
Can Vertical Specialization Explain the Growth of World Trade?

Author(s): Kei-Mu Yi

Source: *Journal of Political Economy*, Vol. 111, No. 1 (February 2003), pp. 52-102

Published by: The University of Chicago Press

Stable URL: https://www.jstor.org/stable/10.1086/344805

Can Vertical Specialization Explain the Growth of World Trade?

Kei-Mu Yi

Federal Reserve Bank of New York

The striking growth in the trade share of output is one of the most important developments in the world economy since World War II. Two features of this growth present challenges to the standard trade models. First, the growth is generally thought to have been generated by falling tariff barriers worldwide. But tariff barriers have decreased by only about 11 percentage points since the early 1960s; the standard models cannot explain the growth of trade without assuming counterfactually large elasticities of substitution between goods. Second, tariff declines were much larger prior to the mid 1980s than after, and yet, trade growth was smaller in the earlier period than in the later period. The standard models have difficulty generating this nonlinear feature. This paper develops a two-country dynamic Ricardian trade model that offers a resolution of these two puzzles. The key idea embedded in this model is vertical specialization, which occurs when countries specialize only in particular stages of a good's production

This paper is a revision and extension of Ishii and Yi (1997). I thank the editor, Robert E. Lucas, Jr., and an anonymous referee for extremely helpful comments that greatly improved the paper. I have also benefited from comments by Scott Baier, Marianne Baxter, Jeff Bergstrand, Eric Bond, Satyajit Chatterjee, Jonathan Eaton, Carolyn Evans, Paul Evans, Raquel Fernandez, Caroline Freund, Gerhard Glomm, Josh Greenfield, James Harrigan, Jane Ihrig, Beth Ingram, Bob King, Narayana Kocherlakota, Ayhan Kose, Mordechai Kreinin, Kala Krishna, Robert E. Lipsey, Enrique Mendoza, B. Ravikumar, Dan Trefler, Neil Wallace, and David Weinstein, as well as seminar participants at the Federal Reserve Board, Penn State, Rochester, Miami, State University of New York at Albany, INSEAD, Notre Dame, Michigan State, Iowa, Brandeis, Federal Reserve Bank of Philadelphia, Virginia, Ohio State, Duke, North Carolina, Kentucky, Toronto, Queen's, New York University, the National Bureau of Economic Research Summer Institute, the Summer Econometric Society meetings, the Society of Economic Dynamics meetings, and the Fed System Conference in Macroeconomics. Mychal Campos, Josh Greenfield, and Stefan Papaioannou provided outstanding research assistance. The views expressed here are those of the author and are not necessarily reflective of views at the Federal Reserve Bank of New York or the Federal Reserve System.

[*Journal of Political Economy,* 2003, vol. 111, no. 1]

sequence. The model generates a nonlinear trade response to tariff reductions and can explain over 50 percent of the growth of trade. Finally, the model has important implications for the gains from trade.

I. Introduction

One of the most important developments in the global economy in the past half century is the enormous growth in world trade. The standard explanation for this growth is the worldwide tariff reductions that have occurred. Lower tariffs reduce the cost of foreign goods relative to domestic goods; imports and exports rise. This intuitive explanation is so simple and seemingly obvious that—while it is consistent with all the standard models of international trade—it hardly seems necessary to formalize it.

Nevertheless, there are two features of the growth of trade that present challenges to the standard models. First, since the early 1960s, despite the tariff reductions engendered by the Kennedy, Tokyo, and Uruguay General Agreement on Tariffs and Trade (GATT) rounds, worldwide tariffs have decreased by only about 11 percentage points on manufactured goods, the dominant traded commodity. During this period, the world manufacturing export share of gross domestic product has risen by a factor of 3.4 (see World Trade Organization 2000). Figure 1*a* illustrates manufacturing tariff rates and the U.S. and world manufacturing export shares of GDP between 1962 and 1999. The elasticity of exports with respect to tariffs implied by the figure is about 20, which is much larger than what standard trade models would imply. Consequently, the relatively small tariff decline juxtaposed against the large increases in trade is a *quantitative* puzzle.

Second, the response of exports to tariffs has increased sharply since the mid 1980s, as shown in figure 1*b*. For example, between 1962 and 1985, the elasticity of trade with respect to tariffs was seven, whereas between 1986 and 1999 it was 50. This nonlinear effect is a *qualitative* puzzle from the perspective of the standard models, because they usually imply little or no nonlinear effects.[1]

The main contribution of this paper is to develop, calibrate, and simulate a two-country dynamic Ricardian trade model that offers a resolution of these puzzles. The key idea embedded in the model is *vertical specialization*. Vertical specialization involves 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.

---

[1] Adding data on transport costs, as measured by cost, insurance, and freight/free on board ratios or by Hummels (1999), will not change the basic nonlinearity of the figure.

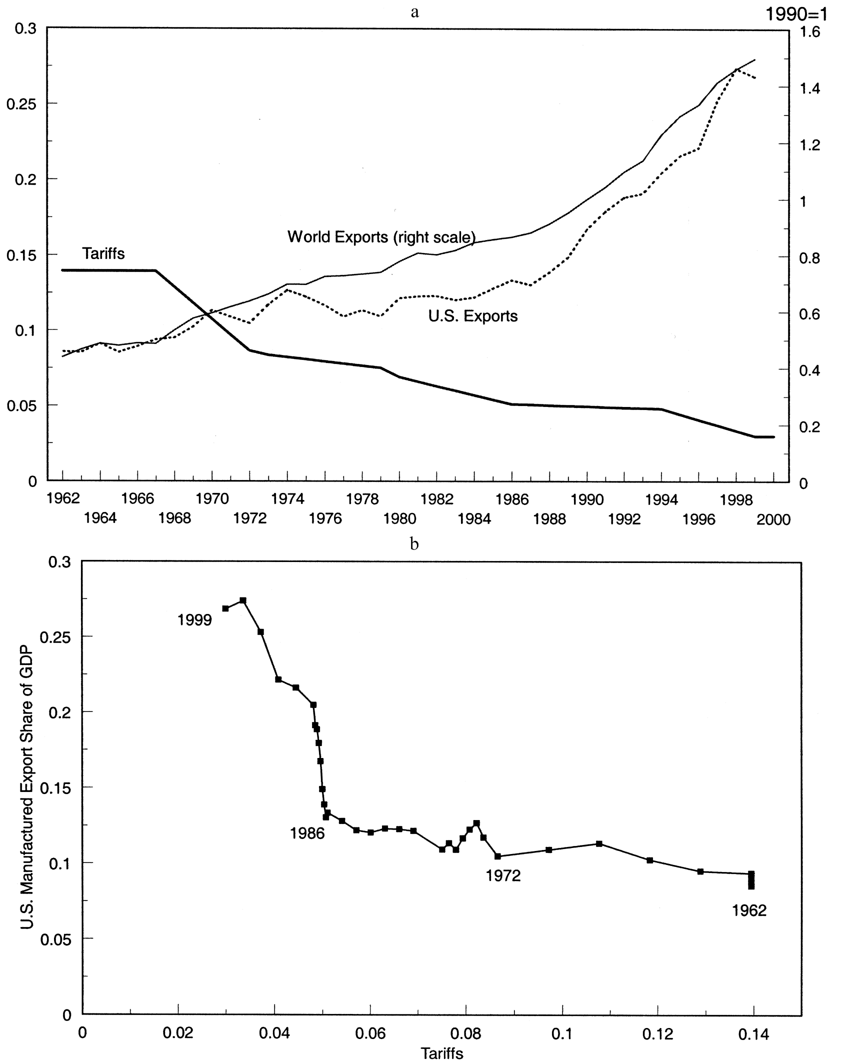

FIG. 1.—Manufacturing export share of GDP and manufacturing tariff rates. Source: World Trade Organization (2002) and author's calculations (see App. A and Sec. V).

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. It is then exported to the United States, 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. Recent empirical research has documented that vertical specialization has grown about 30 percent and accounts for about one-third of the growth in trade in the last 20–30 years.[2]

I demonstrate that the model can generate both magnified and nonlinear responses to tariff reductions. Vertically specialized goods or goods in process cross multiple international borders while they are being produced.[3] Each time these goods in process cross a border, a tariff is incurred. Consequently, global reductions in tariffs lead to a magnified reduction in the cost of producing these goods. 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 one percentage point, the cost of producing this good will fall by N percent, in contrast to a 1 percent decline in the cost of a "regular" traded good. The magnified cost reduction leads to a magnified increase in trade. In addition, because of tariff reductions, it may be efficient for goods that were previously produced entirely in one country to now become vertically specialized. This will also lead to an increase in trade. Through both an internal margin and an external margin, then, 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.

Moreover, through the external margin, vertical specialization can generate a nonlinear trade response to tariffs. This would occur in the following scenario. Suppose that tariffs are initially sufficiently high that there is no vertical specialization. Now tariffs begin to fall. At first, they are still sufficiently high that vertical specialization does not occur. Nevertheless, trade still increases for the standard reasons. 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, generating a nonlinear response.

---

[2] See Hummels, Rapoport, and Yi (1998) and Hummels, Ishii, and Yi (2001). Others have called this phenomenon outsourcing, fragmentation, multistage production, slicing up the value chain, disintegration of production, and intraproduct specialization (see Hummels et al. 2001). I follow Balassa (1967) and Findlay (1978), who were apparently the first to note this phenomenon in international trade in calling it vertical specialization.

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

To assess the quantitative importance of vertical specialization in resolving the two puzzles, I calibrate the model and then simulate global tariff reductions. The results indicate that the model can explain over half of the growth of trade and generate a nonlinear effect, although the size of the effect is smaller than in the data. The model is also able to capture some of the key features of the vertical specialization data. Simulations of a standard, one-stage, trade model reveal that it has only one-third to one-half of the explanatory power of the vertical model. Moreover, the standard model cannot generate any nonlinear effects. Finally, the welfare gains to tariff reductions in the vertical model are high, in absolute terms, as well as compared to the standard model.

I conduct several sensitivity analyses including calibrating the model with alternative productivity specifications, running the dynamic version of the model, and varying key parameters. The sensitivity analysis is consistent with the main results. Section II provides stylized facts for the growth of vertical specialization, focusing on the United States. Section III shows briefly the difficulty of matching the magnitude and nonlinearity of trade growth in the 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, and Section VII presents conclusions.

II. Empirical Importance of Vertical Specialization: Evidence from the United States

Following Hummels et al. (2001), 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; and (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.[4] 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 interme-

---

[4] Hummels et al. (2001) 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.

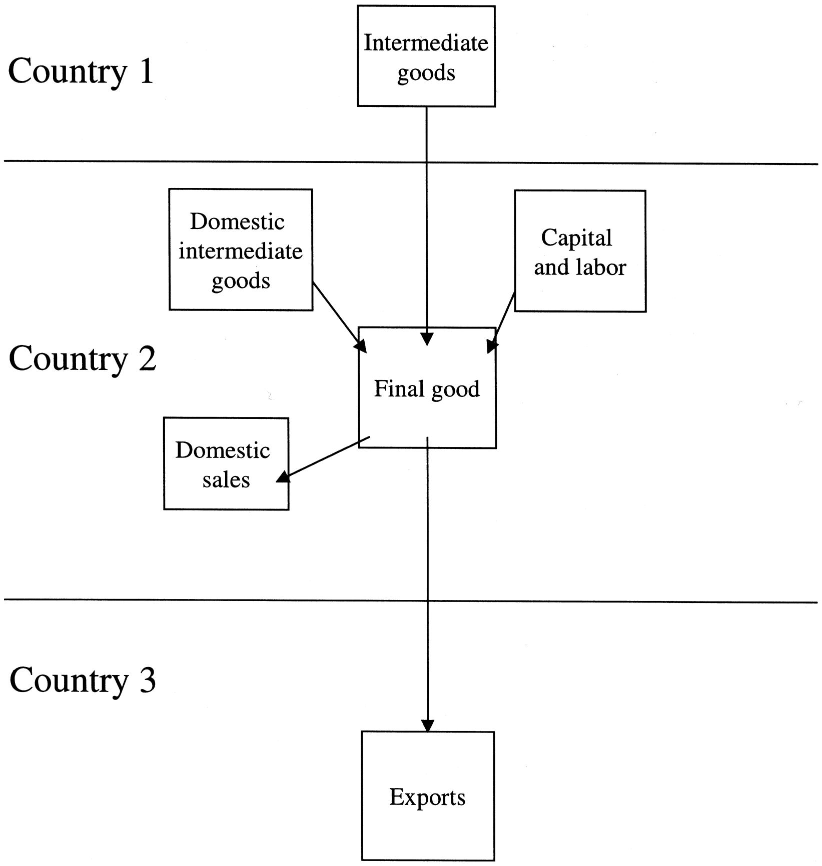

FIG. 2.—Vertical specialization

diates 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 are absent, then there is no vertical specialization.[5]

Hummels et al. (2001) develop two vertical specialization measures, called VS and VS1, that follow from this definition. Both are relevant for the United States. The first one, VS, measures the imported input content of export goods, and VS1 measures the value of exported goods that are used as imported inputs to produce other countries' export goods. Specifically,

$$\mathrm{VS}_{ki} = \left(\frac{\text{imported intermediates}_{ki}}{\text{gross output}_{ki}}\right)\text{exports}_{ki}, \qquad (1)$$

---

[5] It is easy to see that countries can have export shares of GDP exceeding one only if there is vertical specialization.

where k and i denote country and good, and

$$\mathrm{VS1}_{ki} = \sum_{j=1}^{n} \text{exported intermediates}_{kji}\left(\frac{\text{exports}_{ji}}{\text{gross output}_{ji}}\right), \tag{2}$$

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

Ideally, VS and VS1 would be calculated at the level of individual goods and then aggregated up. As these data do not exist, Hummels et al. (2001) rely primarily on input-output tables, which provide industry-level data on imported inputs, gross output, and exports. The main advantage of these tables is that they avoid the need to create arbitrary classification schemes on what goods are or are not intermediates. The main drawback of these tables is their relatively low level of disaggregation. As Hummels et al. discuss (p. 81), using industry-level data can bias the calculated VS and VS1 measures from their "true" values. For example, suppose that the motor vehicles industry produces two types of cars, one that is exported and one that is not exported. If the production process for the exported car is imported-input intensive, then the measures will be biased downward. On the other hand, if the cars that are exported are not imported-input intensive, then the measures will be biased upward. To assess the importance of these biases, Hummels et al. use Korean input-output tables at several levels of aggregation (28, 77, and 168 industries) and find that a slight downward bias exists when using the more aggregated tables.

