN
Chile	CHL
China	CHN
China (Hong Kong SAR)	HKG
China (Macao SAR)	MAC
Colombia	COL
Cyprus	CYP

Table A.1 – Continued

Country	**Isocode**
Czech Republic	CZE
Denmark	DNK
Ecuador	ECU
Estonia	EST
Ethiopia	ETH
Fiji	FJI
Finland	FIN
France	FRA
Georgia	GEO
Germany	GER
Greece	GRC
Hungary	HUN
Iceland	ISL
India	IND
Indonesia	IDN
Iran	IRN
Ireland	IRL
Israel	ISR
Italy	ITA

Table A.1 – Continued

Country	**Isocode**
Japan	JPN
Jordan	JOR
Kazakhstan	KAZ
Kenya	KEN
Kyrgyzstan	KGZ
Latvia	LVA
Lithuania	LTU
Luxembourg	LUX
Madagascar	MDG
Malawi	MWI
Malaysia	MYS
Malta	MLT
Mauritius	MUS
Mexico	MEX
Mongolia	MNG
Morocco	MAR
Netherlands	NLD
New Zealand	NZL
Norway	NOR

Table A.1 – Continued

Country	**Isocode**
Oman	OMN
Panama	PAN
Paraguay	PRY
Peru	PER
Philippines	PHL
Poland	POL
Portugal	PRT
Republic of Korea	KOR
Republic of Moldova	MDA
Romania	ROM
Russia	RUS
Senegal	SEN
Singapore	SGP
Slovak Republic	SVK
Slovenia	SVN
South Africa	ZAF
Spain	ESP
Sweden	SWE
Thailand	THA

Table A.1 – Continued

Country	**Isocode**
Macedonia	MKD
Trinidad and Tobago	TTO
Turkey	TUR
Ukraine	UKR
United Kingdom	GBR
Tanzania	TZA
United States of America	USA
Uruguay	URY
Viet Nam	VNM
Yemen	YEM

APPENDIX B
MATERIAL FOR CHAPTER 2

B.1 A static, two-country, two-sector example

In this section I provide an analytical description of the key mechanisms underlying the dynamic multi-country model by studying a static, two-country, two-sector version. I adopt the framework of Dornbusch, Fischer, and Samuelson (1977), (henceforth DFS). There are two countries, 1 and 2. Country i ($i = 1, 2$) is endowed with a labor force of size L_i, which is not mobile across countries. Labor markets are competitive and labor is paid the value of its marginal product, which is denoted by w_i. There are two sectors, denoted by $b \in \{a, m\}$.

Production In each sector $b \in \{a, m\}$ there is a continuum of individual goods belonging to the unit interval indexed by $x_b \in [0, 1]$. The technology available to country i for producing good x is described by

$$y_{bi}(x) = z_{bi}(x)^{-\theta} \ell_{bi}(x),$$

where the term $\ell_{bi}(x)$ is the amount of labor used to produce good x_b and $z_{bi}(x_b)^{-\theta}$ is country i's productivity of producing good x_b. $z_i(x)$ can be interpreted as the cost of making good x. For each good x_b, $z_{bi}(x_b)$ is an independent random draw from an exponential distribution with parameter λ_{bi}. I assume that $z_{bi}(x_b)^{-\theta}$, country i's productivity for producing good x_b, has a Fréchet distribution. Since the index of the good is irrelevant, I identify goods by their vector of *cost* draws $z_b = (z_{b1}, z_{b2})$.[1] So I express y as a function of z.

$$y_{bi}(z_b) = z_{bi}^{-\theta} \ell_{bi}(z).$$

In each sector, all individual goods are used to produce a composite good. The technology for producing the sector-specific composite good is given by

$$C_{bi} = \left[\int c_{bi}(z_b)^{\frac{\eta-1}{\eta}} \varphi_b(z_b) dz_b \right]^{\frac{\eta}{\eta-1}}, \tag{B.1}$$

where η is the elasticity of substitution between any two tradable goods, and $c_{bi}(z_b)$ is the quantity of good z_b, used by country i. $\varphi_b(z_b) = \prod_j \varphi_{bj}(z_b)$ is the joint density of cost draws.

