

# A Simple Explanation for 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. 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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*Keywords:* border effect, home bias in consumption, vertical specialization

# 1 Introduction

A large body of empirical research finds the existence of a significant “border” effect.<sup>1</sup> According to the typical estimates, regions within countries trade 10 to 20 times more with each other than do regions across countries, relative to what they would trade in the absence of border barriers. 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.<sup>2</sup> Consider, for example, the U.S. 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 lower, 19 percent (because goods flows are more sensitive to border barriers). Existing measures of tariff rates and transport costs between the U.S. and Canada suggest that, taken together, they are about 5 percent. 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.<sup>3</sup>

In this paper, I propose an alternative explanation, one 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 specializing in particular stages of a good’s production sequence. Previous research has documented the empirical importance of vertical specialization across countries, and has shown that it helps explain the growth of world trade without having to rely on counterfactually high elasticities of substitution. This paper applies this concept to regions within countries and across countries in

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<sup>1</sup>McCallum (1995) was the first to find this effect. Other research includes that by Wei (1996), Helliwell (1998), and Evans (2001). The most theoretically consistent research on the border effect is Anderson and Van Wincoop (2001). 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.

<sup>2</sup>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.

<sup>3</sup>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.

order to explain the border effect.

The main idea can be conveyed by the following (extreme) 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. Moreover, the cost increase may lead to a change in the specialization pattern; the international specialization pattern may be replaced by an intra-national “back and forth” pattern. This external margin effect further reduces international trade. 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 conduct two exercises. In the first exercise, 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 20.1 percent is needed to generate the AvW border effect. By contrast, the standard one-stage model requires a border barrier almost twice as large, 37.4 percent, to generate the AvW border effect. When the elasticity is 10, similar results obtain.

The state of Washington is one of the few states in the U.S. for which survey-based input/output tables exist. Moreover, Washington may be the only state for which the tables distinguish between domestic exports and imports and international imports and exports. The tables were constructed

for selected years between 1963 and 1987. From these tables I calculate four types of vertical specialization flows, according to whether the imported inputs are from domestic or international sources and whether the exports are to domestic or international destinations. In the second exercise with the model, I loosely parameterize the model to Washington, the rest of the U.S. and the rest of the world. I then solve the model under several border barriers; for each barrier I calculate the implications for the four types of vertical specialization and compare them to the data. The model shows that an appropriate reduction in international barriers can qualitatively and quantitatively replicate the levels and changes in all four vertical specialization flows between 1963 and 1987.

Thus, while preliminary, these two sets of 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 (2003) focuses on fixed costs of exporting. 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 (2003). 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 rich input-output structure, and firms are mobile across locations. In Rossi-Hansberg (2003) 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, intuition on how vertical specialization works, and the two exercises undertaken with the model; 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.<sup>4</sup> In order to accommodate regions as the basic geographic unit, I modify the definition from Hummels, Ishii, and Yi (2001):

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:

$$VS_{ki} = \left( \frac{\text{imported intermediates}_{ki}}{\text{Gross output}_{ki}} \right) \text{Exports}_{ki} \quad (1)$$

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.<sup>5</sup> These tables are not widely available at the sub-national level. However, several U.S. states, including Hawaii and Washington, have constructed these tables.

Table 1 lists vertical specialization in merchandise exports, expressed as a fraction of total merchandise exports, in these two states for selected years. For comparison, the table also lists vertical specialization for the entire U.S. and for Canada. The table shows that vertical specialization

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<sup>4</sup>See Hummels, Rapoport, and Yi (1998), Hummels, Ishii, and Yi (2001), and Yi (2003).

<sup>5</sup>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).

at the state-level is considerably larger than at the national level. Also, in both states vertical specialization has been growing over time.

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: 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 evidence from both states 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) continuum of goods Ricardian model.

The basic geographic unit is a region. In most of the discussion below the number of regions

is four, and the number of countries is two; however, the number of regions and countries can be generalized. Each country has two regions. 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  $4 \times 4 = 16$  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:

$$y_1^i(z) = A_1^i(z)l_1^i(z) \quad z \in [0, 1] \quad (2)$$

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:

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

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.<sup>6</sup> 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 Fréchet distribution as the probability distribution of total factor productivities. This distribution facilitates a straightforward solution of the EK model in a many-country world with non-zero border barriers.

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<sup>6</sup>To the extent the barrier includes tariffs, I assume that tariff revenue is “thrown in the ocean”.

Unfortunately, such a straightforward solution does not carry over in my multi-stage framework.<sup>7</sup> Nevertheless, I employ this distribution to facilitate comparisons of my model with the EK model, which I view as the benchmark model.<sup>8</sup>

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:

$$p_1(z)y_1^i(z) - w^i l_1^i(z) \quad (4)$$

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

Stage-2 firms maximize:

$$p_2(z)y_2^i(z) - p_1(z)x_1^i(z) - w^i l_2^i(z) \quad (5)$$

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

$$p_2(z)y_2^i(z) - (1 + \tau_{ij})(1 + b_{ij})p(z)x_1^i(z) - w^i l_2^i(z) \quad (6)$$

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:

$$\int_0^1 \ln(c^i(z)) dz \quad (7)$$

subject to the budget constraint:

$$\int_0^1 p_2(z)d^i(z)c^i(z) dz = w^i L^i \quad (8)$$

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.

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<sup>7</sup>The reason is because my framework requires two draws from the Fréchet distribution. Neither sums nor products of Fréchet distributions has a Fréchet distribution. I thank Sam Kortum for pointing this out to me.

<sup>8</sup>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 implies that the sensitivity of trade flows to changes in trade barriers is essentially the same as in the standard trade model. The vertical specialization model I employ does imply that trade flows are more sensitive to changes in trade barriers.

