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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. In the context of the standard trade models, the large "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 puzzle based on vertical specialization, which occurs when regions or countries specialize only in particular stages of a good's production sequence. I develop a Ricardian model of intra-national and international trade, and show how endogenous vertical specialization magnifies the effects of border barriers such as tariffs. I calibrate the model to match relative wages, trade shares, and vertical specialization for the U.S. and Canada. The model implies a much smaller border barrier and border effect than previous estimates.

JEL Classification code: F1

Keywords: border effect, home bias in consumption, trade costs, U.S.-Canada trade, vertical specialization

1 Introduction

It is taken for granted that barriers to the flow of goods, services, assets, and information continue to fall with the passage of time. Virtually all of the data on these flows support this presumption. Despite this trend, however, there is a large body of empirical research that indicates that barriers at national borders are still large. This research has found 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 barriers at the national border.[1]

These findings are known as the border effect puzzle, because, in the context of the workhorse models of international trade, the 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, a pair of nations with a free trade agreement, with the world's largest bilateral trade flows, and whose border effect has received the most attention. One of the most theoretically consistent estimates of the border effect for Canada is by Anderson and van Wincoop (2003). Their estimate, 10.5, implies that with an elasticity of five, the tariff equivalent of the barrier at the U.S.-Canada border is 48 percent. Existing measures of tariff rates and transport costs between the United States and Canada suggest that, taken together, they are less than five percent; thus, unobservable border barriers need to be about 43 percent in order to explain the border effect![3] It seems difficult to imagine barriers that high between the

[1]McCallum (1995) was the first to find this effect. Other research includes that by Wei (1996), Helliwell (1998), Anderson and Smith (1999), Nitsch (2000), Head and Mayer (2002), Evans (2003), Anderson and van Wincoop (2003), Chen (2004), and Combes *et al* (2005). Most of this research focuses on merchandise trade. Obstfeld and Rogoff (2001) state 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 workhorse models include the monopolistic competition model, the Ricardian model, the Heckscher-Ohlin model, as well as the models built around the Armington aggregator.

[3]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. With an elasticity of 8, the tariff equivalent of the border barrier is 26 percent, implying an unobservable border barrier of 21 percent.

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.

United States and Canada.[4] Moreover, it seems difficult to reconcile these high barrier numbers with the presence of a highly integrated automobile market between the United States and Canada, a market that accounts for about 3/10 of U.S.- Canada trade.

In this paper, I propose a resolution to the puzzle based on vertical specialization. Vertical specialization involves the interconnectedness of production processes in a sequential, vertical trading chain stretching across multiple countries and regions, with each country or region specializing in particular stages of a good's production sequence. Previous research has documented the increasing empirical importance of international vertical specialization.[5] There is evidence as well as good reason to expect that vertical specialization is more prevalent at the intra-national level.

I develop a model of intra-national and international trade with endogenous vertical specialization that draws from the model developed in Yi (2003).[6] The core part of the model involves Ricardian productivity-based comparative advantage with a continuum of goods in which each good is produced in two stages. The primary extension beyond Yi (2003) is that the fundamental geographic unit is a region within a country, rather than a country. For a special case of the model, I derive an analytical expression for the border effect and contrast it with the analogous expression from a standard trade model in which production occurs in just one stage. When there is vertical specialization, the border effect is a power of the standard border effect, where the power is increasing in the share of first stage goods used in second stage production. The special case facilitates the intuition for how vertical specialization magnifies the effects of national border barriers.

In the standard trade model, high border barriers imply a large border effect – the ratio of intra-national trade to international trade (normalized by the ratio under free trade) – via the usual mechanism that the cost of imported goods is high, so households spend more on domestically produced goods and less on imported goods. In a model with endogenous vertical specialization, there are two additional, mutually reinforcing, mechanisms by which border barriers impact the border effect. The first mechanism can be conveyed via the following intuition. Goods are produced in multiple, sequential stages. Suppose that in the absence of border barriers, the United States specializes in the odd-numbered stages and Canada specializes in the even-numbered stages. There

[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) survey estimates of the border barriers due to differences in language, currency, information, and security; some of these estimates are large, but it is likely that these barriers are lower for U.S.-Canada interactions.

