Vertical Specialization and the Border Effect

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Abstract

A large body of empirical research finds that a pair of regions within a country tends to trade 10 to 20 times as much as an otherwise identical pair of regions across countries. This result has been called the "border" effect puzzle. In the context of the standard trade models the border effect is problematic, because it is consistent only with high elasticities of substitution between goods and/or high unobserved national border barriers. I propose a resolution to this problem centered around the idea of vertical specialization, which occurs when regions specialize only in particular stages of a good's production sequence. I show that vertical specialization magnifies the effects of border barriers such as tariffs, and, hence, can potentially explain the border effect without relying on high elasticities of substitution and/or high unobserved trade barriers.

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1 Introduction

A large body of empirical research finds that a pair of regions within a country tends to trade 10 to 20 times as much as an otherwise identical pair of regions across countries, relative to what they would trade in the absence of border barriers. This result is known as the "border" effect puzzle.[1] In the context of the standard models of international trade, this large border effect can only be reconciled with parameters implying high elasticities of substitution between goods and/or high unobserved trade barriers between countries.[2] Consider, for example, the United States and Canada, the pair of nations with the world's largest international trade, and whose border effect has received the most attention. The most theoretically consistent estimate of the border effect for Canada is by Anderson and van Wincoop (2003). Their estimate, 10.5, implies that with an elasticity of 5, the tariff equivalent of the U.S.-Canada border barrier is 48 percent. With an elasticity of 10, the tariff equivalent is 19 percent. Existing measures of tariff rates and transport costs between the United States and Canada suggest that, taken together, they are about 5 percent.[3] Even with an elasticity of 10, then, unobservable trade barriers would need to be about 14 percentage points, or three times larger than observable barriers, in order to explain the border effect.[4]

In this paper, I propose a resolution to the puzzle based on vertical specialization. Vertical specialization involves the increasing interconnectedness of production processes in a sequential, vertical trading chain stretching across many countries and regions, with each country or region

[1] McCallum (1995) was the first to find this effect. Other research includes that by Wei (1996), Helliwell (1998), Evans (2003), and Anderson and van Wincoop (2003). Obstfeld and Rogoff (2001) declare that the "home bias in consumption" problem, i.e., the border effect problem, is one of the six major puzzles of open economy macroeconomics.

[2] The standard models include the monopolistic competition model, the Ricardian model, the Heckscher-Ohlin model, as well as the models built around the Armington aggregator.

The coefficient estimate that underlies the calculation of the border effect is the product of 1-the elasticity of substitution multiplied by the natural log of the gross ad valorem tariff equivalent of the border barrier.

[3] Baier and Bergstrand (2001) report that the overall gross c.i.f./f.o.b. factor - a measure of transportation costs on imported goods - for Canada was 2.5 percent between 1986 and 1988. This is a reasonable proxy for its gross c.i.f./f.o.b. factor with the United States given that 2/3 of its imports at that time were from the U.S. In addition, data from the U.S. International Trade Commission indicate that U.S. tariff collections on imports from Canada were equivalent to 2 percent of imports (from Canada) in 1996.

[4] Some authors, especially Helliwell (1998), contend that institutional forces reflecting national differences in tastes and values can significantly raise transactions costs for interactions between countries. Anderson and van Wincoop (2004) present estimates of the border barriers due to differences in language, currency, information, and security, but it is likely that these barriers are lower for U.S.-Canada interactions.

specializing in particular stages of a good's production sequence. Previous research has documented the empirical importance of international vertical specialization, and has shown that it helps explain the growth of world trade without having to rely on counterfactually high elasticities of substitution. There is evidence as well as good reason to expect that vertical specialization matters even more at the intra-national level. This paper applies this concept to regions within countries and across countries in order to explain the border effect.

The main idea can be conveyed by the following example. Consider a two-country world, the U.S. and Canada, in which production of goods requires multiple, sequential stages. Suppose that in the absence of border barriers, the U.S. specializes in the odd-numbered stages and Canada specializes in the even-numbered stages. In this world, there is a great deal of "back and forth" or vertically specialized trade. Now, suppose a border barrier between the U.S. and Canada is introduced. Every time the good-in-process crosses the border, the barrier is imposed. The effect of the barrier, then, is to raise the cost of the final good by a multiple of the barrier. This magnified cost increase leads to a larger reduction in international trade than would occur in a world where production of goods occurs in just one stage. The reduction in trade can occur at the internal margin via fewer purchases of existing vertically specialized goods. Or the reduction can occur at the external margin, as emphasized in this paper, via a reduction in the number of vertically specialized goods, which reduces trade sharply by reducing each "back" and each "forth" in the trading sequence. From these two forces then, international trade falls by more than what would be implied by the standard model. In addition, a key insight from Anderson and van Wincoop (AvW) is that when international trade is relatively low, all else equal, intra-national trade is relatively high. Consequently, the magnification effect of vertical specialization on international trade works in the opposite direction for intra-national trade, which increases by more than what would be implied by the standard model. These are the primary forces that generate a large border effect from a relatively small border barrier.

To illustrate my point more generally, I develop a Ricardian model of trade with vertical specialization. The model extends the Dornbusch, Fischer, Samuelson (1977) continuum of goods model in two ways. To allow for vertical specialization in the model, each good is produced in two stages. To allow for intra-national trade, each country has two regions.

I then quantitatively assess the ability of vertical specialization to magnify the effect of border barriers. I calibrate and solve the model to find the border barrier that generates the U.S.-Canada border effect found in AvW. When the relevant elasticity is 5, a border barrier of 26.3 percent is needed to generate the AvW border effect. By contrast, the standard one-stage model requires a border barrier almost twice as large, 49.5 percent, to generate the AvW border effect. When the elasticity is 10, similar results obtain.

Thus, while preliminary, these results are promising, and indicate that vertical specialization is a potentially fruitful direction to pursue to better understand intra-national and international trade flows. There are several related papers on explaining the border effect. Evans (2003b) and Chaney (2005) focus on fixed costs of exporting.[5] Chaney's framework also includes for firm heterogeneity; both forces help deliver a higher trade elasticity with respect to trade barriers than would be implied by the elasticity of substitution alone. Hillberry (2002) examines aggregation bias and compositional change. Two other papers with explanations that involve forces similar to vertical specialization are Hillberry and Hummels (2002) and Rossi-Hansberg (2004). Both frameworks have intermediate and final goods, as well as "back and forth" trade between regions and countries. These latter papers also rely on economic geography / agglomeration forces. The former paper is a generalization of the Krugman and Venables (1995) framework. In particular, production occurs in a rich input-output structure, and firms are mobile across locations. In Rossi-Hansberg (2004) labor is mobile across locations; in addition, a higher density of workers generates a positive externality in production. All of these explanations are at least partially successful in reconciling large border effects with relatively small border barriers.

Section 2 provides empirical motivation for applying vertical specialization to this problem. It shows that, for the U.S., vertical specialization at the state level is more widespread than at the country-level. Section 3 presents the model and intuition on how vertical specialization works; this is followed by the calibration and solution method. Section 5 presents the results, and section 6 concludes.

2 Vertical Specialization at the State Level

In this section, I provide evidence suggesting that vertical specialization plays an important role in understanding the border effect. First, I define vertical specialization. In previous research, D. Hummels, J. Ishii, D. Rapoport, and I have documented the increasing importance of international vertical specialization in OECD and other countries.[6] In order to accommodate regions as the basic geographic unit, I modify the definition from Hummels, Ishii, and Yi (2001):

[5] Hummels and Klenow (2004) provide evidence consistent with a fixed cost of exporting framework.

[6] See Hummels, Rapoport, and Yi (1998), Hummels, Ishii, and Yi (2001), and Yi (2003).

1. Goods are produced in multiple, sequential stages.

2. Two or more *regions* provide value-added in the good's production sequence.

3. At least one *region* must use imported inputs in its stage of the production process, and some of the resulting output must be exported.

In this context, imports and exports refer to shipments from one region to another; in particular, these flows can occur within a country. Figure 1 illustrates an example of vertical specialization involving three regions. Region 1 produces intermediate goods and exports them to region 2. Region 2 combines the imported intermediates with other inputs and value-added to produce a final good (or another intermediate in the production chain). Finally, region 2 exports some of its output to region 3. If either the imported intermediates or exports are absent, then there is no vertical specialization.

Hummels, Ishii and Yi (HIY) develop two vertical specialization measures. Again, I modify their primary measure, VS, which measures the imported input content of export goods, to accommodate regions. Specifically:

$$VS_{ki} = \left(\frac{imported\ intermediates_{ki}}{Gross\ output_{ki}}\right) Exports_{ki} \tag{1}$$

where k and i denote *region* and good, respectively.

Ideally, VS_{ki} would be calculated at the level of individual goods, and then aggregated up. These data do not exist, at either the country or regional level. HIY relied on national input-output tables, which provide industry-level data on imported intermediates, gross output, and exports.[7] These tables are not widely available at the sub-national level. However, several U.S. states, including Hawaii and Washington, have constructed (survey-based) input-output tables.

Table 1 lists vertical specialization in merchandise exports, expressed as a fraction of total merchandise exports, in these two states for selected years. (The Washington tables have not been constructed since 1987.) For comparison, the table also lists vertical specialization for the entire U.S. and for Canada. The table shows that vertical specialization at the state-level is considerably larger than at the national level. Also, in both states vertical specialization has been growing over time.

