How Much of South Korea's Growth Miracle Can be Explained by Trade Policy?

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July 2012

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Abstract

South Korea's growth miracle has been well documented. A large set of institutional and policy reforms in the early 1960s is thought to have contributed to the country's extraordinary performance. In this paper, we assess the importance of one key set of policies, the trade policy reforms in Korea, as well as the concurrent GATT tariff reductions. We develop a model of neoclassical growth and trade that highlights two forces by which lower trade barriers can lead to increased per worker GDP: comparative advantage and specialization, and capital accumulation. We calibrate the model and simulate the effects of three sets of tariff reductions that occurred between early 1962 and 1995. There are two main findings. First, the model can explain about 20 percent of South Korea's catch-up to the G7 countries in output per worker in the manufacturing sector. Second, these effects are driven by multi-stage production and access to imported investment goods.

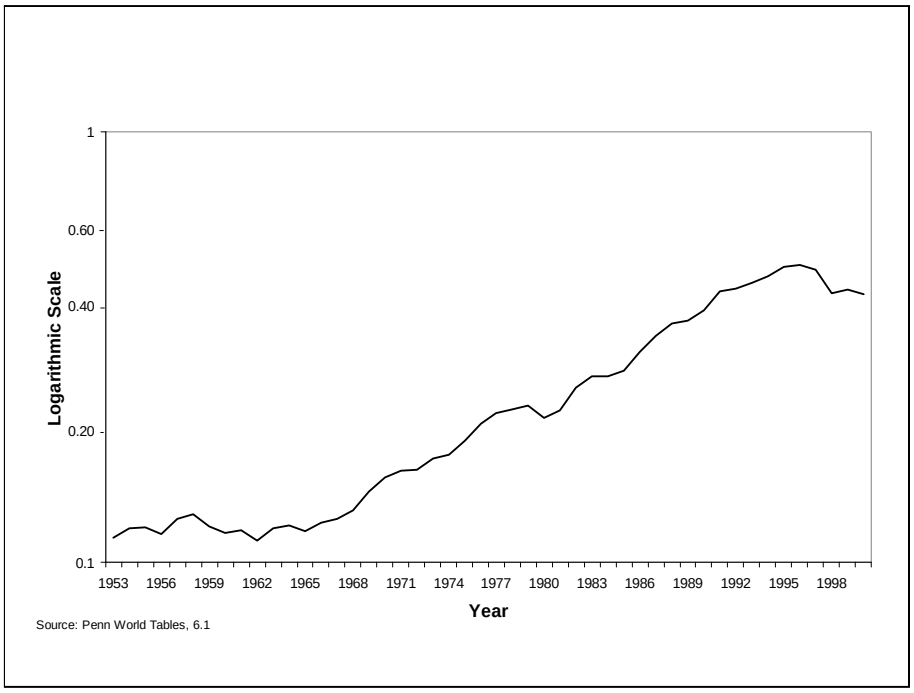
JEL Classification code: F4, O110, O4, O530

Keywords: Growth, trade, calibration, multi-stage production, South Korea

1 Introduction

Well before India and China burst onto the global scene, there were the growth miracles of the Newly Industrializing Countries. South Korea was one of those countries and its experience since the early 1960s has been widely documented.[1] Figure 1 illustrates that in 1961, according to the Penn World Tables, South Korea's per capita GDP was 11% of that of the United States, about the same as in Cote D'Ivoire and Sri Lanka at that time. By 1995 its per capita GDP was 49% of the United States, comparable to Portugal or Slovenia. In the intervening period, South Korea (hereafter, "Korea") experienced growth rates of real per capita GDP that averaged 6.6 percent per year.

Figure 1: Ratio of South Korea to United States GDP per capita

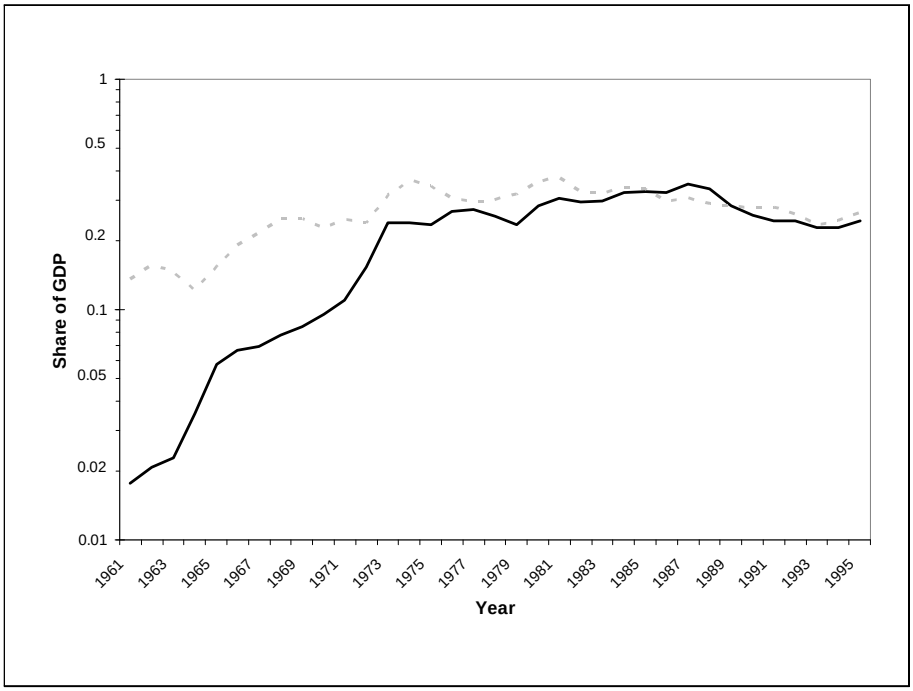


A key feature of this miracle was an enormous increase in Korea's international trade. Figure 2 shows that Korea's merchandise export share of GDP rose from just 2 percent in 1962 to 30 percent in less than 20 years. Virtually all of this increase was in manufactured goods. In 1960, only 35.2 percent of Korea's merchandise exports consisted of manufactured goods. In 1995, it was 96.9 percent.[2]

[1] See, for example, Lucas (1993). The other NICs are Hong Kong, Taiwan, and Singapore.

[2] If the food, beverages and tobacco sector is counted as manufacturing, the manufacturing share of total merchandise imports was 46.6 percent in 1960 and 98.9 percent in 1995.

Figure 2: South Korea Merchandise Exports and Imports. (Solid line: Exports; Dashed line: Imports)



The growth miracle came on the heels of a sweeping set of policy reforms following the ascension of Park Chung Hee to power in 1961. One major area of reforms was in trade policy. Park believed that Korea needed to start exporting, but recognized that the country had few natural resources. Consequently, trade policy shifted from largely focusing on import substitution to one focused on export expansion. Hong (1979) documents 38 reforms designed to promote exports. Of these reforms, two stand out. In the early 1960s, Korea eliminated tariffs on imported inputs and capital goods, but only as long as these imports were used to produce goods for export. The imports could not be used for production of goods sold domestically. Westphal and Kim (1977) show that, at least until 1975, this was the most important export-oriented policy. Second, beginning in the 1970s and continuing for the next two decades, Korea engaged in a broader, gradual reduction of general tariff rates from about 40 percent to 13 percent. During this period, there were significant changes occurring in the global trading environment, as well. Perhaps GATT's two most important set of global tariff reductions occurred between 1968 and 1986 with the implementation of the Kennedy Round and the Tokyo Round agreements.

The purpose of this paper is to assess the importance of these trade reforms in explaining Korea's growth in output per worker and trade between 1962 and 1995, the growth miracle period.

Our methodology departs from the usual empirical methodology of the trade and growth literature. We conduct our quantitative assessment through the lens of a neoclassical model of growth and trade. The growth theory underlying our model is Cass-Koopmans. The trade theory underlying the model is Ricardian; relative productivity differences across countries helps determine differences in comparative advantage. Two additional features of the model are that some goods are produced in multiple stages and investment goods are tradable. These features allow the calibrated model to capture important features of the Korean data.

In the model, lower tariffs raise efficiency because it facilitates specialization. The presence of multiple stages of production deepens the extent of specialization. Countries specialize by stages, rather than by goods. The efficiency gains raise aggregate total factor productivity (TFP) even though there are no intrinsic increases in the productivity of any individual good. In addition, lower tariffs generate increased imports of investment goods. The efficiency gains and capital accumulation ensuing from the trade liberalization lead to increases in output per worker.

We calibrate the model to match key features of the Korea's manufacturing sector vis-a-vis the G7 countries in 1962 and 1963. We then simulate the tariff reductions mentioned above. Our main findings are as follows. Taken together, the tariff reductions can explain 20 percent of Korea's catch-up in manufacturing output per worker. Also, we find that the effect of the three trade policies taken together is almost twice as large as the sum of the effect from each policy applied separately. Finally, we show that the presence of multiple stages of production and imported investment goods explains the vast majority of the model's implications for the catch-up and the growth in trade.

The role of trade policy in affecting long run growth is a story involving macroeconomics, development economics, and international economics. Economists from each of these sub-disciplines have approached this question with varying empirical methodologies including reduced form regressions, micro and macro growth regressions, event studies, and growth accounting and structural change accounting. In this large literature, we believe one of the most important is Rodriguez and Rodrik (2001). Rodriguez and Rodrik (RR) demonstrated that some of the leading empirical research that found a strong role for trade policy had either flaws in the methodology or results that were not robust.[3] Two of RR's prescriptions for future research were to study contingent relationships and to study the "channels through which trade policies influence economic performance." Our methodology is consistent with these prescriptions. We conduct a case study, i.e., a particularly

[3] Wacziarg and Welch (2008) address most of Rodriguez and Rodrik's critique of Sachs and Warner (1995). However, some of the broader concerns in the critique remain.

sharp contingent relationship, and by using a structural model, we study several channels by which trade can influence growth.