[5] See section 2.

[6] Yi (2003) shows that vertical specialization can help explain the growth of world trade.

is a great deal of international "back and forth" or vertically specialized trade. Now, suppose a border barrier between the United States and Canada is introduced. Now, 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 the standard, one-stage-of-production, model. In addition, a key insight from Anderson and van Wincoop (2003), hereafter, 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. Hence, because of both larger intra-national trade, and smaller international trade, the border effect is larger.

The second mechanism can be conveyed by the following example. Suppose, at existing border barriers, the lowest cost automobiles for U.S. consumers are produced in Canada, from U.S.-made parts. That is, the cheapest production method involves engines, tires, and other parts produced in the United States, and then exported to Canada where the parts are assembled into the automobile, which is then exported back to the United States. Also, suppose that the second cheapest production method is for parts production and assembly to occur in the United States. Because both production methods involve parts produced in the United States, the assembly stage is the "marginal" production stage. Then 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. Because this cost is a fraction of the total cost of the good, yet the border barrier is applied to the total cost, the "effective" border cost is magnified.

I then use the model to quantitatively assess the magnitude of border barriers and border effects. Specifically, I calibrate a two-country, two regions per country model to the United States and Canada in 1990. I calibrate the key parameters – international trade costs and the mean level of productivity – so that the model generates implications for Canadian wages, trade shares, and vertical specialization that match the data. From these trade costs and productivity, border barriers and the border effect can be inferred. I find that both the U.S.-Canada border barrier and Canada's border effect are relatively small. When the relevant elasticity is five, the import-weighted trade barrier is about 23 percent, and the border barrier is about 19 percent. This border barrier generates a larger border effect owing to the presence of vertical specialization, but the border effect is still not large – around five. The border barrier and border effect numbers are less than one-half of those in AvW and other research.

Vertical specialization plays a key role in the quantitative results. Currently, Canada has a good deal of international vertical specialization. Because the effect of border barriers is magnified under vertical specialization, the only way to explain the data in the context of the model is for at least some goods to face very low border barriers. Based on the importance of multinationals in U.S.-Canada trade, I specify that one-third of the goods face low trade barriers. Because these goods already face low barriers, the increase in international trade predicted by the model from the elimination of border barriers is more limited – which implies a smaller border effect.

There is a broader way to interpret the role of vertical specialization. The key is that it is endogenous and responds to changes in border barriers. The source of the endogeneity is that goods are produced in sequential, tradable stages, and regions vary in their efficiency in producing them. In the usual trade models, production occurs in just one stage. Of course, this is not taken to be literally true; rather, the production function can be thought of as a "reduced form" amalgam of a multiple stage process. However, the maintained assumption is that the nature of production – the mapping of production stages to regions, for example – is invariant to changes in trade costs. In other words, changes in border barriers may alter which country or region produces the (entire) good, but there is no change in the underlying nature of production. For many research questions this assumption is appropriate. However, in the context of the border effect puzzle, this paper shows that the assumption leaves out forces that are quantitatively important. The reduced form production function does change in response to changes in trade costs; this is the source of the magnification effect.

There are several related papers on explaining the border effect. Evans (2003b) and Chaney (2005) focus on fixed costs of exporting.[7] Chaney's framework also includes 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. Head and Mayer (2002) focus on appropriately measuring internal distance, Combes *et al* (2005) examine the effects of business and social networks, and Hillberry and Hummels (2005) emphasize the importance of co-location. Rossi-Hansberg (2004) presents a model with intermediate and final goods, an agglomeration externality, and endogenous firm location. The latter drives endogenous changes in productivities, which also helps to magnify the effects of border barriers. Most of these explanations are at least partially successful in reconciling large border effects with

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

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 magnifies border barriers into a large border effect. 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 intra-national vertical specialization is quantitatively important. 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.[8] 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:

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

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

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.[9] 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.

