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

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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 15 percent of South Korea's catch-up to the G7 countries in output per worker in the manufacturing sector. Second, these output gains, as well as most of the welfare gains, are attributed to two key transmission channels: multi-stage production and imported investment goods.

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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] 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 the 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. A key feature of this miracle was an enormous increase in Korea's international trade. 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]

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. We conduct our quantitative assessment through the lens of a neoclassical model of growth and

[1] See, for example, Lucas (1993). The other Newly Industrializing Countries 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.

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 facts in Korea's growth experience.

The growth theory and the trade theory in our model are linked in the following ways. Lower tariffs raise allocative 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 show up as increases in aggregate total factor productivity (TFP) even though there are no intrinsic increases in the productivity of any individual good. The lower tariffs also generate increased imports of investment goods, and greater capital accumulation more broadly. 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 15 percent of Korea's catch-up in manufacturing output per worker. The Korea tariff reduction alone leads to a reduction in output per worker, largely owing to terms of trade effects, but welfare nevertheless still rises, as it does for the other policies. 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 trade, productivity, and long run growth is a story involving international economics, development economics, and macroeconomics. Economists from each of these sub-disciplines have typically approached this question with varying empirical methodologies including reduced form regressions, structural regressions, micro and macro growth regressions, and event studies. What these approaches have in common is a focus on differences across countries, industries, or firms. By contrast, our focus is on the aggregate impacts over time of the change in Korea's and GATT's trade policies. Our methodology addresses that focus, because it employs an open economy dynamic general equilibrium framework. The framework is used to simulate the dynamic effects of a change in policy, and also to study the transmission channels from trade policy to trade and output per worker.

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 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 overviews key facts about the manufacturing sector, the focus of our calibration. Section 3 presents the model and discusses the core intuition of the effects of trade barrier reductions. Section 4 provides the calibration of the model. This is followed by the simulation of the trade liberalizations and the main results. Section 6 discusses further results, and the final section concludes.

2 Overview of Manufacturing GDP and Trade

This section provides key manufacturing facts about South Korea, as well as for the G7 countries. (Unless indicated, all variables refer to the manufacturing sector). These facts underlie the model that we develop, the model's calibration, and our assessment of the validity of the model.

Table 1 shows that Korea's value-added (VA) per worker (L) grew by close to an order of magnitude between 1963 and 1995. During this period the capital/labor ratio in manufacturing grew by considerably less, only about 50%. We use the Hall and Jones (1999) or Klenow and

[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.

[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.

Rodriguez-Clare (1997) methodology in which capital accumulation induced by higher TFP is attributed to TFP. We find that TFP accounts for about 87% of Korea's growth in value-added per worker. In addition, Table 1 shows that Korea's value-added per worker relative to the G7 countries more than doubled from 0.17 to 0.4.[5]

Table 1: South Korea Manufacturing GDP and Growth Accounting

Variable	1963	1995	(log) Growth	Contribution to growth of VA/L
VA/L (mill of 2005 won)	2.47	21.43	2.16	
K/Y	1.40	2.14	0.43	13.2%
TFP			1.88	86.8%
VA/L (Korea/G7; current U.S.$)	0.17	0.40		

Notes: VA: value-added; See Appendix A.2 for accounting methodology

The top row of Table 2 shows the well known fact of the enormous increase in Korea's exports. Expressed as a share of value-added, exports rose by a factor of six between 1963 and 1995. The growth of manufactured trade had two important features associated with it. First, a large fraction of the growth in trade consisted of increased imports of capital goods. Imported equipment and machinery, expressed as a fraction of total manufacturing value-added rose from 19% to 38% between 1963 and 1995. Second, an increasing fraction of imported inputs were used to make goods that were ultimately exported. In the language of Hummels, Ishii, and Yi (2001), there was an increasing amount of vertical specialization. Table 2 below shows that the value of manufactured imported inputs embodied in manufactured exports, expressed as a share of manufactured GDP, rose from 4.9% to 28.9% between 1963 and 1995.

[5] 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. 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.

Table 2: South Korea Manufacturing Trade (share of manuf VA)

Variable	1963	1995
Exports	0.15	0.92
Imported equipment/machinery	0.19	0.38
Vertical specialization	0.049	0.29

Sources: See Appendix A.2; Korea I-O tables.

3 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).[6] In the neoclassical growth framework, aggregate TFP and the capital stock 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 and the capital stock. Trade will increase of course, as well. Two channels that can potentially accentuate the effect of trade barrier reductions are trade in investment goods, and production that occurs in multiple, sequential stages. Below, we first lay out the benchmark model, then we discuss the key transmission channels. We also show how the model is modified to allow for Korea's tariff exemption policy.

3.1 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.[7] First, capital, labor and the aggregate intermediate are combined to make a "stage 1" good. Then, the stage 1 good is combined with capital

[6] See also Alvarez and Lucas (2007), Waugh (2010), and Caliendo and Parro (2014).

[7] 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.

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.[8] 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 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,

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

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.

3.2 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 $1 + \tau_{ij} = (1 + b_{ij})(1 + d_{ij})(1 + tr_{ij})$. Revenue from tariffs are rebated to households as lump-sum transfers. The transport costs and all other trade 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 $1/((1 + d_{ij})(1 + tr_{ij})$ units of z arrive in country j. 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.

3.3 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 $p_{j2}(z) = \min\left[p_{ij2}(z); i = H, F\right]$. From (7) and (8), it can be seen that $p_{j2}(z)$ potentially embodies two sets of trade costs — one in importing the stage 2 good, and one in importing the stage 1 good to make the stage 2 good. This multiplicative possibility is one of the forces underlying the magnification effect with multi-stage production and vertical specialization.

The price that an investment aggregator firm in country j pays to purchase the 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 $p_{jI}(z) = \min\left[p_{ijI}(z); i = H, F\right]$.

