# Can Vertical Specialization Explain The Growth of World Trade?

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**Abstract**

The growth in the trade share of output is one of the most important features of the world economy since World War II. The growth is generally thought to have been generated by falling tariff barriers worldwide. This thinking, however, does not square with standard static and dynamic international trade models. Because tariff barriers have decreased little since the early 1960s, these models cannot explain the growth of trade without assuming counterfactually large elasticities of substitution between domestic and foreign goods. I show that this growth can be reconciled with the relatively small declines in tariffs once vertical specialization is included in the models. Vertical specialization, which occurs when countries specialize only in particular stages of a good's production sequence, magnifies the trade growth effects of trade barrier reduction. To show this, I calibrate and simulate a dynamic Ricardian model of trade with vertical specialization. I show that this model can explain about 70% of the growth of trade with just a unitary elasticity of substitution. The model also has important implications for the gains from trade.

# 1 Introduction

Almost all discussions of globalization and the internationalization of production highlight the growing trade shares of output. Indeed, trade's growing share is one of the most striking features of the world economy since World War II. For the last half century world merchandise trade has grown two percent per year faster than world merchandise output. World manufactured trade has outpaced manufactured output even more, by about three percent per year. (See Figure 1). Most countries, and many types of countries - small and large, rich and poor, fast growers and slow growers - have experienced increases in their trade shares of GDP.

The standard explanation for the worldwide growth of trade is the worldwide tariff reductions that have occurred. Lower tariffs reduce the cost of traded goods relative to domestic goods, leading consumers and firms to substitute traded goods for domestic goods. Imports and exports rise. Tariffs did decline considerably in the immediate aftermath of World War II. However, since the early 1960s, worldwide tariffs have decreased little, despite the global tariff reductions engendered by the Kennedy, Tokyo, and Uruguay General Agreement on Trade and Tariff (GATT) rounds. These three rounds have generated declines of only about 10 percentage points. During this period, on the other hand, the world manufacturing export share of output has tripled.

In this paper I first examine the trade effects of tariff reductions in three well-known static and dynamic (Ricardian, monopolistic competition, and international real business cycle) trade models. I find that these models can explain the growth of the manufactured export share of output only when very high elasticities of substitution between domestic and foreign goods are assumed. Elasticities on the order of *nine or higher* are needed to explain all of the growth of trade; these are considerably higher than the usual estimates and values used in computable general equilibrium models. It is a puzzle that the three models, which are based on comparative advantage, increasing returns, and the Armington aggregator, have difficulty in explaining the growth of trade, because they represent the theoretical and empirical paradigms that economists use to explain trade patterns.

To resolve the puzzle of reconciling large trade growth with relatively small tariff reductions, I assert that we need to go beyond the growth of trade in these broad terms, which is masking important changes occurring in the nature of trade. One of the most important changes is the increasing interconnectedness of production processes in a sequential, vertical trading chain stretching across many countries, with each country specializing in particular stages of a good's production sequence. Before, U.S. steel would be used to produce U.S. farm equipment, with some of that equipment exported. Now, Japanese steel is exported to Mexico, where it is stamped and pressed, and then exported to the U.S., where it is used to produce farm equipment, with some of that equipment exported. The amount of trade involved in getting a tractor to its final destination has increased considerably. Hummels, Rapoport, and Yi (HRY, 1998) and Hummels, Ishii and Yi (HIY, 1999) document the growth of this phenomenon, which they (and I) call *vertical specialization*.[1] According to HIY, vertical specialization occurs when imported intermediate goods are used to produce goods for export. Their primary measure of vertical specialization is the value of imported intermediates embodied in exported goods. Using case studies, input-output tables, and other sources, HRY and HIY show that vertical specialization accounts for about 30% of world trade today and grew by almost 40% between 1970 and 1995. It also accounted for about 1/3 of the growth in world trade during this period.

In principle, a model with vertical specialization can explain more of the growth of trade than a standard model without vertical specialization. This is because vertical specialization involves goods or goods-in-process which cross multiple international borders while they are being produced.[2] Each time these goods-in-process cross a border, a tariff is incurred. Consequently, global reductions in tariffs lead to a multiplied reduction in the cost of producing these goods. This large cost reduction will engender a larger trade response. To make this point more sharply, consider the following extreme example. A good is produced in N sequential stages, with each stage produced in a different country. The first stage involves value-added only. All remaining stages involve infinitesimally small value-added. Then, when tariffs fall by 1 percentage point, the cost of producing this good will fall by N percent. The cost of a "regular" traded good, by contrast, will decline by

[1] Others have called this phenomenon outsourcing, fragmentation, multi-stage production, slicing-up-the-value-chain, disintegration of production, and intra-product specialization. See Hummels, Ishii, and Yi (1999). I follow Balassa (1967) and Findlay (1978), who were apparently the first to note this phenomenon in international trade, in calling it vertical specialization.

[2] I do not count shipments merely traveling through a country in transit, such as what occurs at entrepots like Singapore, Hong Kong, and Amsterdam.

only 1 percent. In addition, some "regular" goods, that is, goods that were previously produced entirely in one country, may now become vertically specialized, also leading to an increase in trade. Through both these channels, trade in vertically specialized goods grows by more than trade in regular goods, and trade growth overall is higher than what would be predicted by standard trade models.

To investigate this possibility more carefully, I develop, calibrate, and simulate global tariff reductions in a two-country dynamic trade model. In the model, final goods are produced in three sequential stages. The first stage uses capital and labor to produce an intermediate good. The second stage uses the first stage good and capital and labor to produce a second-stage good. In the third stage, the second-stage goods are costlessly assembled into a non-traded final good which is used for consumption or investment. The first two stages are tradable. The motive for trade is Ricardian; it is based on cross-country productivity differentials in producing each of the two stages.

The simulation results indicate that the model can better explain trade growth than a model without vertical specialization. I find that in the 1960s and early 1970s, both a model with vertical specialization and the standard model without vertical specialization can explain trade growth equally well. Tariff rates in that period are sufficiently high that vertical specialization is not an efficient outcome. However, as tariff rates continue to fall, vertical specialization eventually occurs. Consequently, the model with vertical specialization generates more trade growth from the late 1970s onwards. It explains about 80% of the growth of trade over the last 20 years. Over the entire time period (1962-1997), the vertical specialization model explains about 70% of the trade growth. The standard model explains only about 45%. The results show that the growth of trade can be reconciled in the context of the standard paradigms economists use to think about trade, but only when the paradigms are broadened to include for a different kind of trade, vertical specialization.

Vertical specialization has implications for welfare, as well, because the gains to the tariff reductions are about 65% larger than in the standard model. There are two reasons for this. First, opportunities to specialize in particular stages of a good's production sequence provide gains beyond the usual gains from specialization and trade. Second, vertical specialization models can explain the growth of trade without relying on high elasticities of substitution. All else equal, lower elasticities imply greater gains from trade.

Section II provides stylized facts for the growth of vertical specialization, focusing on the U.S. Section III shows briefly the difficulty of matching the growth of trade in standard trade models. Section IV lays out the dynamic Ricardian trade model and Section V describes its calibration and parameterization. Section VI presents the results. Section VII concludes.

# 2 Growth of Vertical Specialization : Evidence from the U.S.

Following Hummels, Ishii, and Yi (HIY) (1999), I define vertical specialization to occur when:

1. Goods are produced in multiple, sequential stages.
2. Two or more countries provide value-added in the good's production sequence.
3. At least one country must use imported inputs in its stage of the production process, and some of the resulting output must be exported.

Note that vertical specialization has an import side and an export side. On the import side, vertical specialization is just a subset of intermediate goods - it is those intermediates that are used to make goods for export. On the export side, vertical specialization can include both final goods and intermediate goods. Hence, the concept is related to, but distinct from intermediate goods.[3] Figure 2 illustrates an example of vertical specialization involving three countries. Country 1 produces intermediate goods and exports them to country 2. Country 2 combines the imported intermediates with capital, labor, and domestic intermediates to produce a final good. Finally, country 2 exports some of the final good to country 3. If either the imported intermediates or the exports is absent, then there is no vertical specialization.

HIY develop two measures, called VS and VS1, that follow from this definition. Both are relevant for the United States. VS measures the imported

[3] HIY (1999) show that trade in intermediate goods has decreased as a share of total trade, so this measure of verticality in trade is clearly not capturing the changes that have occurred.

input content of export goods. VS1 measures the value of exported goods that are used as imported inputs to produce other countries' export goods. Specifically:

$$VS_{ki} = \left( \frac{II_{ki}}{GO_{ki}} \right) X_{ki} \tag{1}$$

where k and i denote country and industry, II is imported intermediates, GO is gross output, and X is exports.

$$VS1_{ki} = \sum_{j=1}^{n} XI_{kji} \left( \frac{X_{ji}}{GO_{ji}} \right) \tag{2}$$

where j is the destination country of country k's exports and XI is exports of intermediates. Country-level measures of VS and VS1 can be derived by summing across industries. It is easy to see how computing VS1 is considerably more difficult than calculating VS. VS1 calculations require knowledge of how a country's exports are used by the export destination country's industries.

To calculate industry and country-level VS and VS1, HIY rely primarily on input-output tables, which provide industry-level data on imported inputs, gross output, and exports. This paper shows that as of 1995, total vertical specialization, VS+VS1, accounts for about 30% of world exports, and between 1970 and 1995, growth in VS alone accounted for almost 1/3 of the growth of world exports.

In this paper I present more detailed results for the U.S. only, drawing from HIY and HRY.[4] The left column of Table 1 presents VS expressed as a share of exports for the years between 1962 and 1997. The values from 1972 to 1990 represent calculations from the OECD Input-Output Database. The values for 1962 and 1997 are extrapolated based on the average growth rate of the VS share between 1972 and 1990. Estimates for VS1, based on data from two case studies (Mexico's *maquiladoras* and U.S.-Canada auto

[4] HRY contains primarily case study evidence: U.S.-Mexican maquiladora trade, auto trade following the U.S.-Canada Auto Agreement, Opel España's auto trade, and Japanese electronics trade. HIY contains broader country-level evidence obtained from input-output tables.

trade), are reported in column 2 of Table 1. Column 3 reports the sum of VS and VS1. In 1997 vertical specialization accounted for at least 21.9% of U.S. exports. Growth accounting shows that growth in VS+VS1 accounts for 30.2% of the growth in the U.S. export share of merchandise GDP between 1962 and 1997. Because there is almost surely VS1 originating from U.S. trade other than that involving these two cases, these estimates are likely to be a lower bound for total U.S. vertical specialization. It is likely that both the level of VS+VS1 as well as the contribution of VS+VS1 to U.S. export growth are higher than the numbers reported here.[5]

# 3 Can the Standard Trade Models Explain the Growth of Trade?

In this section, I examine whether the standard trade models can explain the growth of trade. I draw from two literatures, the (static) international trade models and the (dynamic) international real business cycle (RBC) models. Of course, neither set of models was developed to explain the growth of trade. Nevertheless, they encompass the way economists think about trade from both micro and macro perspectives, and they are a useful starting point in understanding its growth since World War II.[6]

In each model, I include proportional, uniform tariffs. Manufactured tariff rates fell from about 14 percent to about 4 percent between 1962 and 1997. I calculate the trade effects of a tariff decline from 15 percent to zero.[7] I

[5]There is another reason to expect that this estimate is a lower bound. The main results in HIY are based on imported intermediates only. In the U.S., 30% of imports are capital goods. If we interpret capital goods as a kind of intermediate good in the sense that rental services from the capital become embodied in the goods that are produced from it, then these imported capital goods can generate VS exports.

[6]For example, see Bergoeing and Kehoe (1999). They, adapt a monopolistic competition model (and non-homothetic preferences) to a dynamic setting to assess whether the "new trade theory" can explain the growth of trade. They conclude that it cannot, without taking into account changes in trade policy.