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). FF is the vertical specialization that HIY document (and will be referred to as "international" vertical specialization later in this paper). 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.

[9] 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 data presented above are consistent with the idea that vertical specialization is important in understanding the border effect. Trade flows between countries are subject to national border barriers; consequently, opportunities for international vertical specialization are more limited, but opportunities for intra-national vertical specialization are 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.[10]

The basic geographic unit is a region. Countries consist of more than one region. 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 I^2 possible production patterns, where I is the total number of regions, 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 and intermediates:

$$y_1^i(z) = (A_1^i(z) l_1^i(z))^{1-\theta_1} m_1^i(z)^{\theta_1} \qquad z \in [0, 1] \tag{2}$$

where $A_1^i(z)$ is region i's total factor productivity associated with stage-1 good z, and $l_1^i(z)$ and $m_1^i(z)$ are region i's labor and intermediate inputs used to produce $y_1^i(z)$. The share of intermediates in production is θ_1. $y_1(z)$ has two uses: it is used as an input into the production of itself ($m_1^i(z)$) or the stage-2 good z. $m_1^i(z)$ captures the idea that corn is needed to produce corn, or, more generally,

[10]In all three models, changes in trade occur along the extensive margin. Hillberry and Hummels (2005) provide detailed micro-evidence supporting this feature.

the circular nature of input and output.[11]

Stage 2 goods are produced from labor and stage 1 output, also in a nested Cobb-Douglas production function:

$$y_2^i(z) = \left(A_2^i(z) l_2^i(z)\right)^{1-\theta_2} x_1^i(z)^{\theta_2} \qquad z \in [0,1] \tag{3}$$

where $x_1^i(z)$ is region i's use of $y_1(z)$ for stage-2 production, $A_2^i(z)$ 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 $y_2^i(z)$. The share of intermediates for this stage is θ_2.

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 $1/(1+d_{ij}) < 1$ units arrive in region j. The gross ad valorem tariff equivalent of this transport cost is $1 + d_{ij}$. 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.[12] Consequently, I assume the gross 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). I adopt a key part of the framework, which is the use of the Frechét distribution as the probability distribution of total factor productivities:

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

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.[13]

[11] The first stage of production in this model differs from that in Yi (2003) in its inclusion of intermediates. This facilitates matching both gross production and trade, and value-added (GDP). Eaton and Kortum (2002) employ an analogous input-output structure, although it is at the aggregate level.

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

[13] 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. This 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.

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:

$$p_1^i(z)y_1^i(z) - w^i l_1^i(z) - p_1^i(z)m_1^i(z) \tag{5}$$

where $p_1^i(z)$ is the factory gate price of $y_1^i(z)$, and w is the wage rate.[14]

Stage-2 firms maximize:

$$p_2^i(z)y_2^i(z) - w^i l_2^i(z) - (1+d_{ji})(1+b_{ji})p_1^j(z)x_1^i(z) \tag{6}$$

assuming the cheapest source of stage-1 inputs is region j. $p_2^i(z)$ is the factory gate price of $y_2^i(z)$.

3.2 Households

The representative household in region i maximizes:

$$\int_0^1 \ln(c^i(z))dz \tag{7}$$

subject to the budget constraint:

$$\int_0^1 p^i(z)c^i(z)dz = w^i L^i \tag{8}$$

where $c^i(z)$ is consumption of good z, and $p^i(z)$ is the price, inclusive of transport and border costs, that the household pays for good z. For example, if good z is produced in region j, $p^i(z) = p_2^j(z)(1+d_{ji})(1+b_{ji}) \equiv p_2^j(z)(1+\tau_2^i(z))$, where $1+\tau_2^i(z)$ is the total trade cost incurred in shipping the stage-2 good z from its production location to region i.

