Evolving Comparative Advantage, Structural Change, and the Composition of Trade

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Abstract

In this paper 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 period. From 1960 to 1995 manufacture's share in both exports and output increased, with the increase in manufacture's share in exports almost twice as large as the increase in manufacture's share in output. 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 Solow-type 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, as well as the decline in agriculture's share in output. The changes in the compositions across sectors within Korea are are result of a reallocation of production across countries within each sector. To this end, the model also tracks the composition of output for multiple countries.

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1 Introduction

In this paper 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. Moreover, the increase in manufacture's share in exports was almost twice as large as the increase in manufacture's share in output.

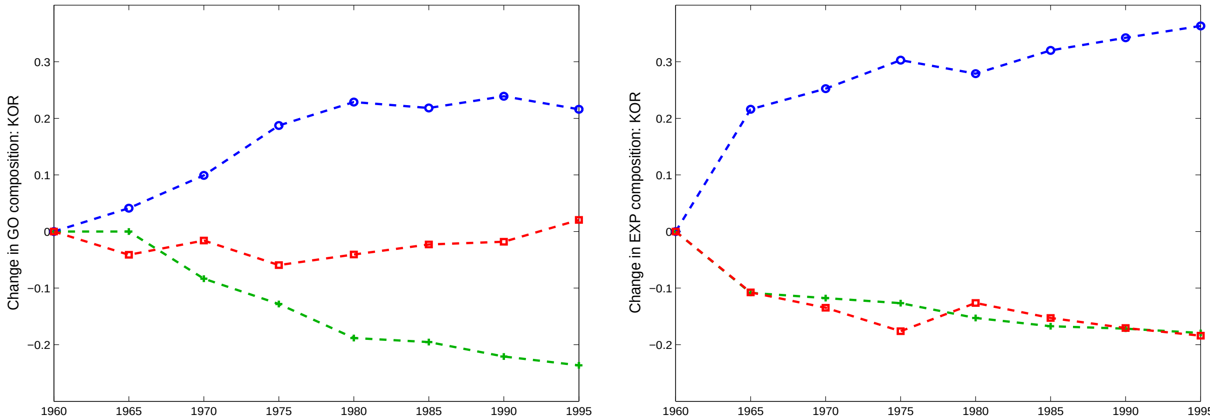
From 1960 to 1995 Korea experienced what is referred to as structural change. In early stages of development, the agricultural sector constitutes a substantial fraction of production. As the process of development begins, the manufactures sector starts growing. Eventually, the manufactures sector tapers off and services account for an increasing share of economic activity. The left panel of figure 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 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.

In this paper 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? 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. I discipline the parameters of the model to match key aspects of Korean production and trade data in 1960, as well as production data for other countries in 1960.

My model includes several unique features. First, I explicitly incorporate dynamics by

Figure 1: Composition of gross output (left) and exports (right) in Korea: 1960-1995



Note: The green line with plus signs (+) represents agriculture, blue circles represent manufactures, and red squares represent services.

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 manufactured 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 measure productivity changes over time, for each sector, using a Solow growth accounting technique, and feed the paths of productivity into the model. I find that 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 three 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 puts quantitative discipline on 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.

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 was trade important for Korea's structural change, but the composition of trade is what matters. I also find that borrowing and lending, 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 much smaller change in manufacture's share in exports 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 paper 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 paper is the first to simultaneously address changes in export compositions and structural change in a quantitative framework. 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:

$$\underbrace{\frac{EXP_{bt}}{\sum_b EXP_{bt}}}_{b\text{'s share in exports}} = \underbrace{\left(\frac{\Phi_{bt}}{\Psi_t}\right)}_{\textit{trade component}} \times \underbrace{\left(\frac{GO_{bt}}{\sum_b GO_{bt}}\right)}_{b\text{'s share in output}} . \tag{1}$$

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 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 displays the time series for Ψ_t. Feeding the sequence $\{\Psi_t\}$ and the composition of output into equation (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 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.

The paper is organized as follows: section 2 develops a simple two-country, two-good framework to provide an understanding of the essential ingredients of the quantitative model that follows; sections 3 and 4 describe the model and equilibrium; section 5 discusses the calibration and fit of the model; section 6 discusses the results and counterfactual implications, and section 7 concludes.

[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: Fraction of aggregate output exported in Korea: 1960-1995

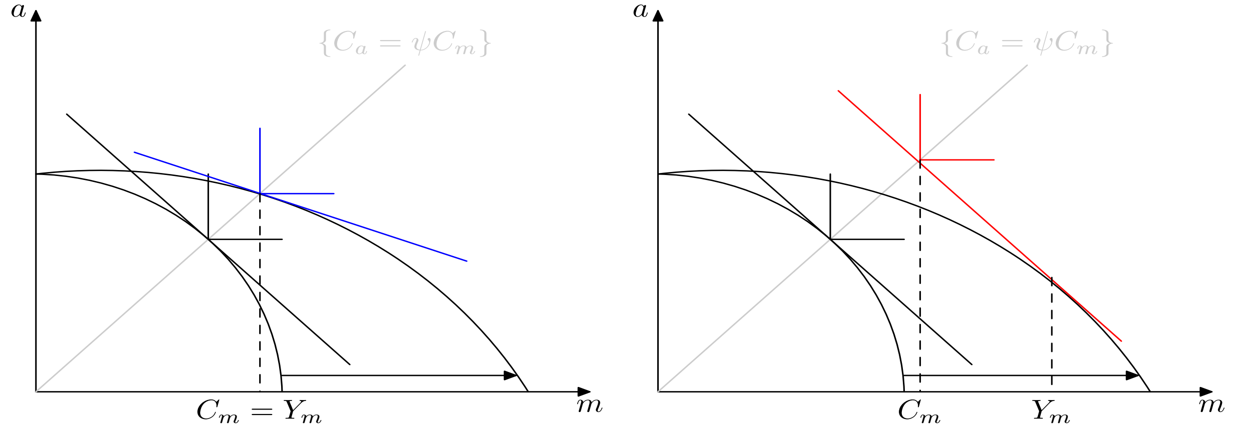
2 A two-good example

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 in two cases: a closed economy, and a small-open economy. Denote the two goods by a and b. There is a household who values consumption of the two goods which 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 PPF shifts to the right, see the left panel of figure 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.

Small-open economy Now consider a small-open economy. Suppose that world prices are 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 prices now remains unchanged, see the right panel of figure 3. Consumption will then take place at

Figure 3: Response to an increase in productivity for good m: Closed economy (left) and small-open economy (right)



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 proportion than the increase in production of good m. Since the relative price in 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]

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 in this paper, they are complements which is all that matters for the intuition to follow through. Finally, 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, within a country, is really a problem of the reallocation of production across countries, within each sector.

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

3 Multi-country dynamic model

I embed a three-sector, multi-country model of Ricardian trade, in the spirit of Eaton and Kortum (2002), into an exogenous growth framework. There are I countries indexed by $i = 1, \dots, I$. Time is discrete and runs from $t = 1, 2, \dots, T$. 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 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 household supplies the factors of production to firms and spends factor income on consumption and investment. Households have access to borrowing and lending by trading assets on an international market.