[7]This is primarily for convenience, but it can be rationalized by appealing to reductions in transportation costs and non-tariff barriers (NTBs). Baier and Bergstrand (1999) calculate transportation costs (measured by c.i.f. imports/f.o.b. imports) for 16 countries. They find that these costs fell by about 4 percentage points between 1958-60 and 1986-88. While some measures of non-tariff barriers (NTB) have fallen, it is difficult to quantify the extent of this reduction. Moreover, sometimes the *imposition* of non-tariff barriers can increase trade (such as when Hong Kong textile firms start sourcing their products

compare the models' predictions for trade growth to the (adjusted) growth of the U.S. manufactured export share of output.[8] The share was about 2.6 times larger in 1997 than in 1962.

## 3.1 Static Trade Models

I examine two workhorse models, the Dornbusch, Fischer, Samuelson (DFS, 1977) Ricardian model and the basic monopolistic competition model (see Krugman, 1980, for example). In both these models, I assume that tariff revenue has no productive or consumption value.

In the DFS model, there is a continuum of goods on the unit interval. Each good is produced from labor with constant returns to scale; unit labor requirements differ across the two countries. Markets are perfectly competitive. DFS show that tariffs create a range of endogenously determined non-traded goods. As tariffs fall, that range narrows, leading to more trade. To obtain simple quantitative estimates of the effects of lower tariffs in this model, I specify the following preferences and technologies:

$$U(c) = \int_0^1 \frac{c(z)^\theta - 1}{\theta} dz \tag{3}$$

for $0 < \theta < 1$. $1/(1-\theta)$ is the elasticity of substitution between any two goods. On the technology side, I employ a specification related to what is employed in Eaton and Kortum (1998).[9]:

$$a(z) = 1 + z; a^*(z) = 2 - z \tag{4}$$

$a(z)$ and $a^*(z)$ denote the unit labor requirements in the home and foreign country. The production technologies are mirror images of each other. I also assume the home and foreign labor forces are the same size. These

through Mexico to avoid the restrictions of the Multifibre Agreement). Finally, some measures of NTBs have risen.

[8] The adjustment reflects the fact that the U.S. GDP share of world GDP has grown smaller over time, which by itself would raise the U.S. export share of GDP. The actual export share grew by a factor of 4.2. See Section 5.

[9] I also employ technologies similar to that in Evenett and Yeung (1998, 1999) and Xu (1993). The results are similar.

symmetries imply that free trade yields a relative wage of 1, that z=0.5 will be the cutoff determining specialization in each country, and that the export share of GDP = 0.5.

The top half of Figure 3 shows the effects of tariff reductions on the export share of GDP under several elasticities of substitution. When the elasticity is 1.5, a 15 percentage point tariff reduction leads to only a 25% increase in the export share. The elasticity needs to be *nine* to generate the actual increase.

In the monopolistic competition model, each of two countries has one factor (labor) and can produce a number of goods with an increasing returns technology:

$$l_i = \alpha + \beta x_i \tag{5}$$

$l$ is labor, $\alpha$ is the fixed cost, $\beta$ is the marginal cost, and $x$ is output of good $i$. The number of goods produced $n$ is endogenous and depends on the interplay of free entry and the zero profit condition with profit maximization in a monopolistic competion setting. The utility function is:

$$U(.) = \sum_{i=1}^{n} c_i^{\theta} \tag{6}$$

$\theta < 1$. $1/(1-\theta)$ is the elasticity of substitution (and demand) between goods and $1/\theta$ is the firms' gross markup. I again assume that the size of the labor force in the two countries is identical.

Tariffs do not affect the number of goods produced or the output of each good. They only affect the level of imports and exports, and their tariff-inclusive relative prices. When tariffs fall, the fraction of total spending devoted to imported goods increases; this is driven primarily by substitution effects. The bottom half of Figure 3 shows the results of the tariff experiment for several elastiticities. With a 15 percentage point tariff reduction, an elasticity of *nine or ten* is needed to replicate the growth of the manufactured export share.

## 3.2 International Real Business Cycle Model

The model draws from Backus, Kehoe, and Kydland (BKK, 1994), which is a two-country RBC model in which home and foreign goods are imperfect substitutes. The model can be thought of as a simple dynamic computable general equilibrium model. I solve the deterministic steady-state version of the BKK model modified to include for tariffs on imports. In this model tariff reductions have additional propagation effects beyond the usual static channels through endogenous capital accumulation.

The model is presented in detail in BKK, so I only summarize its features here. Preferences for the representative agent in the home country are characterized by:

$$\sum_{t=0}^{\infty} \beta^t U(c_t, 1-n_t) \tag{7}$$

where

$$U(c, 1-n) = \frac{\left(c^{\mu}(1-n)^{1-\mu}\right)^{1-\gamma}}{1-\gamma} \tag{8}$$

and $c$ and $n$ represent consumption and hours worked. Each country produces a distinct good. The home production function is:

$$Y_t = A_t K_t^{\theta} n_t^{1-\theta} \tag{9}$$

$A$ and $K$ represent total factor productivity and capital. Output can be used domestically ($D$) or it can be exported ($X$). The equilibrium condition for home output is:

$$Y_t = D_t + X_t \tag{10}$$

The domestic output and the imported good are combined via an Armington aggregator to produce a non-traded final good that is used for consumption and investment:

$$C_t + I_t = \left(w_1 D_t^{1-\alpha} + (1-w_1) X_t^{*1-\alpha}\right)^{1-\alpha} \tag{11}$$

where $\alpha \geq 0$ and the asterisk denotes the imported good (foreign country's exported input). $1/\alpha$ is the elasticity of substitution between domestic and imported goods. The export share of GDP is given by $X_t/Y_t$. Capital is accumulated in the standard way:

$$K_{t+1} = (1-\delta)K_t + I_t \tag{12}$$

I assume all proceeds from the tariffs are returned as lump sum transfers:

$$p_t \tau_t X_t^* = TR_t \tag{13}$$

where $p$ is the relative price of the imported good in terms of the domestic good, $\tau$ is the tariff rate, and $TR$ are transfers. Net foreign assets are accumulated in the standard way. Finally, I assume an initial and final net foreign asset position of zero. The set up for the foreign representative agent is symmetric.

The parameters draw from BKK and King, Plosser, and Rebelo (1988); the parameters are adjusted to reflect the annual period length used here. The key parameter is the elasticity of substitution between the home and foreign goods in the Armington aggregator, $1/\alpha$. I use $1/\alpha = 1.5$ as the benchmark case, (as in BKK), but the effects of higher elasticities are also examined. $\beta$, the preference discount factor, is set to 0.96. The share of consumption in utility, $\mu$, is set to 0.25, which insures that n = 0.2 in the steady-state. The intertemporal elasticity of substitution, $1/\gamma$, = 0.5. The depreciation rate on capital, $\delta$, = 0.1. The coefficient on capital in the production function, $\theta$, = 0.42. The initial steady-state level of net foreign assets, $B$, = 0. I set $w_1$ so that the initial steady-state export share of output is 0.21, which was the median export share for the OECD countries in 1950.

Table 2 presents the results of the tariff experiment for several elasticities of substitution. The table shows that the elasticity of substitution between home and foreign goods needs to be *ten or eleven* to match the growth in the manufacturing export share.[10]

[10] I also simulate the stochastic, dynamic, incomplete markets version of the model. I assume the four exogenous variables - the tariff rate and total factor productivity in both countries - follow a unit root process in their logarithmic deviations from the deterministic steady-state (with zero covariance across the shocks). I assume that agents have access to one-period risk-free bonds; this is more realistic than assuming complete Arrow-Debreu contingent claims. I solve the model using the familiar Blanchard and Kahn (1980) and King, Plosser, and Rebelo (KPR) (1988) linearization and solution techniques. These techniques involve log-linearizing the first order conditions and one (or more) of the equilibrium conditions of the model around the variables' deterministic steady-states. The resulting matrix of difference equations are solved according to well known formulas. Given the initial steady-state of zero net foreign assets, I simulate the effects of a bilateral 15% reduction in tariff rates. The results are even stronger than the deterministic steady-state exercise in the text.

### 3.3 What Have We Learned?

The three models presented above encompass three different, but widely used, paradigms for thinking about international trade: comparative advantage, increasing returns, and the Armington aggregator. Yet, all three paradigms fail to explain the growth of trade without relying on elasticities of substitution between domestic goods and imported goods on the order of nine or higher. These elasticities are counterfactually high. The elasticities that are typically estimated or employed in simulations/calibrations are on the order of two to three. For example, the Michigan Model of World Production and Trade is a large scale computable general equilibrium (CGE) model of 34 countries and 29 industries. Of the 21 non-agricultural traded goods industries, 17 have elasticities of substitution that are less than 3.1 and only two industries have elasticities of substitution greater than four (wearing apparel and rubber products).[11] Also, in Whalley's CGE model (1985), the elasticities of substitution in the three key regions (U.S., Japan, and EC) for the 17 manufacturing industries are all less than three. With these elasticities, my tariff experiment showed that only a small fraction of trade growth is explained.

Baier and Bergstrand (1999) estimate a gravity equation of bilateral trade derived from a standard trade model. Their estimate for the elasticity of substitution between goods is 6.43. This empirical result, then, is consistent with our numerical results: in order for standard trade models to explain the growth of trade, high elasticities of substitution are needed. The elasticities matter because, in general, the higher the elasticity of substitution, the lower the gains from trade. The standard models can only rationalize the large growth in trade by implying small gains from such trade!

I comment briefly on two extensions of my experiment. In one extension, I reduced tariff rates from 20% to 5% instead of from 15% to 0. The results did not change in the dynamic international RBC model, and they changed slightly in the static trade models. A second extension would be to increase the number of countries from 2 to 3 or higher. All countries continue to be symmetric. This will certainly raise the *level* of trade, e.g., under free trade the export share of output implied by the static trade models will now be 2/3 instead of 1/2. At each non-zero tariff rate, the export share of output will be higher than in the two-country case, as well. However, the *growth* of trade in response to tariff reductions is not affected by increasing the number

[11] See Deardorff and Stern (1990).

of countries.

The main reason why all three models cannot explain the growth of trade without relying on counterfactually high elasticities is that observed tariff rates have fallen little. The type of trade in these models involves goods where all the value-added occurs in just one country. Hence, the total amount of trade involving a particular good cannot be higher than the price or value-added of that good.[12] As shown earlier, much of the growth of trade involves a different kind of trade, vertical specialization. With this specialization, goods or goods-in-process cross multiple international borders in the course of their production sequence, generating international trade with each border crossing. The total amount of trade involving the good, while in-process, can be a multiple of the value-added of that good. Because vertical specialization is associated with so much trade, any force that leads to increased vertical specialization can also lead to large trade growth. None of the three models includes vertical specialization. I now turn to such a model.

# 4 Dynamic Ricardian Trade Model

In this section, I lay out the model. The model marries a Dornbusch-Fischer-Samuelson Ricardian international trade framework to a standard dynamic macroeconomic framework. I choose a Ricardian framework, as opposed to the other two frameworks from the previous section, for three reasons. First, recent work by Harrigan (1997) and Eaton and Kortum (1999) have showed the empirical relevance of Ricardian technological differences in explaining trade patterns. Second, empirical evidence clearly in favor of the monopolistic competition model and against other models is sparse. Finally, it is desirable to have a model of trade where firms choose whether to use domestic or imported inputs, that is, a model where vertical specialization occurs endogenously. This rules out Armington aggregator-based models, in which reliance on both domestic and imported inputs is assumed.[13]

I first present the production side of the model and discuss the pattern

[12] This idea also applies to models where value-added occurs in two countries, but where there is no vertical specialization, i.e., models of intermediate goods trade where a typical trade pattern is the following: engines are exported from the U.S. to Canada to produce motor vehicles that are sold in Canada.