Consumption Each country admits a representative household. The household values consumption of the composite goods according to

$$C = \left(C_a^{1-1/\varepsilon} + C_m^{1-1/\varepsilon} \right)^{\frac{\varepsilon}{\varepsilon-1}},$$

where $\varepsilon > 0$ is the elasticity of substation between the two composite goods.

Let P_{ai} and P_{mi} denote the price indexes for the composite goods in each country. Then the household must satisfy

$$P_{ai} C_{ai} + P_{mi} C_{mi} = w_i L_i.$$

[1] I have adopted the notation of Alvarez and Lucas (2007). In DFS, $z_{bi}(x_b)^{-\theta}$ is labeled as $1/a_{bi}(x_b)$, the unit labor requirement. In DFS, goods are ordered in terms of declining comparative advantage for country 1, i.e., according to $A_b(x_b) = a_{b2}(x_b)/a_{b1}(x_b)$. Here I use a probabilistic representation and ignore the ordering of goods along the interval. The implication is that in the context of DFS, under our representation, $A_b(x_b) = \left(\frac{1-x_b}{x_b}\right)^{\theta} \left(\frac{\lambda_{b1}}{\lambda_{b2}}\right)^{\theta}$. This is a result of Eaton and Kortum (2002).

Consumption expenditures across the two goods are allocated according to

$$P_{bi}C_{bi} = \left(\frac{P_{bi}}{P_{ci}}\right)^{1-\varepsilon} w_i L_i,$$

where $P_c = (P_a^{1-\varepsilon} + P_m^{1-\varepsilon})^{\frac{1}{1-\varepsilon}}$ is the aggregate price index for consumption, i.e., $P_{ci}C_i = P_{ai}C_{ai} + P_{mi}C_{mi}$.

The marginal cost of producing one unit of good z_b in country i is $\frac{w_i}{z_{bi}(x_b)^{-\theta}}$. Let τ_{bij} be the trade cost for sending a unit of good from country j to country i. For example, τ_{b12} is the number of sector b units that country 2 must ship in order for one unit to arrive in country 1. I assume that there is no shipping cost for selling goods domestically; $\tau_{bii} = 1$. So the marginal cost of country j to supply one unit to country i is $\frac{w_j \tau_{bij}}{z_{bj}(z_b)^{-\theta}}$. Prices are denoted as follows: $p_{bij}(z_b)$ is the price, in country i, of good z_b of sector b, when the good was produced in country j.

To summarize, exogenous differences across countries are described by the productivity terms λ_{bi}, the endowments L_i, and the trade barriers τ_{bi}. The parameter θ is common to both countries and both sectors and determines the variation in productivity across all of the goods along each continuum.

International trade Each country purchases each individual good from the country that can deliver it at the lowest price. Hence, the price in country i of any good z_b is simply $p_{bi}(z_b) = \min[p_{bi1}(z_b), p_{bi2}(z_b)]$. Given that productivity draws have a Fréchet distribution, Eaton and Kortum (2002) show that the fraction of country i's spending on sector b that will be allocated to goods produced in country

j is given by

$$\pi_{bij} = \frac{w_j^{-1/\theta} \tau_{bij}^{-1/\theta} \lambda_{bj}}{w_i^{-1/\theta} \lambda_{bi} + w_j^{-1/\theta} \tau_{bij}^{-1/\theta} \lambda_{bj}}. \tag{B.2}$$

Equilibrium Equilibrium is characterized by a trade balance condition: $\sum_b P_{b1} C_{b1} \pi_{b12} = \sum_b P_{b2} C_{b2} \pi_{b21}$; that is, country 1's aggregate imports must equal country 1's aggregate exports. Each sector may produce a surplus or deficit, so long as the surplus in one sector is offset by an identical deficit in the other sector.