### 3.3 Equilibrium

All factor and goods markets are characterized by perfect competition. The following market clearing conditions hold for each region<sup>9</sup>:

$$L^i = \int_0^1 l_1^i(z) dz + \int_0^1 l_2^i(z) dz \quad (9)$$

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

$$y_1(z) \equiv \sum_{i=1}^2 y_1^i(z) = \sum_{i=1}^2 d_1^i(z) x_1^i(z) \quad (10)$$

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  $z$ :

$$y_2(z) \equiv \sum_{i=1}^2 y_2^i(z) = \sum_{i=1}^2 d^i(z) c^i(z) \quad (11)$$

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  $\{l_1^i(z), l_2^i(z), y_1^i(z), y_2^i(z), x_1^i(z), c^i(z)\}$ ,  $z \in [0, 1]$ ,  $i = 1, \dots, N$ , such that the first order conditions to the firms' and households' maximization problems 4, 5, 6, and 7, as well as the market clearing conditions 9, 10, and 11, are satisfied.*

### 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

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<sup>9</sup>Of course,  $l_1^i(z) = 0$  whenever  $y_1^i(z) = 0$ , and similarly for  $l_2^i(z)$ .

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.

For each good and each country, the maximum realized productivity across the two regions is that country's productivity for that good. The goods can then be arranged in descending order of home productivity to foreign productivity, that is,  $A'(z) < 0$ . In this setting, international exports of course equals international imports, and international imports is given by:

$$UC = (1 - \underline{z})wL \quad (12)$$

where  $\underline{z}$  is the cutoff  $z$  that separates home and foreign production, and  $wL$  is home country GDP. See Figure 3. In the absence of border barriers, i.e., under free trade,  $\underline{z} = .5$ ; international exports or imports equals 50% of GDP. Intra-national trade is given by:

$$CC = \frac{\underline{z}wL}{2} \quad (13)$$

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

Following AvW, I define the border effect as follows:

$$\frac{\frac{CC_b}{UC_b}}{\frac{CC_0}{UC_0}} = \frac{\frac{\underline{z}_b}{(1 - \underline{z}_b)}}{\frac{\underline{z}_0}{(1 - \underline{z}_0)}} \quad (14)$$

where 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.

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 Fréchet distribution, then the relative productivities will have the following functional form:

$$A(z) = \left( \frac{1 - z}{z} \right)^{\frac{1}{n}} \quad (15)$$

where  $A(z)$  can be interpreted as the fraction of goods  $z$  where the home productivity relative to the foreign productivity is at least  $A$ .<sup>10</sup>  $n$  is a smoothness parameter that governs the heterogeneity of the draws from the productivity distribution. The larger is  $n$ , the lower the heterogeneity. EK show that  $n$  is analogous to an elasticity in that a larger  $n$  implies a flatter or more “elastic”  $A(z)$ . Then, the solution for  $\underline{z}$  is given by:

$$\underline{z} = \frac{(1+b)^n}{1+(1+b)^n} \quad (16)$$

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

$$\frac{1}{1+(1+b)^n} = \frac{2}{\frac{1}{2} + (1+b)^n} \quad (17)$$

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  $n$ , 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:

$$\frac{(1+b)^n}{1+(1+b)^n} = \frac{2(1+b)^n}{\frac{1}{2} + (1+b)^n} \quad (18)$$

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. 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.

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<sup>10</sup>See footnote 15 in EK (2002).

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

$$(1 + b)^n$$

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 = 2.56.

With the vertical specialization model, analytical expressions cannot be derived. To provide insight into the model, I work with two special cases. The first case imposes perfect correlation between the stage 1 and stage 2 relative productivities. This case generates an analytical expression for the ratio of international trade under barriers to international trade under free trade. The second case involves the simple symmetric case from above extended to include two stages of production. This case is solved numerically.

### 3.4.1 Vertical Specialization Case 1

With the vertical specialization model, relative productivities need to be specified for both stage-1 and stage-2 production. The stage-1 relative productivities are drawn from a Fréchet distribution, as before. I assume that for each good, the stage-2 relative productivity is equal to a fraction  $\lambda$  of the stage-1 relative productivity. Then, the relative productivities can be represented as follows:

$$A_1(z) = \left(\frac{1-z}{z}\right)^{\frac{1}{n}}; \quad A_2(z) = k \left(\frac{1-z}{z}\right)^{\frac{1}{n}} \quad (19)$$

where  $k = \lambda^{\frac{1}{n}} < 1$ .<sup>11</sup> Under this specification, the denominator of the border effect is given by the same general expression as before,  $(1 - \underline{z}_b)/(1 - \underline{z}_0)$ . Plugging in the solution for the  $z$ 's and abstracting from general equilibrium effects on relative wages, the denominator of the border effect is given by:

$$\frac{\omega^n + k^n}{\omega^n + k^n(1 + b)^{\frac{n(1+\theta)}{1-\theta}}} \quad (20)$$

where  $\omega$  is the home wage divided by the foreign wage. This expression is decreasing in the border barrier. As a reminder,  $\theta$  is the share of stage-1 inputs in stage-2 production. As long as multi-stage production and vertical specialization exist, i.e.,  $\theta > 0$ , then the sensitivity of international trade to the border barrier is greater than in the standard one-stage model. Moreover, comparing 17 to 20, it is easy to see that the larger is  $\theta$ , the more sensitive is the above expression to changes in

<sup>11</sup>This case is essentially the example illustrated in Figures 5 and 6 of Yi (2003).

the border barrier. The intuition for these effects is straightforward. When goods cross multiple national borders while in-process, they incur multiple border costs. These costs are larger, the greater the share of goods crossing the border multiple times, i.e., the larger is  $\theta$ . 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 trade by more than would be the case if goods were not vertically specialized. This is an internal margin effect. In addition, if the cost rises enough, the pattern of specialization itself may change, with trade becoming less vertically specialized internationally. This is an external margin effect. Through these two margins, the greater the amount of vertical specialization, the greater the adverse impact of border barriers on international trade flows. These two margins are captured in 20 above.<sup>12</sup>

### 3.4.2 Vertical Specialization Case 2

This case extends the one-stage-of-production symmetric case from above to include two stages. I assume that each region's productivities for *both stages* of all goods are drawn from the same distribution. First, consider international trade under free trade and under border barriers. Under free trade, each of four production methods,  $HH$ ,  $HF$ ,  $FH$ , and  $FF$  – 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 – will account for 25% of global production, as the top segment of Figure 6 shows.  $HF$  and  $FH$  involve 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  $\theta$ , 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.<sup>13</sup> 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 foreign country's expenditures on  $HH$  falls from 25% to 11.4%, while expenditure on  $FH$  falls much more, from 25% to just 0.23%. (See the middle segment of Figure 6). The reason for this sharp fall stems from

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<sup>12</sup>The expression for the numerator is more complicated, and cannot be easily signed, but simulations show that intra-national trade also responds more positively to border barriers under vertical specialization.