On the theoretical side, led by Grossman and Helpman (1991), the last 20 years has seen the development of the endogenous and semi-endogenous growth frameworks and the numerous models engendered by them. However, very few models have been applied to study actual growth experiences, including the growth miracles. Broda, Greenfield, and Weinstein (2006) estimate the effect of imported varieties in the context of a Romer-type variety growth model. While our model is not a direct descendant of the endogenous or semi-endogenous growth literature, we believe our neoclassical framework is a useful one and provides a benchmark for further studies using the more modern frameworks.[4]

The next section presents the model and discusses the core intuition of the effects of trade barrier reductions. Section 3 provides the calibration of the model along with the key facts and policies that are used to both calibrate and evaluate the model. This is followed by the simulation of the trade liberalizations and the results. The final section concludes.

2 The Model

In this section, we describe the model. The model combines neoclassical trade with neoclassical growth. In a neoclassical trade framework, comparative advantage and the costs of international trade determine the pattern of production, specialization, and trade. We employ a Ricardian setting that draws from Eaton and Kortum (2001, 2002), as well as Yi (2003, 2010).[5] In the neoclassical growth framework, aggregate TFP and the stock of capital determine per capita output. The link between these two frameworks is that trade barrier reductions – by facilitating the reallocation of resources to their most efficient use – will increase aggregate TFP in the economy. If the trade barrier reductions also facilitate imports of investment goods, the aggregate capital stock will increase. Trade will increase of course, as well. A channel that can potentially accentuate the effect of trade barrier reductions is multi-stage production and the possibility of vertical specialization. Below, we first lay out the benchmark model, then we describe some of the key transmission

[4] Two papers that also use a neoclassical framework to study Korea in an open economy growth setting are Sposi (2012) and Teignier (2012). However, both papers are focused more on explaining Korea's structural transformation, rather than Korea's growth or growth catch-up as a result of trade policy. There have been closed economy models that have been calibrated to study Korea's experience; see, for example, Chang and Hornstein (2011) and Papageorgiu and Perez-Sebastian (2006).

Ventura (1997) develops a neoclassical growth framework with Heckscher-Ohlin trade.

[5] See also Alvarez and Lucas (2007), Waugh (2010), and Caliendo and Parro (2011).

channels. We also show how the model is modified to allow for one of Korea's trade policy reforms.

2.1 Technologies

There are two countries, H and F. There are two sectors, an investment goods sector and a consumption-cum-intermediate goods sector. (Hereafter, we will refer to the second sector as the consumption sector.) Each sector consists of a continuum of goods. An investment good $z \in [0,1]$ is produced from capital, labor, and the aggregate intermediate good. These investment goods are costlessly combined to yield an aggregate, non-traded, investment good that adds to the economy's capital stock. A consumption good $z \in [0,1]$ is produced in two sequential stages, i.e., there is multi-stage production of consumption goods.[6] First, capital, labor and the aggregate intermediate are combined to make a "stage 1" good. Then, the stage 1 good is combined with capital and labor to make the "stage 2" good. These stage 2 goods are costlessly combined to yield an aggregate, non-traded good used for consumption and as an intermediate in production. All stages of the continuum of investment and consumption goods are tradable. Only the aggregate goods are non-tradeable.

The production function for stage 1 consumption goods is given by:

$$y_{i1}(z) = (A_{i1}(z)k_{i1}(z)^{\alpha}l_{i1}(z)^{1-\alpha})^{1-\theta_1}M_i(z)^{\theta_1} \qquad z \in [0,1] \tag{1}$$

where $A_{i1}(z)$ is country i's total factor productivity associated with stage 1 good z, and $k_{i1}(z)$, $l_{i1}(z)$, and $M_i(z)$ are country i's inputs of capital, labor and aggregate intermediate M_i used to produce $y_{i1}(z)$. The share of intermediates in production is θ_1.[7] This first stage is a Cobb-Douglas version of the production function in Eaton and Kortum (2002) with value-added augmented to include capital.

The production function for stage 2 consumption goods is given by:

$$y_{i2}(z) = (A_{i2}(z)k_{i2}(z)^{\alpha}l_{i2}(z)^{1-\alpha})^{1-\theta_2}x_{i1}(z)^{\theta_2} \qquad z \in [0,1] \tag{2}$$

where $x_{i1}(z)$ is country i's use of $y_1(z)$ for stage 2 production, $A_{i2}(z)$ is country i's total factor productivity associated with stage 2 good z, and $k_{i2}(z)$ and $l_{i2}(z)$ are country i's labor used in

[6] Eaton and Kortum (2001) show that capital goods production is dominated by a few advanced countries. Consequently, we assume these goods are produced in a single stage.

[7] Including intermediates in the first stage of production facilitates matching gross output, trade, and value-added in the calibration.

producing $y_{i2}(z)$. Under autarky, $x_{i1}(z) = y_{i1}(z)$. The share of intermediates for this stage is θ_2.

The stage 2 consumption goods are costlessly assembled to produce an aggregate non-traded good X_i, which is used for consumption, C_i, and as an intermediate in production, M_i:

$$X_i = \exp\left[\int_0^1 \ln(x_{i2}(z))dz\right] = C_i + M_i \tag{3}$$

where $x_{i2}(z)$ is the amount of the stage 2 good z used to produce X_i.

Investment goods are also produced from capital, labor and the aggregate intermediate:

$$y_{iI}(z) = (A_{iI}(z)k_{iI}^{\alpha}(z)l_{iI}(z)^{1-\alpha})^{1-\theta_1}M_{iI}(z)^{\theta_1} \qquad z \in [0,1] \tag{4}$$

where $A_{iI}(z)$ is country i's total factor productivity (TFP) associated with the investment good z, and $k_{iI}(z)$, $l_{iI}(z)$, and $M_{iI}(z)$ are country i's inputs of capital, labor and aggregate intermediate M_i used to produce $y_{iI}(z)$. These investment goods are costlessly assembled into an aggregate non-traded investment good, I_i:

$$I_i = \exp\left[\int_0^1 \ln(I_i(z))dz\right] \tag{5}$$

where $I_i(z)$ is country i's use of $y_{iI}(z)$ for production of I_i.

Note that the capital share of value-added is the same across all production functions and countries. This is a requirement for comparative advantage to be based solely on Ricardian motives. In a Ricardian trade model, comparative advantage is based on relative productivity differences across countries. That is, the TFP terms $A_{i1}(z), A_{i2}(z)$, and $A_{iI}(z)$ determine comparative advantage. Following Eaton and Kortum (2002), hereafter, EK, we model the TFPs as being drawn from a Frechét probability distribution:

$$F(A_{ix}) = e^{-T_{ix}A_{ix}^{-n}} \quad i = H, F \tag{6}$$

The mean of A_{ix} is increasing in T_{ix}. n is a smoothness parameter that governs the heterogeneity of the draws from the productivity distribution. The larger n is, the lower the heterogeneity or variance of A.

2.2 Trade Costs

When the stage 1 or stage 2 consumption goods or the investment goods are shipped from country i to country j, they incur three types of trade costs, all expressed in ad valorem terms: tariffs, b_{ij}; transport costs, d_{ij}, and a stand-in for all other trade costs, tr_{ij}. Total trade costs are given by $1+\tau_{ij} = (1+b_{ij})(1+d_{ij})(1+tr_{ij})$. The costs are modeled as iceberg costs. So, if 1 unit of a good z is shipped from country i to country j, for example, then $1/(1+\tau_{ij})$ units of z arrive in country j.[8] We assume that within country trade costs are zero. $1+\tau_{ix}(z)$ denotes the shipping costs associated with country i purchasing good z of type x (stage 1 consumption, stage 2 consumption, or investment) from its cheapest source, i.e., $1+\tau_{ix} = 1+\tau_{jix}$ if country j is the cheapest source for country i's purchase. Note that the cheapest source for country i's purchase of stage 1 consumption good z may not be the cheapest source for country i's purchase of stage 2 consumption good z or of investment good z.

2.3 Prices

We assume perfect competition in all stages, including the aggregator stages, of both types of goods. The price that a stage 2 consumption good firm in country j pays to purchase stage 1 of consumption good z from a country i firm is given by:

$$p_{ij1}(z) = \frac{\psi_1(1+\tau_{ij1})(R_i^{\alpha} w_i^{1-\alpha})^{1-\theta_1} P_i^{\theta_1}}{A_{i1}(z)^{1-\theta_1}} \tag{7}$$

where $\psi_1 = (\alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)})^{1-\theta_1}\theta_1^{-\theta_1}(1-\theta_1)^{-(1-\theta_1)}$, and w_i, R_i, P_i, and $A_{i1}(z)$ are country i's wage rate, rental rate on capital, price of the aggregate intermediate good, and stage 1 consumption good productivity for good z. The actual price that the stage 2 consumption good firm in country j will pay is $p_{j1}(z) = \min\left[p_{ij1}(z); i = H, F\right]$.

The price that the consumption aggregator firm in country j pays to purchase stage 2 of consumption good z from a country i firm is given by:

$$p_{ij2}(z) = \frac{\psi_2(1+\tau_{ij2})(R_i^{\alpha} w_i^{1-\alpha})^{1-\theta_2} p_{i1}(z)^{\theta_2}}{A_{i2}(z)^{1-\theta_2}} \tag{8}$$

where $\psi_2 = (\alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)})^{1-\theta_2}\theta_2^{-\theta_2}(1-\theta_2)^{-(1-\theta_2)}$. The actual price that the consumption aggregator firm in country j pays is $p_{j2}(z) = \min\left[p_{ij2}(z); i = H, F\right]$.

[8] Tariff revenue is assumed to have no productive or consumption value.

Similarly, the price that an investment aggregator firm in country j pays to purchase investment good z from a country i firm is given by:

$$p_{ijI}(z) = \frac{\psi_1(1+\tau_{ijI})(R_i^{\alpha} w_i^{1-\alpha})^{1-\theta_1} P_i^{\theta_1}}{A_{iI}(z)^{1-\theta_1}} \tag{9}$$

The actual price that the investment aggregator firm in country j pays is $p_{jI}(z) = \min\left[p_{ijI}(z); i = H, F\right]$. Suppose that for the consumption aggregator firm in country j the cheapest source of stage 2 of consumption good z is country i, and for the stage 2 consumption good firm z in country i, the cheapest source of its stage 1 consumption good is from country j. Now suppose trade costs fall by a small enough amount that the cheapest sources for the consumption aggregator firm in country j, and for the stage 2 consumption good firm z in country i, do not change. Then the cost of the stage 2 consumption good z to the aggregator firm in country j falls in log terms by $(1+\theta_2)$ times the reduction in trade costs. This multiplicative effect is one of the forces underlying the magnification effect with vertical specialization.