[13] See Kouparitsas (1997) for a dynamic Armington aggregator CGE model that has vertical specialization.

of specialization and international trade. Then, I present the household's problem, which is where the dynamics enter. Finally, I introduce tariffs into the model and give the intuition for how vertical specialization can magnify the trade effects of tariff reductions.

## 4.1 Production and Trade

There are two countries and two factors of production (capital and labor). Each country possesses technologies for producing a non-traded final good in three sequential stages. The non-traded good is created in the third and final stage, which involves the costless assembly of a unit interval continuum of second-stage goods:

$$Y_t = \exp\left[\int_0^1 \ln[y_{2,t}(z)]dz\right] \tag{14}$$

The second-stage good associated with each z, $z \in [0,1]$, is produced from capital and labor and z's first stage output, combined in a nested Cobb-Douglas production function:

$$y_2(z) = y_1(z)^{\theta}\left(A_2(z)K_2(z)^{\alpha}L_2(z)^{1-\alpha}\right)^{1-\theta} \tag{15}$$

First stage goods are produced from capital and labor:

$$y_1(z) = A_1(z)K_1(z)^{\alpha}L_1(z)^{1-\alpha} \tag{16}$$

The above holds under autarky. The foreign production functions are identical up to the productivity parameters $A_1(z)$and $A_2(z)$, and are denoted by asterisks. All firms maximize profits taking prices as given. Appendix 1 gives the details on their maximization problems and on the market clearing conditions. Perfect competition holds in all three stages of production.

Under free trade, there are four possible production patterns for the first two stages of each good z:

(HH) Home (country) produces stages 1 and 2
(FF) Foreign produces stages 1 and 2
(HF) Home produces stage 1, Foreign produces stage 2
(FH) Foreign produces stage 1, Home produces stage 2

Production patterns HF and FH involve vertical specialization. For example, if HF is the efficient pattern:

$$y_1(z) = A_1(z)K_1(z)^{\alpha}L_1(z)^{1-\alpha} \tag{17}$$
$$y_2^*(z) = y_1(z)^{\theta}\left(A_2^*(z)K_2^*(z)^{\alpha}L_2^*(z)^{1-\alpha}\right)^{1-\theta} \tag{18}$$

Vertical specialization occurs under free trade as long as

$$\frac{A_1(z')}{A_1^*(z\prime)} < \left(\frac{r}{r^*}\right)^{\alpha}\left(\frac{w}{w^*}\right)^{1-\alpha} < \frac{A_2(z')}{A_2^*(z\prime)} \tag{19}$$

or

$$\frac{A_1(z')}{A_1^*(z\prime)} > \left(\frac{r}{r^*}\right)^{\alpha}\left(\frac{w}{w^*}\right)^{1-\alpha} > \frac{A_2(z')}{A_2^*(z\prime)} \tag{20}$$

for some $z\prime$, where $r$ and $r^*$ are the rental rates on capital, $w$ and $w^*$ are the wage rates. The above inequalities are intuitive. Vertical specialization will occur if it is cheaper to produce stage 1 in one country and stage 2 in the other country.

The equilibrium production pattern for each $z \in [0, 1]$ is determined primarily by the relative productivity differences across stages and countries. In other words, Ricardian comparative advantage forces determine the pattern of specialization and trade. Figure 4 illustrates an example of a free trade equilibrium. The y-axis denotes relative factor costs (home/foreign) and relative productivities for stage 1 value-added and for stage 2 value-added. With no loss of generality, the [0,1] continuum can be ordered so that it is declining in home country comparative advantage in stage 1, i.e., z=0 is the good in which the home country's stage 1 productivity (relative to the foreign country) is highest. I illustrate an example where the comparative advantage ordering of home's stage 2 productivity is the same as it is for stage 1. Note that the figure is characterized by two "cutoff" z's that delineate the patterns of specialization. The middle region of the continuum generates vertical specialization (pattern HF). In this region, the home country produces stage 1 and exports it to the foreign country, which uses it to make stage 2. Some of the stage two output, in turn, is exported back to the home country. The arbitrage condition that determines the cutoff separating production pattern HH from production pattern HF is given by:

$$\frac{r^{\alpha}w^{1-\alpha}\chi}{A_1(\underline{z^h})^{\theta}A_2(\underline{z^h})} = \frac{r^{\alpha\theta}r^{*\alpha(1-\theta)}w^{(1-\alpha)\theta}w^{*(1-\alpha)(1-\theta)}\chi}{A_1(\underline{z^h})^{\theta}A_2^*(\underline{z^h})} \tag{21}$$

where $\underline{z^h}$ is the cutoff $z$ at which equality holds. $\chi$ is a constant. The above can be rewritten as:

$$\rho^{\alpha}\omega^{1-\alpha} = \left(\frac{A_2(\underline{z^h})}{A_2^*(\underline{z^h})}\right) \tag{22}$$

where $\rho$ is the ratio of home to foreign rental rates and $\omega$ is the ratio of home to foreign wages. Home and foreign factor prices are expressed in terms of the numeraire. The condition basically says that one country exports until the point where its cost advantage (disadvantage) equals its productivity disadvantage (advantage). This cutoff depends only on stage 2 relative productivity, because the difference between production methods HH and HF lies in which country produces stage 2.

## 4.2 Households

The representative household in the home country maximizes:

$$\sum_{t=0}^{\infty} \beta^t \ln(C_t) \tag{23}$$

subject to a sequence of budget constraints:

$$C_t + K_{t+1} - (1-\delta)K_t = w_t L_t + r_t K_t \equiv Y_t \tag{24}$$

Capital is accumulated in the standard way:

$$K_{t+1} - (1-\delta)K_t = I_t \tag{25}$$

Households own the capital, and rent it period-by-period to the three types of firms. The setup for the foreign country is similar, and is denoted by asterisks. I assume there are no international capital flows. Consequently, trade is balanced, period-by-period.

## 4.3 Tariffs and Intuition on Trade Growth

Tariffs are proportional and apply uniformly to all imports. Tariff revenue is returned to households as lump-sum transfers. On the production side, tariffs raise the cost of imported inputs. For some z, the production patterns will now differ according to whether the ultimate consumer is in the home country or foreign country. This is illustrated in Figure 5, which shows that the tariffs create "wedges" around each free trade cutoff z. Notice that the range of vertical specialization, i.e., those goods produced by technique HF, gets squeezed on both sides. This is because the tariffs impose a tax on the first stage of production twice - once when the first stage enters the foreign country, and once when the second-stage good is imported back into the home country. Tariffs raise the cost of vertical specialization by more than they raise the cost of regular trade.

If tariffs are high enough, all vertical specialization is eliminated, and the model becomes one in which no good incurs more than one tariff. There is no "back and forth" trade, no multiple border crossings. I now describe a simple story for post-World War II trade. Initially, tariffs are sufficiently high so that there is no vertical specialization; many goods are not traded at all. Tariffs begin to fall gradually. At first, tariffs are still sufficiently high that vertical specialization does not occur. Nevertheless, trade increases because non-traded goods become traded goods, and because more traded goods are exchanged. As tariffs continue to fall, vertical specialization becomes more of a possibility. Eventually, a critical tariff rate is reached at which vertical specialization starts to occur. At this point, trade surges. Two forces, one operating on an external margin and one on an internal margin, drive this surge. The first is that as goods switch from being "regular" to "vertically specialized", trade increases because of the back-and-forth aspect of this trade; each good generates more trade before it reaches its final destination. The more goods that become vertically specialized the greater the increase in trade. The second is that the lower tariffs reduce the cost of producing existing vertically specialized goods by a multiple of the tariff reduction, as discussed earlier. What is the size of the cost reduction? In this model, it is $1 + \theta$ multiplied by the reduction in tariffs. The greater the stage-1 input requirement in stage-2 production, the greater the cost reduction from tariff reductions. More generally, in a version of the model with n-stages of production, the change in costs is:

$$\left(\frac{1-\theta^n}{1-\theta}\right) * \Delta\tau \tag{26}$$

where $\Delta\tau$ is the change in tariff rates. As the number of stages increase, the magnification effect of tariff reduction increases. Once vertical specialization occurs, then, each subsequent tariff reduction leads to larger increases in total trade than would be predicted by a standard model.

# 5 Calibration of Model

The goal of this paper is to examine whether vertical specialization is an important propagation mechanism helping to magnify the effects of rather small observed tariff reductions, thus generating the large observed growth of trade. To quantitatively assess the importance of vertical specialization, I simulate tariff reductions in two parameterizations of the model, one with vertical specialization and one without vertical specialization.

Each period represents one year; I start the simulation in 1962. 1962 was a year in the middle of a lull in major tariff reductions resulting from the General Agreement on Tariffs and Trade (GATT) rounds. The first round, in 1947, reduced tariffs considerably, bringing them back down to levels that had existed prior to the increases imposed in the Great Depression. From 1947 until the conclusion of the Kennedy Round in 1967, the GATT rounds achieved little in the way of worldwide tariff reduction.[14]

The two countries are of equal size and represent developed countries. Developed countries still account for almost 70% of world merchandise trade and more than 70% of world manufactured trade. Moreover, more than 70% of developed country exports go to other developed countries.[15] I focus on manufacturing, because 79% of developed country trade is manufactured goods. Finally, from HIY, we know that most vertical specialization by developed countries is with other developed countries.

I think of one country as the U.S. and the other country as the other Rest-of-the-Developed-World (ROW). In 1963, U.S. manufacturing GDP was equal to 54% of the total manufacturing GDP of the G-7 plus other Western Europe countries. In other words, U.S. manufacturing output was approximately equal to ROW manufacturing output. By 1995, due to higher ROW growth rates, the U.S. share of total manufacturing GDP had dropped to

[14] See Irwin (1995). Also, see Crucini and Kahn (1996) for a calibration/simulation of tariff increases during the Great Depression.

[15] These numbers are based on the United Nations definition of "developed", which includes Western Europe, the U.S., Japan, Canada, Israel, South Africa, Australia, and New Zealand.

28%. A well-known result in trade models that feature complete specialization, free trade, and identical, homothetic preferences is that the trade share of output is just $1 - s$, where $s$ is the country's share of world GDP. By this metric, the U.S. trade share of output should have increased by about .72/.46 during this period even if no tariff reductions had occurred.[16] To control for the effect of changing country size on the trade share of output, I adjust the U.S. manufacturing export share of (manufacturing) output series by this factor. Specifically, I assume the growth rate of the ROW relative to the U.S. is constant between 1962 and 1997, and adjust each year's export share of output accordingly. This has the effect of reducing the U.S. manufactured export share of output growth rate from 4.18% per year to 2.73% per year. Over 35 years, then, the adjusted export share of output grows by a factor of 2.6 (the unadjusted export share grew by a factor of 4.2).[17]

I construct the tariff series using data on U.S., European Community (EC), and Japan manufacturing tariff rates. (See Appendix 2 for the sources of the data and details on the series construction). I construct a tariff series for the U.S. and for the ROW (a trade weighted average of the EC and Japan tariffs); these two series are very similar, and consequently I use the average of the two series as a single tariff series that both countries face. Figure 6 illustrates the time path of tariffs, juxtaposed against the (unadjusted) U.S. manufactured export share of manufactured GDP. Tariffs declined sharply from the late 1960s through the mid-1970s, largely as a result of the Kennedy Round GATT treaty. About half of the overall decline of 10.2 percentage points occurred between 1967 and 1972. Thereafter, tariffs declined gradually.

I set $\alpha$, the Cobb-Douglas coefficient on capital, to 0.36, as in BKK (1994) and many other real business cycle papers. I set, $\beta$, the preference discount parameter, to 0.96, which is also typical in models with annual frequencies. The depreciation rate on capital, $\delta$, is set to 0.13, which is the depreciation rate on equipment and machinery given in Jorgenson, Gollop, and Fraumeni (1987). The share of first stage output used as inputs in second

[16] Because our framework involves non-free trade, this result is only an approximation.