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

The tables for Washington have an added feature in that they distinguish between domestic exports, that is exports to other states within the U.S., and international exports. They distinguish between domestic and international imported inputs, as well. Consequently, I am able to compute four types of vertical specialization, according to whether imported inputs are from domestic or international sources and whether the exports are to domestic or international destinations: Inputs are imported from domestic sources and (some of) the output is exported to domestic destinations (DD); inputs are imported from foreign sources and the output is exported to domestic destinations (FD); inputs are imported from domestic destinations and the output is exported to foreign destinations (DF); and inputs are imported from foreign sources and the output is exported to foreign destinations (FF). Figure 2 presents the data on the four types of vertical specialization, expressed as a share of total vertically specialized merchandise exports, for 1963 and 1987. The figure shows that the DD type of vertical specialization is the most common, but also that over time the DD vertical specialization declined significantly, while both types of vertical specialization involving foreign imported inputs (FD and FF) increased considerably.

The data presented above is consistent with the idea that vertical specialization is important in understanding the border effect. Trade flows between regions within a country are not subject to national border barriers; consequently, there are relatively more opportunities for vertical specialization. Trade flows between countries are subject to national border barriers; consequently, opportunities for vertical specialization between countries are more limited, but opportunities for vertical specialization within countries may be greater. Hence, the existence of national border barriers should imply that regions have higher levels of vertical specialization than countries, all else equal.

3 The Model

In this section, I lay out the model and describe the intuition for how vertical specialization can magnify the effects of border barriers. The model is a Ricardian model of trade in which trade and specialization patterns are determined by relative technology differences across countries. It draws from Eaton and Kortum (2002) and Yi (2003), both of which are generalizations and extensions of the celebrated Dornbusch, Fischer, Samuelson (1977, hereafter, DFS) continuum of goods Ricardian model.

The basic geographic unit is a region. Countries consist of more than one region. In most of the discussion below the number of countries is two, and there are two regions per country; however, the number of regions and countries can be generalized. Countries have "border" barriers, but regions do not. Each region possesses technologies for producing goods along a $[0,1]$ continuum. Each good is produced in two stages. Both stages are tradable. Consequently, there are $4x4 = 16$ possible production patterns for each good on the continuum. The model determines which production pattern or patterns occur in equilibrium.

3.1 Technologies and Firms

Stage-1 goods are produced from labor:

$$y_1^i(z) = A_1^i(z) l_1^i(z) \qquad z \in [0,1] \tag{2}$$

where $A_1^i(z)$ is region i's total factor productivity associated with stage-1 good z, and $l_1^i(z)$ is region i's labor used in producing $y_1^i(z)$. $y_1(z)$ is used as an input into the production of the stage-2 good z. The stage-1 input and labor are combined in a nested Cobb-Douglas production function:

$$y_2^i(z) = x_1^i(z)^{\theta} \left(A_2^i(z) l_2^i(z) \right)^{1-\theta} \qquad z \in [0,1] \tag{3}$$

where $x_1^i(z)$ is region i's use of the stage-1 good $y_1(z)$, $A_2^i(z)$ is region i's total factor productivity associated with stage-2 good z, and $l_2^i(z)$ is region i's labor used in producing $y_2^i(z)$.

When either stage-1 or stage-2 goods cross regional or national borders, they incur iceberg transport costs. Specifically, if 1 unit of either stage is shipped from region i to region j, then $1/(1+\tau_{ij}) < 1$ units arrive in region j. The gross ad valorem tariff equivalent of this transport cost is $1 + \tau_{ij}$. Within region transport costs are assumed to equal 0. There is an additional iceberg cost, the national border barrier $(1 + b_{ij})$. This barrier is a stand-in for tariff rates, border-specific transport costs, as well as other barriers associated with regulations, time, and national culture that are relevant for international trade.[8] Consequently, I assume the border barrier exceeds one only when regions i and j are located in different countries.

In terms of the number of countries and goods, the most general Ricardian framework is that developed by Eaton and Kortum (2002, EK). A key part of the framework is the use of the Frechét distribution as the probability distribution of total factor productivities:

$$F(A) = e^{-TA^{-n}} \tag{4}$$

[8] To the extent the barrier includes tariffs, I assume that tariff revenue is "thrown in the ocean".

The mean of A is increasing in T. n is a smoothness parameter that governs the heterogeneity of the draws from the productivity distribution. The larger is n, the lower the heterogeneity or variance of A. EK show that n plays the same role in their model as $\sigma - 1$, where σ is the elasticity of substitution between goods, in the monopolistic competition or Armington aggregator-based trade models. The Frechét distribution facilitates a straightforward solution of the EK model in a many-country world with non-zero border barriers. Unfortunately, such a straightforward solution does not carry over in my multi-stage framework.[9] Nevertheless, I employ this distribution to facilitate comparisons of my model with the EK model, which I view as the benchmark model.[10]

Firms maximize profits taking prices as given. Specifically, in each period, they hire labor, and/or purchase inputs in order to produce their output, which they sell at market prices.

Stage-1 firms maximize:

$$p_1(z)y_1^i(z) - w^i l_1^i(z) \tag{5}$$

where $p_1(z)$ is the world price of $y_1(z)$, and w is the wage rate.

Stage-2 firms maximize:

$$p_2(z)y_2^i(z) - p_1(z)x_1^i(z) - w^i l_2^i(z) \tag{6}$$

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

$$p_2(z)y_2^i(z) - (1+\tau_{ij})(1+b_{ij})p(z)x_1^i(z) - w^i l_2^i(z) \tag{7}$$

if the stage-1 input is produced in region j. $p_2(z)$ is the world price of $y_2(z)$.

3.2 Households

The representative household in region i maximizes:

$$\int_0^1 \ln(c^i(z))dz \tag{8}$$

[9] The reason is because my framework requires two draws from the Frechét distribution. Neither the sum nor the product of Frechét distributions has a Frechét distribution. I thank Sam Kortum for pointing this out to me.

[10] The EK model has an input-output production structure, which implies vertical specialization, and leads generally to more trade flows than in a model without this structure. However, this structure is invariant to changes in trade barriers, which plays a role in the result that the elasticity of trade flows with respect to trade barriers is essentially the same as in the standard trade model. This invariance in production structure to changes in trade barriers is also true for the nested CES frameworks that are commonly used in the computable general equilibrium literature.

subject to the budget constraint:

$$\int_0^1 p_2(z)d^i(z)c^i(z)dz = w^i L^i \tag{9}$$

where $c^i(z)$ is consumption of good z, and $d^i(z)$ is the product of the transport cost and border barrier incurred by shipping the good from its source to region i. In general, in the presence of transport costs and border barriers, there will be more than one source for each stage of each good, depending on the destination region.

3.3 Equilibrium

All factor and goods markets are characterized by perfect competition. The following market clearing conditions hold for each region[11]:

$$L^i = \int_0^1 l_1^i(z)dz + \int_0^1 l_2^i(z)dz \tag{10}$$

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

$$y_1(z) \equiv \sum_{i=1}^{4} y_1^i(z) = \sum_{i=1}^{4} d_1^i(z)x_1^i(z) \tag{11}$$

where $d_1^i(z)$ is the total barrier incurred by shipping the stage 1 good from its source to region i. A similar set of conditions apply to each stage-2 good z:

$$y_2(z) \equiv \sum_{i=1}^{4} y_2^i(z) = \sum_{i=1}^{4} d^i(z)c^i(z) \tag{12}$$

If these conditions hold, then exports equal imports, i.e., trade is balanced for all regions. I now define the equilibrium of this model:

Definition 1 *An equilibrium is a sequence of goods and factor prices, $\{p_1(z), p_2(z), w^i\}$, and quantities $\{l_1^i(z), l_2^i(z), y_1^i(z), y_2^i(z), x_1^i(z), c^i(z)\}$, $z \in [0,1]$, $i = 1, ...4$, such that the first order conditions to the firms' and households' maximization problems 5,6,7, and 8, as well as the market clearing conditions 10,11, and 12, are satisfied.*

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

3.4 Border Barriers, Vertical Specialization, and Border Effects

As defined in section 2, vertical specialization occurs whenever a good crosses more than one regional or national border while it is in process. In the context of the model, a necessary condition for vertically specialized production of a good to occur is for one region to be relatively more productive in the first stage of production and another region to be relatively more productive in the second stage. Under free trade, i.e., in the absence of border barriers and transport costs, if relative wages are "between" these relative productivities, then this necessary condition is also sufficient.

To demonstrate how vertical specialization can magnify border barriers into relatively large border effects, I first develop an analytical relation between border barriers and border effects in the standard model with one stage of production, which is just the DFS model extended to include two regions per country. To facilitate the discussion, I consider a symmetric case in which all regions in both countries have the same labor endowment. In addition, all regions' (total factor) productivities for all goods are drawn from the same distribution. This implies that wages and GDPs are equalized across regions and countries; moreover, wages and GDP are invariant to border barriers.

A country's productivity for a good is defined as the maximum productivity (of that good) across the two regions: $A^h(z) = \max[A^{h1}(z), A^{h2}(z)]$, where h denotes the home country. Without loss of generality, the goods can then be arranged in descending order of the ratio of home productivity to foreign productivity, so that $A^r(z) = \frac{A^h(z)}{A^f(z)}$ is declining in z. International imports by the home country (which equals exports) is given by:

$$(1 - \underline{z}^h) w^h L^h \tag{13}$$

where $\underline{z}^h$ is the cutoff z that separates home and foreign production for the home market, and $w^h L^h$ is home country GDP. See Figure 3. In the foreign country, international imports is given by $\underline{z}^f w^f L^f$. In the absence of border barriers, i.e., under free trade, $\underline{z}^h = \underline{z}^f = 0.5$; international exports or imports equals 50% of GDP. Intra-national imports in the home country is given by:

$$\frac{\underline{z}^h w^h L^h}{2} \tag{14}$$

This follows from the symmetry assumption about each of the two regions. Under free trade, intra-national trade is equal to 25% of GDP.