2.4 Households

The representative household in country i maximizes:

$$\sum_{t=0}^{\infty} \beta^t \frac{C_{it}^{1-\sigma} - 1}{1-\sigma} \tag{10}$$

subject to a sequence of budget constraints:

$$P_{it}C_{it} + P_{iIt}I_{it} = w_{it}L_{it} + r_{it}K_{it} \tag{11}$$

where C_{it} is consumption of the aggregate consumption good in period t. The elasticity of intertemporal substitution is $\frac{1}{\sigma}$. Households own the capital and rent it period-by-period to the consumption and investment goods firms.[9] Capital is accumulated in the standard way:

$$K_{it+1} = (1-\delta)K_{it} + I_{it} \tag{12}$$

[9]Note that we do not allow the countries to run current account deficits. S. Korea ran current account deficits during the 1960s and 1970s, and then balanced trade or surpluses beginning in the mid-1980s. Allowing for current account deficits would be a useful extension.

2.5 Equilibrium conditions

All factor and goods markets are characterized by perfect competition. The following factor market clearing conditions hold for each country in each period:

$$L_i = \int_0^1 l_{i1}(z)dz + \int_0^1 l_{i2}(z)dz \ + \int_0^1 l_{iI}(z)dz \tag{13}$$

$$K_i = \int_0^1 k_{i1}(z)dz + \int_0^1 k_{i2}(z)dz \ + \int_0^1 k_{iI}(z)dz \tag{14}$$

The stage 1 consumption goods market equilibrium condition for each z is:

$$y_1(z) \equiv \sum_{i=1}^{2} y_{i1}(z) = \sum_{i=1}^{2}(1+\tau_{i1}(z))x_{i1}(z) \tag{15}$$

where $1+\tau_{i1}(z)$ is the total trade cost incurred by shipping the stage 1 good from country i's cheapest source to country i. The condition states that total production of the stage 1 good equals the total demand, inclusive of trade costs, for that good. A similar set of conditions applies to each stage 2 consumption good z and each investment good z:

$$y_2(z) \equiv \sum_{i=1}^{2} y_{i2}(z) = \sum_{i=1}^{2}(1+\tau_{i2}(z))x_{i2}(z) \tag{16}$$

$$y_I(z) \equiv \sum_{i=1}^{2} y_{iI}(z) = \sum_{i=1}^{2}(1+\tau_{iI}(z))I_i(z) \tag{17}$$

Finally, the aggregate consumption and intermediate good must be completely absorbed:

$$X_i = C_i + M_i = C_i + \int_0^1 M_i(z)dz + \ + \int_0^1 M_{iI}(z)dz \tag{18}$$

If these conditions hold, then each country's exports equals its imports, i.e., balanced trade holds. We now define the equilibrium of this model:

Definition 1 *An equilibrium is a sequence of goods prices,* $\{p_{i1}(z)$, $p_{i2}(z)$, $p_{iI}(z)$, P_i, $P_{iI}\}$; *factor prices,* $\{w_i, r_i\}$; *factor inputs,* $\{l_{i1}(z)$,$l_{i2}(z)$,$l_{iI}(z)$,$k_{i1}(z)$,$k_{i2}(z)$,$k_{iI}(z)\}$; *intermediate inputs,* $\{M_i(z)$,$M_{iI}(z)\}$; *and outputs,* $\{y_{i1}(z)$,$y_{i2}(z)$,$y_{iI}(z)$,$x_{i1}(z)$,$x_{i2}(z)$,$I_i(z)$,C_i,I_i,$M_i\}$, $z \in [0,1]$, $i =$

H, F, such that the first order conditions to the households' maximization problem 10, the first order conditions to the firms' maximization problems associated with production functions 1-5, as well as the market clearing conditions 13-18 are satisfied.

2.6 Trade, Vertical Specialization, and Growth and Income

We now discuss the model's implications for specialization and trade, and for steady-state per capita income. The former can be characterized in a static context, while the latter involves the dynamics of capital accumulation.

2.6.1 Trade

Under autarky, each country produces the entire range of stage 1 consumption goods, stage 2 consumption goods, and investment goods. There is no specialization.

At the other extreme is frictionless trade – tariffs, transport costs, and all other trade costs are zero – which yields complete specialization. Each stage of each good will be produced by only one country. Which country produces which stage of which good depends on the interplay of relative productivity differences across countries and relative factor costs. For example, consider an investment good z. There are two possible production methods, producing it in country H or producing it in country F. The good will be produced in country H if the following condition holds:

$$p_{HI}(z) \equiv \frac{\psi_1 (w_H^{1-\alpha} r_H^{\alpha})^{1-\theta_1} (P_H)^{\theta_1}}{A_{HI}(z)^{1-\theta_1}} < \frac{\psi_1 (w_F^{1-\alpha} r_F^{\alpha})^{1-\theta_1} (P_F)^{\theta_1}}{A_{FI}(z)^{1-\theta_1}} \equiv p_{FI}(z) \tag{19}$$

This can be rewritten as:

$$(\omega^{1-\alpha} \rho^{\alpha})^{1-\theta_1} (P_H)^{\theta_1} < \left(\frac{A_{HI}(z)}{A_{FI}(z)} \right)^{1-\theta_1} \tag{20}$$

where $\omega = w_H/w_F$, $\rho = r_H/r_F$, and we treat the foreign aggregate consumption (and intermediate) good as the numeraire. The above equation essentially says that if the ratio of production costs between the two countries is less than the ratio of TFPs, the good will be produced in the home country. More generally, the world price of an investment good z, $p_I(z) = \min [p_{HI}(z), p_{FI}(z)]$.

In general equilibrium, wages, rental rates, and intermediate goods prices are determined so that each country's production equals its spending or, put differently, each country's exports equals its imports. Each country will find some goods for which the other country is the low cost producer. This is the essence of comparative advantage and general equilibrium. For example, suppose that consumption and investment goods were produced only in a single stage. If both countries had

the same labor endowment, and if both sets of productivities were drawn from the same Frechét distribution, then in equilibrium wages and rents would be equalized, and the export share of GDP would be 1/2. Each country would specialize in half the goods, and would import the other half.

For stage 2 consumption good z, there are four possible production methods: HH, FH, HF, and FF, where FH means the first stage is produced in country F and the second stage is produced in country H. If the second stage is produced in H, then $p_{H2}(z) = \min[p_{HH}(z), p_{FH}(z)]$. Similarly, if the stage 2 good is produced in F, then $p_{F2}(z) = \min[p_{HF}(z), p_{FF}(z)]$. Then, the world price of the good, $p_2(z) = \min[p_{H2}(z), p_{F2}(z)] = \min[p_{HH}(z), p_{FH}(z), p_{HF}(z), p_{FF}(z)]$.

If one country is relatively more productive at making investment goods than consumption goods, then it will tend to specialize in investment goods, and run a trade surplus in those goods and a trade deficit in consumption goods. However, owing to our distributional assumptions about the productivities, the country will also import some investment goods, and produce and export some consumption goods. In this sense, there is intra-industry trade.[10]

In the presence of non-zero trade costs, there will be incomplete specialization. Some stages of some goods will be made by both countries, as each will find it cheaper to purchase its own-produced goods rather than pay relatively high shipping costs to import an otherwise cheaper good. Trade shares of output will be lower. A key force determining the elasticity of trade with respect to trade costs is the parameter n from the Frechét distribution, which determines the variance of heterogeneity in productivities. If n is low, there is a great deal of heterogeneity, which makes it likely that one country is much more productive at making a good than the other country. Hence, specialization and trade patterns will not respond too much to changes in trade costs. The opposite is true if n is high. Eaton and Kortum (2002) show that n plays the same role in their model as $\sigma - 1$, where σ is the elasticity of substitution between goods, in the monopolistic competition or Armington aggregator-based trade models.

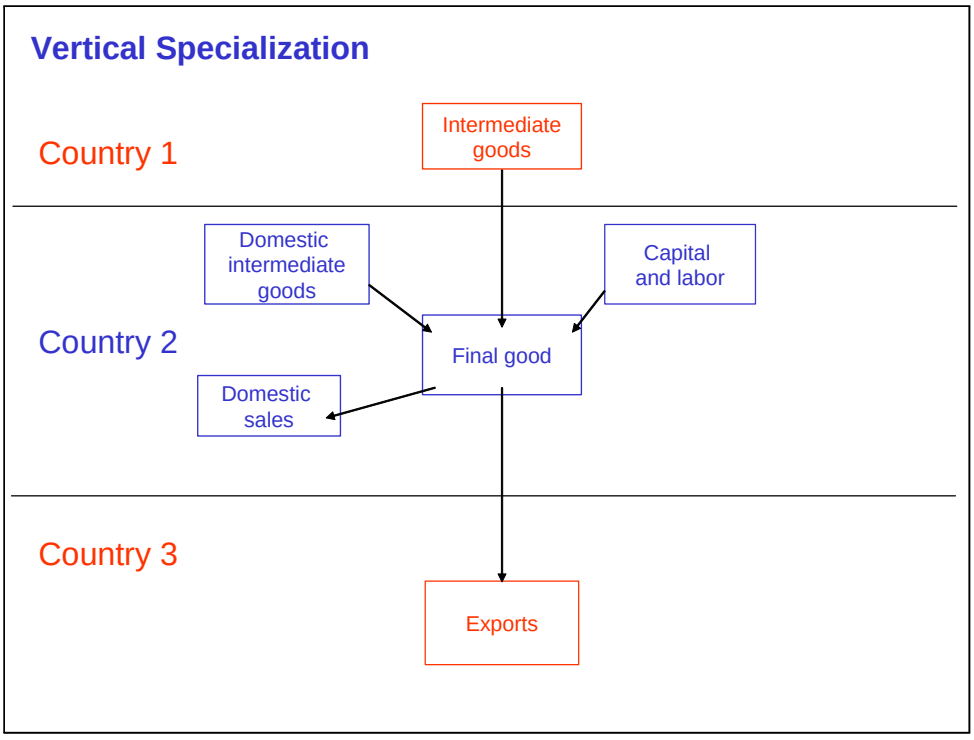
2.6.2 Vertical Specialization

Much of this section follows from Hummels, Ishii, and Yi (HIY, 2001) and Yi (2010).[11] For consumption goods, the presence of multi-stage production leads to the possibility of vertical specialization. Drawing from HIY, we define *vertical* specialization to occur when one country uses inputs

[10] See Davis (1995), which is, to our knowledge, the first model of intra-industry trade in a perfect competition, comparative advantage setting.