3.4 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:

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

where C_{it} is consumption of the aggregate non-traded good, and T_{it} is the lump sum rebate of tariff revenue, 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:

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

3.5 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:

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

where $(1+d_{i1}(z))(1+tr_{i1}(z))$ is the product of transport and all other non-tariff trade costs incurred by shipping the stage 1 good from country i's cheapest source to country i. The condition

[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.

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:

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

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

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.*

3.6 Trade, Vertical Specialization, and Growth and Income

We now discuss the model's implications for trade and for steady-state per capita income. We highlight the transmission channels from reductions in trade costs to higher trade and per capita income..

3.6.1 Trade and Vertical Specialization

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.

Starting from autarky, if trade barriers fall, specialization and trade will emerge as countries find it cheaper to import some stages of some goods. Which country produces which stage of which good depends on the interplay of relative productivity differences across countries, relative factor costs, and trade costs. For example, consider the country H investment aggregator firm. This firm can purchase the investment goods z from country H or country F. A particular good z will be purchased from country H if the following condition holds:

$$p_{HI}(z) \equiv \frac{\psi_1 (w_H^{1-\alpha} r_H^{\alpha})^{1-\theta_1} (P_H)^{\theta_1}}{A_{HI}(z)^{1-\theta_1}} < \frac{(1+\tau_{FH,I})\psi_1 (w_F^{1-\alpha} r_F^{\alpha})^{1-\theta_1} (P_F)^{\theta_1}}{A_{FI}(z)^{1-\theta_1}} \equiv (1+\tau_{FH,I}) p_{FI}(z) \quad (19)$$

The above equation essentially says that if H's production costs relative to its TFP is less than F's production costs (inclusive of trade costs) relative to its TFP, the good will be purchased from H. More generally, the home country price of an investment good z, $p_I^H(z) = \min\left[p_{HI}(z), (1+\tau_{FH,I})p_{FI}(z)\right]$.

To produce a stage 2 consumption good z, there are four possible 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, $p_2(z) = \min\left[p_{H2}(z), p_{F2}(z)\right] = \min[p_{HH}(z), p_{FH}(z), p_{HF}(z), p_{FF}(z)]$.

If one country is relatively more productive at making investment goods than consumption goods, 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]

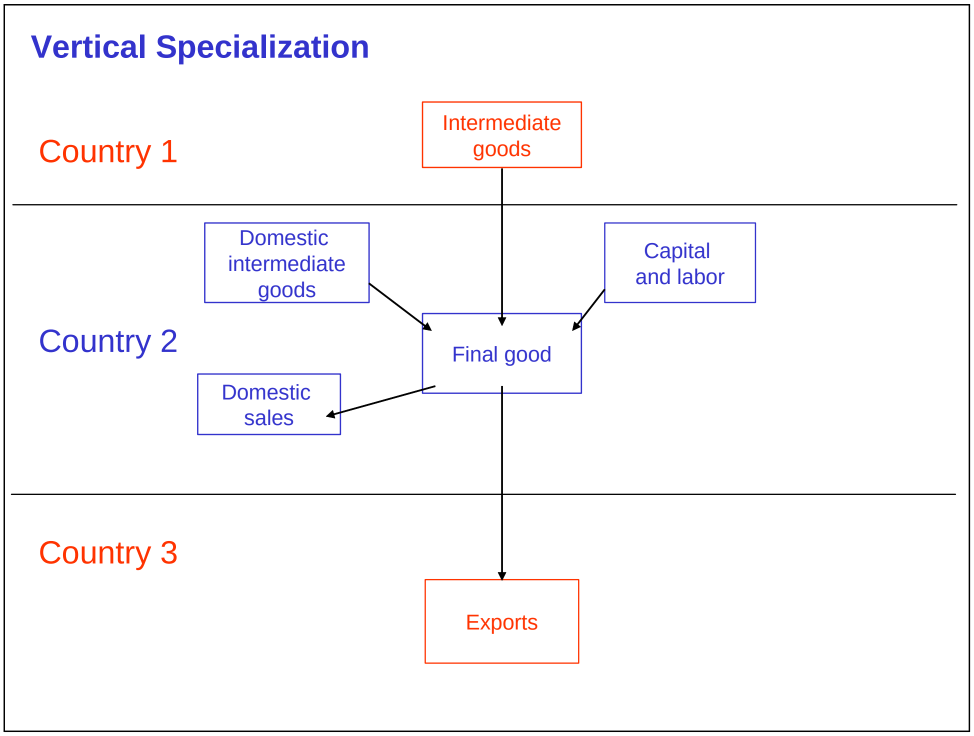
In general equilibrium, wages, rental rates, and intermediate goods prices are determined so that each country's production equals its spending and each country's exports equals its imports. Each country will find some goods for which the other country is the low cost producer. This is the essence of comparative advantage and general equilibrium.

The presence of multi-stage production for consumption goods leads to the possibility of vertical specialization. Drawing from Hummels, Ishii, and Yi (HIY, 2001) and Yi (2010), we define *vertical* specialization to occur when one country uses inputs imported from another country in its stage of the production process, and some of the resulting output is exported to another country.[11] Figure

[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, 2014) and Koopman, Wang, and Wei (2014), among others, have generalized and extended the methodology of HIY (2001). In our

Figure 1: Vertical Specialization



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.

HIY's primary measure of vertical specialization is essentially the imported intermediates content of exports. HIY use data from input-output tables to compute industry-level and national measures of vertical specialization for several countries over time.[12] Table 2 above showed that

calibration, vertical specialization is computed from the model in the same way HIY compute it in the data.

[12] Their primary measure is VS:

$$VS_{ki} = \left(\frac{Imported\ intermediates_{ki}}{Gross\ output_{ki}} \right) Exports_{ki} \tag{20}$$

growth in vertical specialization has been a large part of Korea's trade experience.