Following AvW, I define the border effect as follows:

$$BorderEffect = \frac{\frac{Intra_b}{Intra_0}}{\frac{Inter_b}{Inter_0}} \tag{15}$$

where $Intra$ refers to intranational trade, $Inter$ refers to international trade, the subscript b refers to border barriers, and the subscript 0 refers to free trade. It is a double ratio - the ratio of intra-national trade under border barriers to intra-national trade under free trade divided by the corresponding ratio for international trade. The border effect can also be thought of as the ratio of intra-national trade to international trade under border barriers relative to what that ratio would be under free trade. For the home country the double ratio equals:

$$\frac{\frac{Intra_b}{Intra_0}}{\frac{Inter_b}{Inter_0}} = \frac{\frac{\underline{z}_b}{\underline{z}_0}}{\frac{(1-\underline{z}_b)}{(1-\underline{z}_0)}} \tag{16}$$

where the superscript h has been suppressed for convenience. In the standard one-stage model, then, the denominator of the border effect is $(1-\underline{z}_b)/(1-\underline{z}_0)$ and the numerator is given by $\underline{z}_b/\underline{z}_0$. To solve for the z's, the distribution of relative total factor productivities must be specified. If we assume the productivities follow a Frechét distribution, then the relative productivities will have the following functional form:

$$A^r(z) \equiv \frac{A^h(z)}{A^f(z)} = \left(\frac{1-z}{z}\right)^{\frac{1}{n}} \tag{17}$$

where $A^r(z)$ can also be interpreted as the fraction of goods z where the home productivity relative to the foreign productivity is at least A.[12] As discussed above, n is analogous to an elasticity in that a larger n implies a flatter or more "elastic" $A^r(z)$. Then, the solution for $\underline{z}$ is given by:

$$\underline{z} = \frac{(1+b)^n}{1+(1+b)^n} \tag{18}$$

Thus, the denominator of the border effect (international trade under border barriers divided by international trade under free trade) is:

$$\frac{\frac{1}{1+(1+b)^n}}{\frac{1}{2}} = \frac{2}{1+(1+b)^n} \tag{19}$$

This is clearly decreasing in the border barrier; in other words, through international trade alone the greater the border barrier, the greater the border effect. Note that the higher the elasticity n,

[12] See footnote 15 in EK (2002).

the greater the effect of the border barrier on international trade. Consider an example in which $b = .1$, and $n = 10$. Then, $\underline{z_b} = .722$ (see Figure 4) and the denominator of the border effect $= .56$.

The numerator of the border effect (intra-national trade under border barriers divided by intra-national trade under free trade) is:

$$\frac{\dfrac{(1+b)^n}{1+(1+b)^n}}{\dfrac{1}{2}} = \frac{2(1+b)^n}{1+(1+b)^n} \tag{20}$$

This is increasing in the border barrier. That is, as the barrier between countries increases, intra-national trade increases. The reason for this is essentially the idea that specialization implies that goods must be traded somewhere. If they are not traded internationally, they will typically be traded intra-nationally. This is a key insight from AvW. More specifically, consider a home country consumer in one of the regions. Under border barriers, the fraction of goods purchased from home producers increases. Because the two regions within the home country are symmetric, this implies that the fraction of goods purchased from the other home region's producers, that is, intra-national trade, increases. In the above example, the fraction of goods purchased from home rises from 0.5 under free trade to 0.722 under barriers, an increase of 44%. (Figure 5). Based on the logic just presented, this increase equals the increase in intra-national trade following the imposition of barriers. The numerator of the border effect = 1.44.

Combining the numerator and denominator yields the overall border effect, which is given by:

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

This expression is quite intuitive. In a simple, symmetric case with two countries, two regions per country, the log of the border effect is approximately the elasticity multiplied by the border barrier. In our special example, the border effect = 2.59.

With the vertical specialization model, deriving analytical expressions for the border effect is considerably more difficult. To provide insight into the model, I work with two special cases. The first case brings in two stages of production and vertical specialization in an awkward way, but it has the virtue of yielding an analytical expression for the border effect. The second case is a natural extension of the one-stage-of-production symmetric case from above. This case is solved numerically.

3.4.1 Vertical Specialization Case 1

In this case I assume that the first stage of production is produced in the country that ultimately consumes the second stage good; the second stage production location is determined by the model. Thus, if an automobile is going to be purchased by a U.S. resident, the parts and components are assumed to be produced in the United States, while final assembly can occur either in the United States or Canada. This assumption is clearly awkward, but it facilitates an analytical solution for the border effect, because much of the analysis from above can be applied here.

For goods consumed by the home country, the two possible production methods at the country level are denoted by HH and HF, where HF means that the first stage of production occurs in the Home country and the second stage of production occurs in the Foreign country. Note that production method HF involves international vertical specialization: the foreign country imports inputs and exports its resulting output. Similarly, for goods consumed by the foreign country, the two possible production methods are denoted by FF and FH, where international vertical specialization occurs with FH. I continue to assume that there are four identically sized regions; moreover, each region's productivities for both stages of production are drawn from the same distribution.[13]

If the goods are arranged in descending order of the ratio of home to foreign productivity of stage 2 production, then the analysis in the previous sub-section applies. In particular, $\underline{z}^h$ denotes the cutoff that separates home and foreign production of stage 2 goods for the home market. Moreover, international imports for the home country is still given by $(1-\underline{z}^h)wL$, and intra-national imports is still given by $\underline{z}^h wL/2$. In the appendix, I show that the solution for $\underline{z}^h$ is given by:

$$\underline{z}^h = \frac{(1+b)^{n\left(\frac{1+\theta}{1-\theta}\right)}}{1+(1+b)^{n\left(\frac{1+\theta}{1-\theta}\right)}} \tag{22}$$

Then, the numerator and denominator of the border effect are given by:

$$\frac{2(1+b)^{n\left(\frac{1+\theta}{1-\theta}\right)}}{1+(1+b)^{n\left(\frac{1+\theta}{1-\theta}\right)}} \text{and} \ \frac{2}{1+(1+b)^{n\left(\frac{1+\theta}{1-\theta}\right)}} \tag{23}$$

Hence, the overall border effect is:

$$(1+b)^{n\left(\frac{1+\theta}{1-\theta}\right)} \tag{24}$$

[13] This latter assumption means that under free trade, the production method HH has four *ex ante* equally likely production methods distinguished by region: stage 1 can be produced in either of the two home country's regions and likewise for stage 2 production. Two of these production methods involve intra-national vertical specialization.

This expression differs from (21) by the presence of the $\left(\frac{1+\theta}{1-\theta}\right)$ term in the exponent. Including for vertical specialization can magnify the effects of border barriers. There are two forces behind the exponent on the $(1+b)$ term. Both of these forces draw from the fact that the tradeoff between HH and HF hinges on the second stage of production. This stage is the "marginal" production process. More generally, the marginal production process in a standard model is the entire good's production, but in a model with multiple stages of production, it can be just one stage of production. The relevant border cost is not the cost relative to the total cost of producing the good, but the cost relative to the stage 2 cost. Suppose the second stage is made in the foreign country. Then, the first stage encounters a border barrier when it is shipped to the foreign country. That barrier is equivalent to a barrier on the second stage of production of $(1+b)^{\frac{\theta}{1-\theta}}$. This is the first force. The second force arises when the final good is shipped back to the home country from the foreign country. Recall that the border barrier applies to all stages of the good. Consequently, from the perspective of the home country, a barrier of $1+b$ imposed on both stages of an HF good is effectively a barrier of $(1+b)^{\frac{1}{1-\theta}}$ on the second stage of production.[14] The total effect is the product of these two forces. They clearly magnify the impact of the barrier b on international trade, and the effect is increasing in the share of goods crossing the border multiple times, i.e., θ. In going from free trade to a border barrier, then, the cost of vertically specialized goods rises by a multiple of the barrier. This reduces international trade by more than would be the case if goods were not vertically specialized.

Using the same example as before with $b = .1$ and $n = 10$, and setting $\theta = 0.5$, Figure 6 shows that international trade falls to only about 1/10 of its value under free trade. Intra-national trade rises by a little less than a factor of 2. The overall border effect is 17.45, which is almost seven times larger than in the standard model. A given border barrier generates a much larger border effect in a model with vertical specialization.

3.4.2 Vertical Specialization Case 2

In the previous case the assumption that restricted the first stage of production to occur in the country where the final good was consumed implied that the only alternative production method to making a good completely in the home country was an internationally vertically specialized method. This is one reason why the magnification of border barriers under vertical specialization was so high. This case drops that assumption and deals with a more natural and general case.

[14] The second force is closely related to the forces highlighed by the effective rate of protection literature.

The full range of production methods are now posssible, including those that involve international trade without international vertical specialization. Consequently, the magnification effects on the border barrier resulting from vertical specialization will be smaller.

I continue to assume that each region's productivities for *both stages* of all goods are drawn from the same distribution. I first examine international trade under free trade and under border barriers. Under free trade, each of the four country-level production methods, HH, HF, FH,and FF will account for 25% of global production, as the top segment of Figure 7 shows. HF and FH involve international vertical specialization. As before, it is useful to think about international trade from the import side. In the absence of border barriers, the foreign country will spend 50% of its income on goods produced by HH and by FH. In other words, international exports from these two production methods alone will be equivalent to 50% of the home country's GDP. In addition, stage one of all goods produced by HF will be exported by the home country. Suppose θ, the share of stage-1 inputs in stage-2 production, = 2/3. Then HF exports are equivalent to 1/3 of home country's GDP.[15] The home country's export share of GDP under free trade, then, equals 0.83.