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 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

$$A = \left[\int q_a(x_a)^{1-1/\eta} dx_a \right]^{\eta/(\eta-1)}, \tag{2a}$$

$$M = \left[\int q_m(x_m)^{1-1/\eta} dx_m \right]^{\eta/(\eta-1)}, \quad \text{and} \tag{2b}$$

$$S = \left[\int q_s(x_s)^{1-1/\eta} dx_s \right]^{\eta/(\eta-1)}, \tag{2c}$$

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 the stock of capital, labor, and intermediate goods from each sector. The technologies for producing individual goods in each sector are given by

$$a_i(x_a) = z_{ai}(x_a)^{-\theta_a} \left[K^\alpha L^{1-\alpha}\right]^{\nu_a} \tilde{Q}_a^{1-\nu_a}, \tag{3a}$$

$$m_i(x_m) = z_{mi}(x_m)^{-\theta_m} \left[K^\alpha L^{1-\alpha}\right]^{\nu_m} \tilde{Q}_m^{1-\nu_m}, \quad \text{and} \tag{3b}$$

$$s_i(x_s) = z_{si}(x_s)^{-\theta_s} \left[K^\alpha L^{1-\alpha}\right]^{\nu_s} \tilde{Q}_s^{1-\nu_s}. \tag{3c}$$

The parameters ν_b, for $b \in \{a, m, s\}$, control the value-added shares 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 which combine the three composite goods according to

$$\tilde{Q}_a = \left((1 - \mu_a - \sigma_a)A^{1-1/\varepsilon_a} + \mu_a M^{1-1/\varepsilon_a} + \sigma_a S^{1-1/\varepsilon_a}\right)^{\varepsilon_a/(\varepsilon_a-1)}, \tag{4a}$$

$$\tilde{Q}_m = \left((1 - \mu_m - \sigma_m)A^{1-1/\varepsilon_m} + \mu_m M^{1-1/\varepsilon_m} + \sigma_m S^{1-1/\varepsilon_m}\right)^{\varepsilon_m/(\varepsilon_m-1)}, \quad \text{and} \tag{4b}$$

$$\tilde{Q}_s = \left((1 - \mu_s - \sigma_s)A^{1-1/\varepsilon_s} + \mu_s M^{1-1/\varepsilon_s} + \sigma_s S^{1-1/\varepsilon_s}\right)^{\varepsilon_s/(\varepsilon_s-1)}. \tag{4c}$$

The parameters $\mu_b \in [0, 1]$ and $\sigma_b \in [0, 1]$ control the share of the manufactured and service goods respectively in the aggregate intermediate good for sector b, while $1 - \mu_b - \sigma_b \in [0, 1]$ controls the share of the agricultural composite 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

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

distribution, implying an average factor productivity across the continuum of goods of $\lambda_{bi}^{\theta_b}$.[4] If $\lambda_{ai} > \lambda_{aj}$, then on average, country i is more efficient than country j at producing agricultural goods. Average productivity 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 the agricultural good. The parameter $\theta_b > 0$, which is constant across countries and over time, governs the coefficient of variation of the efficiency draws. A larger θ implies more variation in efficiency across countries 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

$$K_{t+1} = (1 - \delta)K_t + X_t, \tag{5}$$

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

$$X = \left((1 - \mu_x - \sigma_x)X_a^{1-1/\varepsilon_x} + \mu_x X_m^{1-1/\varepsilon_x} + \sigma_x X_s^{1-1/\varepsilon_x}\right)^{\varepsilon_x/(\varepsilon_x-1)}, \tag{6}$$

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

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.

3.3 Preferences

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

$$\sum_{t=1}^{T} \beta^t L_t \frac{(C_t/L_t)^{1-1/\gamma}}{1 - 1/\gamma}, \tag{7}$$

[4] The Fréchet distribution is also known as a type II extreme value distribution, a special case of the generalized extreme value distribution. Its usefulness comes in finding the probability that a given country j is the least cost supplier to country i, which will in turn generate tractable implications for the pattern of specialization.

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:

$$C_t = \left((1 - \mu_c - \sigma_c)(C_{at} - L_t\bar{a})^{1-1/\varepsilon_c} + \mu_c C_{mt}^{1-1/\varepsilon_c} + \sigma_c C_{st}^{1-1/\varepsilon_c}\right)^{\varepsilon_c/(\varepsilon_c-1)}, \tag{8}$$

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 manufactures and services, respectively, in aggregate consumption, while the term $1-\mu_c-\sigma_c \in [0, 1]$ determines the relative importance of agriculture. The term $\varepsilon_c > 0$ is the elasticity of substitution between the three goods. Each parameter is constant across countries and over time.

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

$$\mathcal{A}_{it+1} = \mathcal{A}_{it} + B_{it}. \tag{9}$$

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. All prices are quoted in terms of time 1 prices so I abstract from explicitly including the rate of return on assets. 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 $\mathcal{A}_{iT+1} \geq 0$.

3.5 Budget constraint

At time t, the 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 household purchases or sells assets and respects the following budget constraint each period:

$$\underbrace{P_{ait}C_{ait} + P_{mit}C_{mit} + P_{sit}C_{sit}}_{\text{aggregate consumption spending}} + \underbrace{P_{ait}X_{ait} + P_{mit}X_{mit} + P_{sit}X_{sit}}_{\text{aggregate investment spending}} + B_t = w_{it}L_{it} + r_{it}K_{it}, \tag{10}$$

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

$$P_{xit}X_{it} = \rho_{it}(w_{it}L_{it} + r_{it}K_{it}). \tag{11}$$

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. The following inequality ensures no arbitrage: for any three countries, i, j, and l, $\tau_{bij} \geq \tau_{bil}\tau_{blj}$. As a normalization I assume that there are no barriers to ship goods domestically so that $\tau_{bii} = 1$.

4 Equilibrium

A competitive equilibrium is of a set of prices and allocations that satisfy the following conditions: 1) households maximize lifetime utility taking prices as given, 2) firms set prices equal to marginal costs 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.

4.1 Household optimization

Households maximize lifetime utility by choosing paths for discretionary consumption and asset holdings, subject to their 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

$$\sum_{t=1}^{T} P_{at}C_{at} + P_{mt}C_{mt} + P_{st}C_{st} + P_{at}X_{at} + P_{mt}X_{mt} + P_{st}X_{st} = \sum_{t=1}^{T} w_tL_t + r_tK_t.$$

I assume that minimum consumption requirements are always met so that the optimal solution is always interior. I define aggregate price indices for aggregate discretionary consumption, C, and aggregate investment, X, as follows:[5]

$$P_c = \left((1-\mu_c-\sigma_c)^{\varepsilon_c} P_a^{1-\varepsilon_c} + \mu_c^{\varepsilon_c} P_m^{1-\varepsilon_c} + \sigma_c^{\varepsilon_c} P_s^{1-\varepsilon_c}\right)^{1/(1-\varepsilon_c)} \quad \text{and} \tag{12a}$$

$$P_x = \left((1-\mu_x-\sigma_x)^{\varepsilon_x} P_a^{1-\varepsilon_x} + \mu_x^{\varepsilon_x} P_m^{1-\varepsilon_x} + \sigma_x^{\varepsilon_x} P_s^{1-\varepsilon_x}\right)^{1/(1-\varepsilon_x)}, \tag{12b}$$

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

$$\sum_{t=1}^{T} P_{ct}C_t + P_{xt}X_t = \sum_{t=1}^{T} w_t L_t + r_t K_t - L_t P_{at}\bar{a}, \tag{13}$$

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

The 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 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, households determine the sequence of aggregate investment spending according to equation (11). 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

$$P_{ct}C_t = \underbrace{\frac{L_t \beta^{\gamma t} P_{ct}^{1-\gamma}}{\sum_{n=1}^{T} L_n \beta^{\gamma n} P_{cn}^{1-\gamma}}}_{\xi_t} W. \tag{14}$$

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

$$B_t = (1-\rho_t)(w_t L_t + r_t K_t) - P_{at} L_t \bar{a} - \xi_t W. \tag{15}$$

[5]The aggregate price indices are defined so that $P_c C = P_a(C_a - L\bar{a}) + P_m C_m + P_s C_s$, and $P_x X = P_a X_a + P_m X_m + P_s X_s$, where C_b and X_b, for $b \in \{a, m, s\}$, are the optimal levels of sectoral consumption and investment.