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 drawing from Yi (2010) to illustrate this point and describe the intuition underlying it. Suppose that there are only consumption goods and they are produced only in a single stage. If both countries have the same labor endowment, both countries' productivities are drawn from the same Frechét distribution, and trade costs are symmetric between countries, then in equilibrium the import share of GDP is given by:

$$\frac{1}{1+(1+\tau)^n} \tag{21}$$

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 or 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 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.[13]

Now consider a case in which consumption goods are produced in two stages. There are still no investment goods, and the two countries continue to have the same labor endowments, the same underlying distribution of TFPs for each stage of production, and the same trade costs. This implies that wages, rents, 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

where k and i denote country and good, respectively.

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).

[13] Arkolakis, Costinot, and Rodríguez-Clare (2012) show that the Eaton and Kortum (2002), Armington aggregator, and Melitz (2003) frameworks all yield the same gains from trade. Our model does not fit into the class of models for which this is true.

HF. Note that production method HF involves international vertical specialization: the foreign country imports inputs and exports its resulting output back to H. In Appendix A.1, we show that the import share of GDP can be expressed as:

$$\frac{\varphi}{1+(1+\tau)^{n\left(\frac{1+\theta_2}{1-\theta_2}\right)}} \tag{22}$$

Note that the responsiveness of the import share of GDP to trade costs depends on 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. 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.[14] 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.

3.6.2 Growth and Income

To understand how lower tariffs affects per capita income, we proceed in several steps. We first consider a case without capital and investment goods. As is well known, if tariffs on stage 1 and stage 2 consumption goods decline, then Korea's terms of trade will be adversely impacted. Korea's output measured in units of the foreign consumption good will decline. Partially offsetting

[14] 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).

this decline is the increase in allocative efficiency resulting from increased specialization and trade.

Now consider a case with capital and investment goods, and consider again a reduction in tariffs on consumption goods. Again, the terms of trade falls, lowering Korea's output measured in units of the foreign consumption good, and again there is a partial offset owing to increased specialization. In addition, there is increased capital accumulation. The increase in specialization and allocative efficiency is effectively an increase in aggregate TFP, which then induces the capital accumulation. Note that aggregate TFP rises even though there has been no change in the efficiency of producing individual goods.

Now, consider a reduction in Korea's tariffs on investment goods. As before there is an adverse impact on the terms of trade, and the specialization induced growth owing to increased aggregate TFP and capital accumulation. In addition, there is a direct capital accumulation effect, which can be illustrated via the steady-state household's Euler equation (for country H):

$$\frac{r_{H,ss}}{P_{HI,ss}} = \frac{1}{\beta} - (1 - \delta) \tag{23}$$

$P_{HI,ss}$ is the price of the aggregate investment good:

$$P_{HI,ss} = \exp\left(\int_{H^I} \ln(p_{HI}(z))dz + \int_{F^I} \ln((1 + \tau_{HI})p_{FI}(z))dz \right) \tag{24}$$

where H^I denotes the set of goods z such that the lowest cost production source is in H. The lower tariffs lower the price of the aggregate investment good through an internal margin channel — the prices of imported investment goods declines — and through an external margin channel — there is a shift from relatively high cost domestic investment goods to relatively low cost imported investment goods. H^I falls and F^I rises. The lower price of the aggregate investment good induces capital accumulation, which continues until the return on capital $r_{H,ss}$ falls by enough so that the Euler equation holds again. The increase in capital and TFP imply an increase in per capita output, which could potentially offset the terms of trade effect. Overall, the forces supporting an increase in output are stronger than in the consumption tariff case.

The reduction in G7 tariffs will lead to an improvement in Korea's terms of trade, which, all else equal will raise Korea's output in terms of the foreign consumption good, and it will shift the capital stock away from domestic production towards export production. The tariff exemption on Korea's imported inputs and capital goods has a similar effect as the reduction in G7 tariffs, because the ultimate beneficiary of the exemption is the G7 household. Korea's terms of trade improves and the real exchange rate appreciates.

Turning to (steady-state) welfare, which is captured by aggregate consumption per worker, how it responds to decreases in tariffs depends on the change in the terms of trade, and on the magnitude of the consumption gains arising from increased specialization and capital accumulation. It is important to note that decreases in Korea's own tariffs, will lead to a deprecation of its real exchange rate; its goods have become relatively inexpensive. All else equal, this will imply higher consumption than otherwise. Also, as discussed above, reducing consumption goods tariffs are likely to have less of an effect on output than reducing investment goods tariffs. However, lower consumption tariffs lead more directly to an increase in consumption than lower investment goods tariffs, where the channels to higher consumption are more indirect.

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 divides output per worker growth into TFP growth and growth in the capital-output ratio, K/Y. In our model with two sectors, tariff (and other trade cost) reductions will show up primarily as an increase in aggregate TFP, as discussed above, and partly as an increase in K/Y ratios. In addition, we can interpret reductions in investment goods tariffs 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).

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

The model presented above characterizes the initial steady-state, prior to the implementation of the trade policy reforms. As discussed above, one of Korea's major trade policy reforms was the tariff exemption policy on imported inputs and capital goods. That is, with this reform, the price that Korean firms paid for these imports depended on their ultimate destination. Implementing the tariff exemption on imported inputs is straightforward. 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 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 HH, HF, and 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 HH, HF,and 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:

$$P_{Ht}C_{Ht} + P_{HIt}I_{Ht} + P_{HIt}^E I_{Ht}^E = w_{Ht}L_{Ht} + r_{Ht}K_{Ht} + r_{Ht}^E K_{Ht}^E \tag{25}$$

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.

4 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, as mentioned in the introduction, it was responsible for virtually all of the increase in trade.[15] 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 1962/1963 through 1995, the period that constitutes the growth miracle and that precedes the Asia financial crisis.[16] We assume that Korea was in a steady-state in 1962/1963 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.[17] Our primary growth assumption is that the growth rate of the parameters that govern the mean productivities, T_{ix}, is constant across the two countries. That is, the two countries have identical long run per capita growth rates. As the goal of our paper is to focus on Korea's catch-up in per capita income to the G7, with no loss of generality, we set the long run growth rate of $T_{ix} = 0$.