Now suppose barriers are imposed. Consider our example in which the border barrier = 10%, and $n = 10$. I solve the model numerically, as discussed in the next section. The share of foreign country expenditure on HH falls from 25% to 11.4%; the expenditure share on FH falls much more, from 25% to just 0.23%. (See the middle segment of Figure 7). While the imposition of barriers raises the cost of HH, it raises the cost of FH by more, because barriers are imposed on the first-stage, F, twice: first, when it enters the home country, and second, when it returns to the foreign country. For exactly the same reason, home expenditures on goods produced by HF also suffer a sharp decline, as the bottom segment of Figure 7 shows. The decline in HF implies that foreign imports of stage-1 goods produced at home falls sharply, further reducing trade. Overall, because vertical specialization magnifies the effect of border barriers, the production methods FH and HF both decline sharply, with consequent sharp reductions in trade.[16] In particular, the home country's export share of GDP falls to 0.25, less than 1/3 of the export share under free trade. In this example, the denominator of the border effect, the ratio of international trade under border barriers to international trade under free trade, equals 0.30.

[15] 25% of world spending is on HF; world spending is twice home country's GDP; and the value of stage 1 production equals two-thirds of the final value.

[16] In my framework, all of the adjustment to border barriers is on the external margin via a change in the number of goods and/or stages that are traded across regions and countries. The next sub-section shows that the external margin has two forces.

Turning to intra-national trade, the starting point is the discussion above that increased purchases of home produced goods by home consumers implies increased intra-national trade. Two production methods generate intra-national trade in the home country, HH and FH. Production method HH generates intra-national trade through two channels. First, goods produced entirely in region 1 or in region 2 are exported to the other region. Second, goods produced in a regionally vertically specialized manner involve stage-1 production exported from region 1 to region 2, for example, and then some of the stage-2 goods are exported back from region 2 to region 1. Production method FH generates intra-national trade because after the second stage is produced in one of the home regions, part of the output is exported to the other home region. The top segment of Figure 8 highlights these two production methods. Returning to our example, under free trade, intra-national trade is 41.6% of GDP.

From the perspective of the home consumer, the imposition of barriers raises the cost of all production methods other than HH; it raises the cost of (internationally vertically specialized) production method HF, in particular. Consequently, in this case, home spending on HH rises from 25% of GDP under free trade to 68% of GDP under barriers, a much larger increase than what occurs in the standard model. See the bottom segment of Figure 8. This increases the opportunities from intra-national trade, and by more than in the standard model. Moreover, because more production is sourced at home, the opportunities for intra-national vertical specialization (across the two regions), have increased, as well, providing a further impetus to intra-national trade. Overall, intra-national trade more than doubles due to the increased home spending on HH.

There are two partially offsetting effects. First, the imposition of barriers leads the foreign country to reduce its purchases of goods produced by HH; this will reduce some of the regional vertical specialization. However, the magnitude of the decline in foreign purchases is considerably smaller than the magnitude of the increase in home purchases. Second, home purchases of goods produced by FH declines slightly from 25% of GDP to about 20% of GDP. This slightly reduces intra-national trade flows. The overall intra-national trade effect remains large and in our example, intra-national trade increases under border barriers from 41.6% of GDP to 70.8% of GDP. That is, the numerator of the border effect = 1.70. The overall border effect in our example is $1.70/.30 = 5.63$, which is more than twice as large as in the standard model.[17] In the standard model the numerator was 1.44 and the denominator was 0.56. The presence of vertical specialization in our

[17] Note that the magnification effect is smaller than in the first vertical specialization case for the reasons cited at the beginning of this section.

example means the increase in intra-national trade due to border barriers is 70 percent instead of 44 percent, and the decrease in international trade is 70 percent instead of 44 percent.

As the country sizes become asymmetric, the importance for the smaller country of the numerator or intra-national trade in the border effect increases, while the importance of the denominator or international trade decreases. This is the AvW insight, again. Under free trade, the smaller the country, the more it trades with its partner and the less it trades with itself. In the presence of border barriers, a given reduction in international trade translates into a larger (proportionally speaking) increase in intra-national trade. If the symmetric example above is altered so that one country has 1/10 the labor endowment of the other country, the numerator of the border effect for the smaller country rises to 5.1, while the denominator is now 0.43, yielding a border effect of 11.8, about twice as large as in the symmetric case.[18]

Summarizing, these two cases suggest the following interpretation of the relation between vertical specialization and the border effect. In a world with vertical specialization, border barriers lead to a larger decrease in international trade, and a larger increase in intra-national trade, than what would be implied by a standard trade model, as indicated by (23). International trade decreases by more because of the two forces discussed in the first case: 1) the back-and-forth aspect of vertical specialization implies that at least some stages of the good are affected multiple times by border barriers and 2) the barrier is applied to the entire good, but the marginal unit of production is a single stage, whose cost is just a fraction of the cost of the entire good. Because international trade decreases by more, intra-national trade increases by more; moreover, the ensuing increase in regional vertical specialization also adds to intra-national flows. Overall, the presence of vertical specialization gives rise to a larger border effect from a given border barrier than in the standard model. Moreover, it suggests that a given border effect can be explained by a smaller border barrier than in the standard model. I now examine this latter idea in detail.

4 Solution of Model and Calibration to U.S.-Canada Trade

I solve for the border barrier that generates the AvW U.S.-Canada border effect. I also solve the one-stage version of the model as a benchmark. This section describes how I solve and calibrate

[18] By the same reasoning, the border effect for the larger country is smaller than in the symmetric case. In our example, we also altered the productivity parameters to avoid any terms of trade effects.

Numerical experiments suggest that the overall impact of asymmetric country size on the border effect is roughly the same in both the standard model and the vertical specialization model.

the model.

4.1 Solution

Solving the two-stage model is more complicated than solving the standard one-stage model. Unlike in the EK model, in general there is no straightforward solution for the vertical specialization model. Rather, it must be solved numerically. To do so, I divide the $[0, 1]$ continuum into 100,000 equally spaced intervals, with each interval corresponding to one good. For each good and region, I draw a stage-one productivity and a stage-two productivity from the Frechét distribution. With four regions and two stages of production, there are 16 possible production methods for each good. Given a vector of regional wages, I calculate which production method is cheapest for each of the 100,000 goods. I then calculate whether the resulting pattern of specialization and trade is consistent with labor market equilibrium (or, equivalently, balanced trade). The wages are adjusted until labor market equilibrium in each of the regions is achieved.

I solve the model under a particular border barrier and also under free trade. I then calculate the border effects and other variables. I use (15) to calculate the border effect: the ratio of within country trade under border barriers to within country trade under free trade divided by the ratio of international trade under border barriers to international trade under free trade. I replicate this procedure 10 times. The results in the tables report the averages across the replications.

4.2 Calibration

I calibrate the simplest setting required to examine border effects between the United States and Canada. EK report that, in 1990, human-capital adjusted manufacturing labor in the U.S. was 11.5 times greater than in the U.S. A broader measure of labor, the U.S. labor force, was about 9 times larger than Canada's labor force in 2001. I set the U.S. to be 10 times larger than Canada in terms of labor units. To the extent the AvW estimation is correct, it controls properly for forces like differences in region size and distances between regions within and across countries. Moreover, the border effect is by definition a (log) difference-in-difference. This means that differences in trade due to differences in size and distance are, in some sense, controlled for. Consquently, each of the two regions within a country are set equal in size.[19]

The key parameters to be calibrated are those governing the technologies and the production

[19] Note that I assume that labor is not mobile between regions within a country. However, the assumptions on technologies and on barriers between these regions render this assumption unimportant.

structure. As presented above, following Eaton and Kortum (2002), the distribution of technologies in all four regions is modeled as a Frechét distribution. There are two key parameters in the Frechét, one governing the "average" level of technology, T, and one governing the heterogeneity, or elasticity, of the technologies, n. EK report that the human-capital adjusted manufacturing wage in Canada was 0.99 of the U.S. wage in 1990. Hence, the average technologies are set to generate identical wages under free trade across regions and countries. In other words, the technologies are identical across regions within a country. Moreover, because the U.S. is 10 times larger, its average technology, which can be interpreted as a stock of ideas, is set to be 10 times larger. On a per capita basis, the average technologies are identical across countries.

I study two values of n, 4 and 9, which corresponds to elasticities of substitution in monopolistic competition or Armington aggregator models of 5 and 10, respectively. This elasticity is identical across regions and countries. Table 2 lists the labor, technology, and elasticity parameters. I set the share of stage-1 goods in stage-2 production equal to 2/3, which is consistent with the fact that manufacturing value-added is about 1/3 of gross manufacturing output. For comparison, I also solve the 1-stage version of the model, which is essentially a four-region version of the original EK model. In my framework, this corresponds to a case in which stage-1 goods have a zero share in stage-2 production.