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.

[14] I assume there are no transport costs for the stage 1 goods used as intermediates to produce more stage 1 goods.

3.3 Equilibrium

All factor and goods markets are characterized by perfect competition. The following market clearing conditions hold for each region:[15]

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

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

$$y_1(z) - \sum_{i=1}^{I} m_1^i(z) \equiv \sum_{i=1}^{I} (y_1^i(z) - m_1^i(z)) = \sum_{i=1}^{I} (1 + \tau_1^i(z)) x_1^i(z) \tag{10}$$

where $1+\tau_1^i(z)$ is the total trade cost incurred by shipping the stage-1 good from its production location to region i. A similar set of conditions apply to each stage-2 good z:

$$y_2(z) \equiv \sum_{i=1}^{I} y_2^i(z) = \sum_{i=1}^{I} (1 + \tau_2^i(z)) c^i(z) \tag{11}$$

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,* $\{p_1^i(z), p_2^i(z), w^i\}$*, and quantities* $\{l_1^i(z), l_2^i(z), m_1^i(z), y_1^i(z), y_2^i(z), x_1^i(z), c^i(z)\}$, $z \in [0,1]$, $i = 1, ...\mathbf{I}$*, such that the first order conditions to the households' maximization problem 7, the first order conditions to the firms' maximization problems 5 and 6, as well as the market clearing conditions 9,10, and 11, are satisfied.*

3.4 Border Barriers, Vertical Specialization, and Border Effects

Under free trade and zero transport costs, there will be complete specialization. Each stage of each good will be produced by only one region. Intra-national and international trade will occur so that agents will be able to consume all goods. Under either transport costs or border barriers, complete specialization may no longer occur. A stage of a good may be produced in more than one region. If the transport costs and border barriers are high enough, autarky will occur, and each region will produce every stage of every good.

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

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

productive in the first stage of production and another region to be relatively more productive in the second stage. Under free trade and zero transport costs, if relative wages are "between" these relative productivities, then this necessary condition is also sufficient.

3.4.1 Border Effects in the Standard Model

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 for a special case of the model with two countries, two regions per country, one stage of production, no intermediate goods, and zero transport costs. This is just the DFS model extended to include two regions per country. To facilitate the discussion, I consider a symmetric case. I assume that the regions in each country have the same labor endowment and their (total factor) productivities are drawn from the same distribution. This implies that wages and GDPs are equalized between regions within a country.

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:

$$(1 - \underline{z}^h)w^h L^h \tag{12}$$

where $\underline{z}^h$ is the cutoff z that separates home and foreign production for the home market. The home country produces all goods on the interval $[0, \underline{z}^h]$ and imports all goods on the interval $[\underline{z}^h, 1]$. $w^h L^h$ is home country GDP. See Figure 3. The foreign country produces all goods on the interval $[\underline{z}^f, 1]$ and imports all goods on the interval $[0, \underline{z}^f]$; consequently, foreign international imports is given by $\underline{z}^f w^f L^f$. Intra-national imports in the home country is given by:

$$\frac{\underline{z}^h w^h L^h}{2} \tag{13}$$

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

Following AvW, I define the border effect as follows:

$$BorderEffect = \frac{Intra_b / Intra_0}{Inter_b / Inter_0} \tag{14}$$

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:

$$\frac{Intra_b/Intra_0}{Inter_b/Inter_0} = \frac{\underline{z}_b/\underline{z}_0}{(1-\underline{z}_b)/(1-\underline{z}_0)} \tag{15}$$

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 $\underline{z}_b/\underline{z}_0$.