<sup>13</sup>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.

the discussion above. 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 6 shows. This latter effect implies that foreign imports of stage-1 goods produced at home falls sharply, as well. 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. 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, = .30.

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,  $HH$  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 7 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 7. 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 vertical specialization within home (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  $HH$ .

However, 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 decline in foreign purchases is considerably smaller than 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 slight reduces intra-national trade flows. The overall 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.

Combining the implications of the effect of border barriers on international trade and intra-national trade suggests 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 reduction of international trade, and a larger increase in intra-national trade, than what would be implied by a standard trade model. Intra-national trade rises by so much, because the number of goods produced entirely within home rises by more than in a standard model, and because 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.

## 4 Calibration and Solution of Two Exercises

I conduct two simulation exercises with the model. In the first exercise, 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. In the second exercise I try to replicate the decomposition of Washington's vertical specialization exports into the four types, DD, DF, FD, and FF for 1963 and 1987.

### 4.1 Calibration of U.S.-Canada Border Effect exercise

I calibrate the simplest setting required to examine border effects. Each of the two regions within a country are the same size, and the large country (the U.S.) is 10 times larger than the small country (Canada), measured in labor units.<sup>14</sup> The key parameters to be calibrated are those governing the technologies and the production structure. As presented above, following Eaton and Kortum

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<sup>14</sup>In 2001, the U.S. labor force in 2001 was about nine times larger than Canada's labor force. Also, measured in PPP terms, U.S. GDP was about 11 times larger than Canada's GDP. Note that I assume that labor is not mobile between regions within a country. However, the other assumptions on technologies and on barriers between these regions render this assumption unimportant.

(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, and one governing the heterogeneity of the technologies. 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. Across countries, because the U.S. is 10 times larger, it’s average technology, which can be interpreted as a stock of ideas, is also 10 times larger. On a per capita basis, the average technologies are identical across countries. The heterogeneity parameter acts almost isomorphically as the elasticity of substitution in the monopolistic competition and Armington aggregator based trade models; a low level of heterogeneity corresponds to a high elasticity. (hereafter, it will be referred to as the elasticity). I study two values of the elasticity, 5 and 10. 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 between regions are identical and 0.<sup>15</sup>

## 4.2 Calibration of Washington exercise

The model is loosely calibrated to Washington, the rest-of-the U.S., and the rest-of-the OECD. Washington’s gross state product is about 2 percent of U.S. GDP and its employment is also about two percent of total U.S. employment. In addition, the U.S. manufacturing sector is about  $1/2$  of that of the rest of the OECD. Lastly, U.S. manufacturing wages are about five percent higher than those in the rest of the OECD. The labor force in each region (the OECD is divided into two same-sized regions) as well as the technology parameters are set to generate these facts.

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<sup>15</sup>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 can affect border effect calculations. Sensitivity analysis shows this interactive effect is not large.

### 4.3 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. Following AvW, I calculate the border effect as a double ratio, or in log terms, a difference in difference: 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.

## 5 Results

### 5.1 U.S.-Canada Border Effect

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 37.4% 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 a 37.4% 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 16.8% 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.<sup>16</sup> Second, to the extent that the AvW gravity equation 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 can achieve a Canada border effect of 10.5 with a border barrier of just 20.1%. When the elasticity is 10, a barrier of just 9.2% 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 20.1% in the elasticity = 5 case and 9.2% 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 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 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

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<sup>16</sup>I thank Eric Van Wincoop for pointing this out to me.

goods will tend to raise the amount of vertical specialization under barriers, while at the same time reducing the border effect.<sup>17</sup> 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 relative productivity of U.S. producers is different from the average relative productivity of Canadian producers in the two stages of 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 37.4% and on the other half of the goods of 10.0% generates vertical specialization of about 20% under border barriers, considerably closer to the actual Canadian vertical specialization. When the elasticity is 10, similar results obtain.

## 5.2 Washington

For each of two elasticities (5 and 10), I solve the model under several border barriers to assess whether the model can broadly replicate the decomposition of vertical specialization numbers for 1963 and 1987. Figure 8 presents the results. For 1963, a border barrier of 10 percent (elasticity = 10) can quantitatively capture much of the decomposition. The model underpredicts the importance of the DD (domestic imported inputs, domestic exports) type of vertical specialization, while it somewhat overpredicts the importance of the DF (domestic imported inputs, foreign exports) type of vertical specialization. However, it captures the overall importance of the DD and DF vertical specialization patterns, taken together. Also, the model closely captures the importance of the two types of vertical specialization involving foreign imported inputs (FD and FF). Similar results are obtained for a border barrier of 20 percent in the elasticity = 5 case.

Turning to 1987, a 5 percent border barrier for both elasticities generates predictions broadly consistent with the data. Again the model somewhat underpredicts the shares of certain types

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<sup>17</sup>Hillberry (2002) provides evidence that including for heterogeneity in border barriers across goods can help explain the aggregate U.S.-Canada border effect.

of vertical specialization and overpredict others, but the model matches the changes over time qualitatively for two of the three (independent) types of vertical specialization. As in the 1963 case, the model closely matches the combined shares of the two types of vertical specialization relying on foreign imported inputs.