The key exogenous variables in the model are the border barriers between countries and regions. I focus on border barriers necessary to achieve a border effect of 10.5 in the model. For simplicity, I assume that transport costs within and between regions in a country are zero.[20]

5 Results

I first solve the one-stage version of the model as a benchmark. This is essentially the EK model. I assess its ability to replicate some of the key AvW results. When the elasticity equals 5, a border barrier of 49.5% is needed to generate a border effect for Canada equal to 10.5. At that barrier, Table 3 shows that the implications of the model for intra-Canada trade, intra-U.S. trade, and U.S.-Canada trade are fairly close to AvW's results. For example, the ratio of intra-Canada trade under

[20] If transport costs are identical across all pairs of regions, they can be set to zero without loss of generality. One of the key results from AvW is that an equal change in transport costs everywhere (including within a region) has zero effect on international or intra-national trade. However, if transport costs are not identical across and within regions, then the interaction of the transport costs with the border barriers alters the magnitude of the border effect. Sensitivity analysis shows this interactive effect is not large.

a 49.5% barrier to intra-Canada trade under free trade is 5.63 according to the model; the AvW estimate is 4.31. When the elasticity equals 10, a border barrier of 18.9% is needed to generate a Canada border effect of 10.5. With this elasticity, the model's implications are also close to AvW's results.

It may be surprising that a calibration of a different model from AvW, with just two countries, and two regions per country, yields implications so similar to what AvW obtain. This similarity reflects two forces. First, it can be shown that the EK model generates a gravity equation virtually identical to the gravity equation from the AvW model.[21] Second, to the extent that the AvW gravity equation is not mis-specified and is estimated correctly, the estimates have implications for counterfactual exercises like "holding all else equal what is the border effect for two countries, each with two regions, when the border barrier is x?". A model that produces the same gravity equation as the AvW equation should then generate implications similar to the AvW estimates.

I now solve the vertical specialization model. The main results are presented in Table 4. When the elasticity is 5, the vertical specialization model an achieve a Canada border effect of 10.5 with a border barrier of just 26.3%. When the elasticity is 10, a barrier of just 10.4% is needed. These results indicate that the border effect of 10.5 can be achieved with barriers about one-half of what they are in the standard one-stage model. In addition, the table also reports the border effect implied by the one-stage model when the border barrier is 26.3% in the elasticity = 5 case and 10.4% in the elasticity=10 case. The border effect is less than half of its value in the vertical specialization model. This is the central result of the paper: the effects of border barrier are magnified in the presence of vertical specialization. Large border effects can be rationalized with lower border barriers and/or elasticities of substitution than would be implied by standard trade models.

The implications for the other variables continue to be close to the AvW estimates. In fact, the implications for intra-Canada trade and for U.S.-Canada trade in the vertical specialization model are closer than the corresponding implications from the one-stage model to the AvW estimates.

Table 5 presents the model's implications for vertical specialization in Canada under free trade as well as under the border barrier. For comparison, the latest data for Canada (1990) are also listed. The model implies that vertical specialization will rise considerably if border barriers are eliminated. But, the model also implies that vertical specialization under border barriers is very low, almost zero. The implications under border barriers should match what vertical specialization

[21] See Anderson and van Wincoop (2004).

is currently in the data. In this respect, the model performs poorly.

There are (at least) two possible reasons for why the model implies so little vertical specialization for Canada. First, the model assumes that the border barrier is applied equally to all goods. In reality, the border barrier differs across goods. For example, the tariff component of the border barrier for motor vehicles and parts is zero, as a result of the 1965 U.S-Canada Auto Pact. It is likely that the border barrier for motor vehicles and parts is lower than the barrier for other goods such as lumber, produce, or computers. All else equal, making border barriers heterogeneous across goods will tend to raise the amount of vertical specialization under barriers, while at the same time reducing the border effect.[22] Second, the model assumes that the productivity distributions for the U.S. and Canada are the same for both stage 1 production and stage 2 production (on a per capita basis). This assumption tends to minimize the amount of vertical specialization. It is quite plausible that the average productivity of U.S. producers relative to Canadian producers in stage 1 production is different from the average relative productivity in stage 2 production. All else equal, adding heterogeneity in the average productivities will increase the amount of vertical specialization under both border barriers and free trade, and raise the border effect.

I simulate the model imposing both heterogeneous border barriers and heterogeneous average productivities. In particular, half the goods are subject to a high barrier and half the goods are subject to a low barrier. I set the barriers so that they generate a border effect of 10.5. Moreover, I assume that Canada's average productivity in stage 1 production is half that of the U.S., while Canada's average relative productivity in stage 2 production is twice that of the U.S. Table 5 shows that when the elasticity is 5, a border barrier on half the goods of 53% and on the other half of the goods of 12% generates vertical specialization of about 22% under border barriers, considerably closer to the actual Canadian level of vertical specialization. When the elasticity is 10, similar results obtain.

6 Conclusion

In this paper, I have proposed a resolution to the border effect problem. The problem arises because, from the perspective of standard trade models, there is "too much" trade between regions within countries, and not enough trade between countries. The existing data can only be rationalized by

[22] Hillberry (2002) provides evidence that including for heterogeneity in border barriers across goods can help explain the aggregate U.S.-Canada border effect.

appealing to counterfactually high elasticities of substitution or to very high unobserved border barriers between countries.

My solution involves vertical specialization, which occurs when regions specialize in particular stages of a good's production sequence, rather than in the entire good. Intra-national vertical specialization occurs when the multi-region production chain is contained entirely within a country; international vertical specialization occurs when the production chain cross national borders. I develop a continuum-of-goods Ricardian model of intra-national and international trade in which goods are produced in two stages, and I show that vertical specialization serves as a propagation mechanism magnifying the effects of border barriers into large increases in intra-national trade and large decreases in international trade.

There are two key ideas underlying the magnification effect. The first idea is that "back-and-forth" trade leads to at least some stages of production bearing multiple border costs. For example, for a good produced by HF vertical specialization and consumed in the home country, the first stage is affected twice, first when it is shipped to the foreign country, and second, when it is shipped back to the home country (embodied in the stage-2 good). The second idea is that the "marginal" production process is often a single stage of production. This means that the relevant border cost is not the cost relative to the total cost of the good, but the cost relative to the cost of producing the marginal stage. Each idea alone magnifies the border barrier; in conjunction, these two ideas show that a model with vertical specialization can potentially reconcile the border effect without needing to rely on large unobserved border barriers.[23]

Vertical specialization also breaks the tight link between the elasticity of trade with respect to iceberg-type trade barriers and the elasticity of substitution between goods on either the production or consumption side, as in EK, as well as monopolistic competition or Armington aggregator models. In many models the two elasticities are virtually identical. In the model presented here the elasticity of trade with respect to barriers involves both the elasticity of substitution (i.e., the Frechét distribution variance parameter) and the share of stage-1 inputs in production. Chaney (2005) also presents a model which breaks the link between the elasticity of trade with respect to barriers and the elasticity of substitition.

I calibrate the model to key features of the U.S. and Canada and solve for the border barrier needed to generate the AvW-estimated Canadian border effect. I find that the border barrier is only

[23] In previous reseach (Yi, 2003), I show how vertical specialization can help explain the growth of world trade. The key forces are the same as those driving international trade in this paper.

half of what it would be in a model without vertical specialization. This result may understate the impact of vertical specialization, because there is evidence suggesting that many goods, particularly electronics and motor vehicles, are produced in more than two sequential stages.

The model is counterfactual on one key dimension. Its implications for Canada's current level of vertical specialization are too low by more than an order of magnitude. However, adding heterogeneity in border barriers, as well as heterogeneity across countries in average productivity in stage one production and stage two production, can help reconcile the vertical specialization implications with the data. I am currently working on a more careful calibration of these two types of heterogeneity. To do so, I have divided Canada into two regions, Ontario-Quebec and the rest of Canada. Ontario and Quebec account for the lion's share of Canada's automotive trade with the U.S., while the rest of Canada accounts for the lion's share of Canada's commodity trade with the U.S. This work is ongoing.

A Appendix: Derivation of $\underline{z}^h$ for vertical specialization case 1

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

$$p_2^{HH}(\underline{z}^h) \equiv \frac{Bw^h}{A_1^h(\underline{z}^h)^{\theta} A_2^h(\underline{z}^h)^{1-\theta}} = (1+b)\frac{B(1+b)^{\theta} w^{h\theta} w^{f(1-\theta)}}{A_1^h(\underline{z}^h)^{\theta} A_2^f(\underline{z}^h)^{1-\theta}} \equiv (1+b) p_2^{HF}(\underline{z}^h) \tag{25}$$

where $B = \theta^{-\theta}(1-\theta)^{(\theta-1)}$. Simplifying yields:

$$\omega^{1-\theta} = \left(\frac{A_2^h(\underline{z}^h)}{A_2^f(\underline{z}^h)}\right)^{1-\theta} (1+b)^{(1+\theta)} \tag{26}$$

where $\omega = w^h/w^f$. Using the result from 17, yields:

$$\omega^{1-\theta} = \left(\frac{1-\underline{z}^h}{\underline{z}^h}\right)^{\frac{1-\theta}{n}} (1+b)^{(1+\theta)} \tag{27}$$

Solving for $\underline{z}^h$ yields 22.