Prices I denote the sector b composite good price index in country i by P_{bi}. Since the composite good described by equation (B.1) uses a CES aggregator, the price index is given by

$$P_{bi} = \left[\int p_{bi}(z_b)^{1-\eta} \varphi_b(z_b) dz_b \right]^{\frac{1}{1-\eta}}.$$

Given that productivities are drawn from a Fréchet distribution, the price index relative to the wage in each country can be written as follows:

$$\frac{P_{b1}}{w_1} = \left[\lambda_{b1} + \left(\frac{w_2}{w_1} \right)^{-1/\theta} \tau_{b12}^{-1/\theta} \lambda_{b2} \right]^{-\theta} \tag{B.3}$$

$$\frac{P_{b2}}{w_2} = \left[\left(\frac{w_1}{w_2} \right)^{-1/\theta} \tau_{b21}^{-1/\theta} \lambda_{b1} + \lambda_{b2} \right]^{-\theta} \tag{B.4}$$

Comparative statics Here I work out the implications for output and export compositions in country 1 in response to an increase in productivity in sector m in country 1. That is, suppose λ_{m1} increases to λ'_{m1}, and all other exogenous variables are held constant. This exercise can be interpreted as a change from time

t to time $t+1$ since the trade balance condition makes the problem a sequence of static problems anyway.

Equilibrium wages Once I know how wages adjust in equilibrium, then I can recover how other variables will respond. Through some manipulation the trade balance condition can be stated as

$$\frac{w_1}{w_2} = \left(\frac{L_2}{L_1}\right) \frac{\left(\frac{P_{a2}}{P_{c2}}\right)^{1-\varepsilon} \pi_{a21} + \left(\frac{P_{m2}}{P_{c2}}\right)^{1-\varepsilon} \pi_{m21}}{\left(\frac{P_{a1}}{P_{c1}}\right)^{1-\varepsilon} \pi_{a12} + \left(\frac{P_{m1}}{P_{c1}}\right)^{1-\varepsilon} \pi_{m12}}. \tag{B.5}$$

Equilibrium is solved by finding a relative wage rate w_1/w_2 that solves (B.5). As $w_1/w_2 \to 0$ the left-hand side goes to zero and the right-hand side goes to ∞. As $w_1/w_2 \to \infty$ the left-hand side goes to ∞ and the right-hand side goes to L_2/L_1. Since both sides are monotone and continuous there exists a unique equilibrium relative wage rate. If λ_{m1} increases, then the right-hand side of (B.5) shifts up for every value of w_1/w_2. Therefore, the equilibrating relative wage rate must increase; $w_1'/w_2' > w_1/w_2$.

Expenditure shares It is clear to see from equations (B.3) and (B.4) that P_{mi}/P_{ai} decreases in both countries, and, hence, P_{ai}/P_{ci} increases while P_{mi}/P_{ci} decreases. Assume that the two goods are gross complements so that $\varepsilon < 1$. Then expenditures on m would fall relative to expenditures on a. In a closed economy, sectoral output equals sectoral expenditures, which would imply that sector m's share in aggregate output would decrease in country 1. However, in an open economy the link between sectoral expenditures and sectoral output is broken. Next I will show that an increase in λ_{m1} can actually generate a rise in sector m's share in output through trade.

Export shares Consider the ratio of sector m exports to sector a exports in country 1. This ratio is given by

$$\frac{EXP_{m1}}{EXP_{a1}} = \left(\frac{P_{m2}C_{m2}}{P_{a2}C_{a2}}\right)\left(\frac{\pi_{m21}}{\pi_{a21}}\right).$$

I have already argued that the first component decreases when λ_{m1} increases. Inspection of equation B.2 implies that π_{m21} increases while π_{a21} decreases. The intuition is that as country 1 becomes relatively more efficient at producing sector m goods, country 2 will allocate a larger share of its sector m spending towards goods produced by country 1. Therefore the second component increases. Typically, as long as τ_m is not *too* large, the increase in the second term outweighs the decrease in the first term leading to an increase in sector m's share in aggregate exports. The intuition is that as country 1 becomes relatively more efficient in sector m, country 1's comparative advantage moves towards sector m. Country 1 will then become more specialized in sector m and country 2 will purchase a lager share of its sector m goods from country 1.