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 endowment, intermediate input shares, capital income share, tariff rates and transport costs are set to match their data counterparts. 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] See Young (1995) for a comparison of manufacturing TFP growth versus economy-wide TFP growth.

[16] 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.

[17] 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. We leave an analysis of the transition dynamics for future work.

4.1 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.[18] 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.[19] 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 3 below.

[18] Hummels and Lugovskyy (2006) show that small amounts of measurement error can have large effects on the magnitude of these costs. However, we do not run any experiments with this measure; hence, we do not need to take a stand on these costs. Another interpretation of our trade costs is that there are tariffs, and there are all other trade costs, where the latter subsumes transport costs.

[19] 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.

Table 3: Tariff Rates (percent)

	Country	
	Korea	G7
1962	39.9	13.95
1989	12.7	5.00

Sources: Nam (1995) and Yi (2003)

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.

4.2 Calibration of Other Variables and Parameters

Korea's manufacturing employment grew substantially over this period, while the G7 employment remained relatively stable. We calibrate the labor endowments L_i to match average manufacturing employment in Korea and the G7 between 1963 and 1995.[20] This yields employment of 2.8 million for Korea and 60.5 million for the G7.

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).[21] 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 $\alpha = 0.4$.

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

[20] For the G7, the average is taken over 1970 and 1995.

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

the annual capital depreciation rate, δ, to 0.1.[22] 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 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.[23] (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; their preferred estimate is 8.28. Other prominent estimates include Baier and Bergstrand (2001) and Head and Ries (2001), who estimate substitution elasticities of 6.43 and 7.9, respectively. Overall, estimates tend to be in the $5 - 10$ range. In the previous section, we demonstrated that under multi-stage production the responsiveness of 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.[24] Following the approach of Edmond, Midrigan, and Xu (2012), we use our model to compute the partial elasticity of substitution or trade under different values of n.[25] In particular, we solve for the value of n that generates a partial elasticity of trade = 9.29, which is the value for manufacturing estimated in Caliendo and Parro (2014). We find that our model generates that elasticity when $n = 3.75$.

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,

[22] Given that most investment goods produced by the manufacturing sector are 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.

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

[24] Simonovska and Waugh (2012) show that one approach used in EK yields estimates that are upwardly biased. They employ an estimator to correct for the bias. There results indicate an elasticity of around 4.

[25] We thank one of the referees for this suggestion. We compute the partial elasticity — we hold all goods and factor prices constant — starting from the initial steady-state and then reducing transport costs by one percentage point.

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.[26] 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 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.[27] 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.[28] 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.

[26] 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 financed primarily via foreign aid from the United States, and that aid was mainly in the form of grants, not loans. In the absence of that foreign aid, it is likely that its imports would have been much lower and closer to its exports. The four data targets are listed in Table 4. Matching these targets also implies that the model will match the share of intermediates in Korean trade.

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

[28] 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.

Table 4 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 (64.7 percent) are considerably higher than for investment goods (12.9 percent). This largely reflects the fact that Korea had an extensive quota and quantitative restriction system applied primarily to final 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 $1.399 \times 1.092 \times 1.647 - 1 = 151.6$ percent.

Table 4: Other Calibrated Parameters and Variables

Parameter		Value
Korea labor, L_{Korea}		2.839
G7 labor, L_{G7}		60.55
Intermediate input share, $\theta_1 = \theta_2$		2/3
Capital income share, α		0.4
Frechét heterogeneity, n		3.75
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)	0.146
$\left(\frac{T_{Korea,I}/L_{Korea}}{T_{G7,I}/L_{G7}}\right)$	Korean export share of GDP (0.1469)	0.091
$tr_{G7K,C2}$	Consumption share of imports (0.02523)	0.647
$tr_{ij,I}; tr_{ij,C1}; tr_{KG7,C2}$	Imported investment share of GDP (0.03991)	0.129

4.3 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.

5 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. (As a reminder, GDP refers to manufacturing 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 5: 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	0.0494	0.98
Initial steady-state	0.171	0.147	0.0399	0.0252	0.0075	0.92

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 only about 1/6 of what it is in the data. On the other hand, it implies an initial capital share devoted to domestic sales that is close to the true value of 0.98.[29]

The first two rows of Table 6 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.[30] We

[29] 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.

[30] 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.

refer to that growth rate, 83.7 percent, as Korea's "catch-up" in relative value-added per worker.

Table 6: Main Results

Variable	$\frac{Y_{Kt}/L_{Kt}}{Y_{G7t}/L_{G7t}}$	$\frac{X}{Y}$	$\frac{\text{Inv}_M}{Y}$	$\frac{\text{Con}_M}{M}$
Actual data (1963)	0.171	0.147	0.040	0.025
Actual data (1995)	0.395	0.923	0.42	0.095
Actual growth rate (1963-95, logs)	**0.837**	1.84	2.36	1.33
Trade policy reform	(log) Growth rate implied by model			
(1) Korea tariff exemption	**0.0837**	0.67	0.64	−0.51
(2) Korea tariff reduction (27.2 pp)	**−0.0397**	1.14	1.06	−0.027
(3) GATT tariff reduction (8.95 pp)	**0.0928**	0.38	0.35	−0.020
(2)+(3)	**0.0812**	1.44	1.29	0.022
(1) + (2) + (3)	**0.123**	1.73	1.55	−0.27

Note: Y, GDP; L,labor; X, exports; M, imports; Inv_M and Con_M,imported investment and consumption;

Our presentation of the main results will proceed by variable. The first variable, given by the left-most column of numbers, is the growth in GDP per worker in Korea relative to the G7, $\frac{Y_{Kt}/L_{Kt}}{Y_{G7t}/L_{G7t}}$. The row labeled "(1)+(2)+(3)" at the bottom of the table gives the model's implication of all three trade policies. They generate an increase in Korea's relative GDP per worker of 12.3 percent.[31] This increase is 14.7 (= 0.123/0.837) percent of Korea's actual GDP per worker catch-up. That a single set of policies can explain 14.7 percent of Korea's catch-up seems significant; however, it obviously leaves 85 percent unexplained.