Hummels et al. (2001) perform calculations on 10 OECD countries, as well as Mexico, Ireland, Taiwan, and Korea. They also perform extrapolations under the assumptions that the rest of emerging Asia is similar to Taiwan and Korea and the rest of Europe is similar to the European countries in the sample. In this latter case, the authors' results show that as of 1990, total vertical specialization, VS + VS1, accounts for about 30 percent of world exports, and between 1970 and 1990, growth in VS alone accounted for almost one-third of the growth of world exports.[6]

I now present more detailed results for the United States only, drawing

---

[6] Note that VS as a share of trade has been increasing even as imported intermediates as a share of trade are decreasing. This can happen for two reasons: (1) a sufficiently greater fraction of output is exported, and (2) industries with high vertical specialization sufficiently expand their use of imported intermediates.

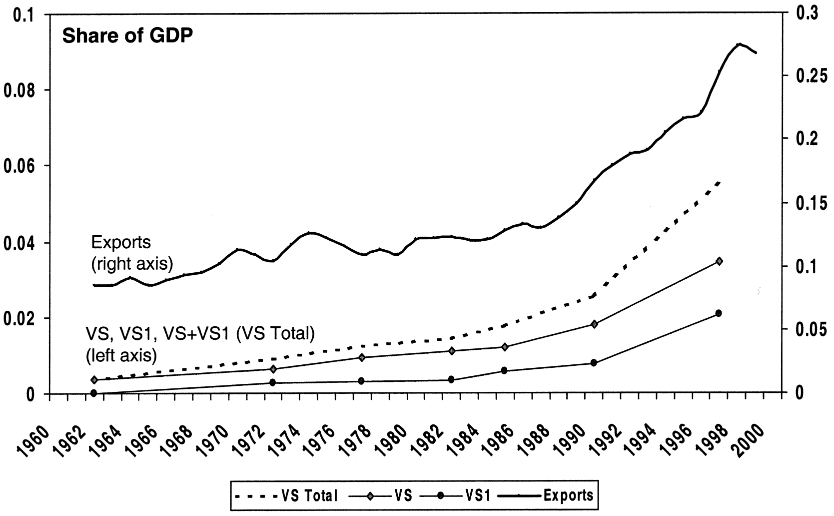

FIG. 3.—United States VS, VS1, VS+VS1, and exports

from Hummels et al. (1998) and Hummels et al. (2001).[7] Figure 3 presents VS, VS1, total vertical specialization, and merchandise exports, all merchandise expressed as a share of GDP. The vertical specialization numbers are for selected 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 from the average growth rate of the VS share between 1972 and 1990. The estimates for VS1 are based on data from two case studies (Mexico's *maquiladoras* and U.S.-Canadian auto trade). In 1997, vertical specialization accounted for at least 21.9 percent of U.S. exports. Growth accounting shows that growth in VS + VS1 accounts for 30.2 percent 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, for example, U.S. trade with emerging Asia, 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 and the con-

---

[7] Hummels et al. (1998) present primarily case study evidence: U.S.-Mexican *maquiladora* trade, auto trade following the United States–Canada Auto Agreement, Opel España's auto trade, and Japanese electronics trade. Hummels et al. (2001) present broader country-level evidence obtained from input-output tables.

tribution of VS + VS1 to U.S. export growth are higher than the numbers reported here.[8]

III. Can the Standard Trade Models Explain the Magnitude and Nonlinearity of the Growth of Trade?

In this section, I show that the standard trade models have difficulty explaining both the magnitude and the nonlinearity of the growth of trade. I draw from two literatures, the static international trade models and the dynamic international real business cycle (RBC) models. While neither set of models was developed to explain the growth of trade, they do encompass the way economists think about trade from both micro and macro perspectives. Hence, they are a useful starting point in understanding its growth during the last 40 years.

In each model, I include proportional, uniform tariffs. Manufactured tariff rates fell from about 14 percent to about 3 percent between 1962 and 1999. For expository convenience, I examine the trade effects of a tariff decline from 15 percent to zero. In the data, the (adjusted) U.S. manufactured export share of output grew 210 percent between 1962 and 1999.[9] To generate this increase from a 15-percentage-point tariff reduction, the model needs, roughly speaking, a trade elasticity with respect to tariffs on the order of 15. In two of the models, I show that the trade elasticity is driven primarily by the elasticity of substitution between goods. I argue that the implied elasticities of substitution needed to reconcile the models with the data are counterfactually high.

A. *Static Trade Models*

I examine two workhorse models, the Dornbusch, Fischer, and Samuelson (1977) Ricardian model and the basic monopolistic competition model (see, e.g., Krugman 1980). In both these models, I assume that tariff revenue has no productive or consumption value. Also, in both models, the setup is symmetric so that under free trade, the export share of GDP is 0.5.

In the Dornbusch et al. model, there is a continuum of goods on the unit interval. Each good is produced from labor with constant returns

---

[8] There is another reason to expect that this estimate is a lower bound. The main results in Hummels et al. (2001) are based on imported intermediates only. In the United States, 30 percent 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.

[9] 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 4.1, or 310 percent (see Sec. V).

to scale; unit labor requirements differ across the two countries. Markets are perfectly competitive. Dornbusch et al. show that tariffs create a range of endogenously determined nontraded 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 $0 < \theta < 1$. The fraction $1/(1-\theta)$ 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 (2002):[10]

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

where $a(z)$ and $a^*(z)$ denote the unit labor requirements in the home and foreign country, respectively. The production technologies are mirror images of each other. I also assume that the home and foreign labor forces are the same size. These symmetries imply that free trade yields a relative wage of one, that $z = 0.5$ will be the cutoff determining specialization in each country, and that the export share of GDP equals 0.5.

Figure 4*a* shows the effects of tariff reductions on the export share of GDP under several elasticities of substitution. When the elasticity is five, a 15-percentage-point tariff reduction leads to only a 55 percent increase in the export share. The elasticity needs to be *12 or 13* to generate the actual increase. Moreover, the figure shows that the response is essentially linear.

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:

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

where l is labor, α is the fixed cost, β 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 competition setting. The utility function is

$$U(\cdot) = \left(\sum_{i=1}^{n} c_i^\theta\right)^{1/\theta}, \tag{6}$$

$\theta < 1$. Again, $1/(1-\theta)$ is the elasticity of substitution (and demand)

---

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

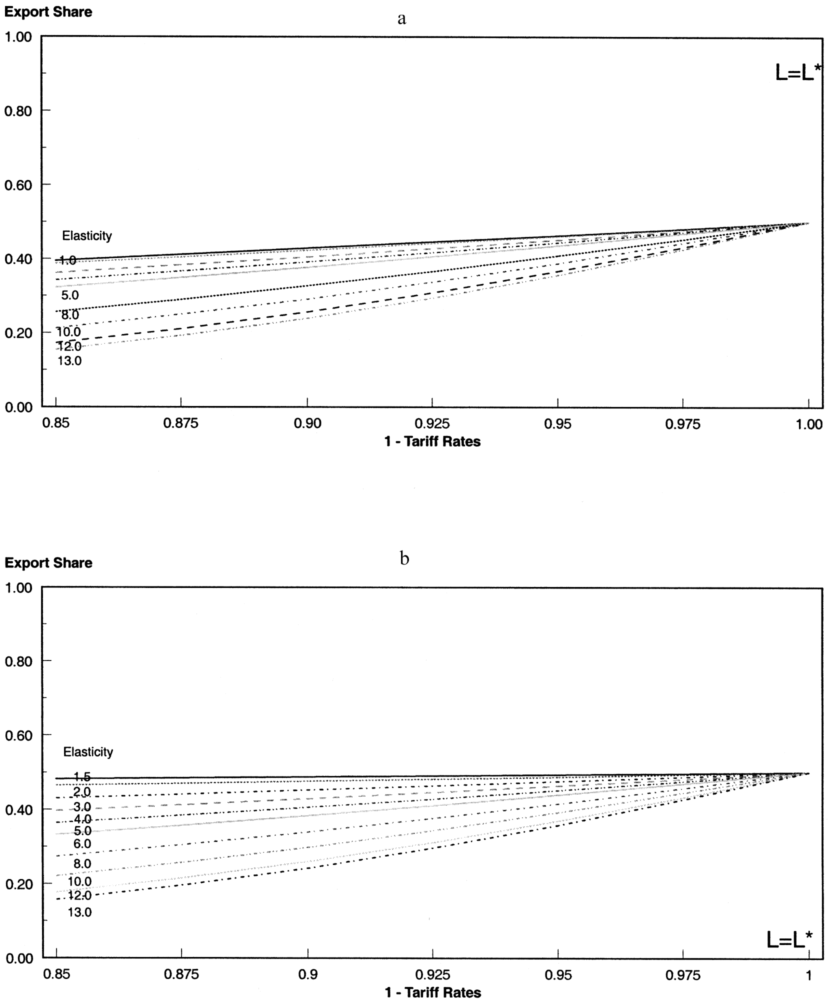

FIG. 4.—International trade models: export share of output as a function of tariffs. *a*, Ricardian model. *b*, Basic monopolistic competition model.

between goods, and $1/\theta$ is the firms' gross markup. I again assume that the sizes of the labor force in the two countries are identical.

When tariffs fall, the fraction of total spending devoted to imported goods increases; this is driven primarily by substitution effects. Figure 4*b* shows the results of the tariff experiment for several elasticities. With a 15-percentage-point tariff reduction, an elasticity of *12 or 13* is needed to replicate the growth of the manufactured export share. In addition, it is easy to see that the tariff response is essentially linear. In fact, it can be shown that the trade elasticity with respect to tariffs is

$$\frac{\theta}{1-\theta}\left[\frac{(1+\tau)^{\theta/(1-\theta)}}{1+(1+\tau)^{\theta/(1-\theta)}}\right]. \tag{7}$$

As θ approaches one, the expression in brackets approaches one, and the trade elasticity is approximately equal to the elasticity of substitution. Moreover, it is not difficult to see that the trade elasticity has little nonlinearity. In fact, as τ falls, the elasticity actually decreases.[11]

B. *International Real Business Cycle Model*

I draw from the model of Backus, Kehoe, and Kydland (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 Backus et al. model modified to include 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 by Backus et al., so I only summarize its main features here. Preferences for the representative agent in the home country are characterized by

$$\sum_{t=0}^{\infty}\beta^t\frac{[c_t^{\mu}(1-n_t)^{1-\mu}]^{1-\gamma}}{1-\gamma}, \tag{8}$$

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

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

where A and K represent total factor productivity (TFP) 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

---

[11] For simplicity the symmetric setups tend to preclude terms of trade effects. If they are large, then the possibility of nonlinear effects is larger. However, this will tend to occur more with lower elasticities of substitution, which would make it more difficult to match the magnitude of trade growth.

Armington aggregator to produce a nontraded final good that is used for consumption and investment:

$$C_t + I_t = [w_1 D_t^{1-\alpha} + (1 - w_1) X_t^{*1-\alpha}]^{1/(1-\alpha)}, \tag{11}$$

where $\alpha \geq 0$, and the asterisk denotes the imported good (the foreign country's exported input). The fraction $1/\alpha$ 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 perpetual inventory way. I assume that all proceeds from the tariffs are returned as lump-sum transfers. Finally, I assume an initial net foreign asset position of zero. The setup for the foreign representative agent is symmetric.

The parameters draw from King, Plosser, and Rebelo (1988) and Backus et al. (1994); 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 Backus et al.), but the effects of higher elasticities are also examined. The preference discount factor, β, is set to 0.96. The share of consumption in utility, μ, is set to 0.25, which ensures that $n = 0.2$ in the steady state. The intertemporal elasticity of substitution, $1/\gamma$, is 0.5. The depreciation rate on capital, δ, is 0.13. The coefficient on capital in the production function, θ, is 0.36. The initial steady-state level of net foreign assets, B, is zero. 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.

The results are very similar to those presented earlier.[12] The elasticity of substitution between home and foreign goods needs to be *14* to match the growth in the manufacturing export share. Again, it is straightforward to show that the trade elasticity is very closely related to the elasticity of substitution; when $w_1 = .5$, the elasticity equals

$$\frac{1}{\alpha}\left(\frac{D_t}{Y_t}\right). \tag{12}$$

As τ falls, D/Y decreases, and the elasticity decreases; hence, the nonlinearity that does exist is counterfactual.

C. *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

---

[12] Because of the similarity in results, I do not present them here. They are available on request.

three paradigms cannot generate any of the nonlinearity of observed trade growth. And they cannot match the magnitude of trade growth unless the elasticity of substitution between domestic goods and imported goods is 12 or higher, which is counterfactually high. The elasticities that are typically estimated or employed in simulations/calibrations are on the order of two to three.[13] The elasticities matter because, in general, the higher the elasticity of substitution, the lower the gains from trade. The standard models can rationalize the large growth in trade only by implying small gains from such trade!

The main reason why all three models cannot explain the magnitude of trade growth without relying on counterfactually high elasticities is that observed tariff rates have fallen little. It is possible to modify the standard models to generate larger magnitudes, as well as nonlinear trade growth. For example, nonhomothetic preferences can lead to a nonlinear relation between tariffs and trade growth. If, for example, the income elasticity of demand for traded goods is greater than one and greater than the income elasticity of demand for nontraded goods, lower tariffs, to the extent that they increase income, will lead to larger (possibly nonlinear) increases in trade than predicted by homothetic models. Bergoeing and Kehoe (2001) apply nonhomethetic preferences in a model in which income growth is driven by gains in TFP. However, their calibration results show that nonhomothetic preferences can explain only a little more relative to homothetic preferences. They conclude that changes in trade policy may be needed to explain the growth of trade.[14]

The type of trade in the standard models involves goods for which 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.[15] As shown earlier, much of the growth of trade involves a different kind of trade, vertical specialization. With this

---

[13] 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 nonagricultural 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) (see Deardorff and Stern 1990). Also, in Whalley's (1985) CGE model, the elasticities of substitution in the three key regions (United States, Japan, and European Community) for the 17 manufacturing industries are all less than three. Baier and Bergstrand (2001) 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 is consistent with my numerical results: in order for standard trade models to explain the growth of trade, high elasticities of substitution are needed.

[14] Feeney (1999) and Bajona (2000) develop models that generate trade growth from learning-by-doing effects.

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

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. Moreover, when an economy evolves from relatively nonvertically specialized to relatively vertically specialized, it will exhibit nonlinear trade growth. None of the three models includes vertical specialization. I now turn to such a model.

IV. Dynamic Ricardian Trade Model

In this section, I lay out the model and describe the intuition for how vertical specialization propagates the effects of tariff reductions. 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*b*), Golub and Hsieh (2000), and Eaton and Kortum (2002) has shown the empirical relevance of Ricardian technological differences in explaining trade patterns. Second, there is little empirical evidence that clearly favors the monopolistic competition model against other models. Finally, it is desirable to have a model of trade in which firms choose whether to use domestic or imported inputs, that is, a model in which vertical specialization occurs endogenously. This rules out Armington aggregator-based models, in which reliance on both domestic and imported inputs is assumed.[16]

A. *Technologies and Firms*

There are two countries, *H* and *F*, and two factors of production, capital and labor. Each country consumes and invests a single nontraded final good. The final good is produced in three sequential stages. In both the first and second stages, a continuum of goods along the unit interval [0, 1] is produced. These goods are tradable, and *both countries possess technologies for producing both stages.* Hence, there are four possible production patterns for the first two stages of each good on the continuum: *HH:* Home (country) produces stages 1 and 2; *FF:* Foreign produces stages 1 and 2; *HF:* Home produces stage 1 and Foreign produces stage

---

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

2; and *FH:* Foreign produces stage 1 and Home produces stage 2 ($HH \cup FF \cup HF \cup FH \equiv [0, 1]$).