[11] Also, see Hummels, Rapoport, and Yi (1998), and Yi (2003). Johnson and Noguera (2012), among others, have generalized and extended the methodology of HIY (2001). In our calibration, vertical specialization is computed from the model in the same way HIY compute it in the data.

Figure 3: Vertical Specialization

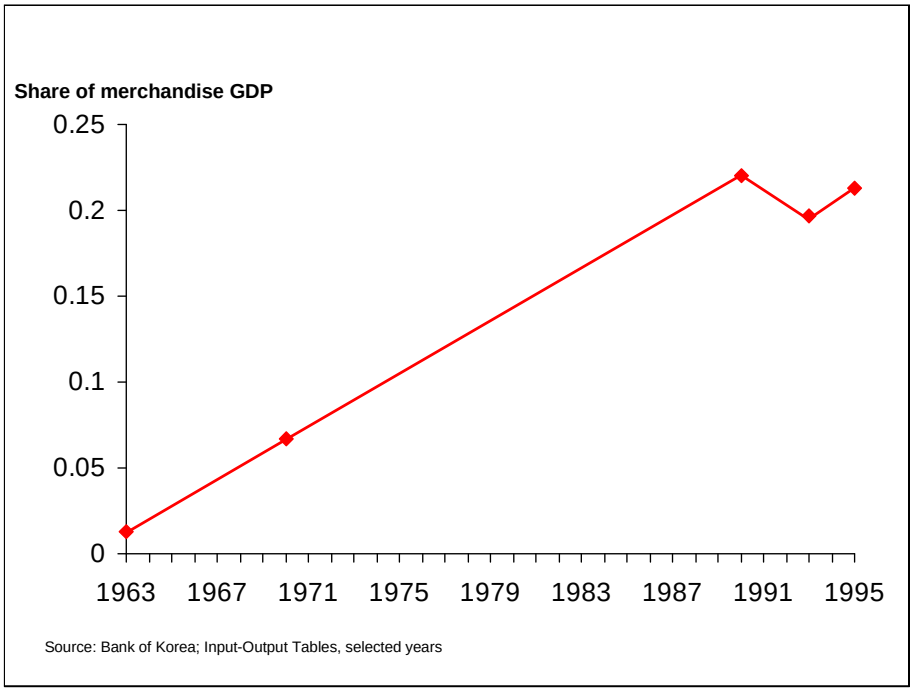


imported from another country in its stage of the production process, and some of the resulting output is exported to another country. Figure 3 illustrates an example of vertical specialization involving three countries. The key country is country 2. It combines the imported intermediates with other inputs and value-added to produce a final good or another intermediate good in the production chain. Then, it exports some of its output to country 3. If either the imported intermediates or exports are absent, there is no vertical specialization. By this definition, consumption goods produced by production method FH and exported back to country F or goods produced by production method HF and exported back to country H are vertically specialized. A necessary condition for vertically specialized production of a good to occur is for one country to be relatively more productive in the first stage of production and another country to be relatively more productive in the second stage. Under frictionless trade, if relative production costs are "between" these two relative productivities, then this necessary condition is also sufficient.

Hummels, Ishii, and Yi (HIY) develop two measures of vertical specialization. Their primary measure is VS:

$$VS_{ki} = \left(\frac{Imported\ intermediates_{ki}}{Gross\ output_{ki}} \right) Exports_{ki} \tag{21}$$

Figure 4: Korea Vertical Specialization (VS) as share of merchandise GDP



where k and i denote country and good, respectively. The measure is essentially the imported intermediates content of exports. HIY use data from input-output tables to come up with industry-level and national measures of vertical specialization for several countries over time.[12] Figure 4 illustrates VS_{korea} expressed as a share of merchandise GDP. The figure shows that it rose rapidly in Korea from around 0.01 to 20 times that by the 1990s.

Clearly, growth in vertical specialization has been a large part of Korea's trade experience. This is the reason we model consumption goods production as a multi-stage process. Yi (2003) demonstrates that with multi-stage production and vertical specialization, the effects of trade barrier reductions on trade are magnified. Here, we provide a simple example to illustrate this point and describe the intuition underlying it.

Consider a special case of the model in which the countries are symmetric and there is only one sector, the consumption goods sector. The capital stock is exogenous and fixed. We assume that the two countries have the same capital and labor endowments, the same underlying distribution of TFPs for each stage of production, and the same trade costs. This implies that wages, rents,

[12] An additional advantage of using input-output tables is that they facilitate measuring the indirect import content of exports. Inputs may be imported, for example, and used to produce an intermediate good that is itself not exported, but rather, used as an input to produce a good that is. See Hummels, Ishii, and Yi (2001).

and GDPs are equalized across countries. We also assume that the first stage of production is produced in the country that ultimately purchases the second stage good; only the second stage production location is determined by the model. Thus, if an H aggregator firm seeks to purchase an automobile, the parts and components are assumed to be produced in H, while final assembly can occur either in H or F. This assumption ensures that an analytical expression for the import share of GDP exists.

For goods consumed by the home country, the two possible production methods are HH and HF. Note that production method HF involves international vertical specialization: the foreign country imports inputs and exports its resulting output back to H. Following Dornbusch, Fischer, and Samuelson (1977) we can arrange the stage 2 goods in descending order of the ratio of home to foreign productivity of stage 2 production. International imports for the home country expressed as a share of GDP are given by:

$$\varphi(1 - \underline{z}_h) \tag{22}$$

where $\underline{z}_h$ denotes the cutoff that separates home and foreign production of stage 2 goods for the home market. φ is a constant that depends on θ_1 and θ_2. In the appendix, we show that the solution for $\underline{z}_h$ is given by:

$$\underline{z}_h = \frac{(1+\tau)^{n\left(\frac{1+\theta_2}{1-\theta_2}\right)}}{1+(1+\tau)^{n\left(\frac{1+\theta_2}{1-\theta_2}\right)}} \tag{23}$$

Then, the import share of GDP is:

$$\frac{\varphi}{1+(1+\tau)^{n\left(\frac{1+\theta_2}{1-\theta_2}\right)}} \tag{24}$$

Note that the responsiveness of the import share of GDP to trade costs depends on the "elasticity" n, and also on the term $\left(\frac{1+\theta_2}{1-\theta_2}\right)$, which shows that multi-stage production magnifies the effects of trade costs. If $\theta_2 = 2/3$, for example, the exponent on the trade cost is five times larger than in a one-stage model. As discussed in Yi (2010), two forces underlie the $\left(\frac{1+\theta_2}{1-\theta_2}\right)$ term. The first force is a "back-and-forth" force. With the HF production process, the first stage encounters trade costs twice; recall that the share of stage 1 goods in stage 2 production is θ_2. Consequently, the total effect of the trade cost owing to this force is $1 + \theta_2$. The second force is an "effective rate of protection" force, because the concept is analogous to the concept from the literature of that name. The trade-off between HH and HF hinges on the second stage of production. The key

idea is that the relevant or effective trade cost is the trade cost divided by the share of the second stage's value-added in the total cost. This is because the second stage is the marginal production stage, but the trade cost is applied to the entire good. If the second stage value-added accounts for one-third of the total cost, for example, then the effective trade cost is three times the nominal trade cost. This explains the $\frac{1}{1-\theta_2}$ term.[13] Note that the magnification of trade costs is independent of the intermediate input share θ_1. The presence of intermediates is necessary, but not sufficient, for a magnification effect.

2.6.3 Growth and Income

In this paper, we focus on the steady-state.[14] Long run per capita income growth in our model is driven by long run growth in TFP. In this context, our primary growth assumption is that the growth rate of the parameters that governs the mean productivities, T_{ix}, is constant across the two countries. That is, the two countries have identical long run per capita growth rates.

The goal of our paper is to focus on Korea's catch-up in per capita income to the G7. Hence, with no loss of generality, we set the long run growth rate of T to be zero. Per capita growth in the steady-state is zero. What determines the *level* of per capita income? The key equation arises from the consumption Euler equation. For the home country, the steady-state Euler equation is:

$$\frac{r_{H,ss}}{P_{HI,ss}} = \frac{1}{\beta} - (1-\delta) \tag{25}$$

All else equal, the lower the steady-state price index for investment goods, $P_{hI,ss}$, the lower the required rate of return on capital, leading to a higher capital stock and a higher per capita income. $P_{HI,ss}$ is given by:

$$P_{HI,ss} = \exp\left(\int_{H^I} \ln(p_{HI}(z))dz + \int_{F^I} \ln((1+\tau_{HI})p_{FI}(z))dz\right) \tag{26}$$

where H^I denotes the set of goods z such that the lowest cost production source is in H. A

[13] Another way to explain the $\left(\frac{1+\theta_2}{1-\theta_2}\right)$ term is via the following decomposition. In the HF production process, the first stage encounters trade costs when it is shipped to the foreign country. The trade costs are equivalent to a cost on the second stage of production of $(1+\tau)^{\frac{\theta_2}{1-\theta_2}}$. Trade costs are encountered again when the final good is shipped back to the home country from the foreign country. Now the trade cost is applied to the entire good. Consequently, a cost of $1+\tau$ is imposed on the entire HF-produced good, which is effectively a cost of $(1+\tau)^{\frac{1}{1-\theta_2}}$ on the second stage of production. The total effect is the product of these two forces. If trade costs fall, the cost of producing vertically specialized goods declines by a multiple of the fall. See Yi (2010).