The model predicts that lower border barriers will raise the importance of the FF and FD types of vertical specialization, while lowering the importance of the DD type of vertical specialization. With lower border barriers, the relative cost of vertical specialization that involves international trade falls. Moreover, proportionately speaking the model predicts that FF rises the most in importance. FF vertical specialization benefits doubly, loosely speaking, from lower barriers, because both the imported input flows and the export flows become cheaper. For vertical specialization overall, as a share of exports, the model predicts virtually no change as barriers drop from 20% to 5% in the elasticity = 5 case (and similarly for the elasticity = 10 case). While this is counterfactual, it does show that when border barriers fall, there is a “substitution” of intra-national vertical specialization for vertical specialization involving one or more international flows.

## 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 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. It serves as a propagation mechanism magnifying the effects of border barriers into large increases in within country trade. In a simple, Ricardian model with two stages of production, two countries, and two regions per country, loosely calibrated to U.S.-Canada trade, I show that the border barrier needed to generate the observed Canadian border effect is only half of what it would be in the absence of vertical specialization. This result probably understates 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. I also use the model to generate implications for different types of vertical specialization for the state of Washington; for reasonable trade barriers the implications

are broadly consistent with the relative importance of each type of vertical specialization.

The model is counterfactual on one key dimension; in the U.S.-Canada exercise, its implications for current levels 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.

It would be useful to combine the Washington exercise with the U.S.-Canada exercise. In addition, recently, input-output tables for Canadian provinces have become available. These tables provide more data against which the implications of the vertical specialization model can be assessed. Lastly, it would be useful to empirically estimate and test for the importance of vertical specialization in explaining the border effect.