The other rows give the effect on Korea's relative GDP per worker of the trade policies in isolation, as well as the two tariff reductions implemented together. For example, the tariff exemption, shown in the row labeled "(1)", leads to an increase in relative GDP per worker of 10.2 percent.[32]

[31] Both countries' GDP per worker rises, but owing to its smaller size, Korea's grows by about two orders of magnitude more.

[32] 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

The row labeled "(2)" shows that Korea's tariff reduction leads to a decline in its relative GDP per worker of 3.97 percent. This result is driven by the fact that Korea's terms of trade deteriorates with the lower tariffs. Related, Korea's real exchange rate depreciates by more than 10 percent, which implies that Korea's consumption good is valued less in terms of the G7 consumption good. Finally, note that the effect of all three policies implemented together ("(1)+(2)+(3)") is less than the sum of the effects of Korea's tariff exemption "(1)" and the two tariff reductions implemented together "(2)+(3)". This is because the effect of the tariff exemption is larger the higher the initial tariffs. When the tariffs are also reduced, the effect of the exemption is diminished. In the extreme, if tariffs are taken to zero, the marginal effect of the exemption would be zero.

The second variable is the growth in Korea's export share, $\frac{X}{Y}$. The row labeled "(1)+(2)+(3)" shows that all three policies implemented together yields an increase in the export share, 173 percent, that is close to the actual increase of 184 percent. The Korea tariff reduction generates a larger increase in exports, 114 percent, than the Korea tariff exemption, which generates an increase of 67 percent. Both policies generate a larger increase in exports than the GATT tariff reduction, although the increase in export share per percentage point reduction in tariffs is about the same across the two types of tariffs.

The final two variables give the growth in the imported investment goods share of GDP and the consumption goods share of imports. The model does fairly well in capture the growth in imported investment goods, but it generates counterfactual implication for the consumption share of imports. Most of the tariff policies imply a decline in the consumption share, although in the data it grew by 133 percent. This is because most of the policies, especially the tariff exemption, encourage imports of inputs and capital goods, and consumption good imports are "crowded out". We return to this subject in the next section.

Summarizing the final row of Table 6, the model implies that all three trade policies can explain more about 15 percent of Korea's catch-up in GDP per worker, virtually all of Korea's trade growth, the majority of Korea's increase in imports of investment goods, but none of the increase in imports of consumption goods.

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.

Table 7: Role of Imported Investment and Multi-Stage Production

Variable	$\frac{Y_{Kt}/L_{Kt}}{Y_{G7t}/L_{G7t}}$	$\frac{X}{Y}$	$\frac{\text{Inv}_M}{Y}$	$\frac{\text{Con}_M}{M}$	$\frac{C}{L}$
Actual data (1963)	0.171	0.147	0.040	0.025	
Actual data (1995)	0.395	0.923	0.42	0.095	
Actual growth rate (1963-95, logs)	**0.837**	1.84	2.36	1.33	
Trade policy reform	(log) Growth rate implied by model				
(1) + (2) + (3)	**0.123**	1.73	1.55	−0.27	0.174
(1)+(2)+(3) without imported investment	0.075	1.69	0.00	−0.23	0.132
(2)+(3)	**0.0812**	1.44	1.29	0.022	0.163
(2) + (3) without multi-stage production	0.0388	1.36	1.19	0.867	0.079
(2)+(3) without multi-stage production and without imported investment	−0.0526	1.80			0.026

Note: Y, GDP; L,labor; X, exports; M, imports; Inv_M and Con_M,imported investment and consumption; C,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 7 presents the results of that simulation.[33] For comparison, 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 about 3/5 as large compared to the benchmark model. Put differently, access to trade in investment goods generates more than a 60 percent larger catch-up. The right-most column shows that welfare gains are about 1/3 larger.

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

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

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 a more than twice as large an increase (0.0812 vs. 0.0388) 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 without multi-stage production. The results are given in the final row of Table 7. The table shows that, instead of increasing, Korea's output per worker relative to the G7 declines by 5 percent. In this sense, the two transmission channels explain "all" of the output effects of the Korea and GATT tariff reductions. In terms of welfare, in the absence of these two transmission channels, the gains are only about 1/6 as large. The presence of these two channels, then, explains more than 80% of Korea's welfare gain and (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.

Table 8: Welfare

Variable	$\frac{Y_{Kt}/L_{Kt}}{Y_{G7t}/L_{G7t}}$	$\frac{C}{L}$
Actual data (1963)	0.171	
Actual data (1995)	0.395	
Actual growth rate (1963-95, logs)	**0.837**	
Trade policy reform(log) Growth rate implied by model		
(1) Korea tariff exemption	**0.0837**	0.044
(2) Korea tariff reduction (27.2 pp)	−**0.0397**	0.075
(2a) Korea Cons tariff reduction	−**0.056**	0.046
(2b) Korea Inv tariff reduction	−**0.0062**	0.028
(3) GATT tariff reduction (8.95 pp)	**0.0928**	0.061
(2)+(3)	**0.0812**	0.163
(1) + (2) + (3)	**0.123**	0.174

Note: Y, GDP; L,labor; C, consumption; VS, vertical specialization;

Table 8 presents the model's implications for welfare. The change in welfare is captured by the change in consumption per worker. The first column of numbers presents again the results for the growth in Korea's relative GDP per worker. The second column presents the results for consumption per worker. The column shows that all of the trade policies achieve welfare gains. In other words, Korea's initial tariffs-cum-trade costs are clearly above optimal, initially. In the rows labeled "(2a)" and "(2b)", we separate the Korea tariff reduction into one applied only to consumption goods and one applied only to investment goods, respectively. Each tariff reductions also result in welfare gains.