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_cC denotes aggregate discretionary consumption expenditures. Then total consumption expenditures on each of the three sectoral composite goods are given by

$$P_aC_a = (1-\mu_c-\sigma_c)^{\varepsilon_c}\left(\frac{P_a}{P_c}\right)^{1-\varepsilon_c} P_cC + P_aL\bar{a}, \tag{16a}$$

$$P_mC_m = \mu_c^{\varepsilon_m}\left(\frac{P_m}{P_c}\right)^{1-\varepsilon_c} P_cC, \quad \text{and} \tag{16b}$$

$$P_sC_s = \sigma_c^{\varepsilon_s}\left(\frac{P_s}{P_c}\right)^{1-\varepsilon_c} P_cC. \tag{16c}$$

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

$$P_aX_a = (1-\mu_x-\sigma_x)^{\varepsilon_x}\left(\frac{P_a}{P_x}\right)^{1-\varepsilon_c} P_xX, \tag{17a}$$

$$P_mX_m = \mu_x^{\varepsilon_x}\left(\frac{P_m}{P_x}\right)^{1-\varepsilon_x} P_xX, \quad \text{and} \tag{17b}$$

$$P_sX_s = \sigma_x^{\varepsilon_x}\left(\frac{P_s}{P_x}\right)^{1-\varepsilon_x} P_xX. \tag{17c}$$

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} is the marginal cost in country j. Since each country purchases each individual good from their least cost supplier, the actual price in country i, for the individual good z_b, is $p_{bi}(z_b) = \min_{j=1,\ldots,I}[p_{bij}(z_b)]$.

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

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

where $\varphi_b = \prod_i \varphi_{bi}$ is the joint density 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:

$$P_{bi} = \Gamma_b B_b \left[\sum_l \left(u_{bl} \tau_{bil} \right)^{-1/\theta} \lambda_{bl} \right]^{-\theta}, \tag{18}$$

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

$$u_{bi} = \left[r_i^{\alpha} w_i^{1-\alpha} \right]^{\nu_b} \tilde{P}_{bi}^{1-\nu_b}, \tag{19}$$

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

$$\tilde{P}_b = \left((1 - \mu_b - \sigma_b)^{\varepsilon_b} P_a^{1-\varepsilon_b} + \mu_b^{\varepsilon_b} P_m^{1-\varepsilon_b} + \sigma_b^{\varepsilon_b} P_s^{1-\varepsilon_b} \right)^{1/(1-\varepsilon_b)}. \tag{20}$$

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 the argument inside is positive.

Trade shares There is a tractable implication for bilateral trade flows. For each sector b, the fraction of country i's expenditure allocated towards goods that were produced in country j is given by [6]

$$\pi_{bij} = \frac{\left(u_{bj} \tau_{bij} \right)^{-1/\theta} \lambda_{bj}}{\sum_l \left(u_{bl} \tau_{bil} \right)^{-1/\theta} \lambda_{bl}}. \tag{21}$$

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

$$\begin{aligned}
K_{bi} &= \int K_{bi}(z_b) \varphi_b(z_b) dz_b, \\
L_{bi} &= \int L_{bi}(z_b) \varphi_b(z_b) dz_b, \\
A_{bi} &= \int A_{bi}(z_b) \varphi_b(z_b) dz_b, \\
M_{bi} &= \int M_{bi}(z_b) \varphi_b(z_b) dz_b, \quad \text{and} \\
S_{bi} &= \int S_{bi}(z_b) \varphi_b(z_b) dz_b,
\end{aligned}$$

[6] 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.

where the notation $L_{bi}(u)$ 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.[7]

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

$$r_i K_{bi} = \alpha \nu_b Y_{bi}, \tag{22a}$$

$$w_i L_{bi} = (1-\alpha)\nu_b Y_{bi}, \tag{22b}$$

$$P_{ai} A_{bi} = (1-\mu_b-\sigma_b)^{\varepsilon_b} \left(\frac{P_{ai}}{\tilde{P}_{bi}}\right)^{1-\varepsilon_b} (1-\nu_b) Y_{bi}, \tag{22c}$$

$$P_{mi} M_{bi} = \mu_b^{\varepsilon_b} \left(\frac{P_{mi}}{\tilde{P}_{bi}}\right)^{1-\varepsilon_b} (1-\nu_b) Y_{bi}, \quad \text{and} \tag{22d}$$

$$P_{si} S_{bi} = \sigma_b^{\varepsilon_b} \left(\frac{P_{si}}{\tilde{P}_{bi}}\right)^{1-\varepsilon_b} (1-\nu_b) Y_{bi}. \tag{22e}$$

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

$$K_{ai} + K_{mi} + K_{si} = K_i, \tag{23a}$$

$$L_{ai} + L_{mi} + L_{si} = L_i, \tag{23b}$$

$$A_{ai} + A_{mi} + A_{si} + C_{ai} + X_{ai} = A_i, \tag{23c}$$

$$M_{ai} + M_{mi} + M_{si} + C_{mi} + X_{mi} = M_i, \quad \text{and} \tag{23d}$$

$$S_{ai} + S_{mi} + S_{si} + C_{si} + X_{si} = S_i. \tag{23e}$$

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.

[7]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.

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

$$Y_{ai} = \sum_{j=1}^{I} L_j P_{aj} A_j \pi_{aji}, \tag{24a}$$

$$Y_{mi} = \sum_{j=1}^{I} L_j P_{mj} M_j \pi_{mji}, \quad \text{and} \tag{24b}$$

$$Y_{si} = \sum_{j=1}^{I} L_j P_{sj} S_j \pi_{sji}. \tag{24c}$$

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 country j's spending on good that were produced by country i.

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:[8]

$$B_i = \underbrace{Y_{ai} - P_{ai}A_i}_{\text{surplus in } a} + \underbrace{Y_{mi} - P_{mi}M_i}_{\text{surplus in } m} + \underbrace{Y_{si} - P_{si}S_i}_{\text{surplus in } s}. \tag{25}$$

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.

I model the world as six economies consisting of: 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

[8]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 $Y = C + I$.

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), *Manufacturing* (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).

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, $\bar{a}$, in order to match key aspects of agricultural output in Korea. This is done jointly with other parameters and I postpone discussion until section 5.3.

The elasticity of substitution across 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.

I set the intertemporal elasticity of substitution to be $\gamma = 0.5$, in line with 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 grow at constant rates, the real rate of return is about 4 percent. These parameters are summarized in table 1.

Capital's share, depreciation, and η I measure 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 stock in the model to be $\delta = 0.06$, a standard value used in the literature. Given this notion of investment, 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 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 subs within composite goods	2

Sector-specific weights and elasticities for investment and intermediate spending 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, while the remaining parameters for other aggregates follow an identical procedure. The model implies that, in country i, at period t, the share of total investment spending allocated to each composite good is given by

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

$$\frac{P_{mit}X_{mit}}{P_{xit}X_{it}} = \frac{\mu_x^{\varepsilon_x}P_{mit}^{1-\varepsilon_x}}{(1-\mu_x-\sigma_x)^{\varepsilon_x}P_{ait}^{1-\varepsilon_x}+\mu_x^{\varepsilon_x}P_{mit}^{1-\varepsilon_x}+\sigma_x^{\varepsilon_x}P_{sit}^{1-\varepsilon_x}}, \quad \text{and}$$

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

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.[9] 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.