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Figure 1

**Vertical Specialization**

Region 1



Region 2



Region 3

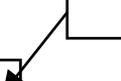


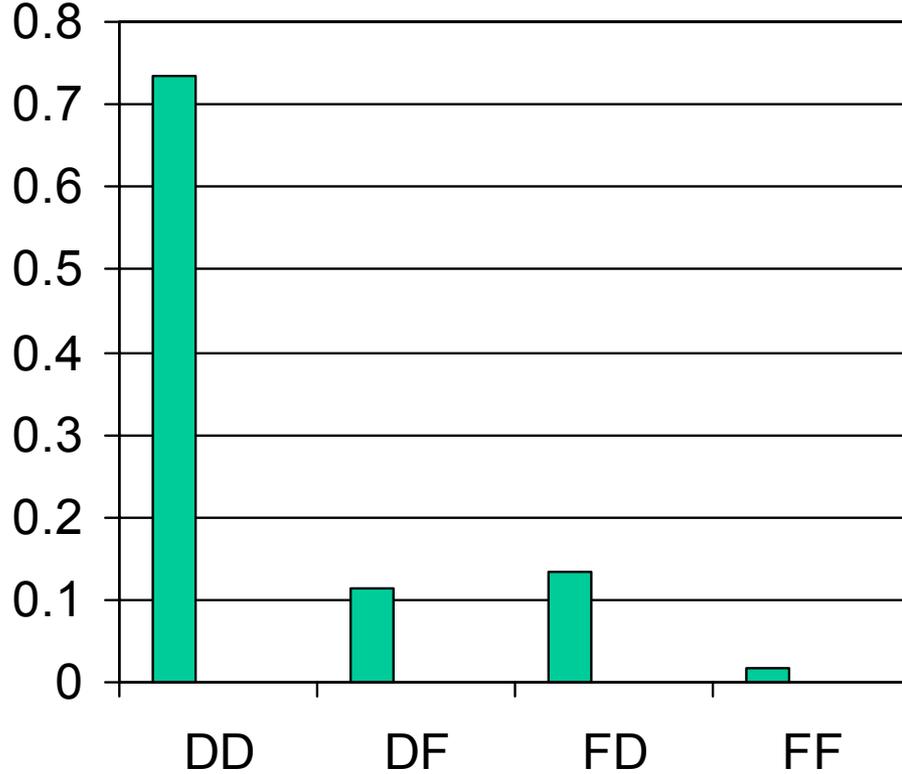
Figure 2

# Decomposition of Vertical Specialization Exports

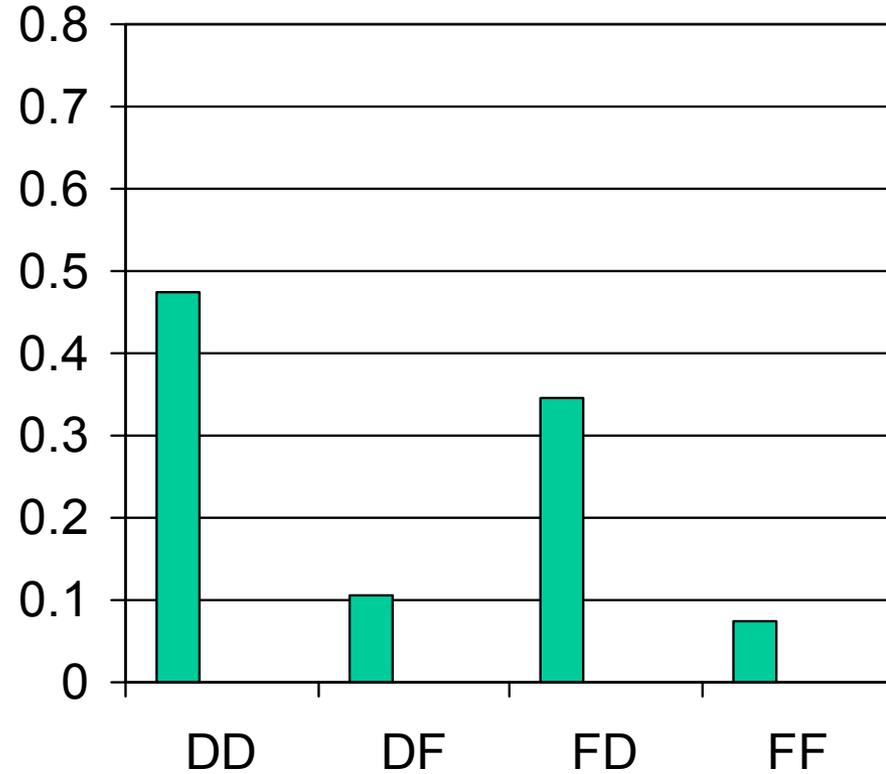
1963

1987

Share of Total VS



Share of Total VS



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

DF: Domestic imported inputs; exports to Foreign destinations

Figure 3

# Standard DFS Model

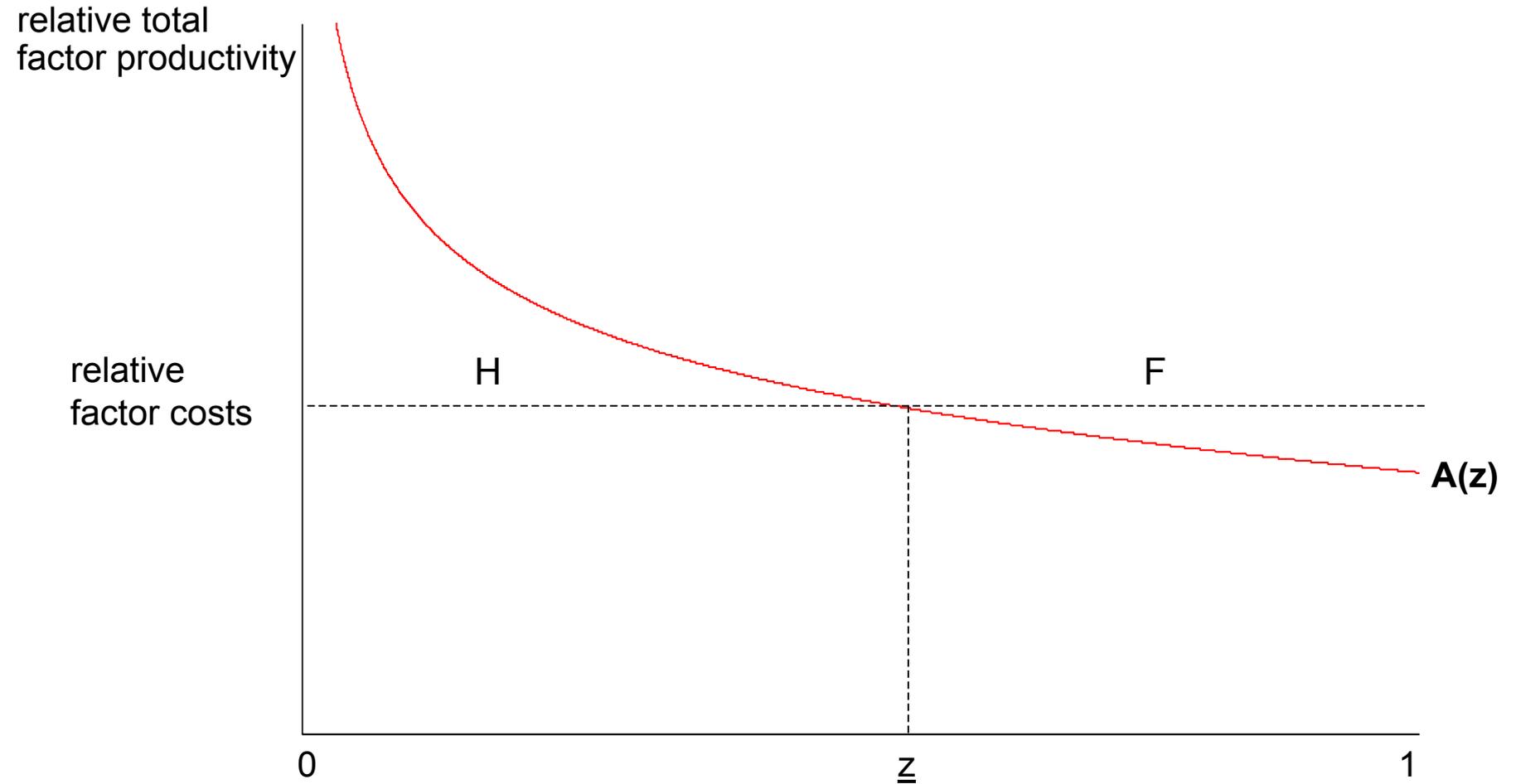
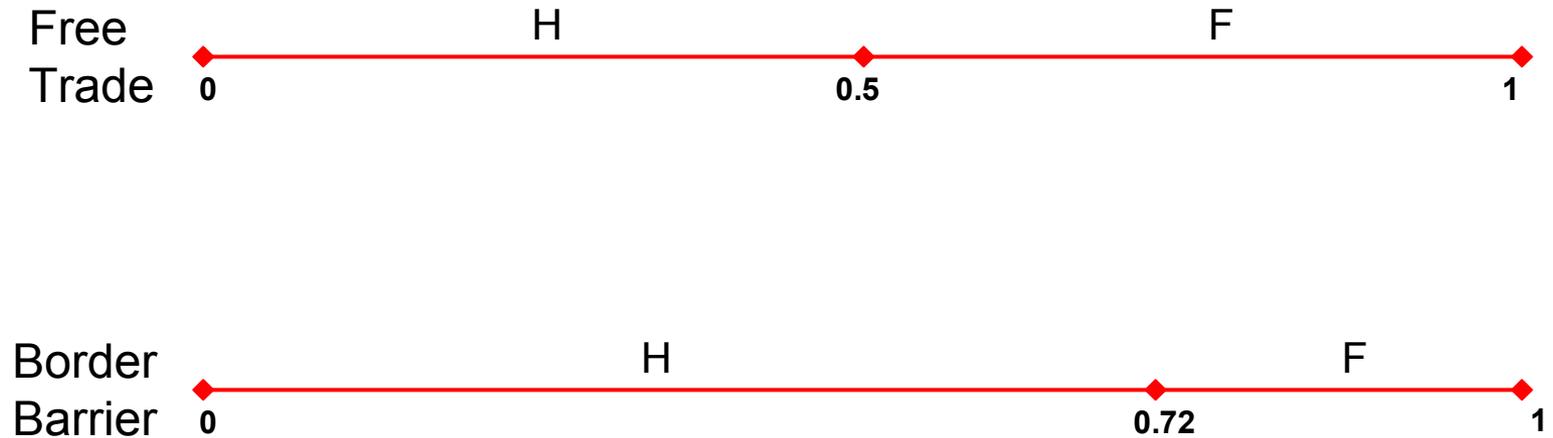