Output shares Output in country 1 is comprised of domestic sales plus exports. When λ_{m1} increases I argued that expenditures in country 1 shift away from sector m and into sector a, therefore domestic sales does the same. However, I also showed that exports may shift away from sector a and into sector m. Depending on the relative magnitude of these opposing forces it is possible that output shifts away from sector a and into sector m.

What happens with dynamics? In the quantitative model I allow for borrowing and lending in order to finance aggregate trade deficits and surpluses. That is, in each period I relax the aggregate trade balance condition. What this does is the following. Suppose there are two time periods and $\lambda_{m1,t+1} > \lambda_{m1,t}$, with all other exogenous variables held constant over time. Country 1 will borrow and run an aggregate trade deficit in period t and pay back in period $t+1$ by running an aggregate surplus. Hence, at time t, the demand for labor in country 1 will be smaller than it otherwise would have been and higher in period $t+1$ than it otherwise would have been. Thereby magnifying the increase in the relative wage, w_1/w_2, over time, and therefore leading to a larger increase over time in sector m's share in both exports and output.

Non-homothetic preferences One more mechanism that is important for structural change is a non-homotheiticty in consumption of good a. In particular, consider

$$C = \left((C_a - L\bar{a})^{1-1/\varepsilon} + C_m^{1-1/\varepsilon}\right)^{\frac{\varepsilon}{\varepsilon-1}},$$

where $\bar{a} > 0$ is the minimum required level of consumption of good a. Then, all else equal, as income grows the fraction of total expenditures allocated toward good a declines. This affects the composition of output through both domestic expenditure shares as well as foreign expenditure shares.

B.2 Data

Korean input-output tables Input-output tables for Korea are published officially by the Bank of Korea and are available at http://www.bok.or.kr/. They are published in benchmark years, which occur approximately every 5 years or so. I make use of the following years: 1960, 1963, 1970, 1975, 1980, 1985, 1990, 1995, and 2000. I impute values for missing years using piecewise cubic Hermite interpolation.

US input-output tables Input-output tables for the United States are published by Bureau of Economic Analysis and are available at http://bea.gov/. They are published in benchmark years, which occur approximately every 5 years or so. I make use of the following years: 1958, 1963, 1967, 1972, 1977, 1982, 1987, 1992, 1997, and 2002. I impute values for missing years using piecewise cubic Hermite interpolation.

EU Klems The data are published by EU Klems and are available at http://www.euklems.net/. The data is an annual series starting from 1970. Specifically, I make use of tables for Canada as well as the country grouping called EU-15. Specifically, I use the variables `GO` and `VA` in order to compute both the value added composition over time, as well as the share of value added in gross output for the three main sectors. As for the value added composition, this data only goes back to 1970. I impute the composition for 1960 using visual inspection and then interpolate from 1960-1970.

From the same source I take data on purchase price of intermediates for Korea and the United States. This variable is called `II_P`. These prices are available at a more disaggregate level than the three main sectors so I construct expenditure-weighted prices for each sector by using data on intermediate inputs, the variable called `II`. I use these as purchase prices when estimating elasticities and weights in aggregate investment and the three types of aggregate intermediates. I restrict use of this data to 1970-2000..

GGDC Timmer and de Vries (2009) provide data on value added in both current and constant dollars, as well as labor allocations across 10 sectors of the economy which can be downloaded at http://www.ggdc.net/databases/10_sector.htm. This covers the countries KOR, LAM, SEA, and USA. Data for CAN and EUR comes from a different source. For LAM and SEA I convert value added into common units by using the relevant exchange rate and then aggregate across countries within each group.

Penn World Tables version 6.3 Data on capital stocks, labor endowments, investment rates, exchange rates, and GDP per worker are all taken from http://pwt.econ.upenn.edu/php_site/pwt63/pwt63_form.php.