The model will "determine" which pattern or patterns occur in equilibrium. In the third stage of production, the continuum of stage 2 goods is costlessly assembled into the nontraded final good. I now describe the production technologies and firm maximization problems in detail.

1. Technologies

Stage 1 goods are produced from capital and labor:

$$y_1^i(z) = A_1^i(z)k_1^i(z)^{\alpha}l_1^i(z)^{1-\alpha}, \quad i = H, F, \; z \in [0, 1], \tag{13}$$

where $A_1^i(z)$ is country *i*'s TPF associated with stage 1 good *z,* and $l_1^i(z)$ and $k_1^i(z)$ are country *i*'s labor and capital used in producing $y_1^i(z)$.

First-stage output $y_1(z)$ is used as an input into the production of the stage 2 good *z*. The stage 1 input, labor, and capital are combined in a nested Cobb-Douglas production function:

$$y_2^i(z) = x_1^i(z)^{\theta}[A_2^i(z)k_2^i(z)^{\alpha}l_2^i(z)^{1-\alpha}]^{1-\theta}, \quad i = H, F, \; z \in [0, 1], \tag{14}$$

where $x_1^i(z)$ is country *i*'s use of the stage 1 good $y_1(z)$, $A_2^i(z)$ is country *i*'s TFP associated with stage 2 good *z,* and $l_2^i(z)$ and $k_2^i(z)$ are country *i*'s labor and capital used in producing $y_2^i(z)$.

In the third stage, stage 2 goods are costlessly assembled into the nontraded final good via a constant elasticity of substitution (CES) aggregator:

$$Y^i = \left\{\int_0^1 [x_2^i(z)^{(\sigma-1)/\sigma}]dz\right\}^{\sigma/(\sigma-1)}, \quad i = H, F, \tag{15}$$

where $x_2^i(z)$ is country *i*'s use of the stage 2 good $y_2(z)$, and σ is the elasticity of substitution between goods. In the special case in which $\sigma = 1$, the stage 3 aggregator becomes

$$Y^i = \exp\left\{\int_0^1 \ln [x_2^i(z)]dz\right\}, \quad i = H, F. \tag{16}$$

2. Firms

Firms maximize profits taking prices as given. Specifically, in each period, they hire labor, rent capital from households, and—if they are stage 2 firms—purchase inputs, in order to produce their output, which they sell at market prices.

Stage 1 firms maximize

$$p_1(z)y_1^i(z) - w^i l_1^i(z) - r^i k_1^i(z), \quad i = H, F, \tag{17}$$

where $p_1(z)$ is the world price of $y_1(z)$, and w and r are the wage and rental rates.

Stage 2 firms maximize

$$p_2(z)y_2^i(z) - p_1(z)x_1^i(z) - w^i l_2^i(z) - r^i k_2^i(z), \quad i = H, F, \tag{18}$$

if the stage 1 input $x_1(z)$ is produced at home or

$$p_2(z)y_2^i(z) - (1+\tau)p(z)x_1^i(z) - w^i l_2^i(z) - r^i k_2^i(z), \quad i = H, F, \tag{19}$$

if the stage 1 input is produced abroad. The world price of $y_2(z)$ is denoted by $p_2(z)$, and τ is the ad valorem tariff rate applied to all imports. Tariff revenue is returned to households via lump-sum transfers.

Stage 3 firms maximize

$$P^i Y^i - \int_{z \in HH^i, FH^i} p_2(z)x_2^i(z)dz - \int_{z \in FF^i, HF^i} (1+\tau)p_2(z)x_2^i(z)dz, \qquad i = H, F, \tag{20}$$

where P^i and Y^i are the price and output of the final good in country i, and HH^i denotes the z's for which HH is the production pattern in country i.

B. *Households*

The representative household in country i maximizes

$$\sum_{t=0}^{\infty} \beta^t \ln(C_t^i) \tag{21}$$

subject to a sequence of budget constraints

$$P_t^i C_t^i + P_t^i[K_{t+1}^i - (1-\delta)K_t^i] = w_t^i L^i + r_t^i K_t^i + T_t^i \equiv P_t^i Y_t^i, \tag{22}$$

where C is consumption, K and L are total capital and labor, and T is the lump-sum transfer of tariff revenue, expressed in terms of the home final good. Labor L is assumed to be constant in each period. The home final good is the numeraire, that is, $P_t^H = 1$ for all t. Households own the capital and rent it period by period to stage 1 and stage 2 firms. Capital is accumulated in the standard way:

$$K_{t+1}^i = (1-\delta)K_t^i + I_t^i, \tag{23}$$

where I is investment. I assume that there are no international capital flows. Consequently, trade is balanced, period by period.

C. *Equilibrium*

All factor and goods markets are characterized by perfect competition. The following market-clearing conditions hold in every period:[17]

$$L^i = \int_0^1 l_1^i(z)dz + \int_0^1 l_2^i(z)dz, \quad i = H, F, \tag{24}$$

and

$$K^i = \int_0^1 k_1^i(z)dz + \int_0^1 k_2^i(z)dz, \quad i = H, F. \tag{25}$$

The stage 1 goods market equilibrium condition is

$$y_1(z) \equiv y_1^H(z) + y_1^F(z) = x_1^H(z) + x_1^F(z). \tag{26}$$

Similar conditions apply to stage 2 goods:

$$y_2(z) \equiv y_2^H(z) + y_2^F(z) = x_2^H(z) + x_2^F(z). \tag{27}$$

The market-clearing condition for stage 3 goods is

$$\left\{\int_0^1 [x_{2,t}^i(z)^{(\sigma-1)/\sigma}]dz\right\}^{\sigma/(\sigma-1)} \equiv Y_t^i = C_t^i + K_{t+1}^i - (1-\delta)K_t^i, \quad i = H, F. \tag{28}$$

If these conditions hold, then exports equal imports; that is, trade is balanced. I now define the equilibrium of this model.

Definition 1. An equilibrium is a sequence of goods and factor prices, $\{p_1(z),\ p_2(z),\ P^i,\ w^i,\ r^i\}$, and quantities, $\{k_1^i(z),\ k_2^i(z),\ l_1^i(z),\ l_2^i(z),\ y_1^i(z),\ y_2^i(z),\ x_1^i(z),\ x_2^i(z),\ Y^i\}$, $z \in [0, 1]$, $i = H, F$, such that the first-order conditions to the firms' and households' maximization problems (17), (18), (19), (20), and (21), as well as the market-clearing conditions (24), (25), (26), (27), and (28), are satisfied for all t.

As noted above, there are four possible production patterns for the first two stages of each good z. Ricardian comparative advantage forces determine the pattern of production and specialization in equilibrium.[18]

---

[17] Of course, $l_1^i(z) = 0$ whenever $y_1^i(z) = 0$, and similarly for $l_2^i(z)$, $k_1^i(z)$, and $k_2^i(z)$.

[18] The presence of a constant capital share, α, in all stage 1 and stage 2 production functions ensures that the model is one of Ricardian trade. The production possibility frontier is a hyperplane, which implies that, under free trade, there will be complete specialization.

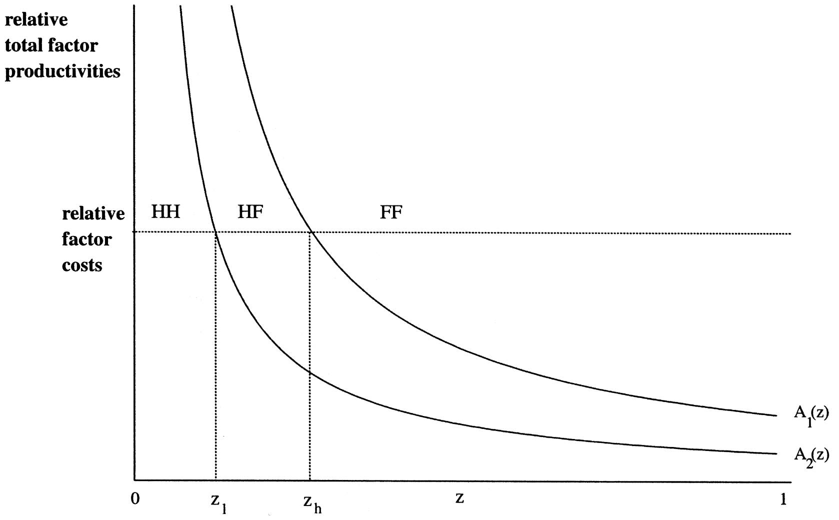

FIG. 5.—Vertical model: free trade. *HF* denotes that Home produces the first stage and Foreign produces the second stage.

In particular, the relative (total factor) productivities, $A_1(z) \equiv A_1^H(z)/A_1^F(z)$ and $A_2(z) \equiv A_2^H(z)/A_2^F(z)$, determine whether *HH, HF, FF,* or *FH* occurs in equilibrium.

Production patterns *HF* and *FH* involve vertical specialization. Under free trade, vertical specialization occurs as long as

$$\frac{A_1^H(z')}{A_1^F(z')} > \left(\frac{r^H}{r^F}\right)^{\alpha}\left(\frac{w^H}{w^F}\right)^{1-\alpha} > \frac{A_2^H(z')}{A_2^F(z')} \quad (HF) \tag{29}$$

or

$$\frac{A_1^H(z')}{A_1^F(z')} < \left(\frac{r^H}{r^F}\right)^{\alpha}\left(\frac{w^H}{w^F}\right)^{1-\alpha} < \frac{A_2^H(z')}{A_2^F(z')} \quad (FH) \tag{30}$$

for some z'. These 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.

Figure 5 illustrates an example of a free-trade equilibrium, which generates complete specialization in the production of all stages of all goods. 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; that is, $z = 0$ is the good in which the home country's stage 1 productivity (relative to the foreign country) is highest. I illustrate an example in which 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, z_l and z_h, 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 2 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

$$\frac{r^{H\alpha}w^{H1-\alpha}\chi}{A_1^H(z_l)^{\theta}A_2^H(z_l)^{1-\theta}} = \frac{r^{H\alpha\theta}r^{F\alpha(1-\theta)}w^{H(1-\alpha)\theta}w^{F(1-\alpha)(1-\theta)}\chi}{A_1^H(z_l)^{\theta}A_2^F(z_l)^{1-\theta}}, \tag{31}$$

where χ is a constant, and z_l is the cutoff z at which equality holds. This equation can be simplified to

$$\rho^{\alpha}\omega^{1-\alpha} = \frac{A_2^H(z_l)}{A_2^F(z_l)} \equiv A_2(z_l), \tag{32}$$

where ρ is the ratio of home to foreign rental rates and ω 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 at which its cost advantage (disadvantage) equals its productivity disadvantage (advantage). This cutoff depends only on stage 2 relative productivity, because the source of stage 2 production is the difference between production patterns *HH* and *HF*.

Tariffs affect the patterns of specialization because they 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 the foreign country. This is illustrated in figure 6, which shows that the tariffs create "wedges" around each free-trade cutoff z. Notice that the range of vertical specialization, that is, those goods produced by technique *HF*, gets squeezed on both sides. The reason is that 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.

D. *Generating Magnification and Nonlinearity*

I now show how the model delivers both magnified and nonlinear trade responses to tariff reductions. To deliver the intuition as clearly as pos-

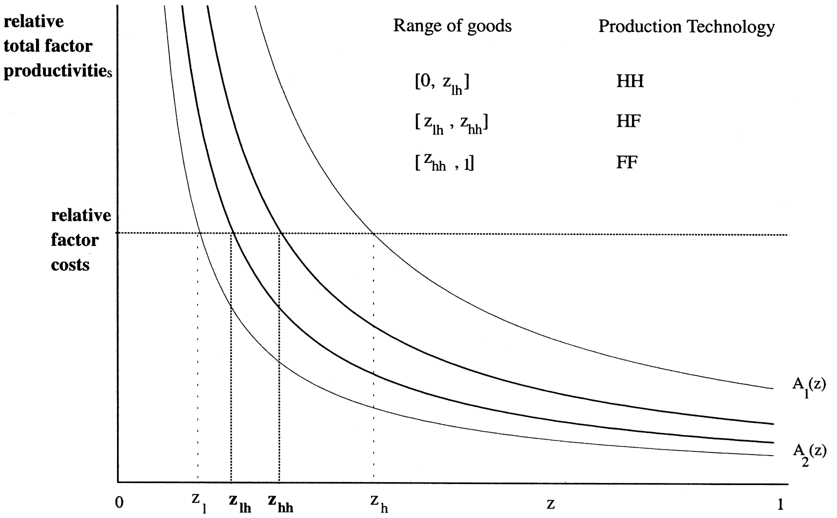

FIG. 6.—Vertical model: tariffs (home consumer's perspective)

sible, I use a simplified version of the model that is static with just one factor, labor. I also assume that all tariff revenue is "thrown in the ocean." The goal is to show how the external margin can generate magnification and nonlinear effects and how the internal margin can generate magnification effects. The external margin involves nonvertically specialized goods that become vertically specialized in response to tariff reductions. The internal margin involves goods that are already vertically specialized.

1. External Margin

The production functions for stage 1 and stage 2 are

$$y_1^i(z) = A_1^i(z) l_1^i(z), \quad i = H, F, \tag{33}$$

and

$$y_2^i(z) = x_1^i(z)^{\theta} [A_2^i(z) l_2^i(z)]^{1-\theta}, \quad i = H, F. \tag{34}$$

The stage 3 aggregator is Cobb-Douglas:

$$Y = \exp\left\{ \int_0^1 \ln\,[x_2(z)]dz \right\}. \tag{35}$$

Stage 3 output is used for consumption. For simplicity, I assume that $A_1^H(z)/A_1^F(z)$ is a proportional shift of $A_2^H(z)/A_2^F(z)$ to the right, as in figure

5. It shows that the home country has a relatively greater comparative advantage in stage 1 goods than in stage 2 goods.

If tariffs are low enough so that vertical specialization occurs, then it can be shown that the home import share of output is given by $1 - z_l$, where z_l is the cutoff good for which the costs (for the home stage 3 firm) of production patterns *HH* and *HF* are the same. The arbitrage condition for z_l is

$$\omega = (1 + \tau)^{(1+\theta)/(1-\theta)} A_2(z_l), \tag{36}$$

where $\omega = w^H/w^F$ is the relative wage, and $A_2(z_l) = A_2^H(z_l)/A_2^F(z_l)$. Taking "hat" calculus and assuming no change in the relative wage yields[19]

$$\widehat{1 - z_l} = \left(\frac{1 + \theta}{1 - \theta}\right)\left[\frac{z_l}{(1 - z_l)\eta_{A_2}}\right]\widehat{1 + \tau}, \tag{37}$$

where $\eta_{A_2} < 0$ is the elasticity of stage 2 relative productivity, $A_2(z_l)$, with respect to z.