[17] Another approach would have been to calibrate the initial capital/labor ratio for the U.S. to be higher than that of the ROW, and to let the ROW economy dynamically converge in size to the U.S. In a Ricardian model with Cobb-Douglas technologies, however, capital/labor ratio convergence has little effect on GDP convergence. This is because gains to country-size due to higher capital/labor ratios are to a large extent offset by terms of trade declines.

stage production, $\theta$, is set to 2/3, which is consistent with the fact that, for manufacturing, value-added represents about 1/3 of gross production. The initial capital/labor ratios are set to their steady-state values consistent with tariff rates remaining at their 1962 values forever. I set the ROW labor force so that ROW GDP and U.S. GDP in 1962 are identical.

The most difficult part of calibrating the model involves the productivity parameters. What is needed is a measure of U.S. productivity relative to ROW productivity over a large range of industries. Even more challenging, the relative productivity parameters are needed for both stage 1 and stage 2 production. Data on industry-level total factor productivity exist. However, data on total factor productivity for the equivalent of stage 1 production and of stage 2 production, industry-by-industry, do not exist. In other words, while data on the total factor productivity of the motor vehicles industry exists, data on the total factor productivity of engines and windshields, as well as on final assembly, do not.

To deal with this challenge, I draw from two sets of data and make one key assumption. The first set of data is the total factor productivity data from Harrigan (1997a, b, 1999). Harrigan calculates U.S. total factor productivity (TFP), relative to the other G-7 countries, for thirteen manufacturing industries over selected years between 1970 and 1988. Table 3 provides his results, along with each industry's share of all industries' value-added for the U.S. U.S. TFPs are typically larger than the ROW TFPs. The relative TFPs range from 1.8 in aircraft and office equipment to 0.9 in electrical machinery, with the median at about 1.3. Harrigan also finds that the relative TFPs have changed little between 1970 and 1988. Bernard and Jones (1996) obtain this latter finding, as well. Consequently, I assume that these (overall) industry relative TFPs are fixed over my sample period 1962 to 1997. This rules out changes in trade growth resulting from changes in relative TFP.[18]

The second set of data is the HIY data on U.S. vertical specialization. I use these data as a guide in setting the relative first-stage and relative second-stage productivity parameters. In particular, I set the parameters to meet the following conditions:

1. The aggregated relative productivity, $\frac{A(z)}{A^*(z)} = \left(\frac{A_1(z)}{A_1^*(z)}\right)^{\theta} \left(\frac{A_2(z)}{A_2^*(z)}\right)^{1-\theta}$ must be consistent with Harrigan's results, i.e., $\frac{A(0)}{A^*(0)} = 1.8$, and $\frac{A(1)}{A^*(1)} = 0.9$.

[18] Evenett and Yeung (1999) argue that the relative productivities across countries have deceased over time, which, all else equal, implies less trade.

2. To allow for vertical specialization, there must be a difference between home relative productivity in stage 1 goods and home relative productivity in stage 2 goods. I parameterize this difference as follows:

$$\left(\frac{A_1(z)}{A_1^*(z)}\right) = \frac{\kappa^{\frac{1}{\theta}} A}{1+z} \tag{27}$$

and,

$$\left(\frac{A_2(z)}{A_2^*(z)}\right) = \frac{A}{\kappa^{\frac{1}{1-\theta}}(1+z)} \tag{28}$$

where $\kappa \geq 1$ and $A > 1$. If $\kappa = 1$, then the relative productivities across stage 1 and stage 2 are equal, and no vertical specialization will occur. $A$ captures the overall productivity advantage of the U.S. and is set to 1.8.[19] In the above formulation, the two productivity curves are parallel to each other, with the U.S. relatively more productive in first-stage goods than in second-stage goods. That the stage-1 and stage-2 relative total factor productivities are parallel to each other is the key assumption in the calibration.[20] The assumption amounts to asserting that when the U.S. is relatively more productive than the G-6 countries in motor vehicle engine production, it is also relatively more productive at final assembly production. I justify this assumption for the following reason. My focus is on aggregate, not industry-level, vertical specialization and trade growth. As discussed below, I choose $\kappa$ so that vertical specialization matches the U.S. vertical specialization data in 1997. This parameterization ensures that the model is not "rigged" to generate enormous vertical specialization and trade growth.[21]

[19] Figure 7 illustrates the aggregate relative productivity curve against Harrigan's industry-level TFP data, ordered from highest to lowest.

[20] Recall that the stage-1 goods can be ordered so that the $A_1(z)/A_1^*(z)$ curve is downward sloping. But the $A_2(z)/A_2^*(z)$ curve could take any shape, in principle; it could be non-monotonic or even discontinuous.

[21] As an alternative, I could have assumed that the relative productivity lines crossed each other rather than were parallel to each other. But I would have adjusted the $\kappa$ parameter to insure that the implied vertical specialization matched the data. This insures that both the trade growth implications, as well as the contribution of vertical specialization to trade growth, across the two radically different productivity specifications are not too different from each other.

Another approach would have been to combine the Harrigan data with input-output

3. I parameterize $\kappa$ so that the model delivers vertical specialization in the U.S. in 1997 roughly equal to the actual level; $\kappa$ is set to 1.084. I also examine a case which generates larger vertical specialization. This case would be appropriate if the calculations in HIY (1999) are underestimates of the true level of vertical specialization.

I solve the model by assuming that the new steady-state is reached after 125 years. The steady-state can be solved for independently of the transition dynamics. I use GAUSS's NLSYS non-linear equations routine to solve the Euler equations and equilibrium conditions characterizing the transition dynamics.

# 6 Results

## 6.1 Main Results

The main results are presented in Table 4 and Figure 8. I examine the effects of the tariff reductions for the two vertical specialization cases and a non-vertical specialization case. Table 4 breaks up the thirty-five year period between 1962 and 1997 into two intervals, 1962-1977, which captures the Kennedy Round, and 1977-1997, which captures the Tokyo Round and much of the Uruguay Round. 1977 is approximately halfway between the end of the phase-in period of the Kennedy Round and the beginning of the phase-in period of the Tokyo Round. Tariffs fell by about six percentage points in the first period and four percentage points in the second period. In other words, average annual tariff reductions were about twice as large in the first period as in the second period.

The top panel of Table 4 lists actual export share growth as well as the implied export share growth predicted by the models. Focusing first on the primary vertical specialization case, $\kappa$=1.084, both the vertical and non-vertical specialization models explain a little more than 60% of the actual export share growth between 1962 and 1976. Their export implications are almost identical because tariffs in this period are high enough to prevent ver-

tables. So, for example, knowing that much of motor vehicles' inputs originate from the steel industry, and knowing the steel industry's TFP could help in obtaining an estimate of the stage 1 TFP for the motor vehicle industry. This approach is problematic, however, because it does not take a stand on *within* industry stage-1 and stage-2 TFP. For most industries, the industry itself is its largest source of inputs.

tical specialization from occurring. Consequently, the vertical specialization model behaves like the standard model in response to tariff reductions. After 1977, tariffs fall low enough to induce vertical specialization. For the 1977-1997 period, the model with vertical specialization implies annual export growth of 2.0%, which is two and one-half times higher than the prediction of the non-vertical specialization (hereafter, "standard") model. This growth rate is 80% of the actual export share growth. For the entire period, 1962-1997, the standard model captures less than 1/2 of the actual export growth. The vertical specialization (hereafter, "vertical") model explains about 70% of the actual export growth. The vertical model explains about 50% of the gap between the actual export growth and the export growth implied by the standard model. In the second vertical case, $\kappa$ is set so that the vertical model explains 75% of the gap between actual growth and the growth implied by the standard model. Both vertical cases explain much of what the standard model cannot explain, especially in the last 20 years, during which time tariff rates did not fall by much, yet trade flows continued to increase.

The bottom panel of Table 4 lists the implications for vertical specialization. Recall that $\kappa$ is set to 1.084 in order for the vertical model to match the 1997 U.S. data on vertical specialization. In the other two years, 1962 and 1977, the model implies that tariffs are too high for vertical specialization to occur; this is contrary to the data. Once tariffs fall sufficiently low, the model predicts large and rapid increases in vertical specialization. In the data, however, vertical specialization rises gradually over time. Also, in the model, vertical specialization accounts for 2/3 of the export growth between 1977 and 1997, which is almost twice as much as in the data. The second vertical case generates non-zero vertical specialization in 1977, but it also predicts a vertical specialization share of exports of 0.36 by 1997, which is about 50% higher than the data. This prediction appears to be counterfactually high, even allowing for the fact that the data probably is an underestimate of the truth. Hence, the vertical model does not generate enough vertical specialization in the earlier period, and too much in the later period. One way to reconcile the gradual growth of vertical specialization in the data to the very rapid increase implied by the model lies in the fact that different industries face different tariff rates. Broad, general tariff reductions such as those provided by the GATT rounds would lead different industries to achieve vertical specialization in different years. When averaged across all industries, the time path of aggregate vertical specialization could be smoother than the time path of each industry.

What are the welfare consequences of vertical specialization? Welfare is defined in the usual way as the infinite horizon discounted sum of utilities. For both the vertical and standard models, I compare the time path of consumption under the actual tariff reductions to the time path of consumption if tariffs remained at their 1962 levels forever. Specifically I compute the percentage increase in consumption needed in every period to raise welfare in the latter case to the welfare level of the former case. I calculate the average of the two countries' consumption increase. For the standard model, I find that the welfare gains to tariff reduction are equivalent to an increase in consumption of 1.13 percentage points forever. For the vertical model, the welfare gains are equivalent to a 1.48 percentage point increase in consumption, which is 31% higher than in the standard model. The welfare gains are greater because the vertical model simply has more specialization possibilities than the standard model.

I also compare the vertical model against a constant elasticity of substitution version of the standard model where the elasticity of substitution between goods is chosen so that the standard model's implied trade growth rate is equivalent to the implied trade growth rate of the vertical model. This occurs when the elasticity of substitution is about eight. All else equal, raising the elasticity of substitution between goods tends to lower the welfare gains from trade; in the extreme when goods are perfect substitutes, there are no gains from trade. In this high elasticity case, I find that the welfare gains in the vertical model are about 65% higher than in the standard model. When $\kappa$=1.115, the vertical model produces welfare gains that are more than twice as high as in (the high elasticity case of) the standard model.

Summarizing, the primary vertical specialization case can explain about 70% of the growth of world trade; this is about 50% more than what the standard model can explain. Allowing for larger relative productivity differences across countries increases the explanatory power of the vertical specialization model. However, the implied time path of vertical specialization is sharper than the actual time path. Finally, the welfare gains to tariff reductions are about 2/3 larger than in the standard model.

## 6.2 Sensitivity Analysis

I engage in several sensitivity analyses to assess the robustness of the main findings. In one exercise, I examine a different set of sub-periods. It is not desirable to split up the overall period into too many sub-periods, because business cycle effects, such as those due to the extensive appreciation and then depreciation of the dollar in the 1980s, affect the benchmark numbers that the model is compared against. Nevertheless, I examine three subperiods, 1962-72, 1973-85, and 1985-97, corresponding approximately to the Kennedy Round, the Tokyo Round, and the Uruguay Round, and also corresponding to years for which I had data on vertical specialization. Similar results are obtained.

Because I focus on longer-run secular trends, rather than events at business cycle frequencies, I also perform the tariff reduction simulation with the capital share of output, $\alpha$, set to 2/3. This is the value consistent with the empirical growth results in Mankiw, Romer, and Weil (1992). Again, the implications for trade growth and vertical specialization are very similar to those obtained when $\alpha = 0.36$.