[14] We leave an analysis of transition dynamics to future work.

reduction in investment good trade costs, such as tariffs on investment goods, lowers $P_{HI,ss}$ through two channels. There is a direct channel arising from the fact that lower investment good trade costs lowers the costs of imported investment goods. There is a second channel in which the lower trade costs lead to a shift from relatively high cost domestic investment goods to relatively low cost imported investment goods. H^I falls and F^I rises, which also reduces the price of the aggregate investment good. Both channels lead to an increase in capital accumulation. Both channels also lead to an increase in trade, including imports of investment goods, and specialization. Because there is more specialization, there is more efficient resource allocation, leading to an increase in aggregate TFP. Note that aggregate TFP rises even though there has been no change in the efficiency of producing individual goods.

Suppose there is a reduction in consumption or investment good tariffs in country F. At existing factor and goods prices, country F will demand more imports of consumption and investment goods from H. This will raise the demand for factors of production, thus bidding up wage and rental rates in H. The increase in $r_{H,ss}$ will lead to greater capital accumulation. Another way of interpreting F's tariff reduction is that, because it facilitates more specialization and a better allocation of resources, aggregate TFP in H and F rise, thus leading to capital accumulation in both countries.

Klenow and Rodríguez-Clare (1997) and Hall and Jones (1999) employ growth accounting decompositions in which capital accumulation that is induced by increased TFP is attributed to TFP. Their decomposition can be thought of as one that divides output per worker growth into adjusted-TFP growth and growth in the capital-output ratio, K/Y. In our model, tariff and other trade cost reductions will show up as aggregate TFP increases with no change in K/Y ratios. In addition, because we have a two-sector model, we can interpret reductions in investment goods trade costs as investment-specific technical change, and reductions in consumption goods trade costs as neutral technical change. Thus, our model implies that trade contributes to the two types of technical change highlighted in Greenwood, Hercowitz, and Krusell (1997).

2.7 Implementing Korea's Tariff Exemption on Imported Inputs and Investment Goods

The model presented above will be used to characterize the initial steady-state, prior to the implementation of the trade policy reforms. One of Korea's major trade policy reforms, as discussed in the introduction, was to exempt imported inputs and imported investment goods from tariffs, as long as these imports were used to make goods that were exported. That is, with this reform, the

price that Korean firms paid for these imports depended on their ultimate destination.

In the language of our model, with this policy, stage 2 goods z that are produced in the following way: country F makes stage 1, and country H (Korea) makes stage 2, i.e., production method FH, and that are subsequently exported to country F, become cheaper to produce. They are cheaper via two channels. First, Korea's import tariff no longer applies to the stage 1 goods z imported from F by Korea. Second, the capital used to produce stage 2 will consist of investment goods z, some of which were imported without tariffs, as well. Consequently, from the perspective of the foreign consumption aggregator firm, stage 2 goods produced via method FH are now cheaper, and more of these goods will be purchased.

Implementing the tariff exemption on these particular imported inputs is straightforward. Implementing the tariff exemption on these particular imported investment goods is more complicated because these investment goods can only be a part of a capital stock that is used to produce goods via FH (and that are exported). To encompass this, we introduce to our model a second capital stock in country H (Korea), K_H^E, which is used only to produce goods via FH that are subsequently exported. This capital stock is accumulated via a second aggregate investment good, I_H^E. This second aggregate investment good is a composite of domestic investment goods z and of investment goods z that are imported duty-free. The first capital stock is the same as before, except it is not used to produce the FH-and-subsequently-exported goods.

The budget constraint for the household in country H is now:

$$P_{Ht}C_{Ht} + P_{HIt}I_{Ht} + P_{HIt}^E I_{Ht}^E = w_{Ht}L_{Ht} + r_{Ht}K_{Ht} + r_{Ht}^E K_{Ht}^E \tag{27}$$

where P_{HIt}^E and r_{Ht}^E are the price of the aggregate investment good and the rental rate on the aggregate capital stock, respectively, that are used to make export goods via FH.

3 Calibration to Korea and G7

We now calibrate the model presented in sections 2.1-2.5. The two countries H and F are Korea and the G7 countries. The latter were recipients of 74% of Korea's exports and shipped 86% of Korea's imports in 1962 (and larger shares subsequently). We calibrate the model to the manufacturing sector of the two sets of countries. We choose this approach rather than calibrating the entire economy for three main reasons. There are more data available on manufacturing, and, because manufactured goods are traded more, it facilitates constructing measures of output that

are comparable across countries. Second, Korea underwent an enormous structural transformation, which would necessitate modeling individual sectors and their interactions, if the calibration was to the entire economy. This is beyond the scope of this paper. Finally, manufacturing has been the single most important sector in Korea's growth; this is the sector that exhibited, by far, the highest productivity growth in Korea, and that also was responsible for virtually all of the increase in trade. Understanding the evolution of manufacturing value-added per worker in Korea relative to the G7 is crucial to understanding Korea's overall growth.

Our coverage is from 1962 through 1995, the period that constitutes the growth miracle and that precedes the Asia financial crisis.[15] We assume that Korea was in a steady-state in 1962 in which the current tariff rates are expected to remain forever. Then there is an unexpected tariff reform, e.g., the reduction in Korean tariffs to their 1989 value – and this new policy is expected to remain in place forever. We compute the new steady-state and compare that to data from 1995.[16]

The parameters and variables that are calibrated include the labor endowments L_i of each country; the intermediate input shares θ_1 and θ_2, the capital income share, the Frechét heterogeneity parameter n, the Frechét mean productivity parameters T, capital depreciation rate, preference discount factor, intertemporal elasticity of substitution, and the trade cost measures for each country and sector. The trade costs include tariff rates, transport costs, and all other trade costs.

The labor endowments, intermediate input shares, capital income share, tariff rates and transport costs are set to match their data counterparts in 1962 or 1963. The Frechét heterogeneity parameter n, capital depreciation rate, preference discount factor, and intertemporal elasticity of substitution draw from past, related research. The Frechét mean productivity parameters for the consumption and investment sectors and "all other" trade costs for consumption goods and investment goods are set so that the model matches Korea's initial relative per worker output, export share of GDP, and shares of trade that correspond to investment goods and final consumption goods. The challenge for the model is whether the tariff liberalizations will replicate the per worker output, trade, vertical specialization, investment, and TFP catch-up that is in the data.

We begin by describing our measures of transport costs and tariff rates. We then show how we calibrated the other variables and the parameters of the model.

[15] 1962 is a desirable starting date, because it is the first full year after Park took office. However, much of our initial data is available only for 1963.

[16] We compare the steady-state of the model economy with the 1989 tariffs to data from 1995 to allow for the transition dynamics to complete.

3.1 Transport Costs and Tariff Rates

We now construct the data counterpart of the trade costs between country i and country j, $(1 + \tau_{ij}) = (1 + b_{ij})(1 + d_{ij})(1 + tr_{ij})$. For transport costs, d_{ij}, we use Korea's cost, insurance, and freight (cif) imports / free on board (fob) imports ratio in 1962, obtained from the 1992 IMF IFS yearbook. The difference between the two measures of imports is primarily the insurance and freight costs. In 1962, the difference was equal to 9.2 percent of Korea's fob imports. We assume these costs apply to Korea's exports, as well, and that the transport costs are the same across all stages of all goods. Because our focus is on the effects of tariff reductions, we hold the transport costs constant over time. We assume that there are no distortions in the economy other than the trade barriers. Westphal and Kim (1977) demonstrate that Korean manufacturing exporters operated in an essentially free-trade environment (once the reforms were implemented).

We obtain measures of Korean tariff rates from Nam (1995). As import-weighted average tariff rates are well known to have downward biases, we use his simple average measure. He reports this average for several years between the early 1960s and the mid 1990s. The average tariff rate was 39.9 percent in 1962 and remained at a high level until the 1970s. Thereafter, it declined steadily to 12.7 percent in 1989. We obtain measures of G7 manufacturing tariff rates from Yi (2003). This is an average of the United States tariff and a tariff measure that is a weighted average of Japan and European Community tariff rates.[17] These tariffs apply to all stages of all goods, except for the tariff exemption policy we will implement below. The initial and post-reform tariff rates are listed in Table 1 below.

Table 1: Tariff Rates (percent)

	Country	
	Korea	G7
1962	39.9	13.95
1989	12.7	5.00

Sources: Nam (1995) and Yi (2003)

[17] The Korean tariff measure is for merchandise, rather than manufacturing. Agriculture and mining tariffs appear to constitute a small number of the total number of goods, so that while these tariffs tend to be lower than manufacturing taiffs, we do not believe this discepancy will exert more than a minor influence on our results. In addition, our G7 measure excludes Canada, but includes countries outside the G7. However, because these additional countries are not large, we believe that this discrepancy will also not exert a large effect on our results.

We have no independent measure of "all other" trade costs. Consequently, we calibrate two trade costs, tr_{ijC} and tr_{ijI}, one for both stages of consumption goods and one for investment goods, as part of our overall calibration of four key variables and parameters to four targets. This is discussed further below.

3.2 Calibration of Other Variables and Parameters

We calibrate the labor endowments L_i to match manufacturing employment in Korea and the G7 in 1963. We begin with the measures of workers from the Penn World Tables (PWT 6.1). We use the Bank of Korea's Economic Statistics Yearbook to obtain the manufacturing share of employment in 1963 and multiply that by Korea's employment from the PWT. This yielded 743.3 thousand manufacturing workers. For the G7, we used the OECD's STAN database, which has manufacturing and total employment data for each of the G7 countries. However, these data start only in 1970. We assume the manufacturing share of employment in 1963 was the same as in 1970. We multiply this share by G7 employment from the PWT and obtain 62.13 million manufacturing workers. We also assume that the labor endowments are constant over time.

Turning to the intermediate shares, θ_1 and θ_2, when $\theta_1 = \theta_2 = \theta$, it can be shown that the value-added/gross output ratio in each country is $1 - \theta$. In Korea, the value-added/gross output ratio in 1963 was 0.31. In the G7 nations, this ratio ranged from a low of 0.32 (Japan) to a high of 0.39 (United States).[18] We set $\theta_1 = \theta_2 = \theta = 2/3$.

The labor income share, $1 - \alpha$, varies widely across countries. According to Young (1995), Korea's labor share of value-added in manufacturing was 0.504 percent in the early 1960s. From the STAN database, the labor share in 1970 ranged from a low of 0.399 (Japan) to 0.742 (United Kingdom). In the United States, it was 0.728. We set $\alpha = 0.4$.