Figure 4

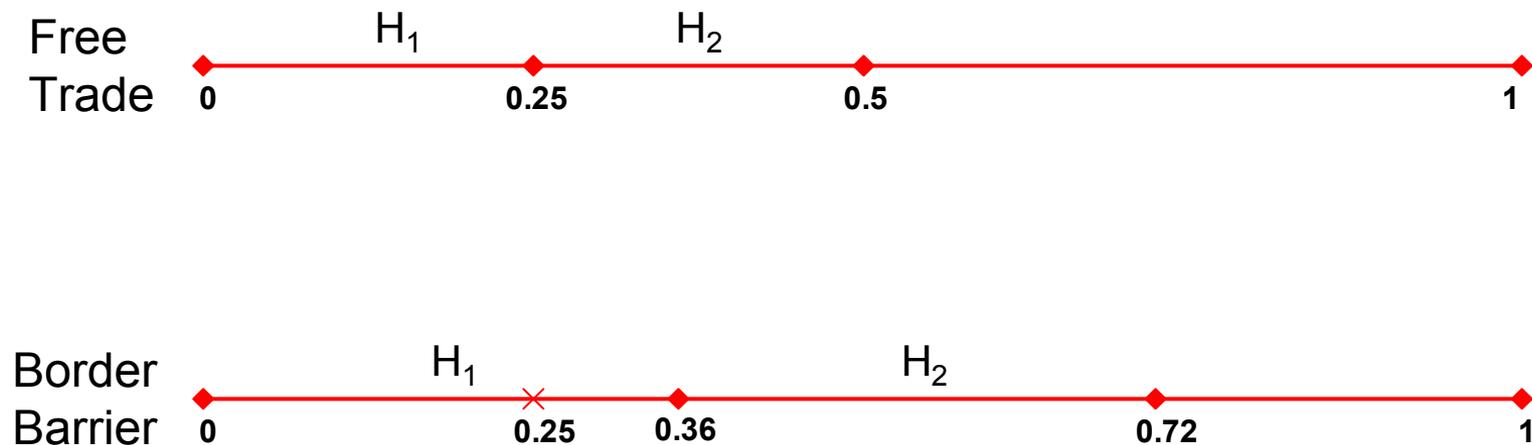
# International Production Specialization: Standard model



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

Figure 5

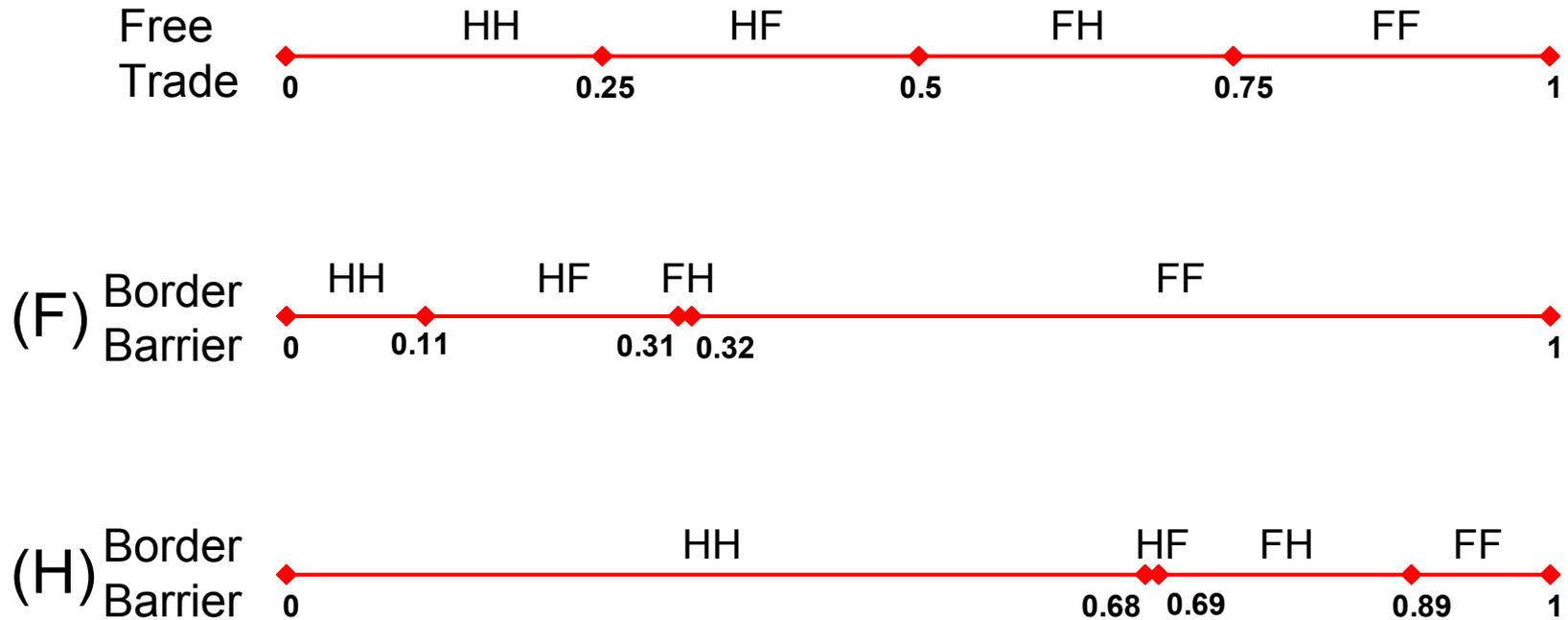
# Intra-national Production Specialization: Standard model