In the model, I assumed that tariff rates are uniform across both stages of production. In reality, tariffs tend to be lower the earlier the stage of production. That is, tariffs on raw materials and intermediate goods tend to be lower than tariffs on final goods. Hence, the "effective" rate of protection on final goods is greater than the nominal rate of protection. Balassa (1965) finds that the effective rate of protection for the U.S., EC, and Japan is about twice as high as the nominal rate. In my model, this effective rate of protection is generated when stage-1 goods face a tariff equal to 1/2 the tariff on stage-2 goods. I perform simulations on a simplified version of my model (one with no dynamic capital accumulation) and found that as long as the ratio of the two tariff rates does not change over time, the trade growth and vertical specialization implications are very similar.

# 7 Conclusion

The growth of the trade share of output is probably the most commonly used piece of evidence to illustrate the increasingly globalized world economy. This growth has been dramatic, averaging 2%-3% per year for the past fifty years. In the time period I focus on, 1962-1997, the merchandise (manufacturing) export share of output grew even faster, by 2.5% (3.5%) per year. The common wisdom about the cause of this growth focuses on the worldwide reductions in trade barriers brought about by several GATT agreements. Each of the three most recent agreements, the Kennedy, Tokyo, and Uruguay rounds, reduced tariff barriers by 35%-40%. However, these reductions amounted to just a few percentage points because tariff barriers since the early 1960s have not been very high. Consequently, it is difficult to rationalize the large growth of trade with standard trade propagation mechanisms under standard trade elasticities.

However, numerous changes have occurred in the nature of trade. The change most relevant to understanding the growth of trade is its increased verticality. Vertical specialization, which occurs when countries specialize in particular stages of good's production sequence, rather than in the entire good, has become more prevalent. Estimates by Hummels, Ishii, and Yi (1999) suggest that vertical specialization can account for 30% or more of the growth of U.S. trade since 1962. The intuition for how vertical specialization can serve as a propagation mechanism magnifying tariff reductions into large increases in trade is straightforward: With vertically specialized goods, a 1 percentage point reduction in tariffs leads to a multiple of 1 percentage point decline in costs and prices. Consequently, trade grows by more than would be predicted by the standard trade model. Moreover, with vertically specialized trade, the amount of trade generated before a good reaches its final destination can be a multiple of the value-added embodied in that good. Hence, the more goods that become vertically specialized, the greater the amount of trade.

I calibrate a two-country dynamic Ricardian model of vertical specialization and simulate the response of trade to a reduction in tariffs. I find that with vertical specialization, more than 70% of U.S. trade growth since 1962 can be explained. By contrast the standard model explains less than half of the actual trade growth. Moreover, the welfare gains to tariff reductions are about 65% larger in a vertical specialization model, relative to a standard model.

My simulations do not include transportation costs. Declines in transportation costs over time would be an additional force to generate vertical specialization and greater trade. However, it is difficult to measure transportation costs. Moreover, existing measures indicate that they have fallen by little, if at all. In a careful study, Hummels (1999) argues convincingly that transportation costs have not changed since the 1970s. He finds that decreases in air transport costs have been offset by increases in ocean transport costs.[22]

What other forces could explain the remaining 30% of the trade growth that the vertical specialization model cannot explain? One possibility is that the GATT-induced tariff reductions have generated even more trade and vertical specialization than implied by a two-country model with two tradable stages per good. Allowing for the more realistic feature of greater than two countries and stages will provide greater opportunities for vertical specialization and trade to respond to tariff reductions. Also, in the model, the number of stages is fixed. Tariff reductions are the only force generating increased trade and vertical specialization. A second possibility, then, is that technology has changed so that goods that in the past were produced in two or three stages are now produced in five or six stages. To paraphrase Bohm-Bawerk, goods production has become even more roundabout. Allowing for increases in the number of stages increases the possibilities for vertical specialization and trade.[23] A third possibility is that an increasing fraction of U.S. trade is with emerging markets. U.S.exports to these countries has increased from about 1/3 of total exports in 1970 to about 2/5 of total exports in 1996. In many of these countries, trade reforms much larger than the GATT rounds of tariff reductions have occurred. Taking into account these countries' trade barrier reductions would probably imply additional trade and VS growth.

There was one other era of great trade growth, the 40 years preceding World War I. During this period the export share of output in Germany doubled and that of the U.S. and the U.K. increased by 50%.[24] However, this period was also characterized by large reductions in tariffs - estimates are of 20 percentage points - and by large reductions in transportation costs, driven by the expansion of steam ships and railroads. The best evidence of declining shipping costs is of declining price differentials between goods in ports-of-exit in the U.S. and in ports-of-entry in the U.K. These price differentials fell enormously, on the order of 40 percentage points.[25] Hence, trade growth between 1870-1913 does not need vertical specialization to explain it. Trade

[22] In their regressions, Baier and Bergstrand (1999) find that tariff reductions explain more than three times as much trade growth than do transport cost reductions. In Rose's (1991) trade growth regressions, tariffs have explanatory power, but transportation costs do not.

[23] See Deardorff (1998), for example.

[24] See Maddison (1991).

[25] See O'Rourke and Williamson (1994).

growth since World War II does.

# A Firms' Profit Maximization and Market Clearing Conditions

The numeraire is the home final good, $Y_t$.

**1. Firms' Profit Maximization**

All firms maximize profits, taking prices as given. In each period, $\forall\ z \in [0,1]$:

**Stage 1 firms maximize:**

$$p_1(z)y_1(z) - wl_1(z) - rk_1(z) \tag{29}$$

**Stage 2 firms maximize:**

$$p_2(z)y_2(z) - p_1(z)y_1(z) - wl_2(z) - rk_2(z) \tag{30}$$

if the first stage inputs come from home, (production process HH) or

$$p_2(z)y_2(z) - (1+\tau)p_1^*(z)y_1^*(z) - wl_2(z) - rk_2(z) \tag{31}$$

if the first stage inputs come from abroad (production process FH).

**Stage 3 firms maximize**:

$$\exp\left[\int_0^1 \ln[x_2(z)]dz\right] - \int_{\substack{z\in FH,\\ HH}} p_2(z)x_2(z)dz - \int_{\substack{z\in FF,\\ HF}} (1+\tau)p_2(z)x_2(z)dz \tag{32}$$

The maximization problems for the foreign country are similar.

The first order conditions for these maximization problems are straightforward. Note that the capital/labor intensity is the same for all goods. This is a feature of the Ricardian nature of this model.

**2. Factor Market Clearing Conditions**. In each period:

Labor:

$$L = \int_{\substack{z\in HF,\\ HH}} l_1(z)dz + \int_{\substack{z\in FH,\\ HH}} l_2(z)dz \tag{33}$$

Capital:

$$K = \int_{\substack{z \in HF, \\ HH}} k_1(z)dz + \int_{\substack{z \in FH, \\ HH}} k_2(z)dz \tag{34}$$

The factor market clearing conditions for the foreign country are similar.

**3. Goods Market Clearing Conditions.**

**Stage 1 goods:**

$$y_1(z) = x_1(z) + x_1^*(z); z \in HH, HF \tag{35}$$
$$y_1^*(z) = x_1(z) + x_1^*(z); z \in FF, FH \tag{36}$$

**Stage 2 goods:**

$$y_2(z) = x_2(z) + x_2^*(z); z \in HH, FH \tag{37}$$
$$y_2^*(z) = x_2(z) + x_2^*(z); z \in FF, HF \tag{38}$$

**Stage 3 goods:**

$$\exp\left[\int_0^1 \ln[x_2(z)]dz\right] \equiv Y_t = C_t + K_{t+1} - (1-\delta)K_t \tag{39}$$
$$\exp\left[\int_0^1 \ln[x_2^*(z)]dz\right] \equiv Y_t^* = C_t^* + K_{t+1}^* - (1-\delta)K_t^* \tag{40}$$

# B Sources of Tariff Data

The tariff data come from Cline *et al* (1978), El-Agraa (1994), Schott (1994), and UNCTAD (1968). (I have also checked that the data from these sources are broadly consistent with data from Balassa (1965), Deardorff and Stern (1990), Preeg (1970), and Whalley (1985)). All of the tariff data are import-weighted averages of actual tariff rates. The tariff rates cover manufactured goods, except for the most recent years, in which the tariff rates are for industrial (essentially, non-agricultural) goods.

The overall tariff series used in the calibration/simulation is a simple average of the U.S. tariff and the rest-of-world (ROW) tariff. The ROW tariff is a weighted average of the European Community (EC) external tariff and the Japan tariff, where the weights are each region's share of U.S. exports to the EC+Japan.

Constructing the annual tariff series for the U.S. and the ROW involved splicing data from the above sources, and also using the phase-in schedules of the Kennedy Round, Tokyo Round, and Uruguay Round GATT agreements. These data and the phase-in schedules cover 1967-1972, 1973, 1979-1986, and 1994-1999. For example, the pre-Kennedy round tariff rate, the post-Kennedy round tariff rate, and the phase-in schedule yields the tariff rates for 1967-1972. For the other years, the data were linearly interpolated. The sources for the tariff series for each year are listed below:

Year Source

1962-1966: UNCTAD pre-Kennedy Round (1968, Table A.2, A.3, A.8). (Note: Balassa (1965, Table 4) reports values about 2 percentage points less than these values).

1967,1972: UNCTAD (1968, Table A.2, A.3, A.8)

1968-1971: Kennedy Round phase-in

1973-1973: U.S.: Cline et al (Table 2-1), using UNCTAD (1968) weights on semi-finished manufactures and finished manufactures; ROW: interpolation

1974-1978: interpolation

1979,1986: El-Agraa (Table 21.5), using UNCTAD weights on semi-finished manufactures and finished manufactures.

1980-1985: Tokyo Round phase-in

1987-1993: interpolation

1994,1999: Schott (Table 7) and El-Agraa (Table 21.5)

1995-1998: Uruguay Round phase-in

2000+ : Same as 1999.