B.3 Solving for the competitive equilibrium

This section describes an algorithm for computing the competitive equilibrium along the transition. There are essentially 5 steps. I first summarize the steps and then go into detail about how each step is executed.

Step 1: Guess at a $I \times T$ matrix of wages.

Step 2: Given wages, compute the sequences of rental rates, capital stocks, prices, trade shares and investment for each country.

Step 3: Given the sequence of prices, income, and investment spending, compute consumption and borrowing at each point in time.

Step 4: Now that trade shares are know and final demand is known (consumption and investment), compute trade deficits.

Step 5: Compare trade deficits with borrowing. If they are not equal in all countries at all points in time, update wages and return to step two. Continue until deficits equal borrowing.

Step 1: Start with a matrix of wages in the space $\Delta = \{w \in \mathbb{R}^{IT}_{++} : \sum_i \sum_t w_{it} = 1\}$.

Step 2: The stock of capital at time $t = 1$ is given exogenously. Optimization by firms in each sector $b \in \{a, m, s\}$ implies that $r_{i1} K_{bi1} = \alpha/(1-\alpha) w_{i1} L_{bi1}$. Since factors are mobile across sectors this implies that $r_{i1} = \alpha/(1-\alpha) w_{i1} L_{i1}/K_{i1}$. Now the rental rate of capital is known. Next solve for all remaining prices at $t = 1$. To do this note that the prices of the composite goods are each functions of the rental rate, the wage, and the prices of the composite goods themselves: $P_{ai1} = f_{ai}(r_1, w_1, P_{a1}, P_{m1}, P_{s1}), P_{mi1} = f_{mi}(r_1, w_1, P_{a1}, P_{m1}, P_{s1})$, and $P_{si1} =$

$f_{si}(r_1, w_1, P_{a1}, P_{m1}, P_{s1})$. This leaves $3I$ equations with $3I$ unknowns which can be found using iterations. Once these are solved for, prices of consumption, P_c, and investment, P_x, can be recovered trivially. Moreover, trade shares are explicit functions of wages, rental rates and prices as well so they too can be recovered.

Income, which is $w_{i1}L_{i1} + r_{i1}K_{i1}$, is known at this point. Given the exogenous investment rate, investment can be solved for: $X_{i1} = \rho_{i1}(w_{i1}L_{i1} + r_{i1}K_{i1})/P_{xi1}$. Using the technology for accumulating capital, the stock of capital at $t = 2$ is $K_{i2} = (1 - \delta)K_{i1} + X_{i1}$. Simply repeat this at each point in time and generate the sequences of rental rates, capital stocks, prices, trade shares and investment for each country.

Step 3: Lifetime income is known, as well as lifetime investment spending. Asset purchases are given by equation (2.10).

Step 4: This step is the most involved. It amounts to solving for both gross spending across sectors, as well as gross output. My approach is to write these objects in terms of labor allocations, then solve for the labor allocations as a function of wages. The following is done for each point in time separately.

The flows of funds conditions are described by equations (2.15a)–(2.15c). Combining these with the demand for factors of production by firms, equations (2.13a)–(2.13e), along with the within-country resource constraints (2.14c)–(2.14e)

I obtain the following:

$$w_{it}L_{ait} = (1-\alpha)\nu_a \sum_{j=1}^{I} P_{ajt}(A_{ajt} + A_{mjt} + A_{sjt} + C_{ajt} + X_{ajt})\pi_{ajit},$$

$$w_{it}L_{mit} = (1-\alpha)\nu_m \sum_{j=1}^{I} P_{mjt}(M_{ajt} + M_{mjt} + M_{sjt} + C_{mjt} + X_{mjt})\pi_{mjit},$$

$$w_{it}L_{sit} = (1-\alpha)\nu_s \sum_{j=1}^{I} P_{sjt}(S_{ajt} + S_{mjt} + S_{sjt} + C_{sjt} + X_{sjt})\pi_{sjit}.$$