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Figure 1

Vertical Specialization

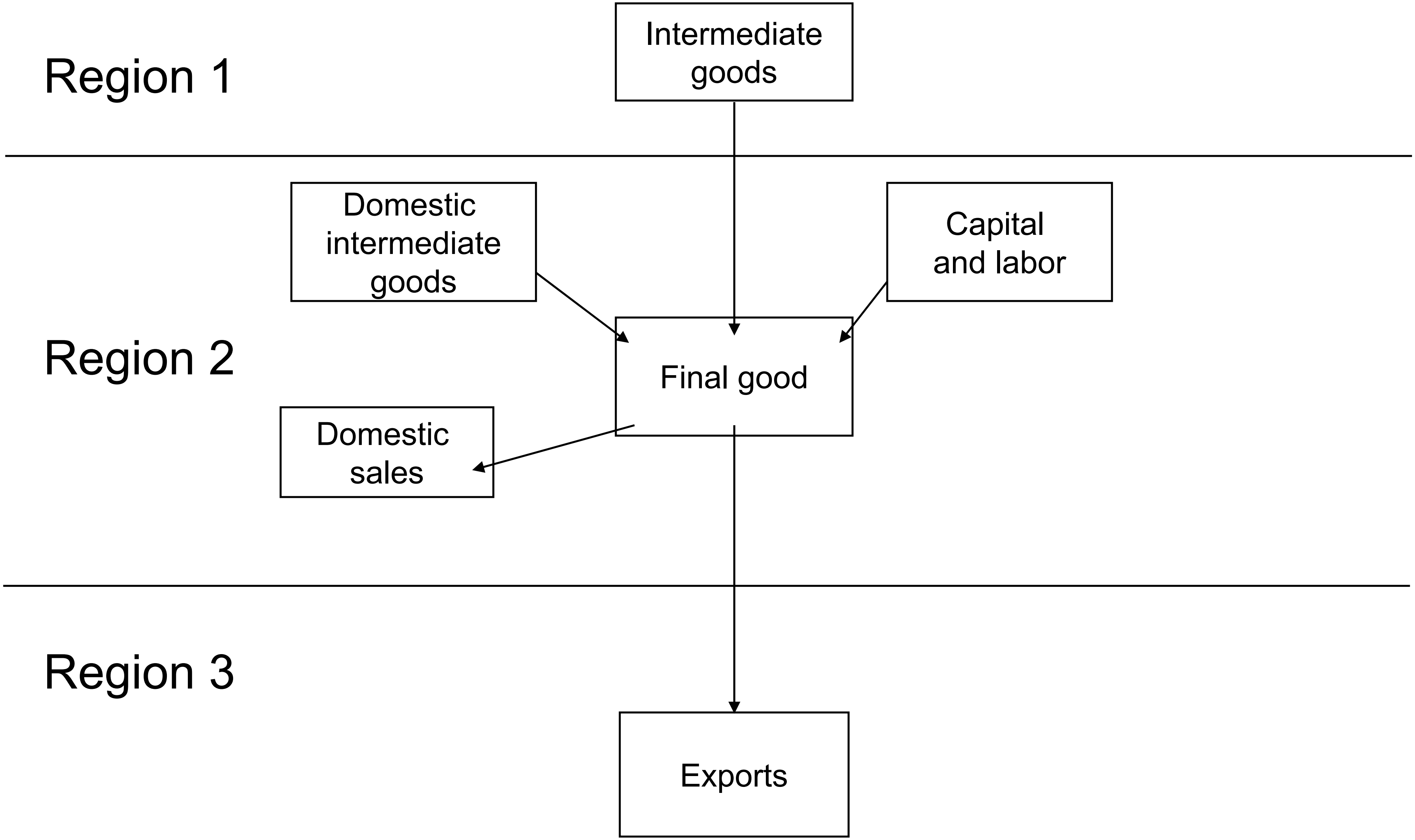
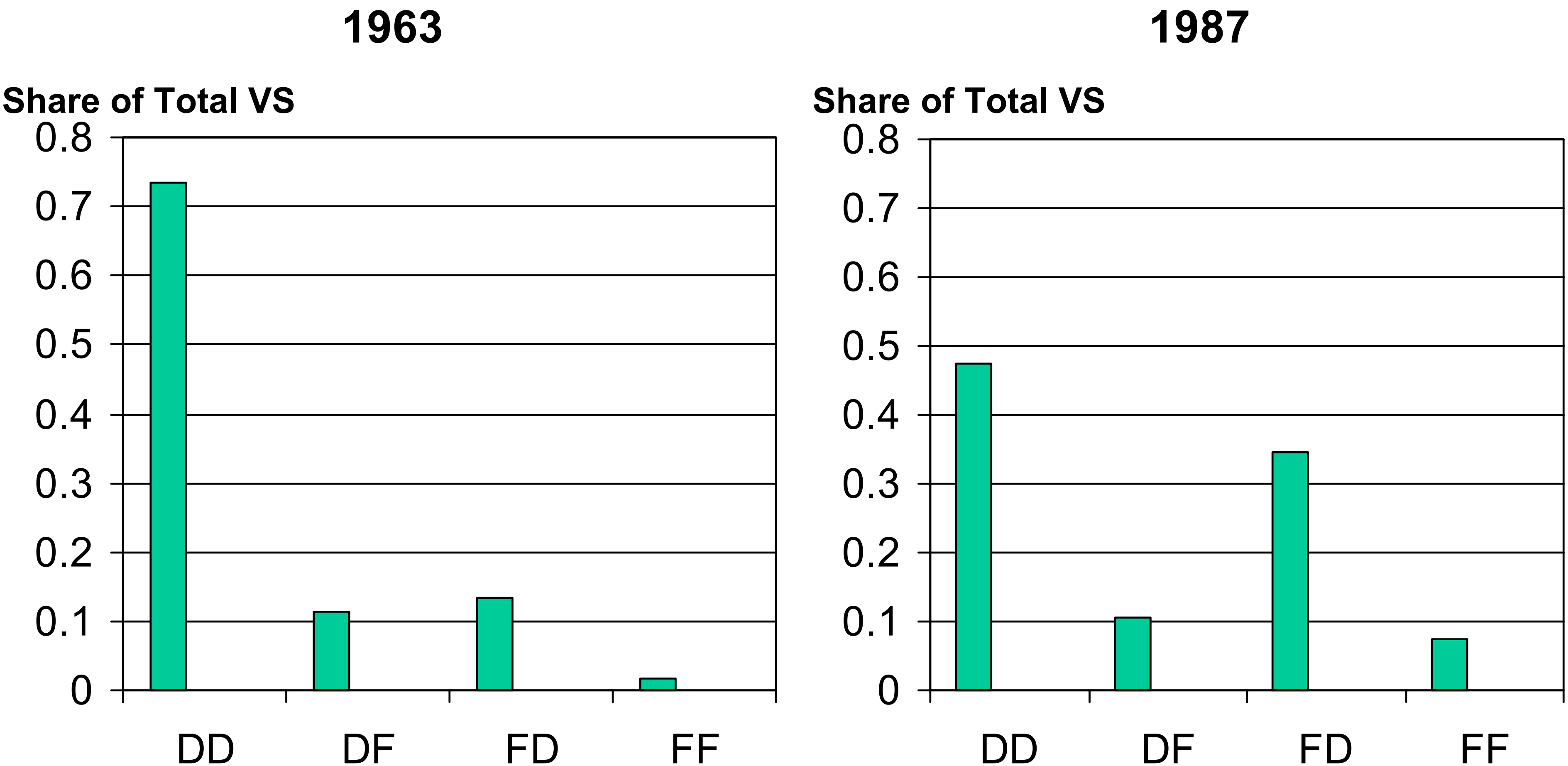


Figure 2

Decomposition of Washington's Vertical Specialization Exports



Note: VS exports = 33% (47%) of total merchandise exports in 1963 (1987)