The estimated weights are fairly intuitive. Manufactures carry the largest weight in intermediate usage by producers of manufactures; manufacturing a computer requires processors, chips, and hard drives, in addition to other manufactured goods. Manufactures also carries a substantial weight in agriculture; for example, fertilizer is a very large manufactured input. 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 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 complementary in all sectors, but with different elasticities of substitution. Producers of services substitute one type of intermediate input for another much more easily than do producers of manufactures. Production of automobile requires manufactured inputs such as engines, paint, etc., which

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

can not be replaced by agricultural or services goods. On the other hand, restaurants notoriously substitute ambiance/entertainment in place of merchandise/portions and vice-versa. With respect to aggregate investment, the elasticity of substitution is very low, 0.18, while it is much higher with respect to consumption, 0.81.

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 draws within each sector and each country. A larger value of θ_b implies more variation in efficiency draws 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 the existing literature which runs from 0.12 in Eaton and Kortum (2002) to 0.22 in Simonovska and Waugh (2010). Estimates are not available for agriculture or services, moreover, sufficient data is not readily available in order to apply the procedures used to estimate these parameters for services. 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.

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 stock K_{i1}, labor endowments L_{it}, investment rates ρ_{it}, sector specific productivity terms $(\lambda_{ait}, \lambda_{mit}, \lambda_{sit})$, and trade barriers $(\tau_{ait}, \tau_{mit}, \tau_{sit})$.

Table 2: Sector-specific parameters

Sector:	Agriculture	Manufacturing	Services	Consumption	Investment
Elasticity of substitution across 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 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 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					
	$\theta_a = 0.15$	$\theta_m = 0.15$	$\theta_s = 0.15$		

Initial capital stocks I compute the initial capital stock by taking the value of capital stock in 1960, which I compute using the perpetual inventory method as in Caselli (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. Following the literature I set $\delta = 0.06$.

Aggregate investment for the group EUR is the sum of aggregate investment over each of its 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.[10] 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

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

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 the Penn World Tables version 6.3. 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 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`).

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

I normalize initial agricultural productivity in the United States so that $\lambda_{a,USA,1}^{\theta_a} = 1$, which leaves 17 initial productivity terms to be identified. I calibrate these jointly with other objects and discuss the details in section 5.3.

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

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

where VAk_{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} are aggregate capital stock and labor in country i at time t. Re-writing 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

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

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 (as per my definition), South Asia (as per my definition), 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 value added data and construct sector-specific producer price indices by weighting prices at more disaggregate levels by the expenditure shares. I also construct sectoral employment figures by summing over the more disaggregate sectors. I report he sector- and country- specific growth rates in table 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 3: Annual growth in average productivity, λ^{θ}

	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 tariff 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 rest of the time period 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.[11] 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 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

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

within the group.

Table 4: Policy related component of trade barriers

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

Notes: Ad-valorem tariff equivalent values. Values for services are average of agriculture and manufactures.

I report the values in ten year intervals for all tariffs used in the model in table 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.

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

Output in Korea is defined by the 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 that in spent on imports (1 moment). Finally, I target the fraction of aggregate gross spending that is imported in Korea (1 moment).

This gives me a total of 21 moments to identify 21 parameters. I choose the parameters by minimizing the distance between the data and the model under the Euclidean norm: $\min \sum(\text{model} - \text{data})^\top W(\text{model} - \text{data})$, where W is a weighting matrix which assigns twice the weight to Korean moments relative to the rest of the moments. I constrain each each parameter to be non-negative. Table 5 reports the values for the calibrated parameters, while the fit of the model in matching the data is given in table 6.

Table 5: Calibrated parameters

	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

Notes: All productivity levels are reported relative to the US value. $\lambda_{aUSA1}^{\theta_a} = 1$ is a normalization, with $\lambda_{mUSA1}^{\theta_m}/\lambda_{aUSA1}^{\theta_a} = 0.05$ and $\lambda_{sUSA1}^{\theta_s}/\lambda_{aUSA1}^{\theta_a} = 0.01$. The minimum level of agricultural consumption implies that, in 1960, Korea allocates 45 percent of aggregate consumption spending to subsistence requirements, while in 1995 this number is 26 percent.

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 that, relative to agriculture output, there is very little agriculture being exported. The barrier in manufactures is somewhat smaller than those found in the literature. For instance, Waugh (2010) and Sposi (2011) 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 domestically. In this paper countries are grouped together so the relative barrier will appear smaller.

Table 6: Fit of calibration

		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*
Manufacturing	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*			
Manufacturing	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
	Data			*0.26*			*0.04*
Manufacturing	Model			0.43			0.54
	Data			*0.43*			*0.53*
fraction of gross spending imported							
Aggregate	Model			0.04			0.02
	Data			*0.07*			*0.02*

Notes: All values are for the year 1960.

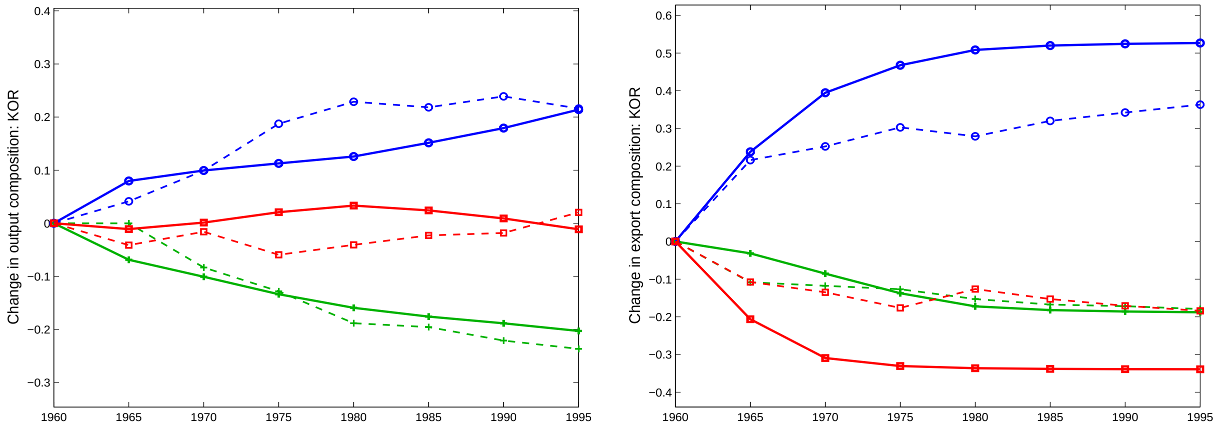
6 Results

In appendix A I provide analytic results for a two-country, two-sector static environment. In this section I present quantitative results 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.

6.1 Korean compositions

The left panel of figure 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.

Figure 4: Composition of output (left) and exports (right) in Korea: 1960-1995



Note: The green line with plus signs (+) represents agriculture, blue circles represent manufactures, and red squares represent services. Dashed lines are data, solid lines are model.

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 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.