First solve for aggregate discretionary consumption spending at each date by using equation (2.9). Next, split aggregate discretionary consumption and investment spending across the three sectors according to equations (2.11a) – (2.12c). Then derive the demands for the three types of goods for use as intermediates, and express them in terms of labor. For example, spending on manufactures by the agriculture sector in country i at time t is $P_{mit}M_{ait}$. Using equations (2.13c) and (2.13b) it can be written in terms of labor used by the agricultural sector as $P_{mit}M_{ait} = \frac{1-\nu_a}{(1-\alpha)\nu_a}\mu_a^{\varepsilon_a}\left(P_{mit}/\tilde{P}_{ait}\right)^{1-\varepsilon_a} w_{it}L_{ait}$, where $\tilde{P}_{ait}$ is the price of a composite bundle of intermediates for the agricultural sector in accordance with the technology specified in equation (2.4a). I use this type of relationship for all goods in order to state the world goods market clearing conditions for each good in terms of labor. This generates a system of equations where labor is the only unknown (recall that we already know prices at this point). There are $3I$ equations with $3I$ labor allocations, with the aggregate labor endowments L_{it} given exogenously.

For any sectors $b \in \{a, m, s, c, x\}$ define the matrices $\Upsilon_{abt}, \Upsilon_{mbt}$, and Υ_{sbt}

component-wise as follows:

$$\Upsilon_{abijt} = (1-\mu_b-\sigma_b)^{\varepsilon_b}\left(\frac{P_{bit}}{\tilde{P}_{ait}}\right)\frac{w_{it}}{w_{jt}}\pi_{aijt},$$
$$\Upsilon_{mbijt} = \mu_b^{\varepsilon_b}\left(\frac{P_{bit}}{\tilde{P}_{mit}}\right)\frac{w_{it}}{w_{jt}}\pi_{mijt},$$
$$\Upsilon_{sbijt} = \sigma_b^{\varepsilon_b}\left(\frac{P_{bit}}{\tilde{P}_{sit}}\right)\frac{w_{it}}{w_{jt}}\pi_{sijt}.$$

Each of the 15 matrices has dimension $I \times I$. This allows me to write the previous system as

$$\begin{aligned}
L_{at} &= (1-\nu_a)\Upsilon_{aat}^{\top}L_{at} + \frac{\nu_a(1-\nu_m)}{\nu_m}\Upsilon_{amt}^{\top}L_{mt} + \frac{\nu_a(1-\nu_s)}{\nu_s}\Upsilon_{ast}^{\top}L_{st} \\
&\quad + (1-\alpha)\nu_a\Upsilon_{act}^{\top}\left((P_{ct}\odot C_t + P_{at}\odot L_t\bar{a})\oslash w_t\right) + (1-\alpha)\nu_a\Upsilon_{axt}^{\top}(P_{xt}\odot X_t\oslash w_t), \\
L_{mt} &= \frac{\nu_m(1-\nu_a)}{\nu_a}\Upsilon_{mat}^{\top}L_{at} + (1-\nu_m)\Upsilon_{mmt}^{\top}L_{mt} + \frac{\nu_m(1-\nu_s)}{\nu_s}\Upsilon_{mst}^{\top}L_{st} \\
&\quad + (1-\alpha)\nu_m\Upsilon_{mct}^{\top}(P_{ct}\odot C_t\oslash w_t) + (1-\alpha)\nu_m\Upsilon_{mx}^{\top}(P_x\odot X_t\oslash w_t), \\
L_{st} &= \frac{\nu_s(1-\nu_a)}{\nu_a}\Upsilon_{sat}^{\top}L_{at} + \frac{\nu_s(1-\nu_m)}{\nu_m}\Upsilon_{smt}^{\top}L_{mt} + (1-\nu_s)\Upsilon_{sst}^{\top}L_{st} \\
&\quad + (1-\alpha)\nu_s\Upsilon_{sct}^{\top}(P_{ct}\odot C_t\oslash w_t) + (1-\alpha)\nu_s\Upsilon_{sxt}^{\top}(P_{xt}\odot X_t\oslash w_t),
\end{aligned}$$