The key trade elasticity parameter other than the intermediate shares is the heterogeneity in productivity parameter, n. As stated above, this corresponds to an elasticity of substitution of $n + 1$ in monopolistic competition or Armington aggregator models.[19] (Hereafter, we refer to the elasticity-equivalent of the parameter.) This elasticity is assumed identical across countries. EK's estimates of n range from 3.6 to 12.86. Other prominent estimates include Baier and Bergstrand (2001) and Head and Ries (2001), who estimate substitution elasticities of 6.43 and 7.9, respectively. In the previous section, we demonstrated that under multi-stage production the responsiveness of

[18] There were no data for West Germany in 1970.

[19] See Eaton and Kortum (2002, p. 1750, fn. 20) or Anderson and van Wincoop (2004, p. 710).

trade to trade costs depends on both the elasticity of substitution and the "magnification effect". Consequently, existing estimates of the substitution elasticity may be upwardly biased. Moreover, Simonovska and Waugh (2011) show that one approach used in EK yields estimates that are upwardly biased. They employ an estimator to correct for the bias and find an elasticity of around 4, roughly half of the EK estimate. Hence, we set $n = 4$.

Three dynamic parameters are set by using values from related research. Ogaki, Ostry, and Reinhart (1996) estimate the intertemporal elasticity of substitution, $1/\sigma$, to be 0.6 for developing countries. The next two parameters are drawn from Backus, Kehoe, and Kydland (1994). We set the annual capital depreciation rate, δ, to 0.1.[20] Finally, we set β, the preference discount factor, to 0.96, which corresponds to a real interest rate in steady-state of a little more than 4 percent.

The final parameters to specify are the Frechét mean productivity parameters, T_{iC} and T_{iI}, for the two stages of the consumption good and the single investment stage for each country – six parameters total – and "all other" trade costs for trade between the two countries in each of the two consumption stages and the single investment stage. With no loss of generality, we normalize the productivity parameters for the United States consumption and investment sectors to 1. We assume that Korea has no particular comparative advantage in stage 2 production relative to stage 1 production. This reduces the six productivity parameters to effectively two. We also assume that there is a single all other trade cost that applies to the final (stage 2) consumption goods imported into Korea, $tr_{RK,C2}$, and there is a single all other trade cost that applies to stage 2 consumption goods imported into the ROW, and to all flows of the stage 1 consumption goods, and the investment goods. This reduces the number of distinct all other trade costs to two, as well. We set the two productivity parameters and the two all other trade costs so that the model matches four targets in 1963: Korea / G7 manufacturing output per worker; Korean export share of GDP; share of imported investment goods in Korea's GDP; share of Korea's imports that are consumption goods.[21] In other words, we set these parameters and costs so that the model-implied steady-state for Korea matches the key facts about Korea's per worker output and trade in manufacturing in

[20] Given that most investment goods produced by the manufacturing sector is equipment, a higher depreciation rate might be warranted. We solved the initial steady-state, as well as the effects of all three trade reforms, using the equipment depreciation rate from Jorgenson, Gollop, and Fraumeni (1987), 0.13. The results were virtually identical.

[21] Details on the calculation of manufacturing output per worker are given in the Appendix. The other three targets are obtained from the U.N. Comtrade database and the 1963 Korea input-output tables. A key issue in calculating the international trade targets is reconciling the balanced trade assumption of the model with the fact that Korea ran a substantial current account deficit in 1963. We assume that Korea's imports in 1963 equal its actual exports in that year. This is mainly because at that time Korea's deficit was finance primarily via foreign aid from the United States. In the absence of that foreign aid, it is likely that its imports would have been much closer to its exports. The four data targets are listed in Table 2. Matching these targets also implies that the model will match the share of intermediates in Korean trade.

1963.

Our assessment of the effects of Korea's and the G7 trade policies focuses on output per worker. It is essential to measure this variable in consistent units across counties, and to ensure that these measures match up with their model counterparts. On the first issue, we use current exchange rates to convert output into common units across countries; hence, our measure of output per worker in each country is the current dollar value of manufactured value-added per worker.[22] We justify this for three reasons. First, manufactured goods tend to be highly tradable, so that the law of one price is relatively more likely to apply.[23] Second, our primary metric in the simulations is the ratio of Korea's value-added per worker in current dollars to G7 value-added per worker in current dollars, i.e., a ratio of nominal values to eliminate effects associated with inflation. Third, using nominal measures avoids the problems that arise when using real measures indexed to a base year in evaluating changes in policies, as discussed in Kehoe and Ruhl (2008). Turning to the model, the natural model counterpart to our data measure is value-added per worker measured in terms of a common unit; we choose the common unit as the foreign (G7) consumption good. An alternative would be to measure Korea's output per worker in terms of home consumption goods, which would be closer to a welfare measure, but it would not be appropriate to compare Korea's output in terms of its consumption goods against G7 output in terms of *its* consumption goods, because they may have different prices, i.e., the real exchange rate may differ from one. Indeed, our simulations deliver real exchange rates that differ from one; moreover, the real exchange rate changes in response to the changes in trade policies.

Table 2 lists all the calibrated parameters and variables. The last four rows of the table show the values of the productivity parameters and trade costs that enable the model to meet the four targets in the initial steady-state. For ease of interpretation, the productivity parameters are normalized relative to the labor force in each country. The productivity parameters indicate that Korea has a comparative advantage at producing consumption goods over investment goods. Also, the all other trade costs for final consumption goods (70.0 percent) are considerably higher than for investment goods (19.3 percent). This largely reflects the fact that Korea had an extensive quota system applied primarily to consumption goods. This fact shows up in the very low share of imports that were consumption goods (2.52 percent). Hence, the total trade cost for consumption goods, including tariffs, transport costs, and all other costs, in 1962 was $1.399 \times 1.092 \times 1.700 - 1 = 159.7$

[22] Details on constructing this variable are in the Appendix.

[23] The ideal would be to construct a purchasing power parity measure for manufacturing in 1963, but, to our knowledge, the micro price and quantity data needed to do this do not exist.

percent.

Table 2: Other Calibrated Parameters and Variables

Parameter		Value
Korea labor, L_{Korea}		0.7433
G7 labor, L_{G7}		62.13
Intermediate input share, $\theta_1 = \theta_2$		2/3
Capital income share, α		0.4
Frechét heterogeneity, n		4
Intertemp. elasticity of substit., $1/\sigma$		0.6
Capital depreciation rate, δ		0.1
Preference discount factor, β		0.96
	Targets in 1963	
$\left(\frac{T_{Korea,C}/L_{Korea}}{T_{G7C}/L_{G7}}\right)$	$\frac{Y_{Korea}/L_{Korea}}{Y_{G7}/L_{G7}}$ (0.1712)	0.453
$\left(\frac{T_{Korea,I}/L_{Korea}}{T_{G7,I}/L_{G7}}\right)$	Korea export share of GDP (0.1469)	0.295
$tr_{RK,C2}$	Consumption share of imports (0.02523)	0.700
$tr_{ij,I}; tr_{ij,C1}; tr_{KR,C2}$	Imported investment share of GDP (0.03991)	0.193

3.3 Solution

Given the parameterization of the model in Table 2 and the trade cost data in Table 1, the model will deliver an equilibrium set of factor prices, goods prices, production quantities, trade flows, and vertical specialization flows. We first solve for the initial steady-state in 1963. Then, we simulate the trade policy reforms, individually and in aggregate. The production structure of our model – with endogenous solutions of which country produces which stage of the consumption goods – implies that, unlike in EK, an exact solution to the model cannot be computed. Instead, we must find an approximate solution. To do so, we approximate the $[0, 1]$ continuum with 2,500,000 equally spaced intervals; each interval corresponds to one good or one stage of one good. Further details on the solution method are in the appendix.

4 Results

We now assess the quantitative importance of the three sets of tariff reductions – holding all other parameters and exogenous variables constant – in explaining Korea's catch-up to the G7 in GDP

per worker, TFP, and export share of GDP. We also assess whether the model can replicate the growth of Korea's vertical specialization, as well as the changing sectoral composition of its trade.

We first present the initial steady-state along with the corresponding data:

Table 3: Initial Steady-State for Korea

Variable	$\frac{Y_K/L_K}{Y_{G7}/L_{G7}}$	$\frac{X}{Y}$	$\frac{\text{Inv}_M}{Y}$	$\frac{\text{Con}_M}{M}$	$\frac{VS}{Y}$	$Kshare$
Actual data (1963)	0.171	0.147	0.0399	0.0252	0.01257	0.98
Initial steady-state	0.171	0.147	0.0399	0.0252	0.00506	1

Note: Y, GDP; L,labor; X, exports; VS, vertical specialization; Inv_M and Con_M, imported investment and consumption; Kshare, share of capital that is for domestic sales;

The first four columns were calibrated to match the data. Among the two columns on the right, note that the model implies an initial steady-state VS/Y ratio that is about 2/5 of what it is in the data, and an initial capital share devoted to domestic sales that is close to the true value of 0.98.[24] These are two diagnostics that suggest the model is an appropriate one to analyze the effects of the three trade policy reforms.

The first two rows of table 4 present the actual data in 1963 and 1995, respectively. In the third row, for relative output per worker, we report the log growth rate between 1963 and 1995.[25] We refer to that growth rate, 83.7 percent, as Korea's "catch-up" in relative value-added per worker. Our first simulation is to implement the tariff exemption on imported inputs and investment goods as long as they are used to produce goods for export. Westphal and Kim (1977) compute effective rates of protection for Korean industries; they conclude that exporters faced essentially a free trade environment.[26] Consequently, in implementing this simulation, we reduce all other trade costs, in addition to tariffs, to zero, as they likely represented other political barriers such as quotas and commodity taxes. Hence, the trade costs for these goods are only the transport costs.

[24] We compute Korea's VS/Y in the model the way it would be computed from an input-output table that does not distinguish between imported inputs that are used to produced export goods and imported inputs that are used to produce domestic goods, and compare this model measure to its data counterpart. That is, our model measure is not the true measure, but what would be measured based on typically available data.