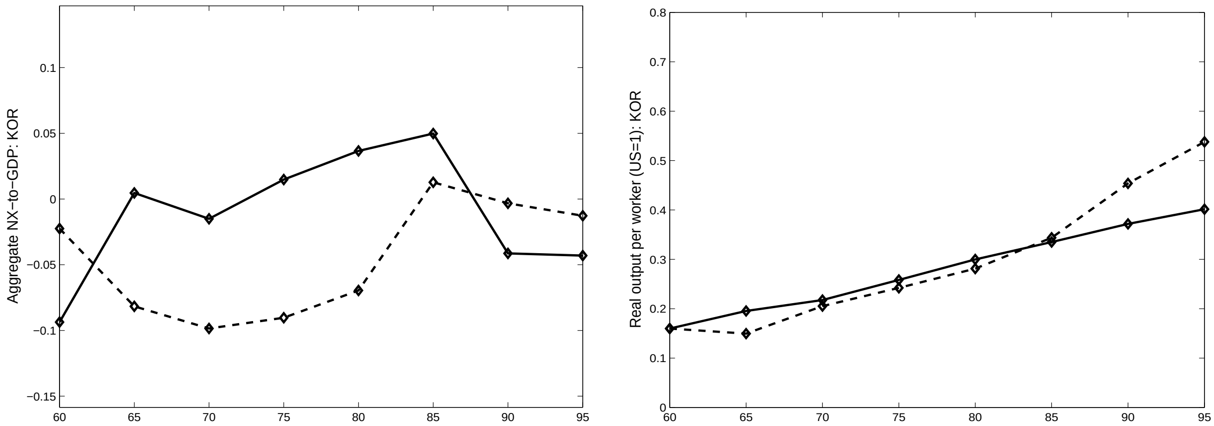
The increase in manufacture's share in exports is driven primarily by the shift in Korea's comparative advantage towards the manufactures sector. This in turn causes the increase in manufacture's share in output through specialization.

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 1980, see the left panel of figure 5.

During this time Korea grew at an annualized rate of 3.3 percentage points higher than the United States, increasing their level of real GDP per worker relative to the United States, at PPP, from 0.16 to 0.54. 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. The model implies that Korea would have achieved a a level of real GDP per worker of 0.40, relative to the United States. I plot the time series for real GDP per worker, relative to the United States, in the right panel of figure 5.

Figure 5: Net export-to-GDP ratio (left) and real GDP per worker relative to the US (right) in Korea: 1960-1995



Note: Dashed line is data, solid line is 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

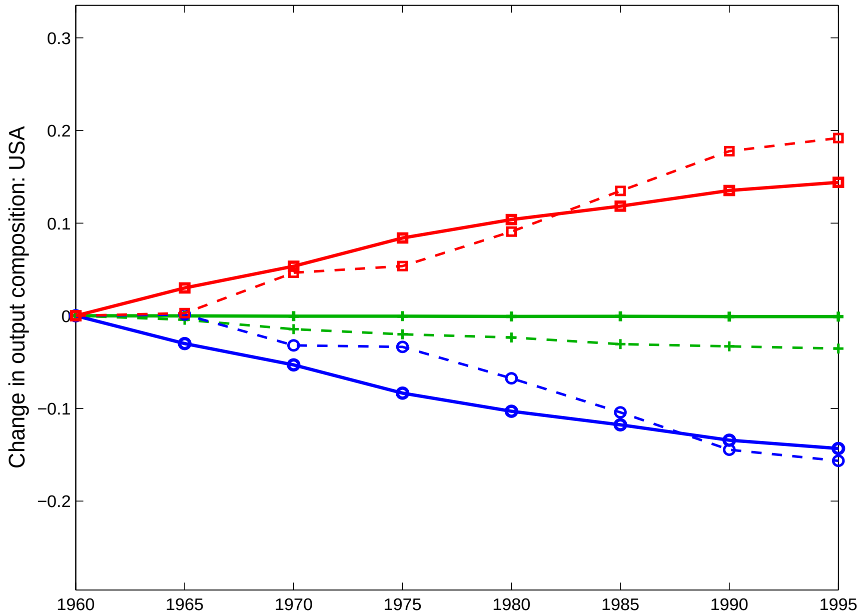
6.3 Structural change in the rest of the world

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 gross output composition in the US. The model predicts the secular increase in services as well as the secular decline in manufactures from 1960 to 1995, see figure 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 7 presents results for changes in value added compositions for the remaining countries: Canada, the EU-15, Latin America, and South-east Asia.

Figure 6: Output compositions in the United States: 1960-1995



Note: The green line with plus signs (+) represents agriculture, blue circles represent manufactures, and red squares represent services. Dashed lines are data, solid lines are model.

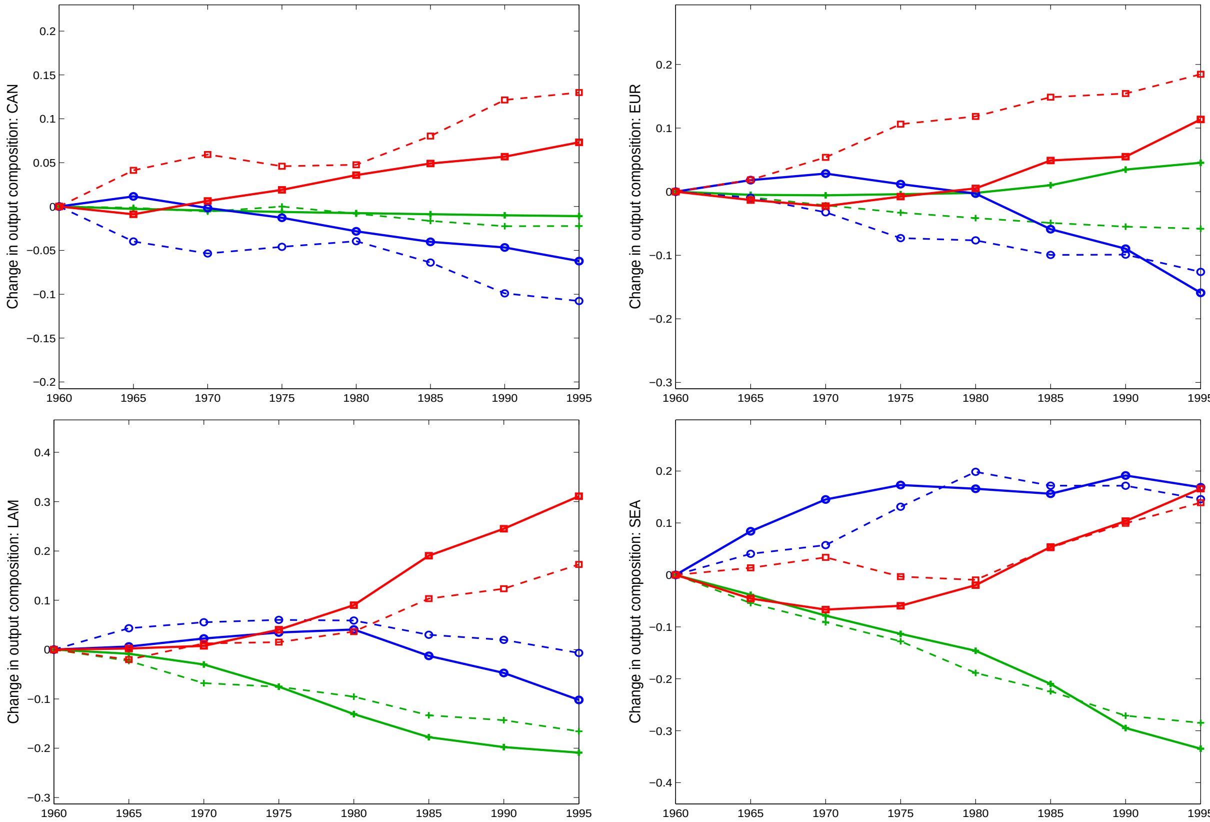
For Canada the model tracks understates the increase in service's share and understates the decline in manufacture's share, but tracks agriculture's share closely.

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 in grows faster than productivity in its other sector, and also faster than in other countries. 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, and 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.