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

Figure 6

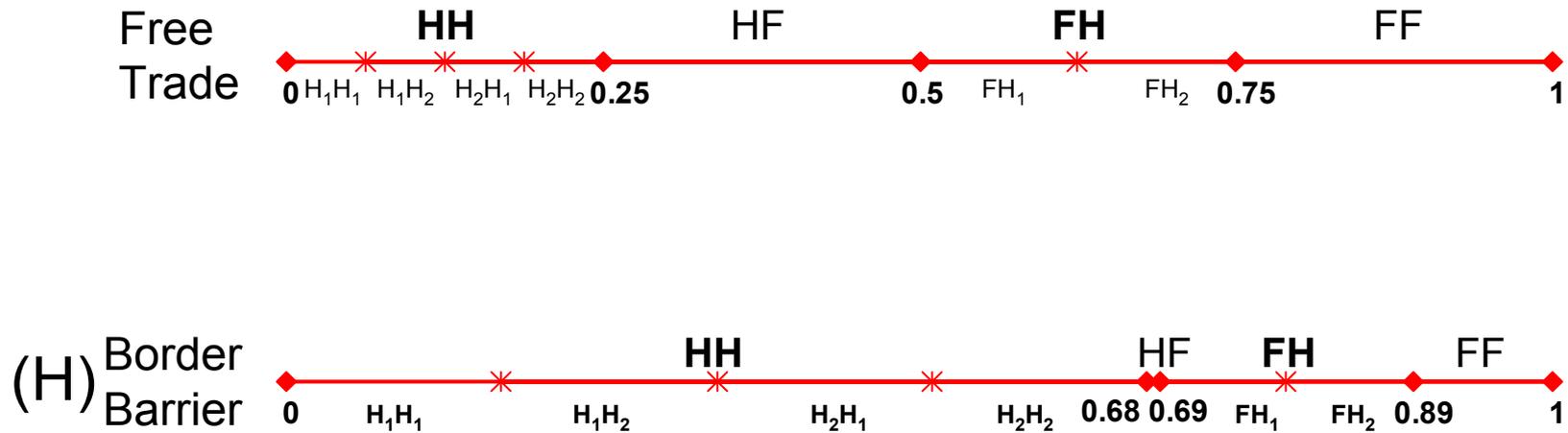
# International Production Specialization: Vertical specialization model