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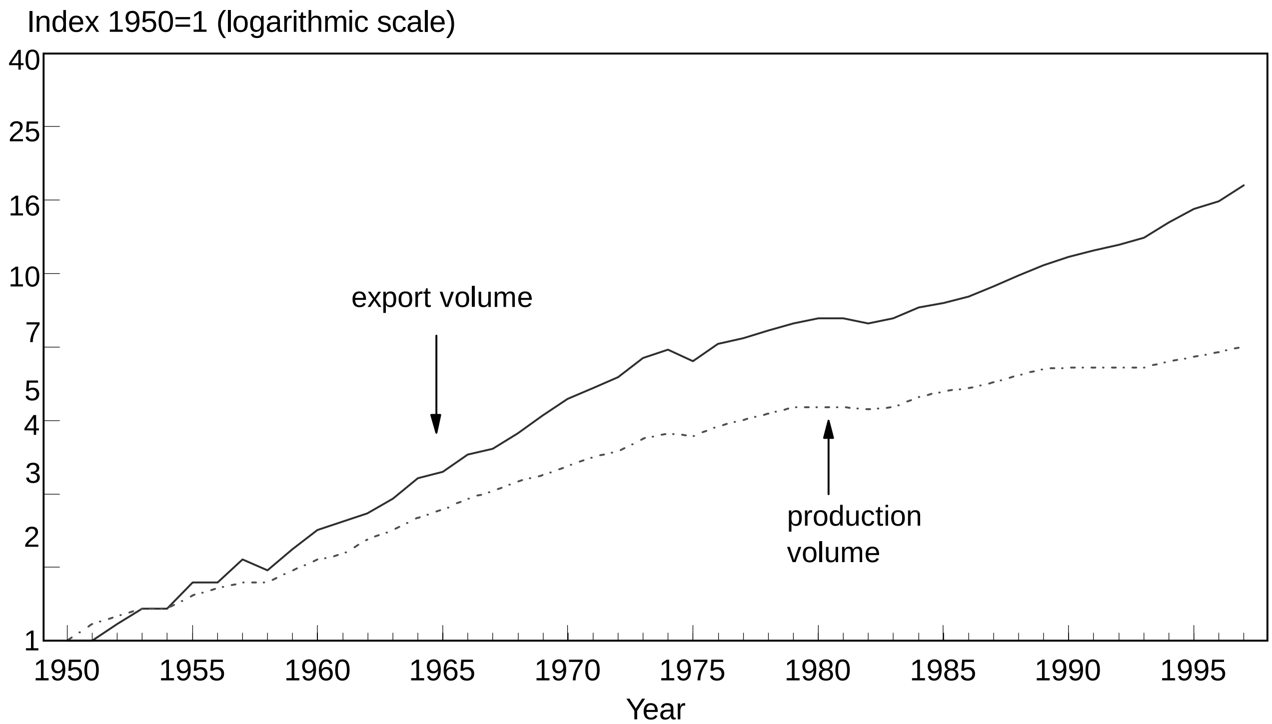
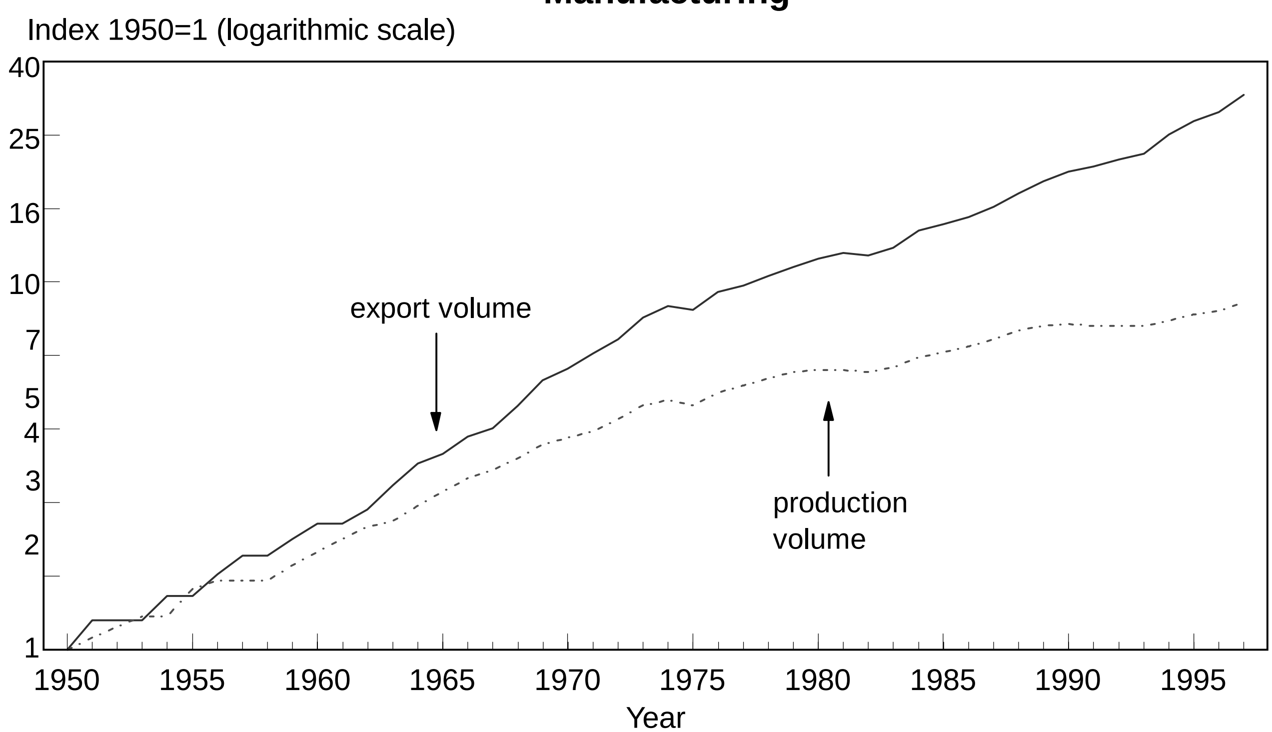
FIGURE 1
World Production and Export Volume

**Merchandise**




Source: WTO Secretariat

**Manufacturing**




Source: WTO Secretariat

FIGURE 2
Vertical Specialization

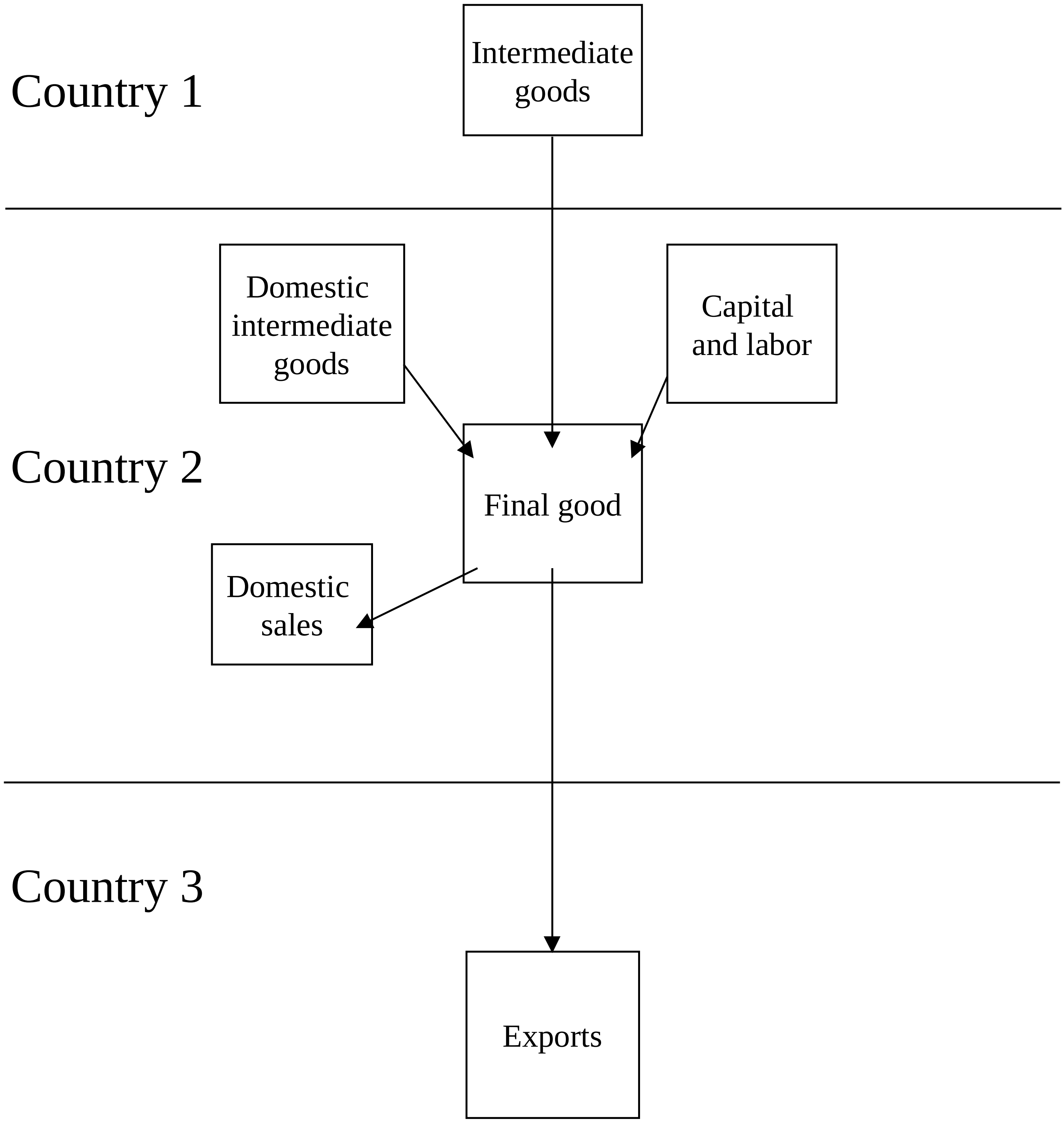
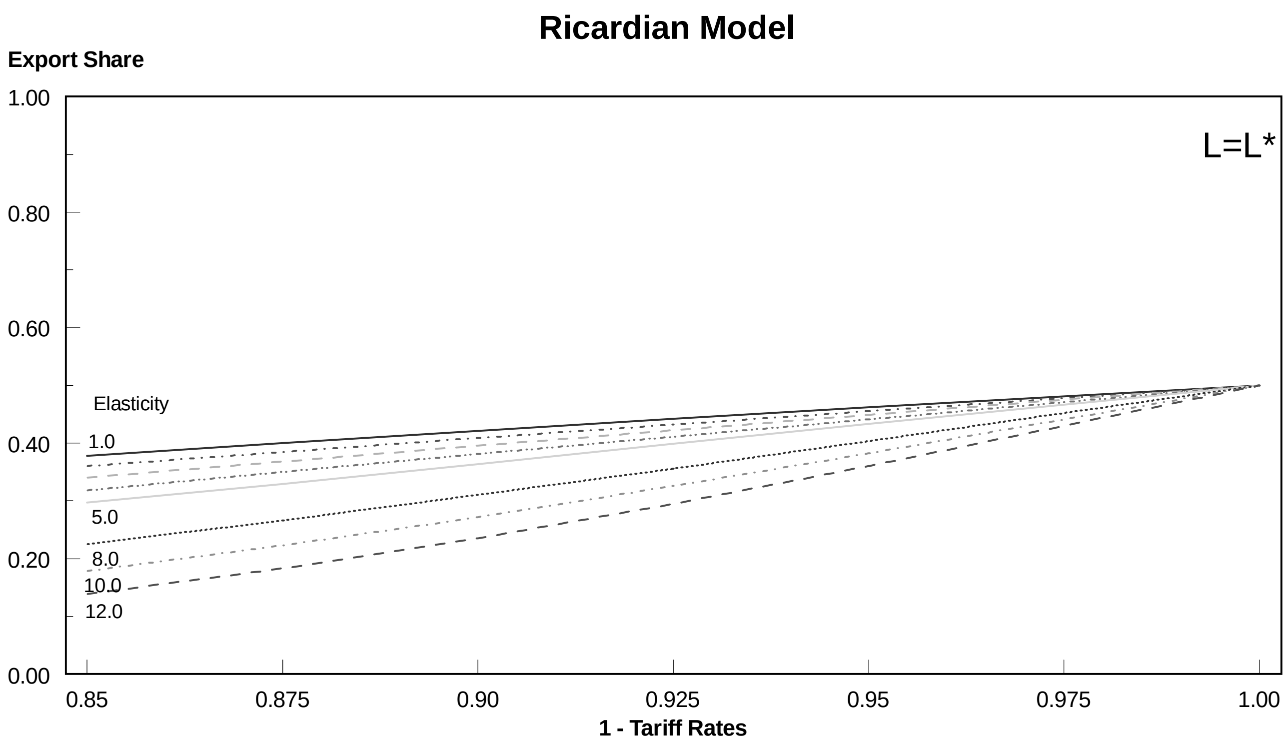


FIGURE 3
International Trade Models
Export Share of Output as a Function of Tariffs