If tariffs are sufficiently high so that there is no vertical specialization, then, from the home perspective, the model is essentially a one-stage model. The import share of output is still given by $1 - z_l$, where z_l is the good for which the costs of production patterns *HH* and *FF* are the same. The arbitrage condition that delivers z_l is

$$\omega = (1 + \tau)A(z_l), \tag{38}$$

where

$$A(z_l) = \frac{A^H(z_l)}{A^F(z_l)} = \frac{A_1^H(z_l)^{\theta} A_2^H(z_l)^{1-\theta}}{A_1^F(z_l)^{\theta} A_2^F(z_l)^{1-\theta}}.$$

Hat calculus yields

$$\widehat{1 - z_l} = \left[\frac{z_l}{(1 - z_l)\eta_A}\right](\widehat{1 + \tau}), \tag{39}$$

where $\eta_A = \eta_{A_2} < 0$ is the elasticity of overall relative productivity with respect to z. The smaller the elasticity, the flatter the relative productivity curve and the greater the trade responsiveness to tariff changes. Each of the equations above gives the response of the import share of output, along the external margin, to changes in tariff rates. Equation (37) is identical to equation (39) except for the presence of the $(1 + \theta)/(1 - \theta)$ term. This term illustrates the magnification effect. If $\theta = \frac{2}{3}$, for example, then the effect of tariff reductions is *five* times higher under vertical specialization.

---

[19] Under the assumptions above, and when $L^H = L^F$, the relative wage changes little—on the order of 0.1 percent—in response to a 10-percentage-point change in tariff rates.

Taken together, equations (37) and (39) illustrate the nonlinear effect of tariff reductions as well. When tariffs are sufficiently high so that there is no vertical specialization, the effects of tariff reductions on trade are relatively small (eq. [39]). When tariffs fall low enough so that vertical specialization kicks in, the effects of further tariff reductions are now much higher (eq. [37]). In the more general case in which $\eta_A \neq \eta_{A_2}$, as long as the elasticities are not too different, both magnification and nonlinearity will continue to occur.

2. Internal Margin

I use the same simplified model as above, except that the Cobb-Douglas aggregator (35) is replaced by the more general CES aggregator (15). Under vertical specialization, the home import share of GDP is given by

$$(1+\tau)^{1-\sigma}\left[\int_{z\in FF} p_2(z)^{1-\sigma}dz + \int_{z\in HF} p_2(z)^{1-\sigma}dz\right], \tag{40}$$

which can be rewritten as

$$(1+\tau)^{1-\sigma}\left\{\int_{z\in FF}\left[\frac{\bar{\theta}w^F}{A_1^F(z)^{\theta}A_2^F(z)^{1-\theta}}\right]^{1-\sigma}dz + \int_{z\in HF}\left[\frac{(1+\tau)^{\theta}\bar{\theta}w^H w^F}{A_1^H(z)^{\theta}A_2^F(z)^{1-\theta}}\right]^{1-\sigma}dz\right\}, \tag{41}$$

where $\bar{\theta}$ is a constant. To simplify notation, I rewrite expression (41) as

$$(1+\tau)^{1-\sigma}[FF(w^H,\ w^F) + (1+\tau)^{\theta(1-\sigma)}HF(w^H,\ w^F)]. \tag{42}$$

Along the internal margin, z is held fixed; also, as before, I hold w^H and w^F fixed. Consequently, the logarithmic derivative of the import share of GDP is given by

$$(1-\sigma)\left\{1+\theta\left[\frac{HF(w^H,\ w^F)}{FF(w^H,\ w^F) + (1+\tau)^{\theta(1-\sigma)}HF(w^H,\ w^F)}\right]\right\}(\widehat{1+\tau}). \tag{43}$$

When there is no vertical specialization, $HF(w^H,\ w^F) = 0$, and the logarithmic derivative of the import share of GDP is given by

$$(1-\sigma)(\widehat{1+\tau}). \tag{44}$$

The term inside the braces in (43) gives the magnification effect associated with the internal margin. It arises from the fact that lower tariffs reduce the cost of producing vertically specialized goods by more than regular goods. The cost reduction for those goods produced by method *HF* is $1 + \theta$ multiplied by the reduction in tariffs. In this model, with just two (traded) stages of production, the magnification effect is less than two. As the number of stages increases, the magnification effect of tariff reduction increases. In a model with n (traded) stages of production and in which each stage's share of the subsequent stage's inputs is θ, the reduction in costs per percentage point of tariff reduction is[20]

$$\frac{1-\theta^{n}}{1-\theta}. \tag{45}$$

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 nontraded 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. Both the external and internal margins drive this surge. Goods switch from being "regular" to "vertically specialized"; the more goods that become vertically specialized, the greater the increase in trade. Also, the lower tariffs reduce the cost of producing existing vertically specialized goods by a multiple of the tariff reduction.[21]

V. Calibration of the Model

The goal of this paper is to examine whether vertical specialization is an important propagation mechanism helping to generate large and nonlinear trade responses to rather small observed tariff reductions. To quantitatively assess the importance of vertical specialization, I calibrate the model and simulate global tariff reductions.

Each period represents one year; I start the simulation in 1962. This was a year in the middle of a lull in major tariff reductions resulting

---

[20] The equations above also illustrate the potential for misinterpreting gravity-type trade regressions when vertical specialization is not taken into account. In most gravity regressions, a term like (44) is estimated. The elasticity of trade with respect to tariffs is essentially the elasticity of substitution and has often been interpreted as such. However, in the presence of vertical specialization, the estimated coefficient is, in fact, a combination of the elasticity of substitution, the use of inputs in stage 2 production, and the magnitude of vertical specialization, as (43) shows.

[21] See Baxter (1992) for a model that also generates large changes in production patterns from small changes in distortions.

from the 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.[22]

The two countries are of equal size and represent developed countries. Developed countries still account for almost 70 percent of world merchandise trade and more than 70 percent of world manufactured trade. Moreover, more than 70 percent of developed country exports go to other developed countries.[23] I focus on manufacturing because 79 percent of developed country trade is manufactured goods. Finally, from Hummels et al. (2001), we know that most vertical specialization by developed countries occurs with other developed countries.

I think of one country as the United States and the other country as the Rest of the Developed World (ROW). In 1963, U.S. manufacturing GDP was equal to 51 percent of the total manufacturing GDP of the Group of Seven (G-7) plus other western European countries.[24] By 1976, owing primarily to higher ROW growth rates, the U.S. share of total manufacturing GDP had dropped to 35 percent. In 1995 (1998), the share was 26 percent (35 percent). 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 $1 - s$, 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 $(1 - .35)/(1 - .51) = 1.33$ between 1962 and 1976, and, when 1995 and 1998 are averaged, by about $(1 - .305)/(1 - .35) = 1.07$ between 1976 and 1999, even if no tariff reductions had occurred.[25] 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 these factors. Specifically, I assume that the annual growth rate of the ROW relative to the United States between 1962 and 1976 is $1.33^{1/14}$ and between 1976 and 1999 is $1.07^{1/23}$, and I 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 3.9 percent per year to 2.9 percent

---

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

[23] See U.N. Conference on Trade and Development (2000). These numbers pertain to 1997 or 1998 and are based on the United Nations definition of "developed," which now includes Western Europe, the United States, Japan, Canada, Israel, South Africa, Australia, and New Zealand.

[24] The non-G-7 countries include Austria, Belgium, Denmark, Luxembourg, Netherlands, Norway, Portugal, Sweden, and Switzerland.

[25] Because the model involves non–free trade, this is only an approximation.

per year. Over 37 years, then, the adjusted export share of output grows by a factor of 2.9 (the unadjusted export share grew by a factor of 4.1).[26]

The export series is also smoothed. I regress adjusted export growth on current and lagged oil price growth and current and lagged appreciation of the U.S. nominal effective exchange rate.[27] I use the coefficient estimates to eliminate export growth occurring from deviations from the means of oil price growth and dollar appreciation. This smoothing primarily affects the behavior of exports from the mid 1970s to the mid 1980s; it does not affect the nonlinear nature of the export growth. The smoothed, adjusted export share increases by a factor of 3.1 between 1962 and 1999.

I construct the tariff series using data on U.S., E.C., and Japanese manufacturing tariff rates. (See App. A for the sources of the data and details on the series construction.) I construct a tariff series for the United States and for the ROW (a trade-weighted average of the E.C. and Japanese 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 1 illustrates the time path of tariffs, juxtaposed against the 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 10.9 percentage points occurred between 1967 and 1972. Thereafter, tariffs declined gradually.

I set α, the Cobb-Douglas coefficient on capital, to 0.36, as in Backus et al. (1994) and many other RBC papers. I set β, the preference discount parameter, to 0.96, which is also typical in models with annual frequencies. The depreciation rate on capital, δ, 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-stage production, θ, is set to two-thirds, which is consistent with the fact that, for manufacturing, value added represents about one-third of gross production. The elasticity of substitution in the stage 3 aggregator, σ, is set to one (Cobb-Douglas). The initial capital/labor ratios are set to their steady-state values consistent with tariff rates

---

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

[27] The U.S. manufacturing GDP data come from U.S. Council of Economic Advisers (2001). The U.S. manufacturing export data come from both U.N. Conference on Trade and Development (2000) and the U.S. Census web site. The oil price and nominal effective exchange rate data come from the International Monetary Fund's International Financial Statistics.

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 calibrating the $A_1(z) \equiv A_1^H(z)/A_1^F(z)$ and $A_2(z) \equiv A_2^H(z)/A_2^F(z)$ curves as illustrated, for example, in figures 5 and 6. Measures of U.S. productivity relative to ROW productivity over a large range of industries are needed. Even more challenging, the relative productivity measures are needed for both stage 1 and stage 2 production. While data on industry-level TFP for many developed countries exist (see, e.g., Harrigan 1997*a*, 1997*b*, 1999), data on TFP for the equivalent of stage 1 and stage 2 production, industry by industry, do not. For example, while data on TFP of the motor vehicles industry exist, data on the TFP of engines and windshields, as well as on final assembly, do not.

To deal with this challenge, I turn to Bela Balassa's concept of revealed comparative advantage (RCA). Balassa (1965*b*) developed these measures as a convenient solution to the problem of calculating autarky prices in many industries for many countries over many years. Balassa's RCA measure for country i and industry j is defined as

$$\mathrm{RCA}_{i,j} = \frac{X_{i,j}/X_i}{X_{W,j}/X_W}, \tag{46}$$

where $X_{i,j}$ denotes exports from country i, industry j, with X_i denoting total exports from country i and the subscript W denoting the world. The U.S. RCA for motor vehicles is the share of motor vehicles in total U.S. exports *relative* to the share of motor vehicles in total world exports. If $\mathrm{RCA}_{i,j} > 1$, then country i is said to have a comparative advantage in industry j. It has been shown that RCAs do reveal comparative advantage in the classic 2 × 2 × 2 Heckscher-Ohlin model with free trade and identical preferences, as well as the classic Ricardian trade model. While it has also been shown that in more general contexts RCAs do not reveal comparative advantage, they *will* reveal comparative advantage under the assumptions of my model. That is, all industries j for which $\mathrm{RCA}_{\mathrm{U.S.},j} > 1$ will be industries for which the United States has a comparative advantage.

I use the RCAs as a proxy for the relative productivities $A_1(z)$ and $A_2(z)$. This is a strong assumption because the mapping from RCAs to comparative advantage is essentially an ordinal mapping; I am also using it to capture a cardinal relation.[28] I also assume that $A_1(z)$ and $A_2(z)$ are fixed between 1962 and 1999. This assumption rules out changes in trade resulting from changes in relative TFP.[29] However, it allows me to isolate as sharply as possible the effects of lower tariffs.

My RCA computations take Balassa one step further because I compute them for production stage k:

$$\mathrm{RCA}_{i,j,k} = \frac{X_{i,j,k}/X_i}{X_{W,j,k}/X_W}. \tag{47}$$

The actual details on the RCA calculations are quite involved and are presented mainly in Appendix B. The reason is that $X_{i,j,k}$ and $X_{W,j,k}$, $k = 1, 2$, are not directly measurable and need to be constructed. A short summary is provided here.

I focus on 1985, which was approximately halfway through the sample. I use U.S. imports as a proxy for the ROW's exports to the United States.[30] Consequently, for each stage 2 industry, the calculation requires data on that industry's exports and imports, as well as exports and imports for the stage 2 industry's "stage 1 counterpart."[31] In the model, the stage 2 industry draws all its inputs from its stage 1 counterpart; conversely, the stage 1 counterpart sends all its output to the stage 2 industry. In the data, such an input-output relation does not exist. To

---

[28] My assumption says that an industry with an RCA of three has twice the relative productivity of an industry with an RCA of 1.5. I conduct an empirical check of the validity of this assumption by computing the correlation between manufacturing relative TFP measures drawn from Harrigan (1997*a*, 1997*b*, 1999) and RCAs computed from the OECD input-output table for the United States in 1985. (Harrigan calculates U.S. TFP relative to the other G-7 countries, for 13 manufacturing industries over selected years between 1970 and 1988.) The correlation is .31. In addition, Davis (1995) presents a model in which interindustry trade is determined by Heckscher-Ohlin forces, but intraindustry trade is determined by Ricardian forces. Davis's framework is consistent with an intuition that establishes a positive relation between the relative productivity and the RCA of an industry. The relative productivity of the industry is an appropriately weighted average of the relative productivity of the goods in that industry. As the number of goods for which a country has higher relative productivity increases, exports from that industry will increase, as will the country's RCA. Consequently, the assumption has some empirical and theoretical support.

[29] Both Bernard and Jones (1996) and Harrigan (1997*a*, 1997*b*, 1999) find that relative TFPs have changed little since the early 1970s. Drawing from RCAs calculated in Balassa (1977), I calculate the Spearman rank correlation coefficient between RCAs in 1962 and 1971. The correlations for the United States, the Common Market, and Japan are .78, .86, and .65, respectively. Also, Proudman and Redding (2000) show that RCAs for the United States and several European countries' manufacturing industries have changed little between 1970–74 and 1990–93. However, Evenett and Yeung (1999) argue that the relative productivities across countries have decreased over time, which, all else equal, implies less trade.

[30] I adjust industry-level U.S. imports via a simple proportionality factor so that they sum to total U.S. exports.

[31] The imports of the stage 2 industry's stage 1 counterpart are the exports of the ROW stage 2 industry's stage 1 counterpart.

reconcile the model with the data, I construct an artificial stage 1 counterpart that is a composite of industries that tend to produce intermediate goods, that is, stage 1 industries. In other words, a subset of each stage 1 industry will be a part of the stage 2 industry's stage 1 counterpart. In addition, the stage 1 counterpart includes a portion of the stage 2 industry itself, because almost all industries draw more of its inputs from itself than from any other industry—no matter how disaggregated the input-output tables are. For example, the motor vehicles industry draws a significant fraction of its inputs from itself because motor vehicle engines are counted as part of the industry. Figure 7 illustrates a sample schematic of two stage 2 industries, their stage 1 counterparts, and two stage 1 industries.