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

Figure 7

# International Production Specialization: Vertical specialization model



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

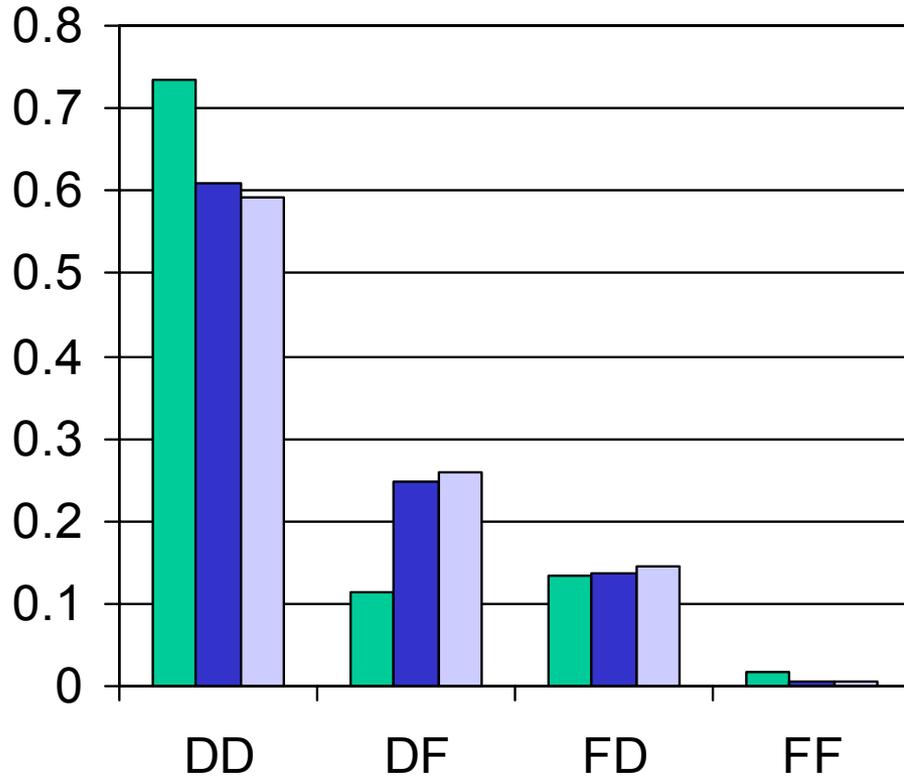
Figure 8

# Decomposition of Vertical Specialization Exports Implied by Model

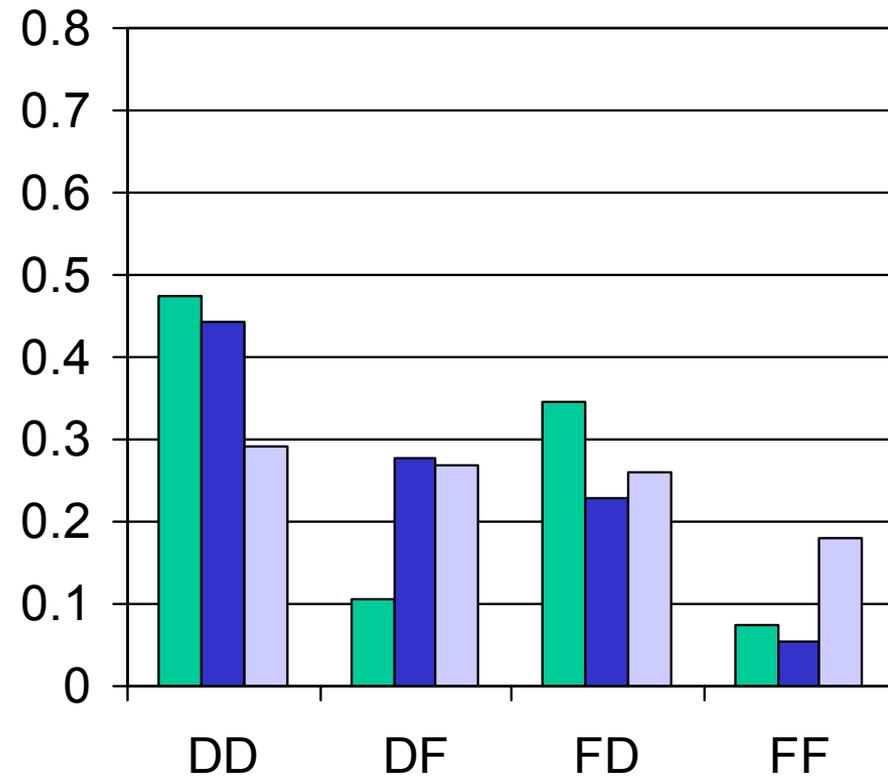
1963

1987

Share of Total



Share of Total



■ Data

■ Model: Elasticity = 10, border barrier = 10% (1963), 5% (1987)

■ Model: Elasticity = 5, border barrier = 20% (1963), 5% (1987)

**TABLE 1**  
**VERTICAL SPECIALIZATION AT THE STATE LEVEL**

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

**TABLE 2**  
**SPECIFICATION FOR TWO EXERCISES**

---

**Specification for U.S.-Canada Border Effect Exercise**

**Labor**

Canada	1
U.S.	10

**Elasticities**

**5                      10**

Elasticity = 5

Elasticity = 10

**Technology parameter**

Canada	0.100	0.100
U.S.	1.000	1.000

---

**Specification for Washington Vertical Specialization Decomposition Exercise**

**Labor**

Washington	1
Rest-of-U.S.	49
OECD (each region)	50

**Elasticities**

**5                      10**

Elasticity = 5

Elasticity = 10

**Technology parameter**

Washington	0.030	0.035
Rest-of-U.S.	1.400	2.000
OECD (each region)	1.000	1.000

---

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

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	<b>Anderson/ Van Wincoop Estimates</b>	<b>Calibrated Eaton/Kortum Model</b>	<b>Calibrated Eaton/Kortum Model</b>
		<b>elasticity=5</b>	<b>elasticity=10</b>
<b>Border barrier that generates Canada border effect = 10.5</b>		37.4%	16.8%
<b>Ratio of Trade Under Estimated Border Barriers to that under Borderless Trade</b>			
Canada-Canada	<b>4.31</b>	5.63	5.64
U.S.-Canada	<b>0.41</b>	0.54	0.54
U.S.-U.S.	<b>1.05</b>	1.23	1.14
<b>Border Effect</b>			
Canada	<b>10.50</b>	10.49	10.52
U.S.	<b>2.56</b>	2.29	2.12

---

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**

	<b>Anderson/ Van Wincoop Estimates</b>	<b>Calibrated Eaton/Kortum Model</b>	<b>Calibrated Vertical Specialization Model</b>
<b>ELASTICITY = 5</b>			
<b>Border barrier that generates Canada border effect = 10.5</b>	48.4%	<b>37.4%</b>	<b>20.1%</b>
<b>Ratio of Trade Under Estimated Border Barriers to that under Borderless Trade</b>			
Canada-Canada	4.31	5.63	4.78
U.S.-Canada	0.41	0.54	0.45
U.S.-U.S.	1.05	1.23	1.25
<b>Border Effect</b>			
Canada	10.50	10.49	10.54
Canada (border barrier = 20.1%)		4.22	
U.S.	2.56	2.29	2.75
<b>ELASTICITY = 10</b>			
<b>Border barrier that generates Canada border effect = 10.5</b>	19.2%	<b>16.8%</b>	<b>9.2%</b>
<b>Ratio of Trade Under Estimated Border Barriers to that under Borderless Trade</b>			
Canada-Canada	4.31	5.64	4.76
U.S.-Canada	0.41	0.54	0.46
U.S.-U.S.	1.05	1.14	1.16
<b>Border Effect</b>			
Canada	10.50	10.52	10.56
Canada (border barrier = 9.6%)		4.15	
U.S.	2.56	2.12	2.76

Note: Vertical specialization model solved numerically. See text for details.  
Results are averages over 50 simulations of model.

**TABLE 5**  
**VERTICAL SPECIALIZATION IMPLICATIONS**  
**Calibrated Vertical Specialization Model**

---

			<b>Vertical Specialization (share of exports)</b>
<b>ELASTICITY = 5</b>			
<b>Vertical Specialization (share of exports)</b>			
<b>Canada</b>			
	Data		<b>27.0%</b>
	Model	Free Trade	<b>35.0%</b>
		Border Barrier = 20.1%	<b>1.1%</b>
	Extended Model	Free trade	<b>54.0%</b>
		Border Barrier = 37.4%, 10%	<b>20.1%</b>
 <b>ELASTICITY = 10</b>			
<b>Vertical Specialization (share of exports)</b>			
<b>Canada</b>			
	Data		<b>27.0%</b>
	Model	Free Trade	<b>35.6%</b>
		Border Barrier = 9.2%	<b>1.5%</b>
	Extended Model	Free Trade	<b>53.9%</b>
		Border Barrier = 16.8%, 4.6%	<b>21.2%</b>

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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