At this point, I make a further symmetry assumption, which is that the regions across countries are also identical in terms of both labor endowments and productivities. This assumption implies that wages and GDPs are equalized across countries, and relative wages and GDPs (across countries) are invariant to border barriers. Assuming the productivities follow a Frechét distribution, the relative productivities will have the following functional form:

$$A^r(z) \equiv \frac{A^h(z)}{A^f(z)} = \left(\frac{1-z}{z}\right)^{\frac{1}{n}} \tag{16}$$

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.[16] As discussed above, n is analogous to an elasticity in that a larger n implies a flatter or more "elastic" $A^r(z)$. In the appendix, I show that the solution for $\underline{z}$ is given by:

$$\underline{z} = \frac{(1+b)^n}{1+(1+b)^n} \tag{17}$$

It is easy to see that under free trade, $\underline{z}_0^h = \underline{z}_0^f = 0.5$; international exports and imports equal one-half of GDP. The denominator of the border effect (international trade under border barriers divided by international trade under free trade) is:

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

This is clearly decreasing in the border barrier; 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

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

$n = 10$. Then, $\underline{z_b} = .722$ (see Figure 4) and the denominator of the border effect = .56, which means that when border barriers are 10 percent, international trade is 44 percent less than it would be under free trade.

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

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

This is increasing in the border barrier – 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 percent. (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:

$$(1+b)^n \tag{20}$$

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.

3.4.2 Border Effects in the Vertical Specialization Model

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 a special case. It introduces two stages of production and vertical specialization in a somewhat awkward way, but it has the virtue of yielding an analytical expression for the border effect. 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 ensures there is vertical specialization with only one set of Frechét productivities compared across regions and countries for each good, which means much of the analysis from the previous sub-section 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.[17] I also assume that the share of intermediates in stage-1 and stage-2 production is identical, $\theta_1 = \theta_2 = \theta$.

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. International imports for the home country is now given by $(1+\theta)(1-\underline{z}^h)wL$; 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:

$$\underline{z}^h = \frac{(1+b)^{n\left(\frac{1+\theta}{1-\theta}\right)}}{1+(1+b)^{n\left(\frac{1+\theta}{1-\theta}\right)}} \tag{21}$$

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

$$\frac{2(1+b)^{n\left(\frac{1+\theta}{1-\theta}\right)}}{1+(1+b)^{n\left(\frac{1+\theta}{1-\theta}\right)}} \text{and} \ \frac{2}{1+(1+b)^{n\left(\frac{1+\theta}{1-\theta}\right)}} \tag{22}$$

Hence, the overall border effect is:

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

This expression differs from (20) by the presence of the $\left(\frac{1+\theta}{1-\theta}\right)$ term in the exponent. The term shows clearly that (endogenous) vertical specialization magnifies the effects of border barriers. There are two mechanisms underlying the $\left(\frac{1+\theta}{1-\theta}\right)$ exponent. The first mechanism is the multiple

[17] 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 countries' regions and likewise for stage 2 production. Two of these production methods involve intra-national vertical specialization.

border crossing force. With the HF production process, the first stage encounters a border barrier twice; recall that the share of stage-1 goods in stage-2 production is θ. Consequently, the total effect of the barrier is $1+\theta$. The second mechanism draws 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, in a model with multiple stages of production, the marginal production process could be the production process for one particular stage, while in a standard model, the marginal production process is always the production process for the entire good. Hence, 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. This explains the $1-\theta$ term.

Another way to explain the exponent is via the following decomposition. In the HF production process, 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 $(1+b)^{\frac{\theta}{1-\theta}}$. A border barrier is encountered again when the final good is shipped back to the home country from the foreign country. The border barrier is applied to the entire good. Consequently, a barrier of $1+b$ imposed on the entire HF-produced good is effectively a barrier of $(1+b)^{\frac{1}{1-\theta}}$ on the second stage of production.[18] The total effect is the product of these two forces. If the border barrier rises, the cost of producing (internationally) vertically specialized goods rises by a multiple of the barrier.