According to whether their output goes to final use or intermediate use, the OECD input-output tables' industries are divided into stage 2 industries and stage 1 industries. I develop two benchmark cases. In the "narrow" case, the stage 1 industries are paper, industrial chemicals, drugs and medicines, petroleum and coal products, rubber and plastic products, nonmetallic mineral production, iron and steel, nonferrous metals, and electrical apparatus. The stage 2 industries are food, beverages, and tobacco; textiles, apparel, and leather; motor vehicles; shipbuilding; aircraft; office and computing machinery; radio and television; and nonelectric machinery. In the "broad" case, the stage 2 industries are the same as in the narrow case, but the stage 1 industries are expanded to include all manufacturing industries. The broad case accounts for the fact that even the industries designated as stage 2 industries produce goods that are used as inputs into other stage 2 industries' production.

In calculating the stage 1 counterpart's exports, I employ the proportionality assumption. If x percent of a stage 1 industry's output goes to a particular stage 2 industry, then I assign x percent of the stage 1 industry's exports to the stage 2 industry's stage 1 counterpart. These data are obtained from the OECD input-output tables for the United States in 1985. Calculating the stage 1 counterpart's exports that draw from the stage 2 industry itself is more complicated because it requires data at a more disaggregated level than the OECD tables. See Appendix B.

Calculating the stage 2 industry's exports and imports, as well as the industry's stage 1 counterpart's imports, is more straightforward. The stage 2 exports are the exports of the stage 2 industry less the exports that are assigned to the stage 1 counterpart. Stage 2 imports, that is, the ROW's stage 2 exports, are simply the (final) imports of the stage 2 industry. The stage 1 counterpart's imports are obtained from the OECD input-output tables, which include imported inputs tables.

Once these numbers are obtained, the RCAs for each stage 2 industry

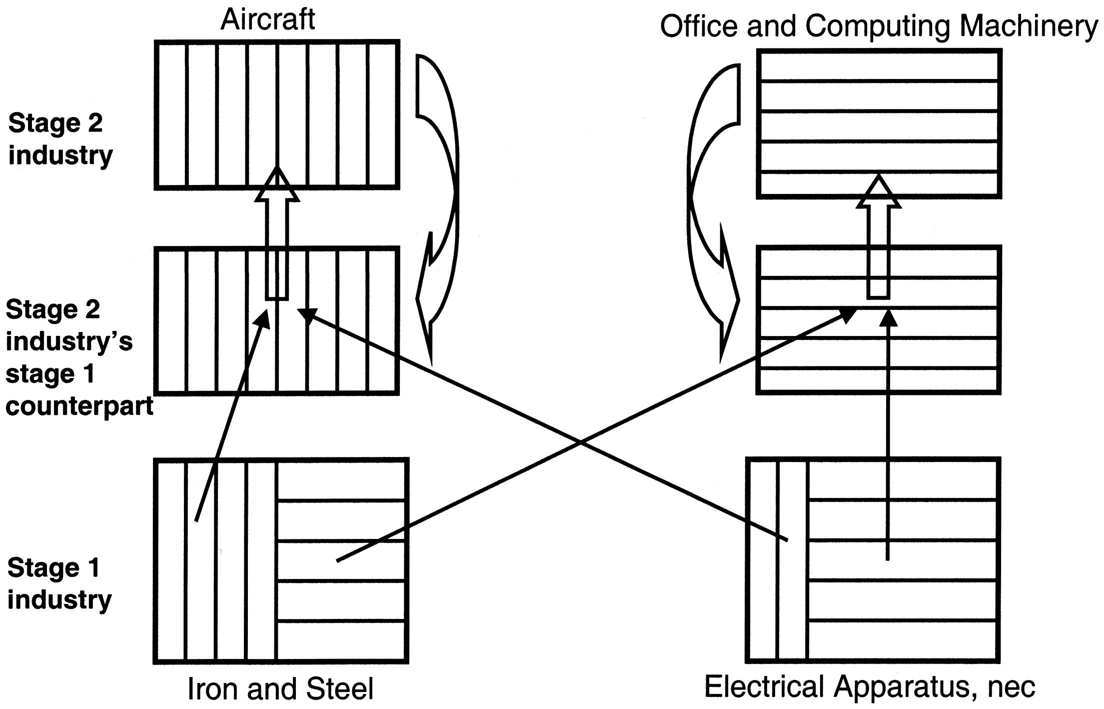

FIG. 7.—Stage 1 and stage 2 input-output relations

TABLE 1
PARAMETERS USED IN BENCHMARK CALIBRATIONS

Parameter	Parameter Name	Parameter Value
β	Preference discount factor	.96
α	Capital's share in production	.36
δ	Depreciation rate on capital	.13
θ	Share of first-stage output in second-stage production	.67
σ	Elasticity of substitution in stage 3 aggregator	1
$A_1(z)$	Narrow benchmark case stage 1 relative productivity	$1.26z^2 - 2.53z + 1.88$
$A_2(z)$	Narrow benchmark case stage 2 relative productivity	$3.095z^2 - 3.38z + 1.63$
$A_1(z)$	Broad benchmark case stage 1 relative productivity	$0.686z^2 - 1.478z + 1.63$
$A_2(z)$	Broad benchmark case stage 2 relative productivity	$3.088z^2 - 3.401z + 1.567$

and its stage 1 counterpart are calculated via (47). To facilitate solving the model, it is convenient to obtain an analytical representation for the relative productivity curves $A_1(z)$ and $A_2(z)$. I discretize the [0, 1] continuum with the eight stage 2 industries and then estimate a quadratic regression of $A_1(z)$ on z, and similarly for $A_2(z)$. Appendix B describes this procedure in detail. Appendix figures B2*a* and *b* below illustrate the $A_1(z)$ and $A_2(z)$ curves for both benchmark cases; in the broad benchmark case, the difference between $A_1(z)$ and $A_2(z)$ is greater, suggesting more "potential" for vertical specialization. The key parameters are listed in table 1.

VI. Results

In this section, I first present the results from the two benchmark cases. For these cases, I solve the model's steady state at each tariff rate from 1962 to 1999. I then present results from several sensitivity analyses.

A. *Main Results*

Figure 8*a* plots actual exports and exports generated by the narrow benchmark case against tariff rates. The simulated exports are normalized to equal the actual export share in 1962.[32] The figure shows that the model tracks the data fairly well until tariff rates reach 5 percent. The model generates nonlinear effects, as well, with the effect kicking in at tariff rates of around 8 percent. Table 2 presents results for the

[32] In other words, I am essentially focusing on matching the *growth* of exports rather than the *level* of exports.

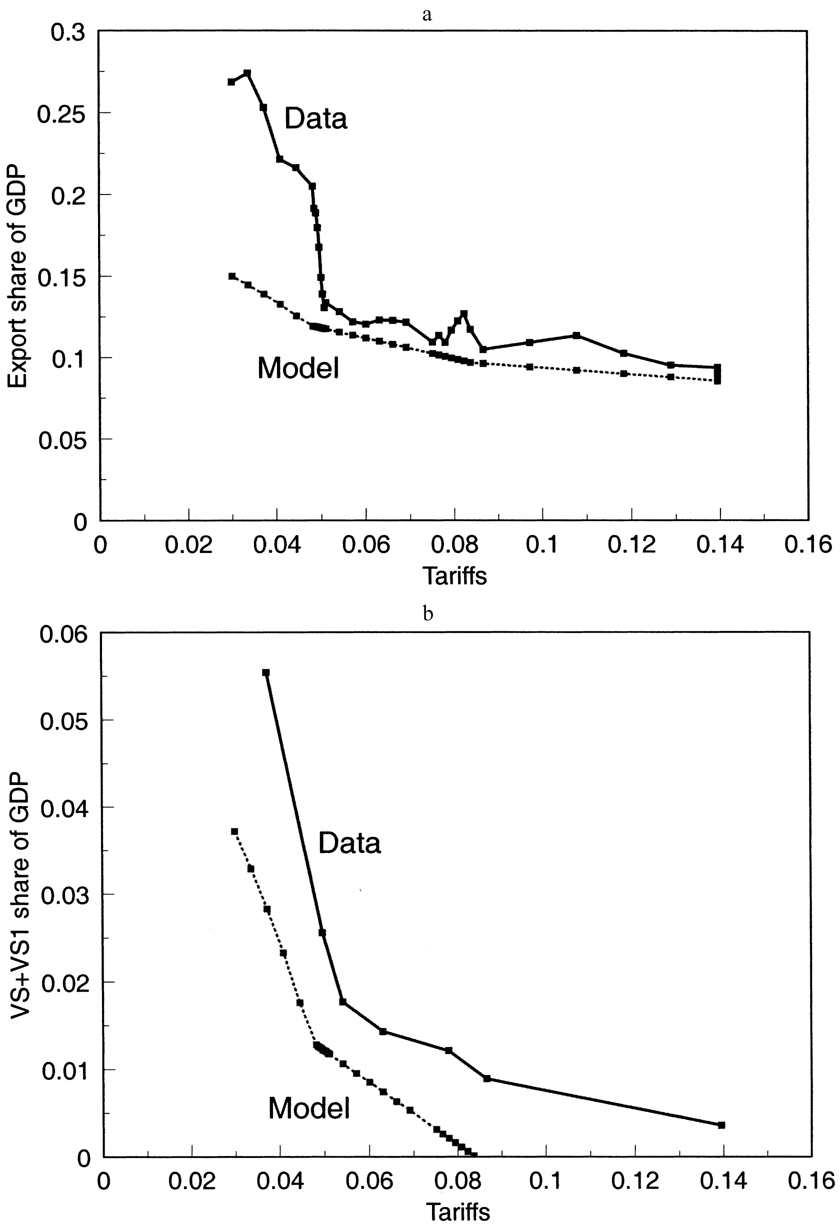

FIG. 8.—Narrow case: exports and VS+VS1 against tariffs

TABLE 2
Results from Benchmark Vertical Model

	U.S. Data[*]	Narrow Case	Broad Case
	A. Export Growth (Percent)		
1962–99[†]	213.0	74.8	113.0
1962–76	36.2	16.2	47.4
1976–99	130.0	50.4	44.6
1962–89	73.9	37.9	87.2
1989–99	80.1	26.8	13.8
	B. Elasticity of Export Growth with Respect to Tariffs		
1962–99	22.0	7.8	11.8
1962–76	6.9	3.1	9.0
1976–99	28.4	11.0	9.7
1962–89	9.4	4.8	11.1
1989–99	42.1	14.1	7.3
	C. Export Share of GDP: Root Mean Square Error		
1962–99		**.049**	**.032**
1962–76		.015	.006
1976–99		.061	.041
1962–89		.015	.016
1989–99		.091	.056
	D. Vertical Specialization (Percentage of GDP)		
1962	.36	.00	.00
1977	1.21	.21	1.50
1990	2.56	1.22	4.25
1997	5.54	2.83	5.46

[*] U.S. data are adjusted in panels A and B.
[†] The fraction explained for the narrow case is 35.1 percent and for the broad case 53.0 percent.

entire period, as well as two sets of subperiods, 1962–76 and 1976–99, and 1962–89 and 1989–99.[33] The model explains about 35 percent of overall export growth. It performs better in the earlier subperiods, where it explains more than half of actual export growth between 1962 and 1989. The nonlinear effect implied by the model is considerable, too. For example, between 1962–76 and 1976–99, the elasticity of trade with respect to tariffs rises from three to 11. But the model fails to match the nonlinearity in the data, especially when tariffs fall below 5 percent. In the data, the elasticity of trade with respect to tariffs rises from seven to 28 between 1962–76 and 1976–99. Table 2 also presents the root mean square error (RMSE) for exports. The overall RMSE is about 4.9 percentage points of GDP; it is considerably smaller in the earlier sub-

---

[33] The year 1976 was halfway between the end of the implementation of the Kennedy Round and the beginning of the implementation of the Tokyo Round, and 1989 was about halfway between the end of the Tokyo Round and the beginning of the Uruguay Round. Results with 1986 as the break point are very similar to the results with 1989 as the break point.

periods (e.g., 1.5 percentage points in 1962–76) than in the later subperiods.[34]

The narrow benchmark case explains about 50 percent of growth of vertical specialization. Moreover, the time path is a close fit to the data, as shown in figure 8*b*. Overall, this benchmark case does well on the timing of the nonlinear effects, in matching export growth before the large nonlinear effects kick in, and in matching the time path and magnitudes of vertical specialization. However, it falls short of matching the magnitude of the nonlinear effects.

The results for the broad benchmark case are illustrated in figure 9. This case generates a closer fit to actual export and growth in vertical specialization than the narrow case. Table 2 shows that it explains about 53 percent of export growth and almost 100 percent of vertical specialization growth. It is able to generate more propagation from tariffs because the relative productivity differences between stage 1 and stage 2 are greater than in the other case, increasing the range of goods for which vertical specialization is the efficient production pattern. The RMSE is 3.2 percentage points of GDP, about one-third lower than in the narrow case. However, the broad case compares unfavorably to the narrow case in the timing and magnitude of the nonlinear effects.

What are the welfare implications of lower tariff rates? I compare the average of home and foreign steady-state consumption levels under the 1962 tariff rates with the levels under the 1999 tariff rates. Lowering tariffs from 13.95 percent to 3.05 percent raises steady-state consumption by 3.2 and 4.7 percent under the narrow and broad benchmark cases, respectively. These are significant gains.

In summary, in the benchmark cases, the model can explain over half of export growth and all of vertical specialization growth. However, it falls short of capturing the magnitude of the nonlinear export surge beginning in the late 1980s. The model also implies large welfare gains from tariff reductions.

B. *Comparison with the Standard One-Stage Model*

To assess the "value added" of the vertical model, I also simulate a model with the two stages of production combined into one:

$$y_2^i(z) = A^i(z)k^i(z)^{\alpha}l^i(z)^{1-\alpha}, \quad i = H, F, \; z \in [0, 1], \tag{48}$$

where $A(z) = A_1(z)^{\theta}A_2(z)^{1-\theta}$, and there is no possibility of vertical specialization. This model is essentially the standard, one-stage, model. Figure 10 shows for the narrow benchmark calibration that the standard model generates much less export growth than the vertical model, and

---

[34] For reference, the standard deviation of the data is 5.2 percentage points of GDP.