Figure 7: Output compositions in remaining countries: 1960-1995



Note: The green line with plus signs (+) represents agriculture, blue circles represent manufactures, and red squares represent services. Dashed lines are data, solid lines are model. The top left panel is Canada, the top right panel is Europe, the bottom left panel is Latin America, and the bottom right panel is South-east Asia.

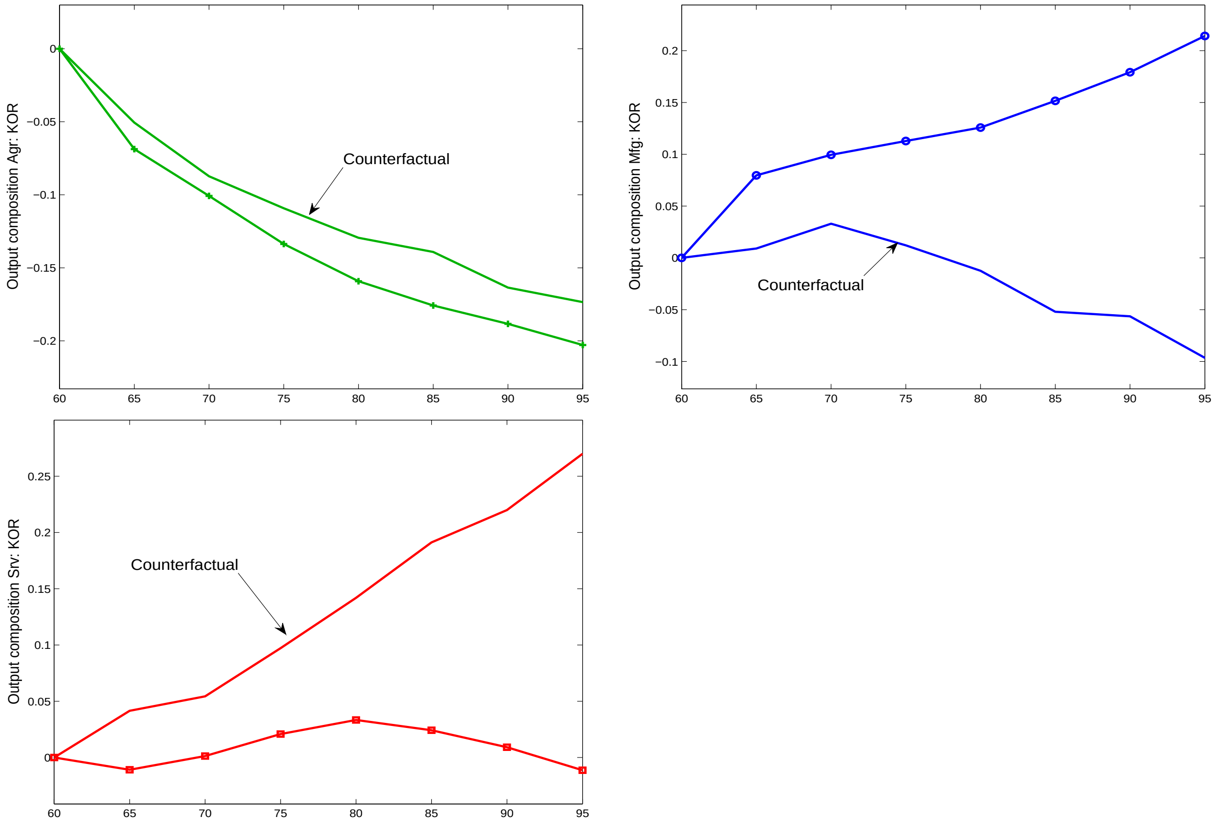
In sum, Canada, Europe and the US are very large and account for anywhere between 70 and 90 percent of output in the model depending on the year. Meanwhile, minimum consumption requirements are quite trivial relative to actual consumption since they are relatively developed in 1960. Therefore, they display similar patterns as a closed-economy model would predict for them. In each of these countries, services productivity grows slower than productivity in the other sectors so the service's share in output increases.

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, and how they relate to the growth miracle. 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 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, as well as in its growth miracle. To execute this experiment I shut down trade in all sectors and all countries by setting the trade barriers sufficiently high. Since there will be no flows of goods across countries, this will imply that there will be no borrowing/lending as well. 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 8: Counterfactual 1: Composition of output in Korea under autarky: 1960-1995

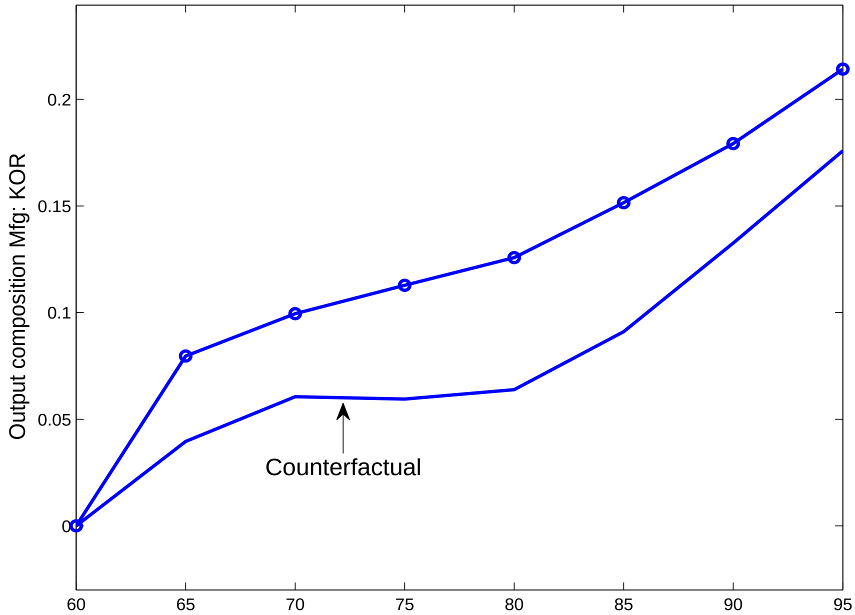


Note: The solid line with markings denotes the baseline result while the solid line with no markings denotes the counterfactual result. The green lines in the upper left panel denote agriculture's share, the blue in the upper right panel denote manufacture's share, and the red lines in the bottom left panel denote service's share.

Figure 1 compares the counterfactual implications for structural change 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 that there be no trade by setting barriers sufficiently high. That resulted in two outcomes. First, there wold be no trade. Second, there would be no borrowing/lending. To isolate these two separate channels I run a separate counterfactual where I do not allow borrowing/lending, but do allow trade. In this experiment countries are allowed to trade, but trade must be balanced at the aggregate level. 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 9: Counterfactual 2: Manufacture's share in the composition of output in Korea with no borrowing/lending: 1960-1995



Note: The solid line with markings denotes the baseline result while the solid line with no markings denotes the counterfactual result.