DF: **D**omestic imported inputs; exports to **F**oreign destinations

Figure 3

Standard DFS Model

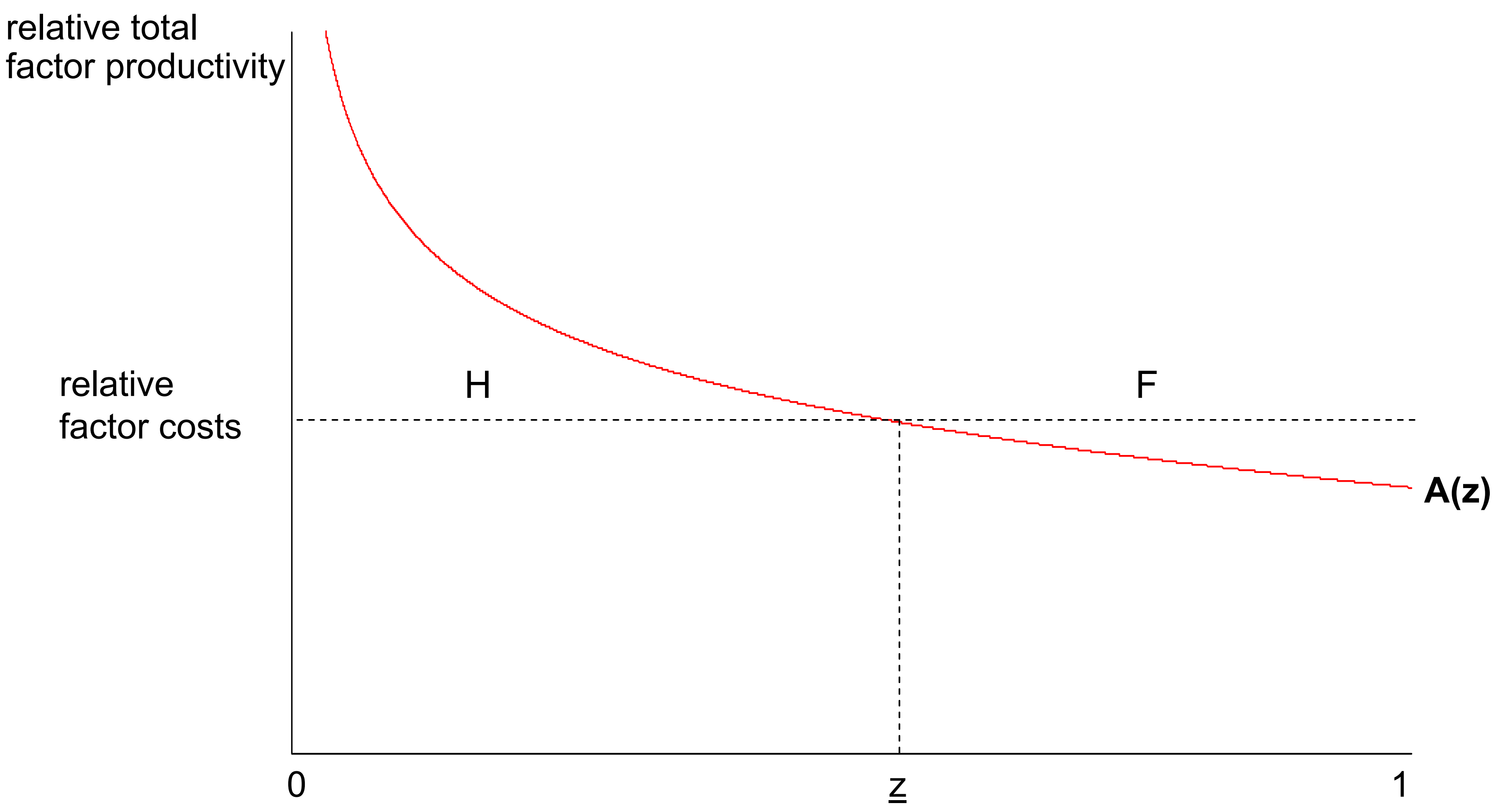
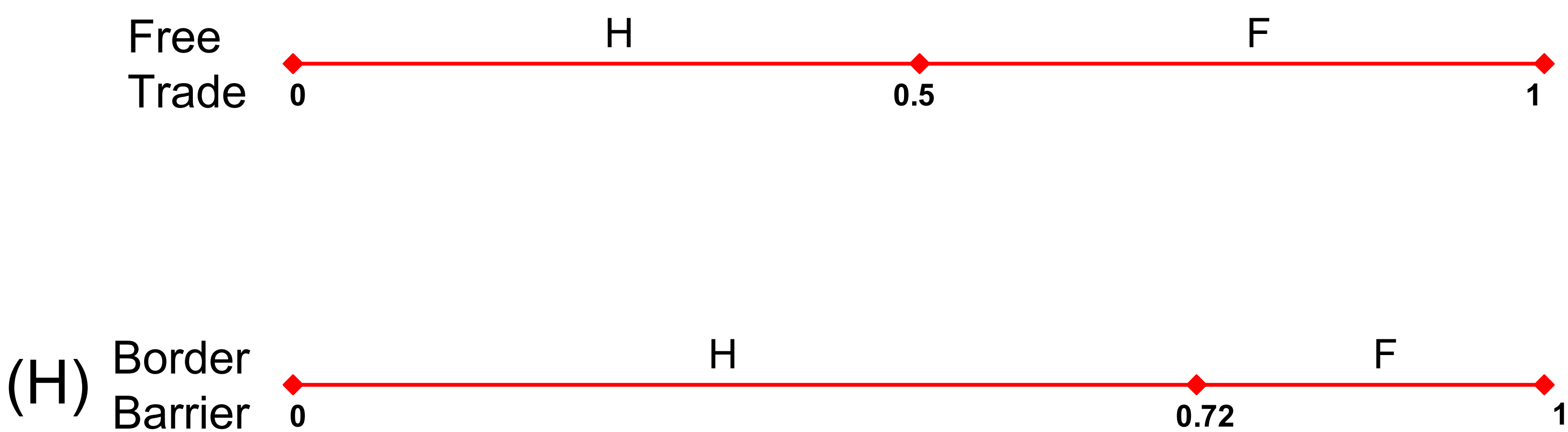


Figure 4

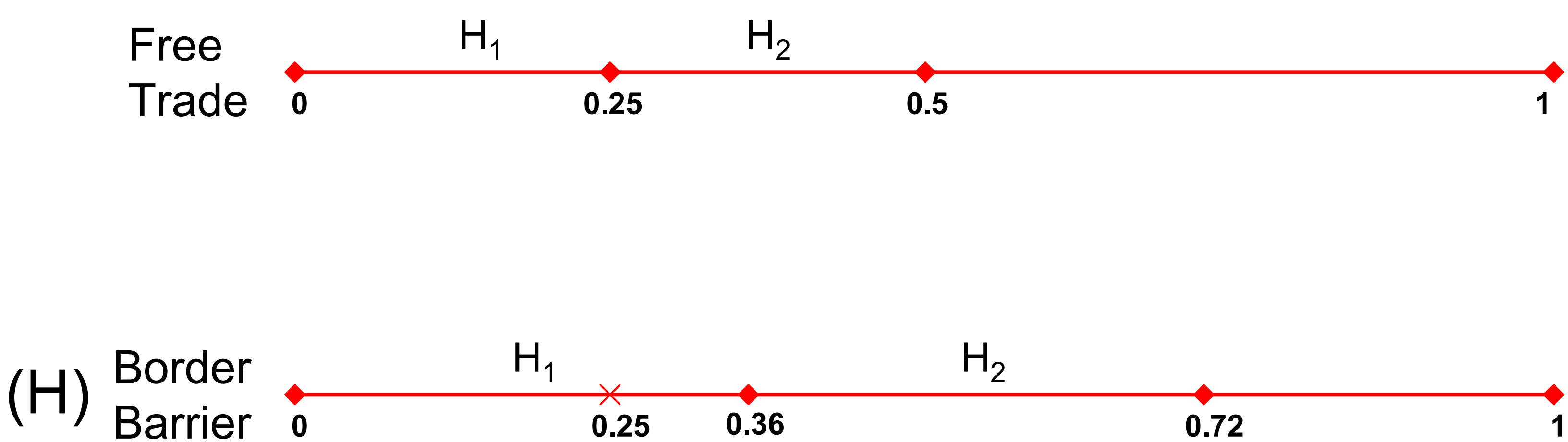
International Production Specialization: Standard model



Note: Symmetric case (identical productivity distributions and labor); border barrier = 10%; elasticity = 11; (H) is for consumer in H

Figure 5

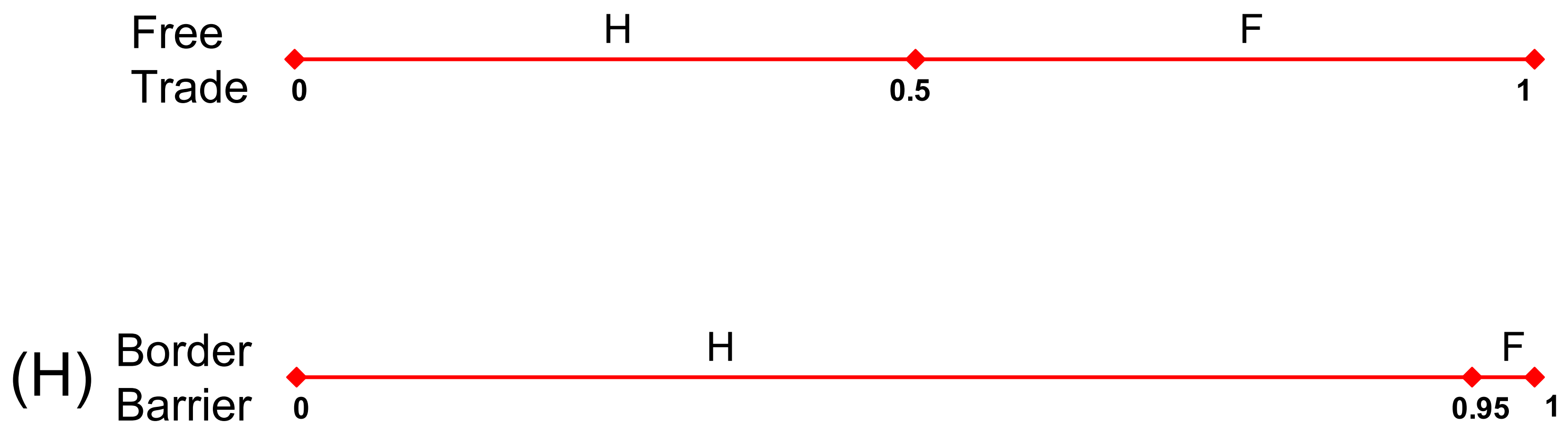
Intra-national Production Specialization: Standard model



Note: Symmetric case (identical productivity distributions and labor); border barrier = 10%; elasticity = 11; (H) is for consumer in H