The difference between the (relative) GDP gains and the consumption gains is essentially the change in the terms of trade (as well as of the real exchange rate). For example, the Korea tariff exemption and the GATT tariff reduction improve Korea's terms of trade and lead to higher output gains than consumption gains. Measured in terms of the foreign consumption good, Korea's output has increased, but part of that is simply because Korea's aggregate price level has risen. Hence, the higher output does not translate one-for-one into higher consumption, and the consumption gains are smaller than the output gains. By contrast, Korea's tariff reductions lead to consumption gains that are greater than the change to output. This is because Korea's aggregate price has fallen (i.e., the terms of trade fall and its real exchange rate depreciates). Here, even though output may decline, consumption increases.

Finally, if we compare the consumption per worker results with the export results in Table 6, we can see that there is not a perfect correlation between increases in consumption and increases in trade. In particular, the tariff exemption leads to a much smaller consumption gain per unit increase in trade than does the GATT tariff reduction. Put differently, owing to the multi-stage production and capital accumulation, our model is not subsumed into the Arkolakis, Costinot, and Rodríguez-Clare (2012) framework.

6 Further Results

This section provides three further results that help establish that the model is a "good" model. Table 9 presents the model's implications for vertical specialization. The row labeled "(1)+(2)+(3)" shows that when all three tariff policies are implemented together, the model implies vertical specialization as a share of GDP (0.215) that is fairly close to the actual data value (0.289).[34] The

[34] 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.

column shows that each policy individually leads to an increase in vertical specialization — that is, lower tariffs encourage greater specialization, including breaking up production chains so that one stage is produced in one country and the other stage is produced in another country.

We do a growth accounting exercise with the model's implications for capital and output resulting from implementing all three tariff reductions. We convert output and capital into Korean consumption units. With that conversion we find that 87% of the growth in output per worker can is attributed to TFP with the remainder to capital accumulation. This is the same as the 87% share in the data reported in Table 2, and indicates that the model matches this feature of Korea's growth experience very well.

Table 9: Vertical Specialization

$\frac{VS}{Y}$	1963	1995
Actual data	0.0494	0.289
Model		
Initial steady-state	0.0075	
(1) Korea tariff exemption		0.0306
(2) Korea tariff reduction (27.2 pp)		0.0613
(2a) Korea Cons tariff reduction		0.0590
(2b) Korea Inv tariff reduction		0.0078
(3) GATT tariff reduction (8.95 pp)		0.0168
(2)+(3)		0.117
(1) + (2) + (3)		0.215

Note: Y, GDP; VS, vertical specialization;

Finally, we briefly discuss the model's counterfactual implications for the consumption share of imports, which increased in the data. In our simulations we hold the "all other" costs of importing final consumption goods constant. As mentioned above, at least some of these "all other" costs were captured by quotas and quantitative restrictions. Over time, the quotas were relaxed. 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, in 1967. 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.[35] Unfortunately, the lack of quantitative data on the changes in these quotas and quantitative restrictions prevents us from including it as one of our main trade policies. However, we conduct a simulation in which, in addition to the three tariff policies, we also reduce the "all other" trade costs by 27.2 percentage points, i.e., the same amount as the tariff decline. In this scenario, the consumption share of imports rises to over 10 percent, more than in the data.

7 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.

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. The three policies taken together explain about 15 percent of Korea's catch-up to the G7 in manufacturing GDP per worker. Our model can match Korea's increase in trade, but it over-predicts the increase in vertical specialization. Also, the model implies substantial increases in imported capital goods. However, the model delivers counterfactual predictions for the importance of consumption goods in trade. Our simulations also show that each of the three trade policies leads to welfare gains, and all three policies together lead to an increase in consumption of more than 17 percent. 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.

How do we interpret our results in light of Rodrik and Rodriguez (2000), as well as other research

[35] 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.

by Rodrik that finds that the importance of trade policy is limited?[36] 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.[37] Our findings, then, represent a lower bound on the importance of trade policies in Korea's growth miracle.

Our paper has focused on Korea's trade policies. Korea also implemented many other policies focused on output, not on trade *per se*. Studying the effects of the trade policies in conjunction with the other policies is left as an exercise for future research.

A Appendix (to be revised)

A.1 Solution for import share of GDP in the special case of the multi-stage production model

For goods ultimately consumed in the home country, there are two production methods, HH and HF. 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. 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:

$$p_{HH}(\underline{z}_h) \equiv (1+\tau_H)p_{HF}(\underline{z}_h) \Longrightarrow \tag{26}$$

$$\frac{\psi(w_H^{1-\alpha}r_H^{\alpha})^{1-\theta_1\theta_2}(P_H)^{\theta_1\theta_2}}{A_{H1}(\underline{z}_h)^{(1-\theta_1)\theta_2}A_{H2}(\underline{z}_h)^{1-\theta_2}} = (1+\tau_H)\frac{\psi(1+\tau_F)^{\theta_2}(w_H^{1-\alpha}r_H^{\alpha})^{(1-\theta_1)\theta_2}(P_H)^{\theta_1\theta_2}(w_F^{1-\alpha}r_F^{\alpha})^{1-\theta_2}}{A_{H1}(\underline{z}_h)^{(1-\theta_1)\theta_2}A_{F2}(\underline{z}_h)^{1-\theta_2}} \tag{27}$$

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

$$\left(\omega^{1-\alpha}\rho^{\alpha}\right)^{1-\theta_2} = \left(\frac{A_2^h(\underline{z}_h)}{A_2^f(\underline{z}_h)}\right)^{1-\theta_2}(1+\tau)^{(1+\theta_2)} \tag{28}$$

which leads to:

$$\omega^{1-\alpha}\rho^{\alpha} = 1 = \left(\frac{1-\underline{z}_h}{\underline{z}_h}\right)^{\frac{1}{n}}(1+\tau)^{\frac{1+\theta_2}{1-\theta_2}} \tag{29}$$

[36] See, for example, Rodrik, Subramanian, and Trebbi (2004).
[37] See Broda, Greenfield, and Weinstein (2006), and Bils and Klenow (2000).