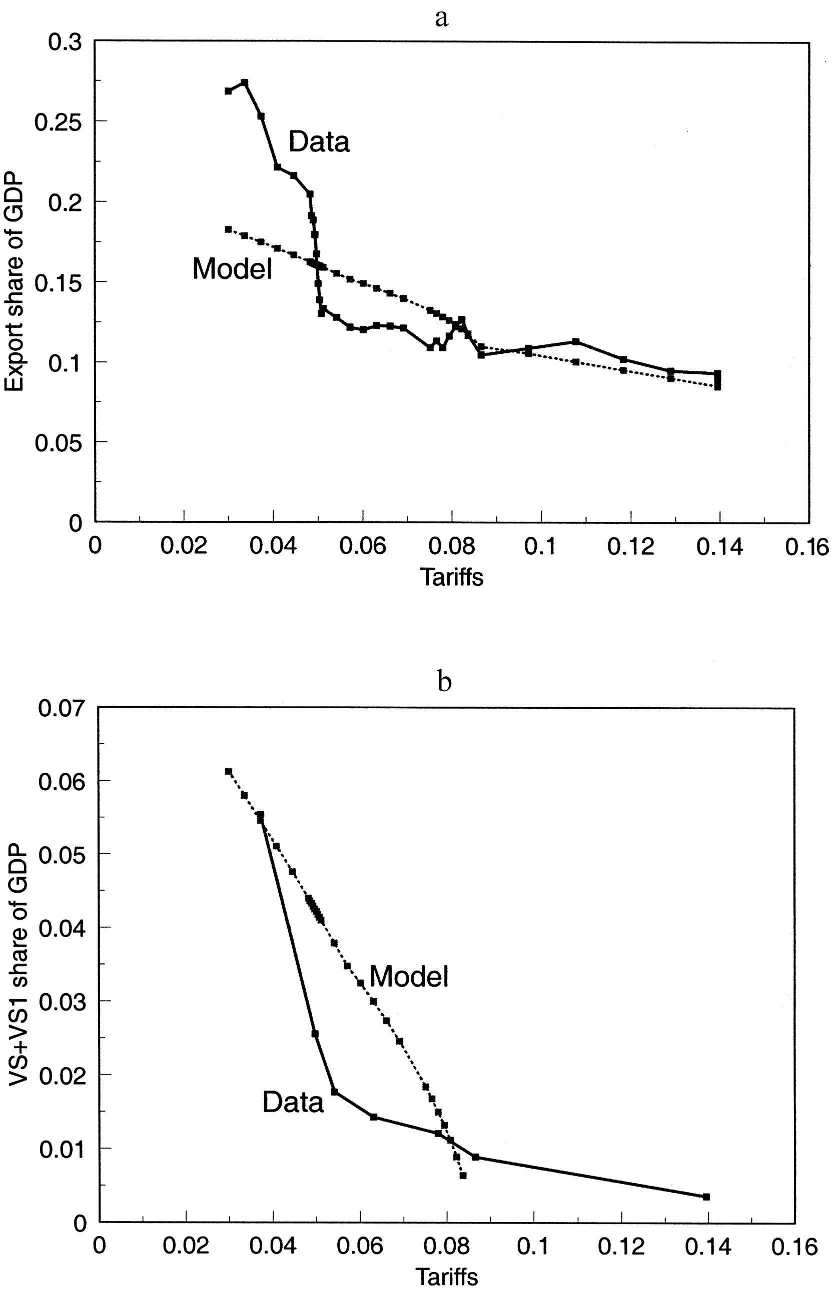

FIG. 9.—Broad case: exports and VS+VS1 against tariffs

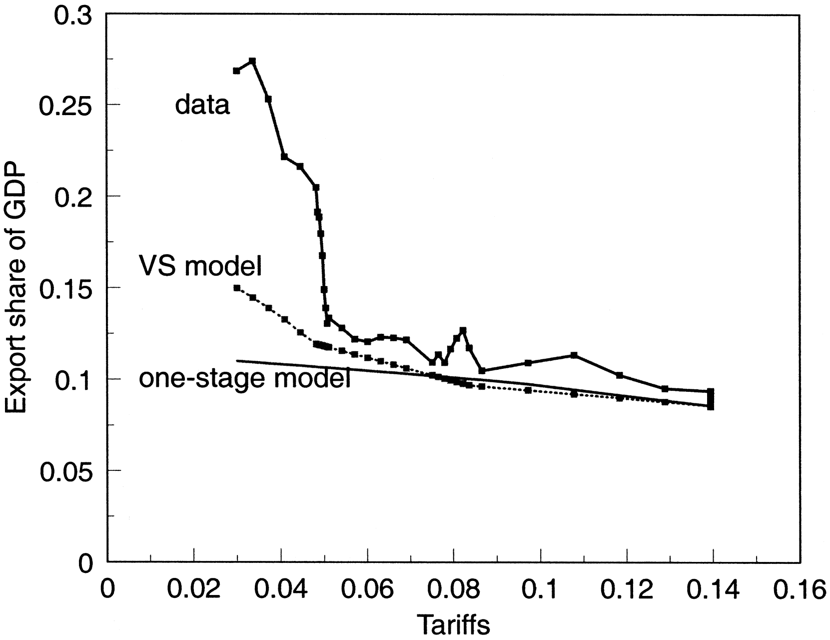

FIG. 10.—Narrow case: vertical model vs. one-stage model

it cannot generate any nonlinear effects. Table 3 indicates that the model can explain only about 13 percent of export growth between 1962 and 1999; this is only one-third of what the vertical model explains. The standard model performs well relative to the vertical model in the earlier subperiods but considerably worse in the later subperiods. For example, between 1962 and 1976, the standard model explains about the same export growth as the vertical model, because vertical specialization is insignificant in this subperiod. However, between 1989 and 1999, the standard model implies export growth of just 3 percent, as opposed to 27 percent in the vertical model and 80 percent in the data. Moreover, the standard model implies elasticities of trade with respect to tariffs that are larger in the earlier subperiods than in the later subperiods, which is counterfactual. Finally, the RMSE is 1.2 percentage points higher than in the vertical model. The results for the broad benchmark case are similar. In every dimension, then, the one-stage model performs more poorly than the vertical model.

I can assess the welfare gains to vertical specialization by comparing the previously computed welfare gains with the welfare gains in the standard model. The gain in steady-state consumption from lower tariffs is 0.95 and 2.2 percentage points higher in the vertical model relative to the standard model in the narrow and broad cases, respectively. These

TABLE 3
Comparison of Vertical Model with Standard Model

		Narrow Case		Broad Case	
	U.S. Data (Adjusted)	Vertical Model	One-Stage Model	Vertical Model	One-Stage Model
	A. Export Growth (Percent)				
1962–99*	213.0	74.8	28.3	113.0	62.7
1962–76	36.2	16.2	18.1	47.4	32.9
1976–99	130.0	50.4	8.7	44.6	22.4
1962–89	73.9	37.9	24.3	87.2	50.3
1989–99	80.1	26.8	3.2	13.8	8.2
	B. Elasticity of Export Growth with Respect to Tariffs				
1962–99	22.0	7.8	2.9	11.8	6.5
1962–76	6.9	3.1	3.4	9.0	6.2
1976–99	28.4	11.0	1.9	9.7	4.9
1962–89	9.4	4.8	3.1	11.1	6.4
1989–99	42.1	14.1	1.7	7.3	4.3
	C. Export Share of GDP: Root Mean Square Error				
1962–99		**.049**	**.061**	**.032**	**.047**
1962–76		.015	.013	.006	.007
1976–99		.061	.077	.041	.060
1962–89		.015	.018	.016	.007
1989–99		.091	.114	.056	.090

* For the narrow case, the fraction explained is 35.1 percent for the vertical model and 13.3 percent for the one-stage model. For the broad case, the fractions are, respectively, 53.0 percent and 29.4 percent.

additional gains arise simply because a vertical model provides more opportunities for specialization than the standard model.

C. *Alternative RCA Calibrations Using Textiles and Electronics*

The two benchmark cases are calibrated to the entire manufacturing sector. An alternative calibration is to choose one manufacturing industry and calibrate that industry as a "representative" industry. I do this for the textiles industry and the electronics industry, each of which is quite vertically specialized. To calculate the RCAs and estimate the $A_1(z)$ and $A_2(z)$ curves, I employ the U.S. 1987 benchmark input-output tables and follow a methodology similar to that of the two benchmark calibrations.[35]

The results for the narrow case calibration are basically the same as in the narrow benchmark simulations, with the model explaining 27 percent (textiles) and 62 percent (electronics), respectively, of export growth and about 60 percent of vertical specialization growth. The model also generates some nonlinearity as well.

---

[35] Details are available from the author on request.

The broad case calibration yields two interesting results. First, the model can explain over 100 percent of export growth and vertical specialization growth. For both textiles and electronics, the $A_1(z)$ and $A_2(z)$ curves cross at a low z, which essentially maximizes the possibilities for vertical specialization. Second, for further insight, I also run the simulation for the standard, one-stage, version of the model. It turns out that the standard model can explain over 100 percent of the growth of trade as well. Because $A_1(z)$ and $A_2(z)$ cross, the one-stage relative productivity curve $A(z) = A_1(z)^\theta A_2(z)^{1-\theta}$ is very flat, as shown in Appendix figure B3*b*. The flat curve implies that small changes in tariffs generate a large increase in trade. In other words, a high elasticity of substitution between goods on the production side delivers large trade growth, analogous to the results obtained in Section III. However, the welfare gains for the vertical model are still considerably larger than for the standard model. For both textiles and electronics, the gains over the standard model are about four percentage points of (steady-state) consumption.

D. Dynamics

To check the sensitivity of the results to the steady-state assumption, I solve the following dynamic scenario: The world is initially at a steady state at the 1962 tariff rate. Then, starting in 1962, the time path of tariffs changes to become the actual time path from 1962 to 1999, with tariffs remaining at their post–Uruguay Round level thereafter. In this scenario, capital accumulation occurs, which could potentially affect export growth through changes in relative country sizes. I solve the model by assuming that the new steady state is reached after 125 years.[36] The results are virtually identical. In this model, capital accumulation affects trade primarily through changes in relative country size. But because capital accumulation occurs in both countries, relative country sizes are little affected.

I compare welfare in the dynamic scenario against a scenario in which tariffs remained at the 1962 level forever. The welfare gains to lower tariffs tend to be about a third as large as the steady-state gains because of the long transition dynamics, during which tariffs are higher than their eventual steady-state values. Welfare gains in the vertical model relative to the standard model also tend to be only one-third as large as they are in the steady state, again because of the transition dynamics. Consequently, the main reason to include dynamics in the model is to

---

[36] The steady state can be solved for independently of the transition dynamics. I use Gauss's NLSYS nonlinear equations routine to solve the Euler equations and equilibrium conditions characterizing the transition dynamics.

facilitate more realistic calculations of the welfare gains to tariff reductions.

E. *Parameter Variation*

I examine the sensitivity of the results to changes in some of the key production parameters. I perform the benchmark simulations using a higher capital share of output α, two-thirds. 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 $\alpha = 0.36$. I also study the effects of different shares of stage 1 input required for stage 2 production, θ. I examine the cases of $\theta = \frac{1}{3}, \frac{1}{2}$, and $\frac{3}{4}$. The results are broadly similar.[37]

For a static version of the model, I examine the effects of using a CES instead of a Cobb-Douglas aggregator. In particular, I considered cases in which $\sigma > 1$. In redoing the narrow benchmark case simulations, I find that higher elasticities of substitution raise trade growth by little. (They do not raise trade growth in the one-stage version of the model, as well.) These results are contrary to the results from Section III because of an asymmetry in the calibrated $A_1(z)$ and $A_2(z)$. As the elasticity of substitution between goods increases, a higher "premium" is placed on goods that are produced most cheaply. With the narrow benchmark calibration, this happens most with the home goods near $z = 0$. Consequently, higher elasticities are associated with higher relative factor prices. The higher factor prices, it turns out, move the economy away from the region with the most vertical specialization. This force offsets the usual substitution forces leading to large trade growth.

VII. Summary and 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 percent per year for the past 50 years. In the time period I focus on, 1962–99, the merchandise (manufacturing) export share of output tripled (quadrupled). The common wisdom about the cause of this growth focuses on the worldwide reductions in trade barriers brought about by several GATT agreements.

The common wisdom, however, leaves two major puzzles in its wake. Tariff rates since the early 1960s have fallen by only about 11 percentage points. The first puzzle, then, is reconciling the large growth in trade

---

[37] Interestingly, both the $\theta = \frac{1}{3}$ and $\theta = \frac{3}{4}$ cases generate less trade and vertical specialization growth, relative to the benchmark case of $\theta = \frac{2}{3}$.

with this relatively small change in tariffs. Equally puzzling is the nonlinearity of trade growth with respect to tariff reductions. Tariff reductions in the mid 1980s and 1990s have been many times more "potent" than earlier reductions. Both of these puzzles are difficult to rationalize under the standard trade models with the standard propagation mechanisms.

To resolve these puzzles I turn to an increasingly prevalent phenomenon in international trade, vertical specialization. Vertical specialization occurs when countries specialize in particular stages of a good's production sequence rather than in the entire good. Vertical specialization can serve as a propagation mechanism magnifying tariff reductions into large increases in trade. With vertically specialized goods, a one-percentage-point reduction in tariffs leads to a multiple of one-percentage-point decline in costs and prices. Hence, trade grows by more than would be predicted by the standard trade model. Moreover, tariff reductions in general lead to more goods becoming vertically specialized. This latter effect generates additional, nonlinear trade growth.

To investigate this possibility more carefully, I calibrate a two-country dynamic Ricardian model of vertical specialization and simulate the response of trade to a steady-state reduction in tariffs. Under the two benchmark calibrations, I find that more than 50 percent of U.S. trade growth since 1962 can be explained. This is close to twice the explanatory power of the standard, one-stage, model. The model can generate the nonlinearity in trade growth as well, although it falls short of matching the extent of the nonlinearity. The model also succeeds in explaining virtually all the growth of vertically specialized exports. Finally, the consumption (welfare) gains from reducing tariffs from 14 percent to 3 percent are 3.2 percent and 4.7 percent in the two benchmark cases, which are considerably larger than the gains in the standard model.

This paper has focused on tariff reductions as a driving mechanism. Vertical specialization and the consequent nonlinear and magnified trade growth can arise from other forces. One force is reductions in transportation costs. The usual cost, insurance, and freight/free on board measures suggest a fairly steady decline of about five percentage points in ad valorem terms since the early 1960s. In a careful study, Hummels (1999) argues convincingly that transportation costs have changed little since the 1970s. According to Hummels, increases in the 1970s were partially offset by a decrease in the late 1980s, which was then followed by a gradual decline in the 1990s. Including such costs would be a good extension.[38]

---

[38] However, Baier and Bergstrand (2001) find that tariff reductions explain more than three times as much trade growth as transport cost reductions do. In Rose's (1991) trade

What other forces could explain the remaining 50 percent of the trade growth? 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. For example, because of the North American Free Trade Agreement, the nature of U.S. textiles and apparel trade has changed dramatically. In some cases, cotton is sent to Mexico, where it is spun into fibers; the fibers are exported back to the United States, where they are transformed into pieces of clothing; these pieces are exported back to Mexico, where they are sewn into clothing; and finally, the clothing is exported back to the United States. Allowing for the more realistic feature of more 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. A second possibility 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 Eugen von Böhm-Bawerk, goods production has become even more roundabout. Allowing for technology-induced increases in the number of stages increases the possibilities for vertical specialization and trade (see, e.g., Jones and Kierzkowski 1997; Deardorff 1998). A third possibility is that an increasing fraction of U.S. trade occurs with emerging markets. U.S. exports to these countries have increased from about one-third of total exports in 1970 to about two-fifths 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 vertical specialization growth. All these forces point to a larger role for vertical specialization than has been shown in this paper.