Figure 6

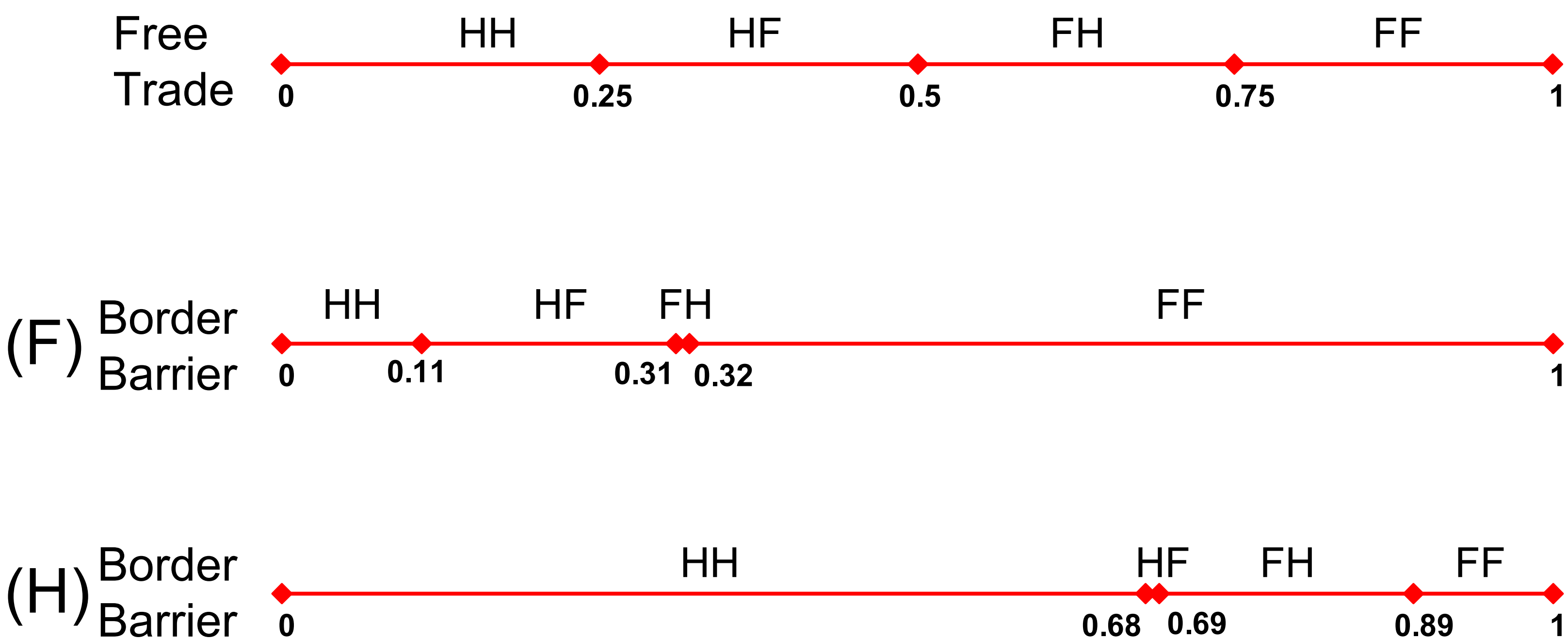
International Production Specialization: Vertical specialization case 1



Note: Symmetric case (identical productivity distributions and labor); border barrier = 10%; elasticity = 11; share of 1st stage inputs in 2nd stage production = 0.5; (H) is for consumer in H

Figure 7

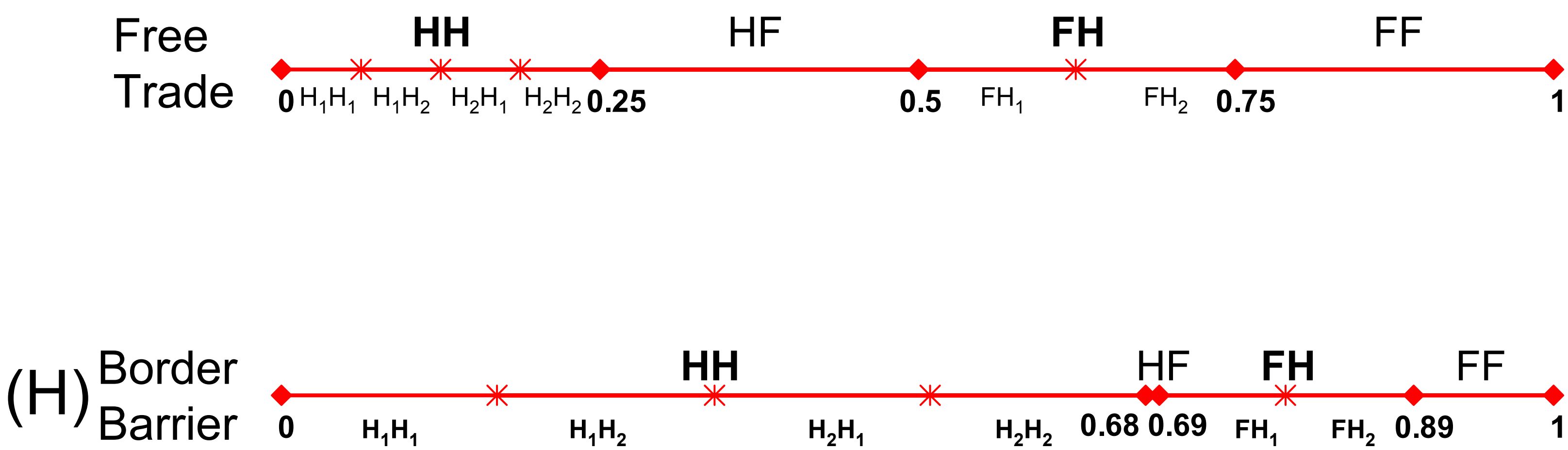
International Production Specialization: Vertical specialization case 2



Note: Symmetric case (identical productivity distributions and labor); border barrier = 10%; elasticity = 11. (F) border barrier case is for consumer in F; (H) case is for consumer in H

Figure 8

Intra-national Production Specialization: Vertical specialization case 2



Note: Symmetric case (identical productivity distributions and labor); border barrier = 10%; elasticity = 11.

TABLE 1
VERTICAL SPECIALIZATION AT THE STATE LEVEL

STATE	Year	Vertical Specialization (percent of total merchandise exports)
Hawaii	1987	36.3%
Hawaii	1992	43.4%
Hawaii	1997	43.0%
Washington	1963	33.3%
Washington	1967	42.3%
Washington	1972	36.9%
Washington	1982	47.9%
Washington	1987	47.3%
U.S.	1972	6.0%
U.S.	1997	12.3%
Canada	1971	20.0%
Canada	1990	27.0%

TABLE 2
SPECIFICATION FOR U.S.-CANADA BORDER EFFECT EXERCISE

Labor	Region 1	Region 2
Canada	1	1
U.S.	10	10

Elasticities (=n+1) **5, 10**

	Elasticity = 5	Elasticity = 10
Technology parameter		
Canada	0.100	0.100
U.S.	1.000	1.000

TABLE 3
SIMPLE CALIBRATED EATON/KORTUM MODEL COMPARED TO ANDERSON/VAN WINCOOP RESULTS

	Anderson/ Van Wincoop Estimates	Calibrated Eaton/Kortum Model	Calibrated Eaton/Kortum Model
		elasticity=5	**elasticity=10**
Border barrier that generates Canada border effect = 10.5		49.5%	18.9%
Ratio of Trade Under Estimated Border Barriers to that under Borderless Trade			
Canada-Canada	**4.31**	5.63	5.64
U.S.-Canada	**0.41**	0.54	0.54
U.S.-U.S.	**1.05**	1.27	1.15
Border Effect			
Canada	**10.50**	10.50	10.51
U.S.	**2.56**	2.37	2.14

Note: Calibrated Eaton/Kortum model involves 2 countries (Canada and U.S.), 2 regions per country. One country is 10 times larger (in labor units) than the other country. Regions within a country are the same size.

TABLE 4
VERTICAL SPECIALIZATION MODEL COMPARED TO EATON/KORTUM MODEL

	Anderson/ Van Wincoop Estimates	Calibrated Eaton/Kortum Model	Calibrated Vertical Specialization Model
ELASTICITY = 5			
Border barrier that generates Canada border effect = 10.5	48.4%	**49.5%**	**26.3%**
Ratio of Trade Under Estimated Border Barriers to that under Borderless Trade			
Canada-Canada	4.31	5.63	4.76
U.S.-Canada	0.41	0.54	0.45
U.S.-U.S.	1.05	1.27	1.29
Border Effect			
Canada	10.50	10.50	10.53
Canada (border barrier = 26.3%)		4.25	
U.S.	2.56	2.37	2.85
ELASTICITY = 10			
Border barrier that generates Canada border effect = 10.5	19.2%	**18.9%**	**10.4%**
Ratio of Trade Under Estimated Border Barriers to that under Borderless Trade			
Canada-Canada	4.26	5.64	4.78
U.S.-Canada	0.41	0.54	0.45
U.S.-U.S.	1.05	1.15	1.17
Border Effect			
Canada	10.50	10.51	10.54
Canada (border barrier = 10.38%)		4.20	
U.S.	2.56	2.14	2.58

Note: Vertical specialization model solved numerically. See text for details.
Results are averages over 10 simulations of model.

TABLE 5
VERTICAL SPECIALIZATION IMPLICATIONS
Calibrated Vertical Specialization Model

			Vertical Specialization (share of exports)
ELASTICITY = 5			
Vertical Specialization (share of exports)			
Canada			
	Data		**27.0%**
	Model	Free Trade	**36.3%**
		Border Barrier = 26.3%	**1.4%**
	Extended Model	Free trade	**54.0%**
		Border Barrier = 53%, 12%	**22.2%**
ELASTICITY = 10			
Vertical Specialization (share of exports)			
Canada			
	Data		**27.0%**
	Model	Free Trade	**36.3%**
		Border Barrier = 10.4%	**1.8%**
	Extended Model	Free Trade	**54.0%**
		Border Barrier = 18.3%, 5.2%	**20.7%**

Note: Vertical specialization model solved numerically. See text for details.
Results are averages over 10 simulations of model.
In extended model: 1] half the goods face one border barrier, half the goods face the other barrier.
2] Canada's average productivity in stage 1 (stage 2) production is half (twice) the value of the baseline parameterization