[25] In EK, the effect of changes in tariffs on trade shares is non-linear; specifically, it is linear in logs. While our model has additional non-linearities, owing to its production structure, we believe presenting results in logs facilitates easier intuition about the results.

[26] See Table 6.B (p. 3-65) of Westphal and Kim.

Table 4: Main Results

Variable	$\frac{Y_{Kt}/L_{Kt}}{Y_{G7t}/L_{G7t}}$	$\frac{X}{Y}$	$\frac{\text{Inv}_M}{Y}$	$\frac{\text{Con}_M}{M}$	$\frac{VS}{Y}$
Actual data (1963)	0.171	0.147	0.040	0.025	0.013
Actual data (1995)	0.395	0.923	0.42	0.095	0.21
Actual growth rate (1963-95, logs)	**0.837**	1.84	2.36	1.33	2.83
Trade policy reform	(log) Growth rate implied by model				
(1) Tariff exemption	**0.0846**	1.743	1.18	−1.31	3.66
(2) Korea tariff reduction (27.2 pp)	**−0.0427**	1.128	1.07	−0.048	2.28
(3) GATT tariff reduction (8.95 pp)	**0.0524**	0.412	0.405	−0.020	0.826
(2)+(3)	**0.0404**	1.463	1.35	−0.024	2.97
(1) + (2) + (3)	**0.169**	2.472	1.81	−0.954	5.13

Note: Y, GDP; L,labor; X, exports; VS, vertical specialization; Inv_M and Con_M,imported investment and consumption;

The row labeled "(1)" provides the results of this simulation. The tariff exemption generates an increase in Korea's GDP per worker relative to the G7 GDP per worker of 8.5 percent; this is 10.1 (= 0.0846/0.837) percent of Korea's actual GDP per worker catch-up. This effect may seem large in that a single trade policy can narrow the per worker GDP gap by about 10 percent; however, it is small compared to Korea's actual performance. Both countries' per worker GDP grows, but the growth in Korea is about three orders of magnitude larger than in the G7. Of the 8.5 percent gain, about 1/4 is due to additional capital accumulation, mainly to produce exports for the G7. The remainder is a result of an appreciation of Korea's real exchange rate. This is because Korean consumption goods become relatively more expensive as G7 consumer goods are the ultimate beneficiaries of the lower prices induced by the tariff exemption.

This row also shows that the implied growth in trade is almost as large as the actual increase. The tariff exemption policy actually over-predicts the increase in Korea's vertical specialization, given in the right-most column.[27] The model generates growth in the share of imported investment goods in GDP that is about half of the actual growth. However, the model does poorly in its prediction for the change in the consumption share of imports – it predicts a decline, although in the

[27] It is useful to remember, however, that in the initial steady-state, the model's implied vertical specialization is less than half of the actual value.

data it grew substantially. This is because the tariff exemption encourages imported intermediates at the expense of imported consumption and investment goods. Overall, implementing this policy yields implications for changes in Korea's GDP, and volume and composition of trade that are reasonably close to the data with the exception of the consumption share of imports.

In the row labeled "(2)", we examine the effects of the broad reduction in Korean tariffs. The policy generates a *reduction* in Korea's relative GDP per worker of 4.3 percent. This result may seem counterintuitive, but it is driven by the familiar optimal tariff argument. Despite its small relative size, Korea is not a small open economy in the model, and hence, the terms of trade are affected by changes in tariffs. In particular, the terms of trade worsen sufficiently with the reduction in tariffs that the model implies that Korean prices of its final consumption and investment goods, expressed in terms of the foreign consumption good, fall by about 10 percent, and its real wage falls by 4.2 percent.

At this point, it is useful to briefly discuss welfare, which we measure in terms of steady-state consumption. In this case, the two policies discussed above are reversed in terms of their effects. The tariff exemption raises steady-state consumption relative to the G7 by about 2.4 percent, while the tariff reduction raises it by 6.4 percent. The latter effect occurs because we model tariffs as real costs of trade similar to transport costs; hence, a decline in tariffs yields a welfare gain from the lower trade costs that more than offsets the welfare loss owing to deviating further from the optimal tariff. Note that in terms of welfare, there is more "bang for the buck" from the tariff reduction than from the tariff exemption.

The row labeled "(3)"of the table presents the results from the GATT reduction in G7 tariffs. The reduction in these tariffs generates an increase in Korea's relative GDP per worker of 5.2 percent; this is 6.3 percent of Korea's actual GDP per worker catch-up. Under this policy, partly because the terms of trade effects are opposite in direction from Korea's tariff reduction, Korea's relative wage rate rises. This contributes significantly to the gain in Korea's relative GDP per worker. The row labeled "(2)+(3)"gives the effects of the two broad tariff reductions, taken together. Notice that the growth in relative GDP per worker exceeds the sum of the growth effects from each individual tariff.

The row labeled "(1)+(2)+(3)" presents the results from combining all three policies. Taken together, the policies generate an increase in Korea's relative GDP per worker of 16.9 percent, which is 20.2 percent of Korea's catch-up to the G7. This increase is larger than the sum of the effects of each policy implemented individually. Clearly, there is a positive interaction effect on

output that goes beyond log-linearity. On the other variables, however, the combination of the policies tends to mitigate the effects of the individual policies. This makes sense, because, for example, the effect of a tariff exemption on trade is mitigated by the broader tariff reduction. The exemption would have larger effects, to the extent the original tariffs are higher. However, despite these mitigating effects, the model over-predicts the export and vertical specialization shares of GDP. [28] The model captures about half of the increase in the imported investment share of GDP, and again counterfactually predicts that the consumption share of trade falls.[29]

Young (1995) performs a growth accounting decomposition of Korea's manufacturing sector. Using Young's data from his Table VII, but applying the method employed by Klenow and Rodríguez-Clare (1997), as well as by Hall and Jones (1999), we find that TFP growth accounts for 73.8 percent of Korea's growth in manufacturing output per worker between 1966 and 1990. As discussed above, in our model the tariff reductions show up only as TFP gains. Capital/output ratios do not change. Using unpublished data from the BLS, we compute the contribution of manufacturing TFP growth in the U.S.'s growth in manufacturing output per hour worked between 1966 and 1990. TFP accounted for 74.1 percent of the growth.[30] If we assume that the United States is representative of the G-7, then TFP growth accounts for about 74 percent of S. Korea's catch-up in manufacturing output per worker. This implies that, in the scenario combining all three trade policies, the model can explain $(1/.74) \times 0.202 = 27.3$ percent of the catch-up in TFP. Of course, the flip side of these calculations is that the model says nothing about the 26 percent of Korea's output per worker growth that is not a result of TFP.

In our simulations we hold the transport costs and the "all other" cost of importing consumption

[28] Koopman, Wang, and Wei (2012) show that in the presence of policies that explicitly encourage vertical specialization, the HIY methodology for computing VS underestimates the true level of VS. This suggests that the actual VS in Korea in 1995 was greater than the reported number, and the gap with this simulation smaller than indicated by the table.

[29] In the early years of Korea's trade reforms, government officials found it difficult to enforce the tariff exemption policy. Taken literally, the policy implied that duty-free imported inputs and capital could not be used at all for production for domestic sale. In practice, owing to wastage allowances, cheating, and other forces, these inputs and capital were often used for domestic production and sale. Indeed, this led to a shift in policies over time from an outright exemption to a duty drawback type of policy in which exporters had to first pay the full price for imports and then file paperwork to claim the rebate. (See Ianchovichina (2007) for an analysis of duty drawbacks.) To model the "leakage" of these imported inputs and capital, we modify the tariff exemption policy to allow for duty-free importation of inputs and capital goods for domestic sale, as well. When we simulate the effects of all three policies, not surprisingly, the model explains an even greater share of Korea's relative output per worker catch-up. The implications for the export share of output, vertical specialization, the imported investment share of GDP and the consumption share of imports are about the same as in the simulation without leakage.

[30] We thank Steve Rosenthal of the BLS for providing this data. With the manufacturing data, we computed a Divisia index of value-added following Basu and Fernald (1997). We then performed the growth accounting calculation. Note: we assume that the difference between output per hour and output per worker in the United States manufacturing sector during this period is small.

goods constant. Undoubtedly some of these "all other" costs were captured by quotas; over time, the quotas were relaxed.[31] For example, Korea went from a positive list quota system, in which goods not subject to quotas were explicitly listed, to a negative list system, in which goods subject to quotas were explicitly listed. Under the new policy, then, the presumption was that goods would not be subject to quotas unless otherwise specified. Hence, this policy probably led to a greater share of consumption goods in imports than otherwise.

Table 5: Further Results

Variable	$\frac{Y_{Kt}/L_{Kt}}{Y_{G7t}/L_{G7t}}$	$\frac{X}{Y}$	$\frac{\text{Inv}_M}{Y}$	$\frac{\text{Con}_M}{M}$	$\frac{VS}{Y}$
Actual data (1963)	0.171	0.147	0.040	0.025	0.013
Actual data (1995)	0.395	0.923	0.42	0.095	0.21
Actual growth rate (1963-95, logs)	**0.837**	1.84	2.36	1.33	2.83
Trade policy reform	(log) Growth rate implied by model				
(1) + (2) + (3)	**0.169**	2.47	1.81	−0.954	5.13
(1)+(2)+(3) without imported investment	0.100	2.14	0.00	−0.431	3.70
(2)+(3)	**0.0404**	1.46	1.35	−0.024	2.97
(2) + (3) without multi-stage production	0.012	1.35	0.19	0.76	
(2)+(3) without multi-stage production and imported investment	−0.048	1.88			

Note: Y, GDP; L,labor; X, exports; VS, vertical specialization; Inv_M and Con_M,imported investment and consumption;

To understand further the quantitative importance of two key transmission channels, we engage in three further simulations. We first assess the importance of imported investment goods. To do this, we study the effects of the three trade policy reforms when trade in investment goods is not allowed, and compare it to a baseline in which such trade is allowed. The row labeled "(1)+(2)+(3) without imported investment"of Table 5 presents the results of that simulation.[32] For comparison,

[31] Anderson and Neary (1992) show that in the presence of both tariffs and quotas, a reduction in tariffs reduces the effect of quotas. Intuitively, it is because lower tariffs lead to substitution from the goods subject to quotas to goods subject to the tariffs. We thank Jim Anderson for this insight.