There are two more points worth making. The greater the share of stage-1 goods used in stage-2 production, that is, the greater the fraction of the final good that crosses the border multiple times, i.e., θ, the larger the magnification effect. Also, the key to the magnification effect is that vertical specialization is endogenous; in the model, there are alternative, non (internationally) vertically specialized production processes that become relatively more efficient as border barriers rise. That the model delivers changes in the *nature* of production and specialization as barriers change is what gives the model "kick" relative to the frameworks employed by AvW or EK, for example.

Using the same numerical example as in the previous sub-section 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 endogenous vertical specialization.

Increasingly, countries apply tariffs only to the value-added that occurs abroad. These arrangements tend to arise specifically to increase opportunities for vertical specialization. When tariffs

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

are applied only to value-added, no part of the final good is taxed more than once. However, from the above discussion, it should be clear that even under value-added tariffs, the multiplicative effect still holds. This is because stage 2 is still the marginal stage, and even if a tariff is levied on the final good only once, that tariff is still a multiple of the barrier applied to the second stage. To a first approximation, the exponent that multiplies n becomes $\left(\frac{1}{1-\theta}\right)$. See the appendix for the derivation of the border effect in this case.

The above discussion has focused on a special case of the model. In the general case, in which the locations of both stage-2 and stage-1 production are endogenous, the margins described by the special case, i.e., HH vs. HF, will arise only for a fraction of the goods. For the other goods, the margins will not involve the two forces described above. One way of thinking about the model, then, is that it is a combination of the special case with its magnified border effect and other cases in which the border effect is the standard one. Consequently, in the general model, the overall effect is magnified, but the extent of the magnification is smaller than what is given by (23).

Summarizing, the discussion above 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 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 (22). International trade decreases by more because of the two mechanisms discussed above: 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.

4 Model Calibration and Solution

I now assess the quantitative importance of vertical specialization in the border effect puzzle. One possible exercise would be to take the estimated border effects from the literature as facts to be explained, and calculate the border barrier in the vertical specialization model that generates that border effect. The goal would be to demonstrate that in a model with vertical specialization, a smaller border barrier is needed to generate a given border effect.[19] However, this exercise is not completely appropriate, because the estimated border effects are model-specific. Consequently, I use my model to calculate both border barriers and border effects for U.S.-Canada trade.

I employ a two country model with two regions per country. This is probably realistic for Canada, as the United States is by far its largest trading partner. This is one reason why I focus on Canada's (as opposed to the United States') border effect.[20] The other reason is that Canada's border effect has generated the most attention in the empirical literature.

In three successively more detailed simulations, I parameterize the model, and then solve for the overall international trade barriers $\tau_{US-Canada}$ and productivities T_{Canada} to match relative wages, trade, and/or vertical specialization between the U.S. and Canada in 1990. Relative wages and trade are key variables to which all other price and quantity variables are linked. I choose 1990, because McCallum's original paper focuses on that year, and because the latest year for which the OECD has Canada input-output tables – the source of the international vertical specialization numbers – is 1990. Then under different assumptions about transport costs, I solve the model when there are no border barriers, which enables me to generate an estimate of Canada's border effect. This section describes these steps in detail.

4.1 Calibration

I first describe the parameters and variables that are drawn directly from the data. Second, I discuss the wage, trade, and vertical specialization data and their values that are used to pin down the key parameters, the τ's and the T's.

4.1.1 Parameters and Variables from the Data

Table 1 in EK indicates that, in 1990, human-capital adjusted manufacturing labor in the United States was 11.5 times greater than in Canada. The unadjusted labor force was about 10.2 times greater. I set Canada's labor force to be 0.09 of that of the United States.[21] In the first two

[19] Indeed, in previous versions of this paper, I conducted such an exercise. The main result is that the vertical specialization model can generate the same border effect with a border barrier about half as large as would be required in a standard model.

[20] Note that AvW estimated a two-country model and a multi-country model and the estimates and border effect implications are quite similar.