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 were 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, manufacture's share in output becomes flatter, see figure 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

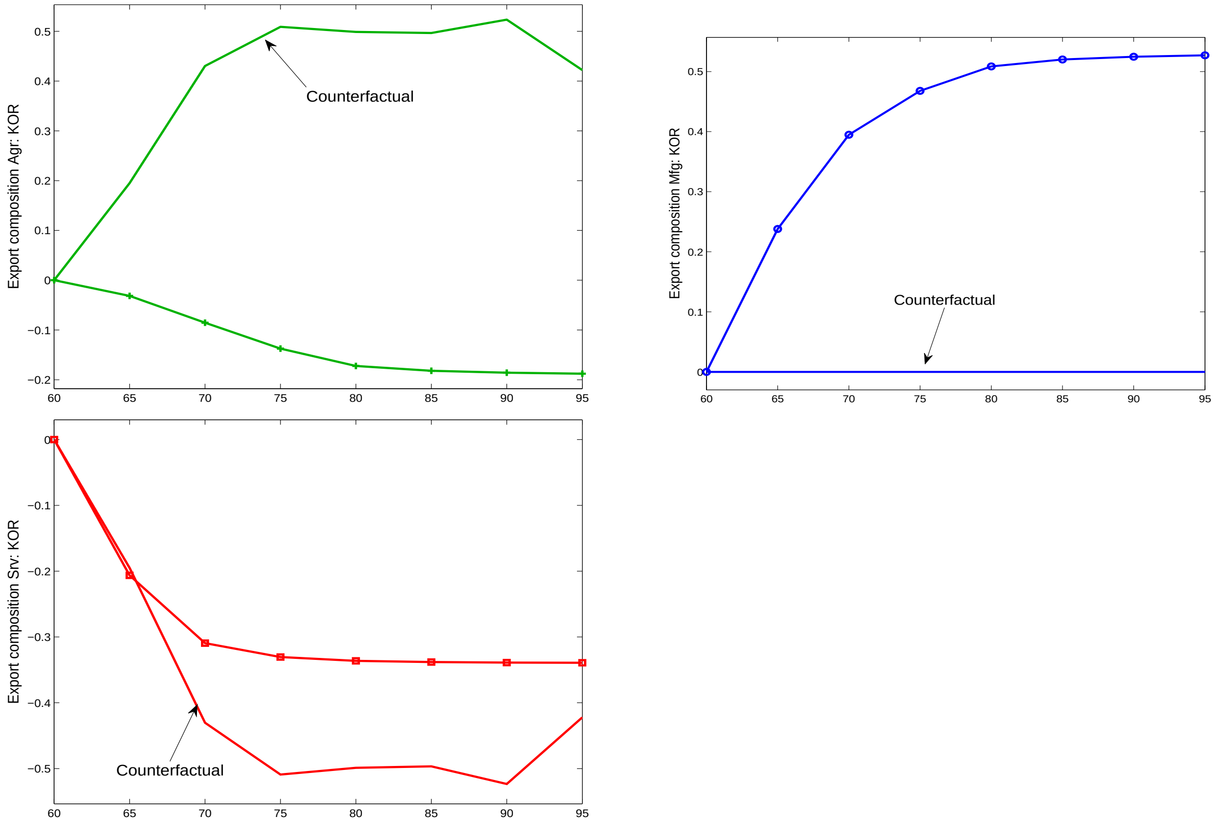
$$\tau_m = \begin{bmatrix} 1 & \# & \infty & \# & \# & \# \\ \# & 1 & \infty & \# & \# & \# \\ \infty & \infty & 1 & \infty & \infty & \infty \\ \# & \# & \infty & 1 & \# & \# \\ \# & \# & \infty & \# & 1 & \# \\ \# & \# & \infty & \# & \# & 1 \end{bmatrix}$$

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 in the shift in comparative advantage. Once trade in manufactures is shut down, there is no channel in which Korea becomes increasingly specialized. At the same time, since Korean productivity grows fastest in manufactures relative to the other sectors, its share in aggregate output diminishes. Figure 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.

Counterfactual 4: Free trade To isolate 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 7 shows that manufacture's share in both exports and 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.

Figure 10: Counterfactual 3: Composition of exports in Korea when Korea's manufactures sector is closed: 1960-1995



Note: The solid line with markings denotes the baseline result while the solid line with no markings denotes the counterfactual result.

Counterfactual 5: Eliminate GATT In the model I assumed that trade costs, in sector b in country i at time t, take the form $\tau_{bit} = d_b + trf_{bit}$, where trf_{bit} is the ad valorem tariff equivalent component measured from GATT negotiations. 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, quantitatively the compositions are unaffected, see table 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.

Implications for aggregate growth In each of the above counterfactuals, the implications for the rate of growth are small. In table 8 I show the annualized growth rate in real GDP per worker for Korea, relative to the United States, under each counterfactual specification. The annualized growth rate does not vary by more than a half of a percentage point

Table 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

Notes: This table reports the percentage point change between the period 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.

relative to the baseline for any counterfactual. However, the counterfactual implications for levels of GDP, relative to the United States, are substantial.

Shutting down trade, in either all sectors or manufactures only, decreases Korea's growth rate. The reason is that Korea does not place increasingly more resources into its sector with the fastest growing productivity. On the other hand, moving to free trade does not increase its growth rate, in fact it decreases it. However, the level of GDP per worker is increased for all periods; the ability to borrow and lend causes this.

Table 8: Real GDP per worker in Korea relative to the US

	Baseline	CF1	CF2	CF3	CF4	CF5
Annualized growth rate	0.026	0.023	0.025	0.025	0.021	0.025
1960 level relative to the baseline	1.00	0.97	0.98	0.94	5.87	1.00
1995 level relative to the baseline	1.00	0.87	0.95	0.92	5.01	0.96

Notes: 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.

7 Conclusion

In this paper 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 also a large contributor to changes in the composition of output.

From 1960 to 2000, the increase in manufacture's share in exports was almost twice as large as the increase in manufacture's share in output. 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, have two effects. First, since manufacture's productivity grows faster in Korea than in other countries, comparative advantage implies that Korea begins to export more manufactures relative to other goods. Non-homothetic preferences are crucial in generating the decline in agriculture's share in both exports and output. The model quantitatively generates changes in export and output compositions for Korea. In addition, the model reproduces output compositions for Canada, Europe, Latin America, South-east Asia, and the United States.

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 borrowing/lending allowed Korea to transfer production from early years when productivity is relatively low to later years when productivity is relatively high, producing an additional increase in manufacture's share in output.

I am currently working on incorporating an endogenous investment rate. This may be quantitatively important since the investment rate depends on the relative price of investment, and investment is comprised almost entirely of manufactures. A key exogenous force in the model is asymmetric productivity growth across sectors which will drive a large portion of the relative price of investment. Moreover, investment accounts for a large chunk of GDP so understanding this channel may shed some additional insight into the process of structural change.

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A A static, 2-country, 2-sector example

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

A.1 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

$$y_{bi}(x) = z_{bi}(x)^{-\theta} \ell_{bi}(x), \tag{26}$$

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 $z_b = (z_{b1}, z_{b2})$. [12] So I express y as a function of z.

$$y_{bi}(z_b) = z_{bi}^{-\theta} \ell_{bi}(z). \tag{27}$$

All individual goods are used to produce a composite goods which will be used for consumption. The technology for producing the composite goods is given by

$$C_{ai} = \left[\int c_{ai}(z_b)^{\frac{\eta-1}{\eta}} \varphi_b(z_b) dz_b \right]^{\frac{\eta}{\eta-1}}, \tag{28}$$

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.

[12] 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).

A.2 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

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

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.

A.3 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

$$\pi_{bij} = \frac{w_j^{-1/\theta}\tau_{bij}^{-1/\theta}\lambda_{bj}}{w_i^{-1/\theta}\lambda_{bi} + w_j^{-1/\theta}\tau_{bij}^{-1/\theta}\lambda_{bj}}. \tag{29}$$

A.4 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.