In our framework, the quotas are captured implicitly by an iceberg trade cost that remains constant as tariffs are reduced. A more accurate implementation of the tariff reduction would be to reduce the iceberg trade costs that capture the quotas by the appropriate amount. This would lead the model to more closely capture the consumption share of imports.

[32] To compute the gain in Korea's relative GDP per capita when investment goods are not traded, we first compute

the preceding row presents the results of the three policies in the benchmark model. When trade in investment goods is not allowed, the increase in Korea's relative GDP per worker is only about 3/5 as large relative to the benchmark model. Put differently, access to trade in investment goods generates about a 70 percent larger catch-up. Note, however, that this simulation also shows that the model without investment goods does better than the benchmark model in capturing the actual growth in trade and vertical specialization.

Second, we assess the importance of multi-stage production. We start from an initial steady-state with no multi-stage production. We then implement the broad Korea tariff reduction and the GATT tariff reduction – the tariff exemption for imported inputs cannot be applied here – and compare the effects against the effects of these two policies in the benchmark model. The results are given in the rows labeled "(2)+(3)" and "(2)+(3) without multi-stage production". They show that multi-stage production facilitates more than three times as large an increase (0.040 vs. 0.012) in Korea's relative GDP per worker.

Finally, we assess the importance of imported investment goods and multi-stage production, together. We implement the broad Korea tariff reduction and the GATT tariff reduction starting from an initial steady-state without imported investment goods and multi-stage production. The results are given in the final row of Table 5. Korea's output per worker relative to the G7 declines by 4.8 percent, driven primarily by a lower relative real wage of about the same amount. The presence of these two channels, then, essentially explains (more than) all of the increase in Korea's relative GDP per worker and of Korea's catch-up. This is one of the main results of the paper.

5 Conclusion

We study the effects of trade policy reforms on per capita gdp growth using a neoclassical model of growth and trade calibrated to South Korea and the G7 countries. South Korea's growth miracle in the three-plus decades following 1961 have been well-documented. There were three key trade reforms. Korea granted tariff exemptions on imported inputs and capital goods used to make export goods. Korea also engaged in a broad tariff reduction. Finally, the advanced nations, the recipients of most of Korea's exports, lowered their tariffs through two GATT rounds, the Kennedy and Tokyo rounds.

the initial steady-state in 1963 with no trade in such goods. We do not change any other parameters. We then implement all three trade reforms and compute the new steady-state. We do similar pairs of simulations for the exercises in the final two rows of Table 5.

Our simulations show that the tariff exemption policy and the GATT tariff reductions increased Korea's relative per worker GDP, while Korea's own tariff reductions decreased its relative per worker GDP. All three policies taken together explain about 20 percent of Korea's catch-up to the G7 in manufacturing GDP per worker. The model explains an even larger fraction, 27 percent, of the catch-up in aggregate TFP. We also find an interaction effect among these policies; the combined effect on Korea's per worker is about twice as large as the sum of the effects of each individual policy. The trade reforms explain too much of Korea's trade and vertical specialization growth, however, and the model falls short in capturing the extent of imported capital goods. Further analysis show that access to imported investment goods, as well as multiple stages of production and the additional specialization this engenders, are the dominant channels in generating the above findings.

Our investigation has focused on Korea's trade policies. Korea also implemented many other policies focused on output, not on trade *per se*. To the extent these policies raised output, then, adding them to our simulations would likely lead to less of an over-prediction of Korea's trade and vertical specialization growth. We leave this exercise for future research.

How do we interpret our results in light of Rodrik and Rodriguez (2000), as well as other research by Rodrik that finds that the importance of trade policy is limited?[33] We give two answers. On the one hand, our results are consistent with his conclusions, because we find that the majority of Korea's catch-up cannot be explained by trade policy. On the other hand, our focus on only neoclassical trade and growth transmission mechanisms necessarily means we have ignored other channels by which trade can affect growth. For example, to the extent learning or technological spillovers are enhanced through exporting and importing, our framework would be understating the role of trade. Also, to the extent the prospect of future tariff reductions imply enhanced earnings opportunities, the trade policies would have implications for human capital accumulation, as well.[34] Our findings, then, represent a lower bound on the importance of trade policies in Korea's growth miracle.

A Appendix

A.1 Solution for $\underline{z}_h$ in the special case of the multi-stage production model case

For goods ultimately consumed in the home country, there are two production methods, HH and HF. Ordering the continuum of goods according to declining home country comparative advantage

[33] See, for example, Rodrik, Subramanian, and Trebbi (2004).

[34] See Broda, Greenfield, and Weinstein (2006), and Bils and Klenow (2000).

in stage 2 production, there is a cutoff $\underline{z}_h$for which goods on the interval $[0, \underline{z}_h]$ are produced by HH, and goods on the interval $[\underline{z}_h, 1]$ are produced by HF. This cutoff is determined by the arbitrage condition that the price of purchasing this good (by a home country consumer) is the same across the two methods:

$$p_{HH}(\underline{z}_h) \equiv (1+\tau_H)p_{HF}(\underline{z}_h) \Longrightarrow \tag{28}$$

$$\frac{\psi(w_H^{1-\alpha}r_H^{\alpha})^{1-\theta_1\theta_2}(P_H)^{\theta_1\theta_2}}{A_{H1}(\underline{z}_h)^{(1-\theta_1)\theta_2}A_{H2}(\underline{z}_h)^{1-\theta_2}} = (1+\tau_H)\frac{\psi(1+\tau_F)^{\theta_2}(w_H^{1-\alpha}r_H^{\alpha})^{(1-\theta_1)\theta_2}(P_H)^{\theta_1\theta_2}(w_F^{1-\alpha}r_F^{\alpha})^{1-\theta_2}}{A_{H1}(\underline{z}_h)^{(1-\theta_1)\theta_2}A_{F2}(\underline{z}_h)^{1-\theta_2}} \tag{29}$$

where ψ is a constant. Assuming $\tau_H = \tau_F$, and simplifying yields:

$$\left(\omega^{1-\alpha}\rho^{\alpha}\right)^{1-\theta_2} = \left(\frac{A_2^h(\underline{z}_h)}{A_2^f(\underline{z}_h)}\right)^{1-\theta_2}(1+\tau)^{(1+\theta_2)} \tag{30}$$

which leads to:

$$\omega^{1-\alpha}\rho^{\alpha} = 1 = \left(\frac{1-\underline{z}_h}{\underline{z}_h}\right)^{\frac{1}{n}}(1+\tau)^{\frac{1+\theta_2}{1-\theta_2}} \tag{31}$$

Solving for $\underline{z}_h$yields (23).

A.2 Constructing manufacturing value-added per worker in Korea and the G7 in 1963 and 1995

A.2.1 Employment

We use the Penn World Tables (PWT) 6.1, BOK Economic Statistics Yearbook, and OECD STAN database. A key goal is to make employment comparable across countries. We first start with 1963. Our procedure takes into account the fact that Korea was not a member of the OECD at that time; also the OECD STAN database does not have data prior to 1970. We first obtain Korea's manufacturing employment share of total employment in 1963 from the 1972 BOK Economic Statistics Yearbook: 0.0794. To construct the G7 manufacturing employment share in 1963, we assume that in each country, the employment share in 1970 is the same as in 1963. Adding up across countries gives us the overall G7 manufacturing employment share for 1963: 0.263. We then multiply these shares by the Penn World Tables (PWT) workers variable in 1963 to get manufacturing employment in each country: 0.743 million in Korea and 62.1 million in the G7.

For 1995 manufacturing employment, we use the OECD STAN for both the G7 and Korea.

A.2.2 Value-added

We use the BOK Economic Statistics Yearbook (ESY) 1972, UNCTAD Handbook of International Trade and Development Statistics 1969, PWT 6.1, the IMF International Financial Statistics (IFS), and the OECD STAN database.

1963 From BOK ESY, we obtained that manufacturing value-added was 13.61 percent of GDP (measured at factor cost). For the G7, we obtain manufacturing value-added as a share of GDP for 1970 for each country from the OECD STAN database. Value-added is measured at basic prices, which are intended to capture the prices that producers receive. We assume that for each country the share in 1963 is the same as in 1970. The UNCTAD handbook reports GDP in 1963 in current U.S. dollars for each country. We multiply the dollar value of GDP in 1963 by the manufactured

value-added shares to obtain total manufacturing value-added for Korea and the G7 in 1963 in current U.S. dollars.

1995 The data are obtained in local currency units from OECD STAN for Korea and each country in the G7, and are converted from local currency to U.S. dollars by multiplying by the 1995 average exchange rate obtained from the IMF IFS.

A.2.3 Value-added per worker

The value-added data are divided by the employment data to obtain value-added per worker in current U.S. dollars for Korea and the G7 in 1963 and 1995. For 1963, the ratio of Korea to G7 manufactured value-added per worker was 0.171. In 1995, the ratio was 0.395.

A.3 Solution Method

We compute an approximate solution to the model. We approximate the $[0, 1]$ continuum with 2,500,000 equally spaced intervals; each interval corresponds to one good or one stage of one good. We first solve for the initial steady-state, which includes the productivity parameters and trade costs that enable the model to match the four targets: relative per worker output, export share of GDP, investment import share of GDP, and consumption share of imports.

We then solve the model under different combinations of the trade reforms. We reduce the model to ten equations in ten unknowns (two wages, four aggregate price indices, three capital stocks and one aggregate intermediate). For each country, we draw a stage 1 productivity and a stage 2 productivity from the Frechét distribution for each of the 2,500,000 consumption goods and a productivity from the Frechét distribution for each of the 2,500,000 investment goods. We then calculate for each country the cheapest production method for each consumption good and each investment good. Finally, we assess whether the resulting pattern of production, trade, and prices is consistent with labor market equilibrium, capital market equilibrium, intermediates goods market equilibrium, and with the candidate aggregate prices. The model uses a Gauss-Newton algorithm to adjust the candidate vector until these conditions are met. The algorithm takes about 15 minutes in Gauss.

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