The solution for $\underline{z}_h$ is given by:

$$\underline{z}_h = \frac{(1+\tau)^{n\left(\frac{1+\theta_2}{1-\theta_2}\right)}}{1+(1+\tau)^{n\left(\frac{1+\theta_2}{1-\theta_2}\right)}} \tag{30}$$

Home country imports expressed as a share of GDP are given by:

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

where φ is a constant that depends on θ_1 and θ_2.

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 the 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.

References

[1] Alvarez, Fernando, and Lucas, Jr., Robert E. "General Equilibrium Analysis of the Eaton-Kortum Model of International Trade." Journal of Monetary Economics, 2007, 54, 1726-68.

[2] Amiti, Mary, and Konings, Jozef. "Trade Liberalization, Intermediate Inputs and Productivity: Evidence from Indonesia." American Economic Review, 2007, 97 (5), 1611-38.

[3] Anderson, James E. and Neary, J. Peter. "Trade Reform with Quotas, Partial Rent Retention, and Tariffs." Econometrica, 1992, 60 (1), 57-76.

[4] Anderson, James E. and van Wincoop, Eric. "Trade Costs." Journal of Economic Literature, 2004, 42, 691-751.

[5] Arkolakis, Costas, Arnaud Costinot, and Andrés Rodríguez-Clare. "New Trade Models, Same Old Gains?" American Economic Review, 2012, 102 (1), 94-130.

[6] Backus, David K., Kehoe, Patrick J., and Finn E. Kydland. "Dynamics of the Trade Balance and the Terms of Trade: The J-Curve?" American Economic Review, 1994, 84 (1), 84-103.

[7] Baier, Scott, and Bergstrand, Jeffrey. "The Growth of World Trade: Tariffs, Transport Costs, and Income Similarity." Journal of International Economics, 2001, 53, 1-27.

[8] Bank of Korea, Economic Statistics Yearbook, various years.

[9] Basu, Susanto, and Fernald, John. "Returns to Scale in U.S. Production: Estimates and Implications." Journal of Political Economy, 1997, 105 (2), 249-83.

[10] Bils, Mark and Klenow, Peter. "Does Schooling Cause Growth?" American Economic Review, 2000, 90 (5), 1160-1183.

[11] Broda, Christian; Greenfield, Joshua and David Weinstein. "From Groundnuts to Globalization: A Structural Estimate of Trade and Growth." NBER Working Paper 12512, 2006.

[12] Caliendo, Lorenzo and Parro, Fernando. "Estimates of the Trade and Welfare Effects of NAFTA." Manuscript, January 2014.

[13] Chang, Yongsung and Hornstein, Andreas. "Transition Dynamics in the Neoclassical Growth Model: The Case of South Korea." Manuscript, 2011.

[14] Davis, Donald R. "Intra-Industry Trade: A Heckscher-Ohlin-Ricardo Approach." Journal of International Economics, 1995, 39, 201-226.

[15] Dornbusch, Rudiger; Fischer, Stanley and Paul Samuelson. "Comparative Advantage, Trade, and Payments in a Ricardian Model with a Continuum of Goods." American Economic Review, 1977, 67, 823-839.

[16] Eaton, Jonathan and Kortum, Samuel. "Technology, Geography, and Trade." Econometrica, September 2002, 70 (5), 1741-1779.

[17] Eaton, Jonathan and Kortum, Samuel. "Trade in Capital Goods." European Economic Review, 2001, 45 (7), 1195-1235.

[18] Edmond, Chris, Virgiliu Midrigan and Daniel Yi Xu. "Competition, Markups, and the Gains from International Trade." Manuscript. New York University, 2012.

[19] Finicelli, Andrea, Pagano, Patrizio, and Massimo Sbracia. "Ricardian Selection." Journal of International Economics, 2013, 89 (1), 96-109.

[20] Greenwood, Jeremy; Hercowitz, Zvi and Per Krusell. "Long-Run Implications of Investment-Specific Technological Change." American Economic Review, 1997, 87 (3), 342-362.

[21] Grossman, Gene and Helpman, Elhanan. Innovation and Growth in the Global Economy. Cambridge, MA: MIT Press, 1991.

[22] Hall, Robert E. and Jones, Charles I. "Why Do Some Countries Produce so Much More Output per Worker than Others?" Quarterly Journal of Economics, February 1999, 114 (1), 83-116.

[23] Head, Keith and Ries, John. "Increasing Returns Versus National Production Differentiation as an Explanation for the Pattern of U.S.-Canada Trade." American Economic Review, September 2001, 91 (4), 858-876.

[24] Heston, Alan; Summers, Robert and Bettina Aten, Penn World Table Version 6.1, Center for International Comparisons at the University of Pennsylvania (CICUP), October 2002

[25] Hummels, David; Ishii, Jun and Kei-Mu Yi. "The Nature and Growth of Vertical Specialization in World Trade." Journal of International Economics, June 2001, 54, 75-96.

[26] Hummels, David; Rapoport, Dana and Kei-Mu Yi. "Vertical Specialization and the Changing Nature of World Trade." Federal Reserve Bank of New York Economic Policy Review, June 1998, 59-79.

[27] Hummels, David, and Lugovskyy, Volodymyr. "Are Matched Partner Trade Statistics a Usable Measure of Transportation Costs?" Review of International Economics, 2006, 14 (1), 69-86.

[28] Ianchovichina, Elena. "Are Duty Drawbacks on Exports Worth the Hassle?" Canadian Journal of Economics, August 2007, 40 (3), 881-913.

[29] Johnson, Robert C. and Noguera, Guillermo. "Accounting For Intermediates: Production Sharing and Trade in Value Added." Journal of International Economics, 2012, 86, 224-236.

[30] Johnson, Robert C. and Noguera, Guillermo. "A Portrait of Trade in Value-Added over Four Decades." Manuscript, Dartmouth College, 2014.