Appendix A

Sources of Tariff Data

The tariff data come from U.N. Conference on Trade and Development (1968), Cline et al. (1978), El-Agraa (1994), and Schott (1994). I have also checked that

---

growth regressions, tariffs have explanatory power, but transportation costs do not. 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 United States and the United Kingdom increased by 50 percent (see Maddison 1991). However, this period was also characterized by large reductions in tariffs—estimates are 20 percentage points—and by large reductions in transportation costs, driven by the expansion of steamships and railroads. The best evidence of declining shipping costs is declining price differentials between goods in ports of exit in the United States and in ports of entry in the United Kingdom. These price differentials fell enormously, on the order of 40 percentage points (see O'Rourke and Williamson 1994). Hence, trade growth between 1870 and 1913 does not need vertical specialization to explain it.

the data from these sources are broadly consistent with data from Balassa (1965*a*), Preeg (1970), Whalley (1985), and Deardorff and Stern (1990). All 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 pertain to industrial (essentially, nonagricultural) goods.

The overall tariff series used in the calibration/simulation is a simple average of the U.S. tariff and the rest of the world tariff. The ROW tariff is a weighted average of the E.C. external tariff and the Japanese tariff; the weights are each region's share of U.S. exports to the European Community and Japan.

Constructing the annual tariff series for the United States and the ROW involved splicing data from the sources listed above 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 1967–72, 1973, 1979–86, and 1994–99. For example, the pre–Kennedy Round tariff rate, the post–Kennedy Round tariff rate, and the phase-in schedule yield the tariff rates for 1967–72. For the other years, the data were linearly interpolated. The sources for the tariff series for each year are listed in table A1.

TABLE A1
SOURCES FOR THE TARIFF SERIES

Year	Source
1962–66	Pre–Kennedy Round: U.N. Conference on Trade and Development (1968, tables A.2, A.3, A.8)*
1967, 1972	U.N. Conference on Trade and Development (1968, tables A.2, A.3, A.8)
1968–71	Kennedy Round phase-in
1973:	
United States	Cline et al. (1978, table 2-1), using weights on semifinished manufactures and finished manufactures from U.N. Conference on Trade and Development (1968)
ROW	Interpolation
1974–78	Interpolation
1979, 1986	El-Agraa (1994, table 21.5), using weights on semifinished manufactures and finished manufactures from U.N. Conference on Trade and Development (1968)
1980–85	Tokyo Round phase-in
1987–93	Interpolation
1994, 1999	Schott (1994, table 7) and El-Agraa (1994, table 21.5)
1995–98	Uruguay Round phase-in
2000+	Same as 1999

* Balassa (1965, table 4) reports values about two percentage points less than these values.

Appendix B

Details on the Construction of Benchmark Revealed Comparative Advantage Indices and the Relative Productivity Curves

There are three main steps in constructing the RCA indices and the relative productivity curves. The first step is to categorize industries into stage 1 industries and stage 2 industries. The second step—constructing U.S. exports and imports for each stage 2 industry as well as exports and imports for the stage 2 industry's "stage 1 counterpart"—is the most involved. The stage 2 industry's stage 1 counterpart is best thought of as a composite of the stage 1 industries. Moreover, a portion of each stage 1 industry will be assigned to every stage 2 industry's stage 1 counterpart. This is the way I link the model, in which each stage 2 industry has a unique stage 1 input, to the data, in which each stage 2 industry derives its inputs from many stage 1 industries. (Note that stage 2 imports and the stage 1 counterpart's imports are the proxies for the ROW's stage 2 and stage 1 counterpart's exports to the United States. The imports are normalized to add up to total exports.) The RCAs are then calculated from the constructed stage 1 and 2 export and import data. The third main step is estimating the relative productivity curves from the calculated RCAs.

I focus on 1985, which was approximately halfway through the sample. There are three main data sources: the OECD input-output tables for 1985, the 1987 U.S. benchmark input-output tables, and the Feenstra (1996, 1997) trade data. There are two benchmark cases, narrow and broad; the differences between them are discussed below.

A. *Categorizing Stage 1 and Stage 2 Industries*

The first step involves categorizing each industry as a stage 1 industry or as a stage 2 industry. I use the OECD input-output tables to do this. I examine the use of each manufacturing industry's output. If the industry's output is used primarily as inputs into another industry's production (intermediate use), then it is classified as a stage 1 industry. If the industry's output is used primarily for consumption, investment, and so forth (final demand use), then it is classified as a stage 2 industry.

In particular, I examined U.S., German, and Japanese data from the OECD tables (all years). The ratio of intermediate use to final demand use was categorized into three groups: (1) intermediate use more than double final demand use, (2) final demand use more than double intermediate use, and (3) in between use. Industries whose outputs were primarily characterized by the first group were classified as stage 1 industries. Industries whose outputs were primarily characterized by the second group were classified as stage 2 industries. For example, for every country and year, the final demand use of office and computing machinery was more than double intermediate demand use. This industry was classified as a stage 2 industry. In both the narrow and broad benchmark cases, stage 2 industries included food, beverages, and tobacco; textiles, apparel, and leather; motor vehicles; shipbuilding; aircraft; office and computing machinery; radio and television; and nonelectric machinery. In the narrow benchmark case, the stage 1 industries are paper, industrial chemicals, drugs and medicines, petroleum and coal products, rubber and plastic products, nonmetallic mineral productions, iron and steel, nonferrous metals, and electrical apparatus.[39] In the broad benchmark case, the stage 1 industries include all manufacturing industries. This case accounts for the fact that even the industries designated as stage 2 industries produce goods that are used as inputs into other stage 2 industries' production.

In addition, a well-known regularity of input-output tables—even in highly disaggregated tables—is that the largest source of an industry's inputs is the industry itself. The motor vehicles industry's greatest source of inputs is itself; for example, motor vehicle engines and other parts are typically categorized under the motor vehicles industry. For this reason, in both benchmark cases, I include the own industry in the list of stage 1 industries making up the stage 2 industry's stage 1 counterpart. In other words, each stage 2 industry's stage 1 counterpart includes the industries listed above, as well as the stage 2 industry itself.

B. *Stage 1 Counterpart and Stage 2 Exports and Imports*

For each stage 2 industry, as noted above, I need to calculate its exports and imports, as well as its stage 1 counterpart's exports and imports. Figure 7 above illustrates a sample schematic of two stage 2 industries, their stage 1 counterparts, and two stage 1 industries.

1. Stage 1 Counterpart Imports

I use the OECD's input-output tables imported inputs matrices to calculate the stage 1 counterpart's imports. Each entry m_{ij} in these matrices gives the imported inputs used from industry i by industry j. Under the narrow benchmark case, for each stage 2 industry, I simply sum the imported inputs used from the stage 1 industries (including the stage 2 industry). For the broad benchmark case, I sum the imported inputs used from all manufacturing industries.

2. Stage 2 Imports

Stage 2 imports for each (stage 2) industry are obtained directly from the imports column in the total final demand section of the OECD input-output tables. This is the same for both benchmark cases.

3. Stage 1 Counterpart Exports

As mentioned above, the stage 1 counterpart should be thought of as a composite of the stage 1 industries (including the own stage 2 industry itself). A key assumption in computing these exports is the proportionality assumption. If x percent of a stage 1 industry's output goes to the motor vehicles industry, for example, then x percent of the stage 1 industry's exports are assigned to the motor vehicles industry's stage 1 counterpart.

I calculate these exports in two steps. The first step involves calculating exports originating from stage 1 industries other than the stage 2 industry. The second step involves calculating exports coming from the own (stage 2) industry.

[39] Several industries in manufacturing were not included as either stage 1 or stage 2, such as wood and other manufacturing, because they were small or it was not possible to assign them.

Stage 1 counterpart exports from the stage 1 industries.—For each stage 2 industry, I first calculate the fraction of each stage 1 industry's output going to that industry. Then I multiply this fraction by the stage 1 industry's exports. This value is "assigned" to the stage 2 industry's stage 1 counterpart. I sum over the stage 1 industries to get the total exports of the stage 1 counterpart to the stage 2 industry (excluding the own industry).

Stage 1 counterpart exports from the own (stage 2) industry.—As mentioned above, the purpose of including these exports is that the own industry is often the single largest source of inputs to an industry. To calculate these exports, then, I need a more disaggregated breakout than what is provided in the OECD input-output tables. The reason is that the OECD tables do not distinguish between, for example, exports of *final* motor vehicles and exports of motor vehicles *parts*. Consequently, I supplement the OECD tables with the Feenstra (1996, 1997) data sets on U.S. exports and imports, which is at the four-digit (standard industrial classification [SIC, 1972]) level, as well as with the 1987 U.S. input-output tables, which are considerably more disaggregated than the OECD input-output tables. The U.S. tables are a source of input-output flows at a six-digit level of disaggregation; they also serve as a concordance linking the OECD tables to the Feenstra data.

In four of the eight stage 2 industries (motor vehicles, aircraft, shipbuilding and repair, and textiles and apparel), the Feenstra data directly provide the stage 1 counterpart exports. For example, the data set provides data on exports (and imports) of motor vehicle parts, as well as of final motor vehicles. In one of these industries, aircraft, a significant amount of inputs originates from the radio, television, and communications equipment industry; these inputs are actually counted as part of the aircraft industry in the OECD tables. Consequently, it is desirable to count the relevant radio, television, and communications equipment exports as part of the own-industry exports for aircraft. Exports for these industries are calculated in a manner similar to that described in the preceding subsection.

For the other four stage 2 industries (food, beverages, and tobacco; radio, television, and communications equipment; nonelectrical machinery; and office computing and machinery), the 1987 U.S. input-output tables are employed. For each of these industries, the U.S. input-output tables contain flow relations for several subindustries. I divide these subindustries into stage 1 and stage 2 subindustries. The stage 1 subindustries are those industries in which 20 percent or more of the output goes to other subindustries within the stage 2 industry.

Once this division is made, the proportionality assumption is applied again to each stage 1 subindustry. If x percent of the subindustry's output goes to any stage 2 subindustry, then x percent of the subindustry's exports are assigned to the stage 1 counterpart exports from the stage 2 industry. I repeat this for all stage 1 subindustries.

I use the standard concordances linking the OECD's international standard industrial classification (rev. 2) system with the Feenstra data's SIC, 1972 system and the 1987 U.S. input-output table's SIC, 1987 system. More details on the categorization of the four-digit SIC subindustries within each stage 2 industry are available from the author on request.

4. Stage 2 Exports

A stage 2 industry's stage 2 exports are simply total industry exports less the exports assigned to the industry's stage 1 counterpart. For example, the motor

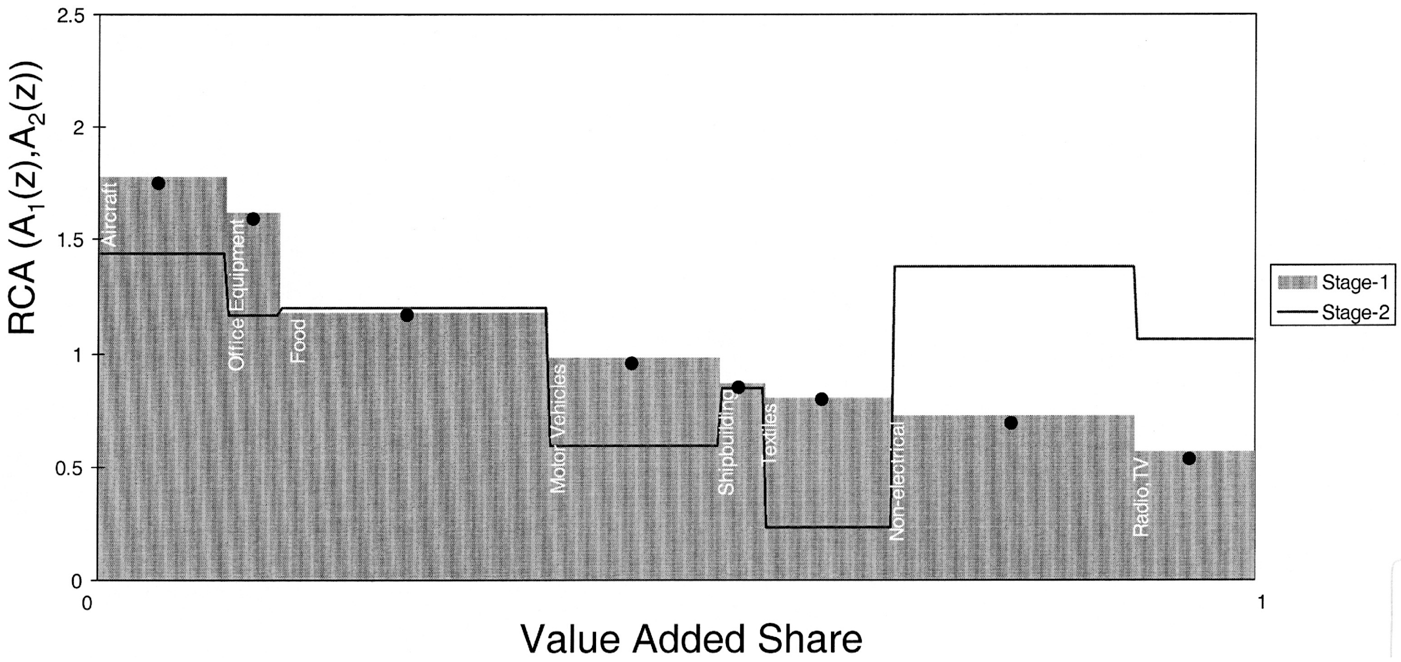

FIG. B1.—Narrow case $A_1(z)$, $A_2(z)$

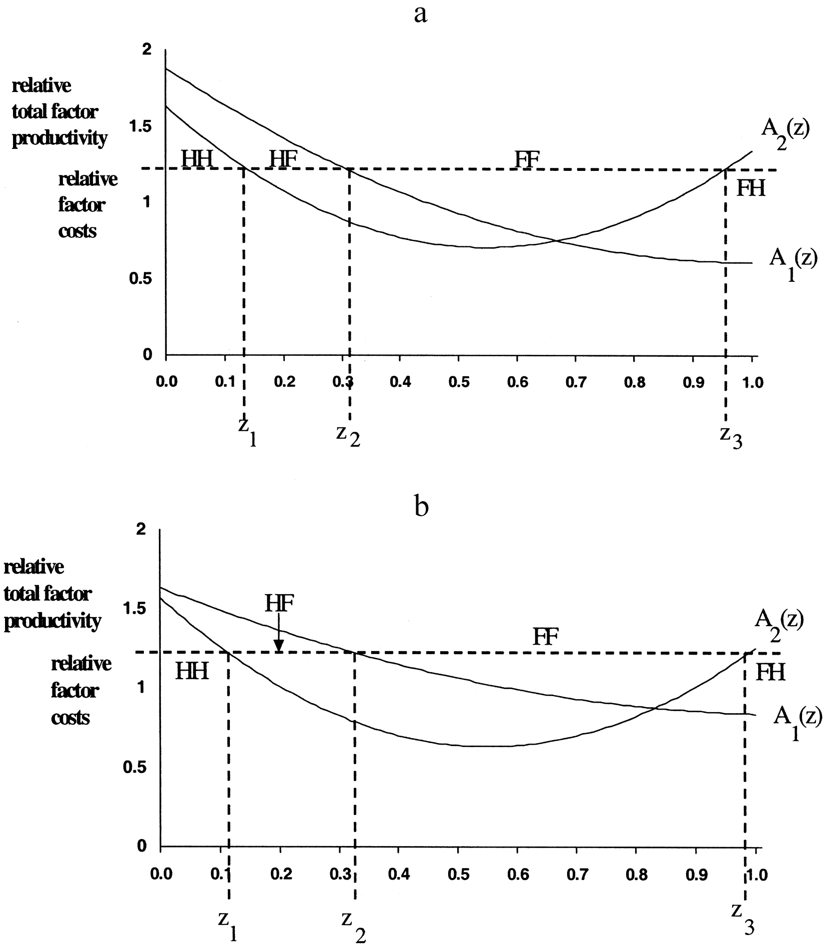

FIG. B2.—Narrow case and broad case estimated $A_1(z)$, $A_2(z)$ curves. *HF* denotes that Home produces the first stage and Foreign produces the second stage.

vehicle industry's stage 2 exports are total exports less motor vehicle parts exports.