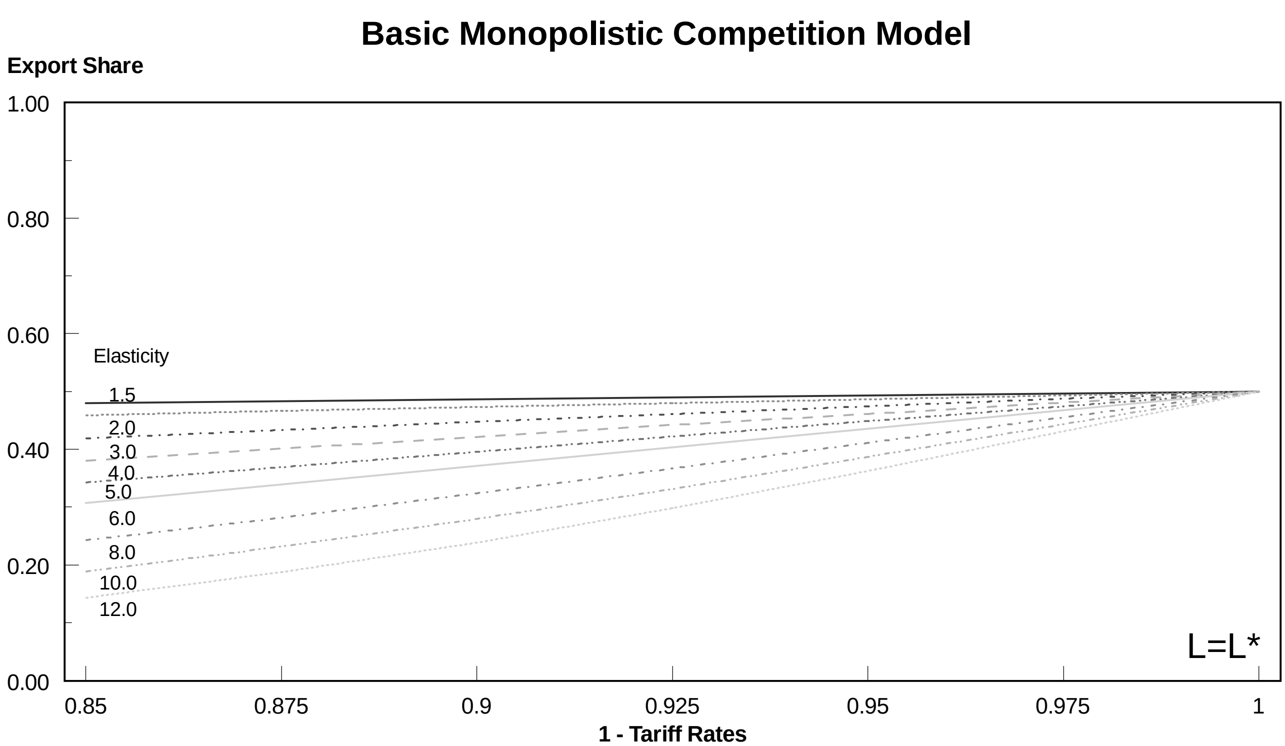



FIGURE 4
Vertical Specialization Model
Free Trade

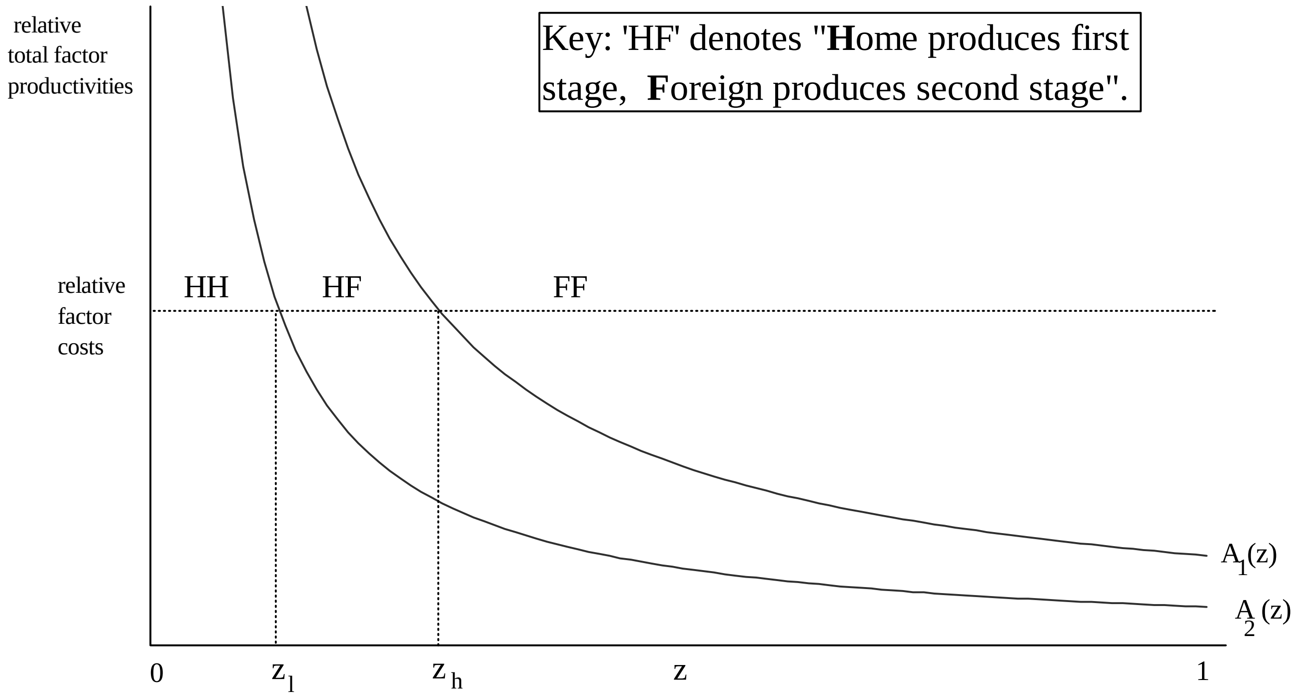



FIGURE 5
Vertical Specialization Model
Tariffs (Home Consumer's Perspective)

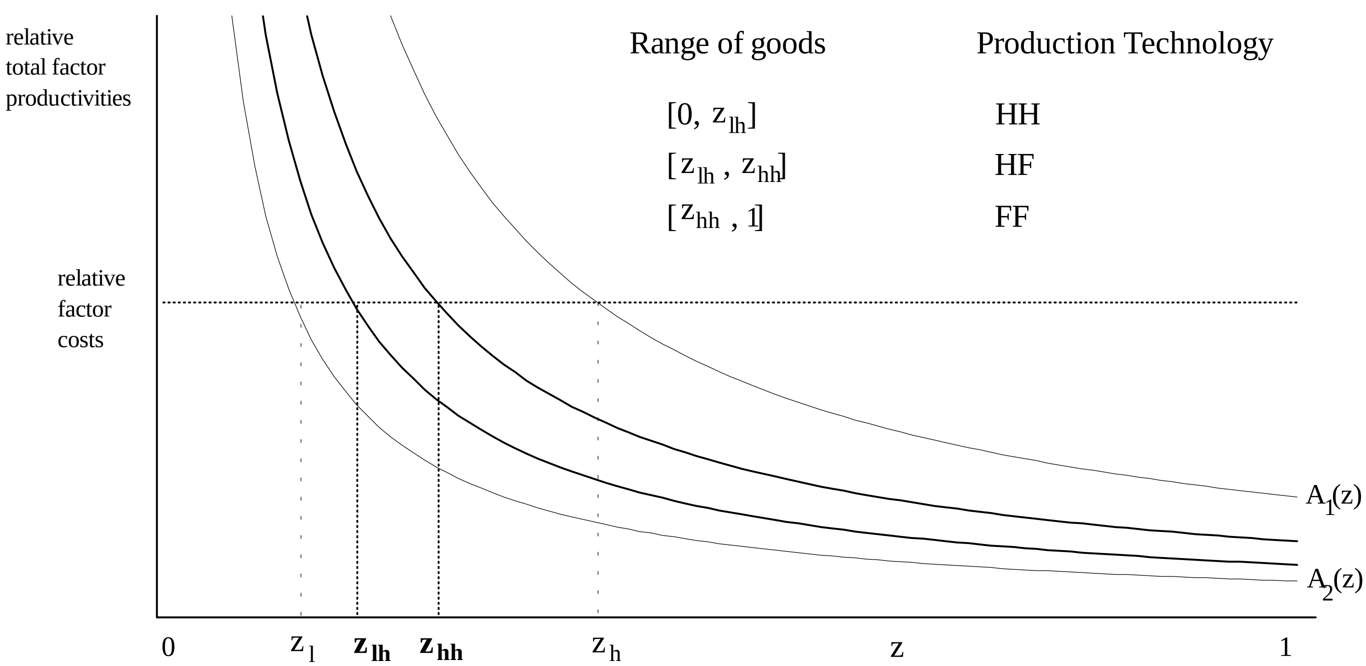


FIGURE 6
MANUFACTURING TARIFF RATES
MANUFACTURED EXPORT SHARE OF MANUFACTURED GDP (%)