A.5 Prices

I denote the sector b composite good price index in country i by P_{bi}. Since the composite good described by equation (28) 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:

$$\frac{P_{b1}}{w_1} = \left[\lambda_{b1} + \left(\frac{w_2}{w_1}\right)^{-1/\theta}\tau_{b12}^{-1/\theta}\lambda_{b2}\right]^{-\theta} \tag{30}$$

$$\frac{P_{b2}}{w_2} = \left[\left(\frac{w_1}{w_2}\right)^{-1/\theta}\tau_{b21}^{-1/\theta}\lambda_{b1} + \lambda_{b2}\right]^{-\theta} \tag{31}$$

A.6 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

$$\frac{w_1}{w_2} = \left(\frac{L_2}{L_1}\right)\frac{\left(\frac{P_{a2}}{P_{c2}}\right)^{1-\varepsilon}\pi_{a21} + \left(\frac{P_{m2}}{P_{c2}}\right)^{1-\varepsilon}\pi_{m21}}{\left(\frac{P_{a1}}{P_{c1}}\right)^{1-\varepsilon}\pi_{a12} + \left(\frac{P_{m1}}{P_{c1}}\right)^{1-\varepsilon}\pi_{m12}}. \tag{32}$$

Equilibrium is solved by finding a relative wage rate w_1/w_2 that solves (32). 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 (32) 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 (30) and (31) 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

$$\frac{EXP_{m1}}{EXP_{a1}} = \left(\frac{P_{m2}C_{m2}}{P_{a2}C_{a2}}\right)\left(\frac{\pi_{m21}}{\pi_{a21}}\right). \tag{33}$$

I have already argued that the first component decreases when λ_{m1} increases. Inspection of equation 29 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.

A.7 Non-homotheticity

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 Data

Korean I-O 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 I-O tables Input-output tables for the United States are published officially 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 aggregates such as aggregate consumption, aggregate investment, and the three types of aggregate intermediates. I restrict use of this data to 1970-2000 and do not extrapolate.

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 stock, aggregate labor, investment rates, exchange rates, and GDP per worker are all taken from http://pwt.econ.upenn.edu/php_site/pwt63/pwt63_form.php.

C Derivations

The following derivations rely on three properties of exponential distributions.

P1: $z \sim \exp(\lambda)$ and $k > 0 \Rightarrow kz \sim \exp(\lambda/k)$.

P2: $z_1 \sim \exp(\lambda_1)$ and $z_2 \sim \exp(\lambda_2) \Rightarrow \min\{z_1, z_2\} \sim \exp(\lambda_1 + \lambda_2)$.

P3: $z_1 \sim \exp(\lambda_1)$ and $z_2 \sim \exp(\lambda_2) \Rightarrow \Pr(z_1 \leq z_2) = \frac{\lambda_1}{\lambda_1+\lambda_2}$.

C.1 Deriving price indices

Here I derive the price index for the composite good of sector b, P_{bi}. Cost minimization by producers of tradable good z_b implies a unit cost of an input bundle used in sector b, which I denote by u_{bi}.

Perfect competition implies that price, in country i, of a good purchased from country j, equals unit cost in country j times the trade barrier of shipping from j to i

$$p_{bij}(z_b) = B_b u_{bj} \tau_{bij} z_{bj}^{\theta_b},$$

where z_b can also be thought of as the vector of draws across countries. The trade structure implies that country i purchases each good z_b from the least cost supplier so that the price of the individual intermediate good is

$$p_{bi}(z_b)^{1/\theta} = B_b^{1/\theta_b} \min_j \left[(u_{bj}\tau_{bij})^{1/\theta} z_{bj} \right].$$

Since $z_{bj} \sim \exp(\lambda_{bj})$, it follows from property P1 that

$$(u_{bj}\tau_{bij})^{1/\theta_b} z_{bj} \sim \exp(\zeta_{bij}),$$

where $\zeta_{bij} = (u_{bj}\tau_{bij})^{-1/\theta_b} \lambda_{bj}$. Then using property P2 this implies that

$$\min_j \left[(u_{bj}\tau_{bij})^{1/\theta_b} z_{bj} \right] \sim \exp\left(\sum_j \zeta_{bij} \right).$$

Lastly, appealing to property P1 again,

$$p_{bi}(z_b)^{1/\theta} \sim \exp\left(B_b^{-1/\theta_b} \sum_j \zeta_{bij} \right).$$

Now let $\xi_b = B_b^{-1/\theta_b} \sum_j \zeta_{bij}$. Then

$$P_{bi}^{1-\eta} = \xi_b \int y^{\theta(1-\eta)} e^{-\xi_b y} dy.$$

Apply a change of variables so that $\omega = \chi_b y$ and obtain

$$P_{bi}^{1-\eta} = \xi_b^{\theta(\eta-1)} \int \omega^{\theta_b(1-\eta)} e^{-\omega} d\omega.$$

Denote the constant $\Gamma_b = \Gamma(1+\theta_b(1-\eta))^{1/(1-\eta)}$, where $\Gamma(\cdot)$ is the Gamma function. Therefore,

$$\begin{aligned} P_{bi} &= \Gamma_b \xi_b^{-\theta_b} \\ &= \Gamma_b B_b \left[\sum_j (u_{bj}\tau_{bij})^{-1/\theta_b} \lambda_{bj} \right]^{-\theta_b}. \end{aligned}$$

C.2 Deriving trade shares

I now derive the trade shares π_{bij} which is the fraction of i's total spending on sector b goods that was purchased from 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, country j is the least cost supplier. Mathematically,

$$\begin{aligned}
\pi_{bij} &= \Pr\left\{p_{bij}(z_b) \leq \min_l \left[p_{bil}(z_b)\right]\right\} \\
&= \Pr\left\{u_{bj}\tau_{bij}u_j^{\theta_b} \leq \min_l \left[u_{bl}\tau_{bil}z_{bl}^{\theta}\right]\right\} \\
&= \Pr\left\{\left(u_{bj}\tau_{bij}\right)^{1/\theta_b} z_{bj} \leq \min_l \left[\left(u_{bl}\tau_{bil}\right)^{1/\theta_b} z_{bl}\right]\right\} \\
&= \frac{\zeta_{bij}}{\sum_l \zeta_{bil}} \\
&= \frac{\left(u_{bj}\tau_{bij}\right)^{-1/\theta_b}\lambda_{bj}}{\sum_l \left(u_{bl}\tau_{bil}\right)^{-1/\theta_b}\lambda_{bl}},
\end{aligned}$$

where the step from line 3 to line 4 uses both properties P2 and P3.

D Solving for the competitive equilibrium

This section describes how 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 (start with a guess at each price then update using the functions f_{ai}, f_{mi}, and f_{si}). 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 (15).

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 these 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 (24a)–(24c). Combining these with the demand for factors of production by firms, equations (22a)–(22e), along with the within-country resource constraints (23c)–(23e) I obtain the following:

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

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

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

First solve for aggregate discretionary consumption spending at each date by using equation (14). Next, split aggregate discretionary consumption and investment spending across the three sectors according to equations (16a) – (17c). 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 manufactured goods by the agricultural sector in country i at time t is $P_{mit}M_{ait}$. Using equations (22c) and (22b) 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 (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 will generate a system of equations where labor is the only unknown. There are $3I$ equations with $3I$ labor allocations, with the aggregate labor endowments L_{it} given exogenously. There is no need to rewrite the final expenditures (consumption and investment) since they are known up to this point.

For any sectors $b \in \{a, m, s, c, x\}$ define the matrices Υ_{abt}, Υ_{mbt}, and Υ_{sbt} component-wise as follows:

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

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

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

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,

$$(1-\Psi_t)\Lambda_t = V_t, \tag{37}$$

where

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

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

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

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 sending 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 $T : \Delta \rightarrow \Delta$. If Tw and w are sufficiently close then stop, else return to step one and set $w = Tw$.