where $\odot$ is component-wise multiplication, $\oslash$ is component-wise division, and superscript $^{\top}$ is the transpose operator. More compactly, the solution can be stated as solving the following linear system for Λ_t,

$$(1-\Psi_t)\Lambda_t = V_t,$$

where

$$\Psi_t = \begin{bmatrix} (1-\nu_a)\Upsilon_{aat}^\top, & \frac{\nu_a(1-\nu_m)}{\nu_m}\Upsilon_{amt}^\top, & \frac{\nu_a(1-\nu_s)}{\nu_s}\Upsilon_{ast}^\top \\ \frac{\nu_m(1-\nu_a)}{\nu_a}\Upsilon_{mat}^\top, & (1-\nu_m)\Upsilon_{mmt}^\top, & \frac{\nu_m(1-\nu_s)}{\nu_s}\Upsilon_{mst}^\top, \\ \frac{\nu_s(1-\nu_a)}{\nu_a}\Upsilon_{sat}^\top, & \frac{\nu_s(1-\nu_m)}{\nu_m}\Upsilon_{smt}^\top, & (1-\nu_s)\Upsilon_{sst}^\top \end{bmatrix},$$

$$V_t = \begin{bmatrix} (1-\alpha)\nu_a\Upsilon_{act}^\top\left((P_{ct}\odot C_t P_{at}\odot L_t\bar{a})\oslash w_t\right) + \\ \qquad +(1-\alpha)\nu_a\Upsilon_{axt}^\top(P_{xt}\odot X_t\oslash w_t) \\ (1-\alpha)\nu_m\Upsilon_{mct}^\top(P_{ct}\odot C_t\oslash w_t) + (1-\alpha)\nu_m\Upsilon_{mxt}^\top(P_{xt}\odot X_t\oslash w_t) \\ (1-\alpha)\nu_s\Upsilon_{sct}^\top(P_{ct}\odot C_t\oslash w_t) + (1-\alpha)\nu_s\Upsilon_{sxt}^\top(P_{xt}\odot X_t\oslash w_t) \end{bmatrix},$$

$$\Lambda_t = \begin{bmatrix} L_{at} \\ L_{mt} \\ L_{st} \end{bmatrix}.$$

Solve this system at each point in time and then proceed to the next step.

Step 5: Once labor allocations are known from the last step, reverse engineer to write the demand for intermediates in place of demand for labor. Now trade deficits can be computed for each country since we know trade shares and quantities. In particular, the deficit in sector b is gross spending less gross output, i.e., the trade deficit in agriculture in country i at time t is $F_{ait} = P_{ait}A_{it} - Y_{ait}$. Let $F_{it} = F_{ait} + F_{mit} + F_{sit}$ be the aggregate trade deficit in country i at time t. Country-specific resource constraints require that the trade deficit be equal to borrowing, i.e., that $F_{it} = -B_{it}$, at all time periods t. For an arbitrary vector of wages this need not hold so I update the wage using an excess demand system similar to that of Alvarez and Lucas (2007).

Define excess demand in country i at time t by $Z_{it}(w) = (-B_{it} - F_{it})/w_{it}$. Consider the updating rule for wages $(T_{it})(w) = w_{it}(1+Z_{it}(w)/N)$, where N is some bound used to ensure that $T > 0$. Then, since $\sum_t B_{it} = 0$ from the household budget constraint, and $\sum_i F_{it} = 0$ from the flows of funds conditions, it follows that $\sum_i \sum_t w_{it} Z_{it}(w) = 0$ (Walras' Law). Now let $\Delta = \{w \in \mathbb{R}^{IT}_{++} : \sum_i \sum_t w_{it} = 1\}$. Then Walras' Law implies that $T : \Delta \to \Delta$. If Tw and w are sufficiently close then stop, otherwise, return to step one and set $w = Tw$.

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