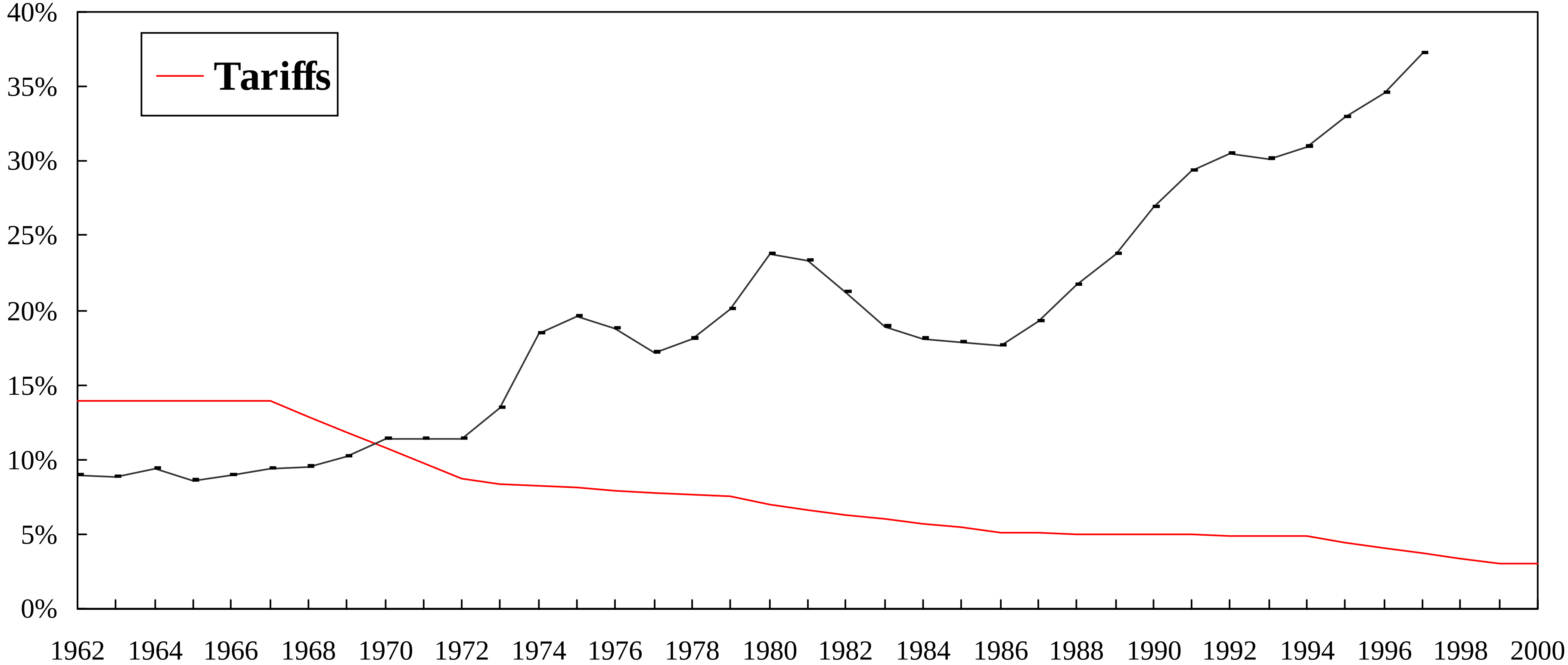


FIGURE 7
U.S./ROW RELATIVE TOTAL FACTOR PRODUCTIVITY

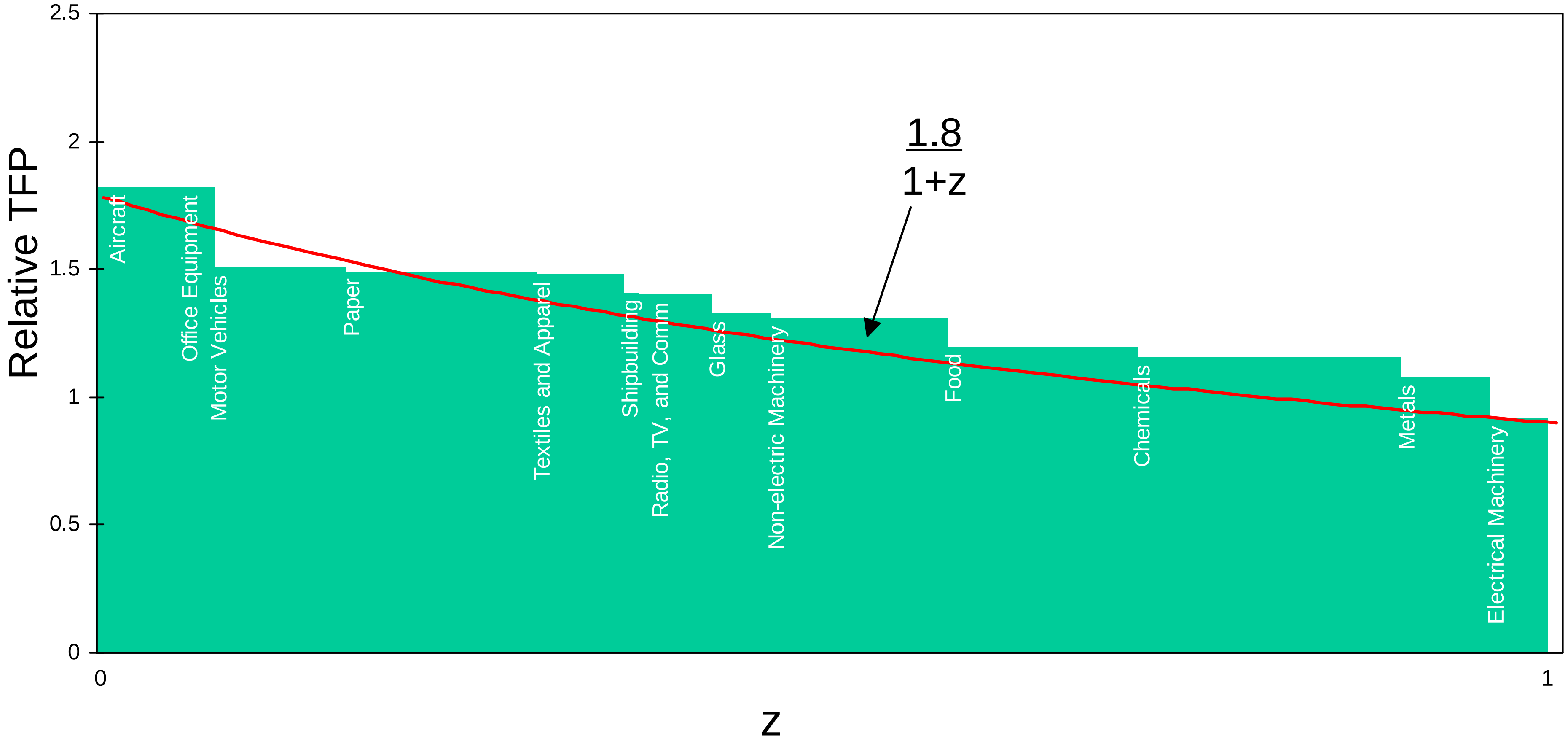


FIGURE 8
RESULTS FROM SIMULATION OF TARIFF REDUCTIONS
Growth of Manufactured Export Share of Manufactured GDP

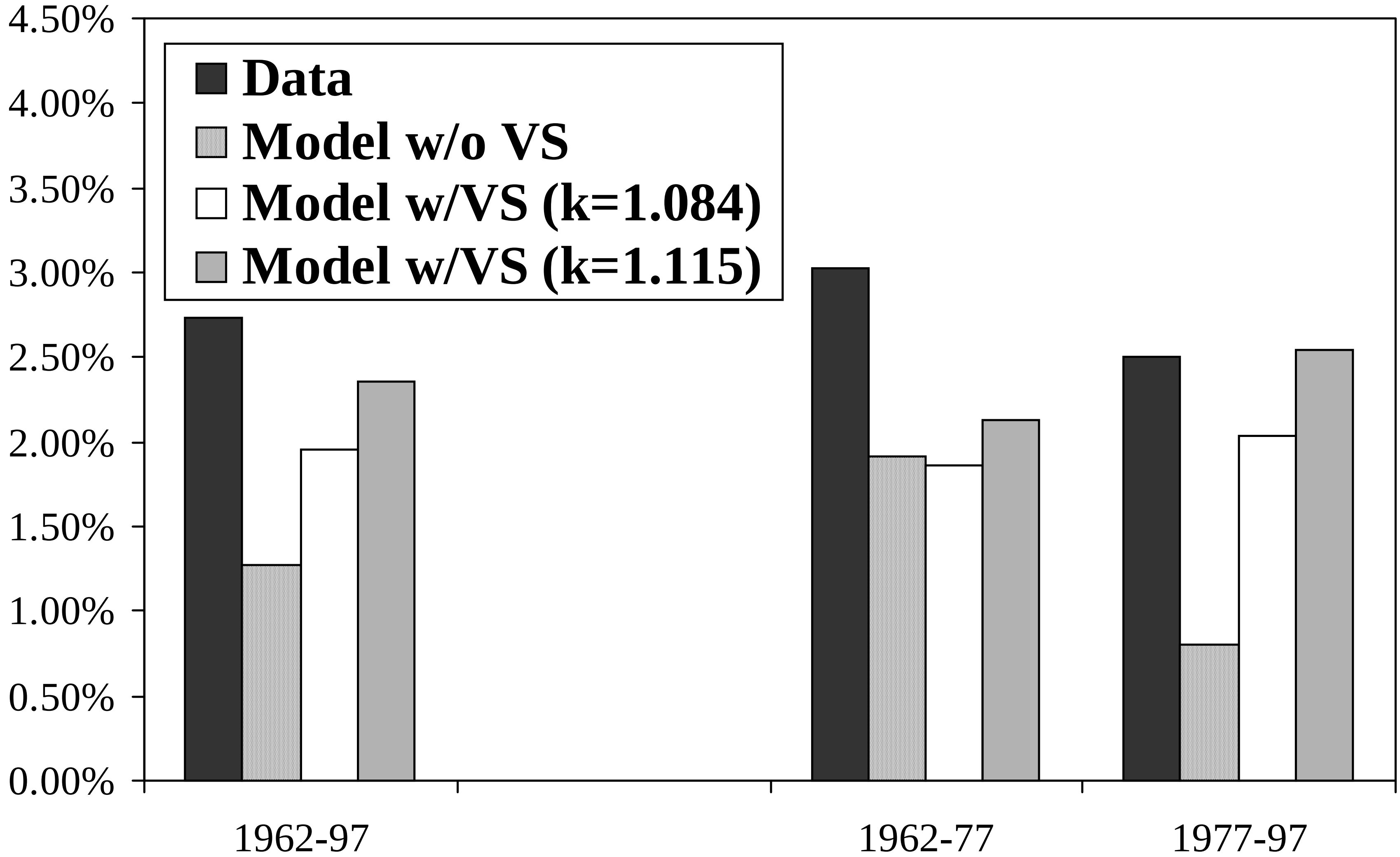


**TABLE 1**

VERTICAL SPECIALIZATION IN THE UNITED STATES

| | VS | VS1 | Total VS+VS1 |
|---|---|---|---|
| | (share of total U.S. merchandise exports) | | |
| 1962 | 0.042 | 0.000 | **0.042** |
| 1972 | 0.059 | 0.026 | **0.085** |
| 1977 | 0.084 | 0.027 | **0.111** |
| 1982 | 0.088 | 0.028 | **0.116** |
| 1985 | 0.093 | 0.045 | **0.138** |
| 1990 | 0.108 | 0.045 | **0.153** |
| 1997 | 0.137 | 0.082 | **0.219** |

Source: OECD Input-Output Database; author's calculations.
Note: VS is based on (1) and VS1 is based on (2). VS1 is calculated from data on U.S.-Mexico maquiladoras and U.S-Canada auto trade. (See HRY).

**TABLE 2**

INTERNATIONAL REAL BUSINESS CYCLE MODEL

**Tariff reduction: 15% to 0%** Initial Export Share of Output = 0.21

| Elasticity of substitution between home and foreign goods | Free Trade Export Share of Output | Export Growth (Expressed as multiple of initial export share) |
|---|---|---|
| 1.5 | 0.25 | 1.18 |
| 2 | 0.26 | 1.24 |
| 2.5 | 0.27 | 1.30 |
| 3 | 0.29 | 1.37 |
| 4 | 0.32 | 1.51 |
| 5 | 0.35 | 1.66 |
| 6 | 0.38 | 1.81 |
| 7 | 0.41 | 1.97 |
| 8 | 0.45 | 2.14 |
| 10 | 0.52 | 2.47 |
| 11 | 0.55 | **2.63** |
| 12 | 0.59 | 2.80 |
| 13 | 0.62 | 2.95 |
| 14 | 0.65 | 3.11 |
| 15 | 0.68 | 3.26 |

Source: Author's calculations.
Note: Actual growth of (adjusted) U.S. manufacturing export share of manufacturing GDP from 1962 to 1997 (expressed as multiple of initial export share) = **2.6**

**TABLE 3**

U.S./R.O.W. RELATIVE TOTAL FACTOR PRODUCTIVITY

| **Industry** | **TFP (U.S./ROW)** | **U.S. Industry Value-Added Share** |
|---|---|---|
| Aircraft | 1.82 | 5.8% |
| Office Equipment | 1.82 | 2.5% |
| Motor Vehicles | 1.51 | 9.4% |
| Paper | 1.49 | 12.9% |
| Textiles and Apparel | 1.48 | 5.7% |
| Shipbuilding | 1.41 | 1.0% |
| Radio, TV, and Comm | 1.40 | 5.1% |
| Glass | 1.33 | 3.6% |
| Non-electric Machinery | 1.31 | 12.3% |
| Food | 1.20 | 12.8% |
| Chemicals | 1.16 | 18.1% |
| Metals | 1.08 | 5.9% |
| Electrical Machinery | 0.92 | 4.8% |

Source: Harrigan (1997a, 1997b, 1998); OECD Input-Output Tables (U.S., 1990)

**TABLE 4**

RESULTS FROM DYNAMIC VERTICAL SPECIALIZATION MODEL

**Growth of Manufacturing Export Share of Manufacturing GDP**

| **Average annual growth rates:** | (adjusted) U.S. Data | Model w/o VS | Model w/ VS k=1.084 | k=1.115 |
|---|---|---|---|---|
| 1962-1977 | 3.03% | 1.91% | 1.86% | 2.13% |
| 1977-1997 | 2.50% | 0.80% | 2.03% | 2.54% |
| 1962-1997 | 2.73% | 1.27% | 1.95% | 2.36% |

| **Vertical Specialization (share of exports)** | U.S. Data | Model w/ VS k=1.084 | k=1.115 |
|---|---|---|---|
| 1962 | 0.042 | 0.000 | 0.000 |
| 1977 | 0.111 | 0.000 | 0.077 |
| 1997 | 0.219 | 0.220 | 0.358 |
| VS contribution to export growth | | | |
| 1962-1977 | 19.0% | 0.0% | 28.4% |
| 1977-1997 | 37.8% | 66.6% | 79.1% |
| 1962-1997 | 30.2% | 44.7% | 64.2% |

Source: Author's calculations