Once the two sets of exports and imports are calculated, it is straightforward to plug these numbers into the Balassa RCA equation 47.

C. *Estimating the Relative Productivity Curves*

I first order the eight stage 2 industries according to declining RCA in their stage 1 counterparts. I line up these industries along the [0, 1] continuum in a bar diagram, where the width of each bar corresponds to the stage 2 industry's share of total value added, and the height of each bar is that industry's stage 1

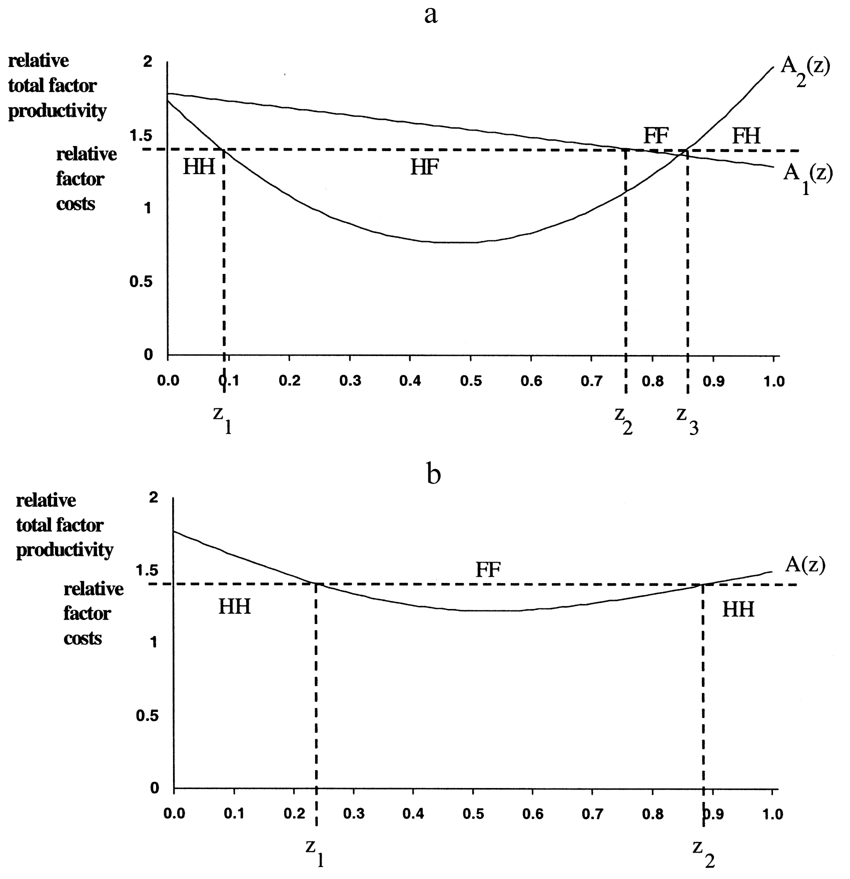

FIG. B3.—Textiles broad case estimated $A_1(z)$, $A_2(z)$, and $A(z)$ curves

counterpart's RCA value. I then take the midpoints of these bars. Each midpoint is interpreted as an (RCA, *z*) pair. With the eight pairs I estimate a quadratic regression of RCAs on the *z*'s. This regression yields an estimate of the relative productivity curve for the stage 1 counterparts to the stage 2 industries (see fig. B1).

Using the same ordering, I line up the stage 2 RCAs and repeat the same exercise, which yields an estimate of the relative productivity curve for stage 2 production (value added). Figures B2*a* and *b* illustrate the $A_1(z)$ and $A_2(z)$ curves for both benchmark cases.[40] The equations are as follows: benchmark case 1, A_1: $1.26x^2 - 2.53x + 1.88$; benchmark case 1, A_2: $3.095x^2 - 3.38x + 1.63$; benchmark case 2, A_1: $0.686x^2 - 1.478x + 1.63$; benchmark case 2, A_2: $3.088x^2 -$

---

[40] In the sensitivity analysis involving the textiles and electronics industries, the quadratic regression yielded estimates inconsistent with the underlying assumptions. The quadratic regression was then replaced by a simple linear regression. More details are available from the author on request.

$3.401x + 1.567$. (See fig. B3 for the estimated $A_1(z)$ and $A_2(z)$ curves for for the textiles broad case.)

References

Backus, David K.; Kehoe, Patrick J.; and Kydland, Finn E. "Dynamics of the Trade Balance and the Terms of Trade: The J-Curve?" *A.E.R.* 84 (March 1994): 84–103.

Baier, Scott L., and Bergstrand, Jeffrey H. "The Growth of World Trade: Tariffs, Transport Costs, and Income Similarity." *J. Internat. Econ.* 53 (February 2001): 1–27.

Bajona, Claustre. "Specific Factors, Learning, and the Dynamics of Trade." Manuscript. Miami: Univ. Miami, October 2000.

Balassa, Bela A. "Tariff Protection in Industrial Countries: An Evaluation." *J.P.E.* 73 (December 1965): 573–94. (*a*)

———. "Trade Liberalization and 'Revealed' Comparative Advantage." *Manchester School Econ. and Soc. Studies* 33 (May 1965): 99–123. (*b*)

———. *Trade Liberalization among Industrial Countries: Objectives and Alternatives.* New York: McGraw-Hill (for Council Foreign Relations), 1967.

———. "'Revealed' Comparative Advantage Revisited: An Analysis of Relative Export Shares of the Industrial Countries, 1953–71." *Manchester School Econ. and Soc. Studies* 45 (December 1977): 327–44.

Baxter, Marianne. "Fiscal Policy, Specialization, and Trade in the Two-Sector Model: The Return of Ricardo?" *J.P.E.* 100 (August 1992): 713–44.

Bergoeing, Raphael, and Kehoe, Timothy J. "Trade Theory and Trade Facts." Staff Report no. 284. Minneapolis: Fed. Reserve Bank, March 2001.

Bernard, Andrew B., and Jones, Charles I. "Productivity across Industries and Countries: Time Series Theory and Evidence." *Rev. Econ. and Statis.* 78 (February 1996): 135–46.

Cline, William R.; Kawanabe, Noboru; Kronsjö, T. O. M.; and Williams, Thomas. *Trade Negotiations in the Tokyo Round: A Quantitative Assessment.* Washington: Brookings Inst., 1978.

Crucini, Mario J., and Kahn, James. "Tariffs and Aggregate Economic Activity: Lessons from the Great Depression." *J. Monetary Econ.* 38 (December 1996): 427–67.

Davis, Donald R. "Intra-industry Trade: A Heckscher-Ohlin-Ricardo Approach." *J. Internat. Econ.* 39 (November 1995): 201–26.

Deardorff, Alan V. "Fragmentation in Simple Trade Models." Manuscript. Ann Arbor: Univ. Michigan, 1998.

Deardorff, Alan V., and Stern, Robert M. *Computational Analysis of Global Trading Arrangements.* Ann Arbor: Univ. Michigan Press, 1990.

Dornbusch, Rudiger; Fischer, Stanley; and Samuelson, Paul A. "Comparative Advantage, Trade, and Payments in a Ricardian Model with a Continuum of Goods." *A.E.R.* 67 (December 1977): 823–39.

Eaton, Jonathan, and Kortum, Samuel. "Technology, Geography, and Trade." *Econometrica* 70 (September 2002): 1741–79.

El-Agraa, Ali M. *The Economics of the European Community.* 4th ed. Trowbridge, U.K.: Harvester Wheatsheaf, 1994.

Evenett, Simon J., and Yeung, Bernard Y. "Willingness to Pay for Tariff Liberalization." Manuscript. New Brunswick, N.J.: Rutgers Univ.; Ann Arbor: Univ. Michigan, 1998.

———. “Decomposing the Growth of OECD Trade during 1970–96.” Manuscript. New Brunswick, N.J.: Rutgers Univ.; New York: New York Univ., 1999.

Feeney, JoAnne. “International Risk Sharing, Learning by Doing, and Growth.” *J. Development Econ.* 58 (April 1999): 297–318.

Feenstra, Robert C. “U.S. Imports, 1972–94: Data and Concordances.” NBER Trade Database, disk 1. Working Paper no. 5515. Cambridge, Mass.: NBER, March 1996.

———. “U.S. Exports, 1972–94: With State Exports and Other U.S. Data.” NBER Trade Database, disk 3. Working Paper no. 5990. Cambridge, Mass.: NBER, April 1997.

Findlay, Ronald. “An ‘Austrian’ Model of International Trade and Interest Rate Equalization.” *J.P.E.* 86 (December 1978): 989–1008.

Golub, Stephen S., and Hsieh, Chang-Tai. “Classical Ricardian Theory of Comparative Advantage Revisited.” *Rev. Internat. Econ.* 8 (May 2000): 221–34.

Harrigan, James. “Cross-Country Comparisons of Industry Total Factor Productivity: Theory and Evidence.” Research Paper no. 9734. New York: Fed. Reserve Bank, November 1997. (*a*)

———. “Technology, Factor Supplies, and International Specialization: Estimating the Neoclassical Model.” *A.E.R.* 87 (September 1997): 475–94.

———. “Estimation of Cross-Country Differences in Industry Production Functions.” *J. Internat. Econ.* 47 (April 1999): 267–93.

Hummels, David. “Have International Transportation Costs Declined?” Manuscript. Chicago: Univ. Chicago, 1999.

Hummels, David; Ishii, Jun; and Yi, Kei-Mu. “The Nature and Growth of Vertical Specialization in World Trade.” *J. Internat. Econ.* 54 (June 2001): 75–96.

Hummels, David; Rapoport, Dana; and Yi, Kei-Mu. “Vertical Specialization and the Changing Nature of World Trade.” *Fed. Reserve Bank New York Econ. Policy Rev.* 4 (June 1998): 79–99.

Irwin, Douglas A. “The GATT’s Contribution to Economic Recovery in Post-war Western Europe.” In *Europe’s Post-war Recovery,* edited by Barry Eichengreen. Cambridge: Cambridge Univ. Press, 1995.

Ishii, Jun, and Yi, Kei-Mu. “The Growth of World Trade.” Research Paper no. 9718. New York: Fed. Reserve Bank, May 1997.

Jones, Ronald W., and Kierzkowski, Henryk. “Globalization and the Consequences of International Fragmentation.” Manuscript. Rochester, N.Y.: Univ. Rochester; Geneva: Grad. Inst. Internat. Studies, 1997.

Jorgenson, Dale; Gollop, Frank; and Fraumeni, Barbara. *Productivity and U.S. Economic Growth.* Cambridge, Mass.: Harvard Univ. Press, 1987.

King, Robert G.; Plosser, Charles I.; and Rebelo, Sergio. “Production, Growth and Business Cycles: I. The Basic Neoclassical Model.” *J. Monetary Econ.* 21 (March–May 1988): 195–232.

Kouparitsas, Michael A. “North-South Business Cycles.” Manuscript. Chicago: Fed. Reserve Bank, 1997.

Krugman, Paul. “Scale Economies, Product Differentiation, and the Pattern of Trade.” *A.E.R.* 70 (December 1980): 950–59.

Maddison, Angus. *Dynamic Forces in Capitalist Development: A Long-Run Comparative View.* Oxford: Oxford Univ. Press, 1991.

Mankiw, N. Gregory; Romer, David; and Weil, David N. “A Contribution to the Empirics of Economic Growth.” *Q.J.E.* 107 (May 1992): 407–37.

O’Rourke, Kevin, and Williamson, Jeffrey G. “Late Nineteenth-Century Anglo-American Factor-Price Convergence: Were Heckscher and Ohlin Right?” *J. Econ. Hist.* 54 (December 1994): 892–916.

Preeg, Ernest H. *Traders and Diplomats: An Analysis of the Kennedy Round of Negotiations under the General Agreement on Tariffs and Trade.* Washington: Brookings Inst., 1970.

Proudman, James, and Redding, Stephen. "Evolving Patterns of International Trade." *Rev. Internat. Econ.* 8 (August 2000): 373–96.

Rose, Andrew K. "Why Has Trade Grown Faster than Income?" *Canadian J. Econ.* 24 (May 1991): 417–27.

Schott, Jeffrey J. *The Uruguay Round: An Assessment.* Washington: Inst. Internat. Econ., 1994.

U.N. Conference on Trade and Development. *The Kennedy Round Estimated Effects on Tariff Barriers.* Geneva: United Nations, 1968.

———. *Handbook of International Trade and Development Statistics.* Geneva: United Nations, various issues.

U.S. Council of Economic Advisers. *Economic Report of the President.* Washington: Council Econ. Advisers, 2001.

Whalley, John. *Trade Liberalization among Major World Trading Areas.* Cambridge, Mass.: MIT Press, 1985.

World Trade Organization. *International Trade Statistics.* Geneva: World Trade Org., 2000.

Xu, Yingfeng. "A General Model of Comparative Advantage with Two Factors and a Continuum of Goods." *Internat. Econ. Rev.* 34 (May 1993): 365–80.