[31] Jorgenson, Dale, Gollop, Frank, and Barbara Fraumeni. Productivity and U.S. Economic Growth. Cambridge, MA: Harvard University Press, 1987.

[32] Kehoe, Timothy J. and Ruhl, Kim J. "Are Shocks to the Terms of Trade Shocks to Productivity?" Review of Economic Dynamics, 2008, 11, 804-819.

[33] Kim, Dae-Il and Topel, Robert H. "Labor Markets and Economic Growth: Lessons from Korea's Industrialization, 1970-1990." in Freeman, Richard and Larry Katz, eds., Differences and Changes in Wage Structures, Chicago: University of Chicago Press for NBER, 1995.

[34] Klenow, Peter, and Rodriguez-Clare, Andrés. "The Neoclassical Revival in Growth Economics: Has it Gone Too Far?" in Bernanke, Ben S. and Julio J. Rotemberg, eds., NBER Macroeconomics Annual 1997. Cambridge: MIT Press, 1997.

[35] Koopman, Robert; Wang, Zhi, and Shang-Jin Wei. "Estimating Domestic Content in Exports When Processing Trade is Pervasive." Journal of Development Economics, 2012, 99 (1), 178-189.

[36] Koopman, Robert; Wang, Zhi, and Shang-Jin Wei. "Tracing Value-Added and Double Counting in Gross Exports." American Economic Review, 2014, 104 (2), 450-494.

[37] Krueger, Anne O. The Developmental Role of the Foreign Sector and Aid. Cambridge: Harvard University Press, 1982.

[38] Lee, Jong-Wha. "Government Interventions and Productivity Growth." Journal of Economic Growth, September 1996, 1, 391-414.

[39] Lucas, Robert E. Jr. "Making a Miracle." Econometrica, 1993, 61 (2), 251-272.

[40] Mason, Edward S., Kim, Mahn Je, Perkins, Dwight H., Kim, Kwang Suk, and David C. Cole. The Economic and Social Modernization of the Republic of Korea. Cambridge: Harvard University Press, 1980.

[41] Melitz, Marc. "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity." Econometrica, November 2003, 71, 695-725.

[42] Nam, Chong-Hyun. "The Role of Trade and Exchange Rate Policy in Korea's Growth." in Ito, Takatoshi and Anne O. Krueger, eds., Growth Theories in Light of the East Asian Experience. NBER East Asian Seminar on Economics Volume 4. Chicago: University of Chicago Press, 1995.

[43] Ogaki, Masao; Ostry, Jonathan D., and Carmen Reinhart. "Saving Behavior in Low- and Middle-Income Developing Countries: A Comparison." International Monetary Fund Staff Papers, March 1996, 43, 38-71.

[44] Papageorgiou, Chris and Perez-Sebastian, Fidel. "Dynamics in a non-scale R&D Growth Model with Human Capital: Explaining the Japanese and South Korean Development Experiences." Journal of Economic Dynamics and Control, 2006, 30, 901-930.

[45] Pavcnik, Nina. "Trade Liberalization, Exit, and Productivity Improvements: Evidence from Chilean Plants." Review of Economic Studies, 2002, 69 (1), 245-276.

[46] Rhee, Yung W., and Westphal, Larry E. "A Micro, Econometric Investigation of Choice of Technology." Journal of Development Economics, 1977, 4, 205-237.

[47] Rodriguez, Francisco and Rodrik, Dani. "Trade Policy and Economic Growth: A Skeptic's Guide to the Cross-National Evidence." in Bernanke, Ben S. and Kenneth Rogoff, eds., NBER Macroeconomics Annual 2000. Cambridge: MIT Press, 2001.

[48] Rodrik, Dani; Subramanian, Arvind, and Francesco Trebbi. "Institutions Rule: the Primacy of Institutions Over Geography and Integration in Economic Development." Journal of Economic Growth, 2004, 9, 131-165.

[49] Sachs, Jeffrey D. and Warner, Andrew. "Economic Reform and the Process of Global Integration." Brookings Papers on Economic Activity, 1995, 1, 1-118.

[50] Simonovska, Ina and Waugh, Michael. "The Elasticity of Trade: Estimates and Evidence." Manuscript, July 2012.

[51] Sposi, Michael. "Evolving Comparative Advantage, Structural Change, and the Composition of Trade." Manuscript, February 2012.

[52] Teignier, Marc. "The Role of Trade in Structural Transformation." Manuscript, April 2012.

[53] Trefler, Daniel. "The Long and Short of the Canada-U.S. Free Trade Agreement." American Economic Review, 2004, 94 (4), 870-895.

[54] Ventura, Jaume. "Growth and Interdependence." Quarterly Journal of Economics, 1997, 112 (1), 57-84.

[55] Wacziarg, Romain and Welch, Karen. "Trade Liberalization and Growth: New Evidence." World Bank Economic Review, 2008, 22 (2), 187-231.

[56] Waugh, Michael. "International Trade and Income Differences." American Economic Review, December 2010, 100 (5): 2093-2124.

[57] Westphal, Larry E. "Industrial Policy in an Export Propelled Economy: Lessons from South Korea's Experience." Journal of Economic Perspectives, Summer 1990, 4, 41-59.

[58] Westphal, Larry E. and Kim, Kwang Suk. "Industrial Policy and Development in Korea.", 1977, World Bank Staff Working Paper 263.

[59] Yi, Kei-Mu. "Can Vertical Specialization Explain the Growth of World Trade?" Journal of Political Economy, February 2003, 111, 52-102.

[60] Yi, Kei-Mu. "Can Multi-Stage Production Explain the Home Bias in Trade?" American Economic Review, March 2010, 100 (1), 364-393.

[61] Young, Alwyn. "The Tyranny of Numbers: Confronting the Statistical Realities of the East Asian Growth Experience." Quarterly Journal of Economics, August 1995, 110 (3), 641-680.