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

simulations, the regions within each country are assumed to be symmetric. In the third simulation, I divide Canada into two asymmetric regions, Ontario-Quebec (OQ) and the rest of Canada (ROC). From Statistics Canada's labor force survey estimates, employment in OQ in 1990 was 63.7 percent of total employment.[22] Consequently, OQ's labor force is set to 0.057 of the U.S. labor force, and ROC's labor force is set to 0.033 of the U.S. labor force.

I focus on a single value of the heterogeneity in productivity parameter n, 4, which corresponds to an elasticity of substitution in monopolistic competition or Armington aggregator models of 5. (Hereafter, I refer to the elasticity-equivalent of the parameter.) This elasticity is identical across regions and countries. This value is on the low end of the estimates reported by EK; their primary estimates range from $n = 3.6$ to $n = 12.86$. Most of AvW's results are presented for elasticities of 5, 8, and 10. One reason I choose a lower elasticity is because of the result from the previous section that, under vertical specialization, the responsiveness of trade to border barriers depends on both the elasticity of substitution and the "magnification effect". Consequently, existing estimates of the substitution elasticity may be upwardly biased. In some of the sensitivity analysis, I examine an elasticity of 10.

Two other key parameters are the intermediate shares, θ_1 and θ_2. When $\theta_1 = \theta_2 = \theta$, it can be shown that the value-added/gross output ratio is $1 - \theta$. The first version of the OECD input-output tables, published in 1995, indicate that for Canada in 1990, the value-added/gross output ratio for merchandise was 39 percent. The latest OECD STAN database indicates that the value-added/gross output ratio in 1990 was 37 percent. I use the average of these two numbers and set both θ_1 and $\theta_2 = 0.62$.

Distance has been shown time and again to matter significantly in explaining bilateral trade patterns. Distance will be my proxy for transportation costs d. There are three transportation costs to calibrate, within Canada costs, within U.S. costs, and between Canada-and-U.S. costs. Using the province-to-province, state-to-province, and state-to-state trade flow data, as well as the corresponding distance data, from AvW, I construct trade-weighted average measures of internal distance for Canada and for the United States, as well as of the distance between Canada and the United States.[23] I find that internal distances within Canada and within the United States are

[22] See Statistics Canada Table 282-0002.

[23] I include within state and within province distance as part of the calculations. Including these distances is important, because the single largest destination for shipments for most states and provinces is itself. Head and Mayer (2002) present a detailed discussion of measuring distance. Their main point is that the usual measures of internal distance tend to over-estimate effective distance, because they ignore the fact that that firms endogenously

about the same: 639 kilometers and 748 kilometers, respectively. In addition, the distance between the United States and Canada is calculated to be 1167 kilometers.

The fact that the two internal distances are very similar is convenient, because it suggests that the within-country transport costs are similar, and because of the following theoretical point made by AvW: A proportionate increase in transport costs in all regions (including costs within regions) does not affect trade flows. This is because what matters for bilateral trade flows is the bilateral barrier relative to the barriers with the rest of the world that each country faces. If all transport costs, including within-region costs, increase proportionately, then the relative barrier is unaffected. Hence, with no loss of generality, I set the within-country transport costs to be zero, and I re-interpret the international transport costs as costs relative to the within-country costs.

These costs must now be specified. The empirical literature provides numerous estimates of the tariff equivalents of distance. EK estimate for OECD countries the effects of distance on trade using a step function in which the effects of distance are constant within each of six intervals, but differ between intervals. The smallest distance interval is 375 miles, which is greater than the difference between internal and cross-country distance for the United States and Canada. In EK, the marginal distance cost of going from a distance interval of [0, 375] miles to [375, 750] miles is 15.0 percent under an elasticity of five. Anderson and van Wincoop (2004) estimate the distance barrier between the United States and Canada to be 29 percent when the elasticity is five. However, as noted above for border effects, the estimates of trade costs owing to distance are model-specific. As my model is different from EK and AvW, it should produce different estimates of distance costs.[24]

An important point is that the larger the measure of international distance, i.e., the larger the international transport cost, the *smaller* the implied border barrier. This is because solving the

choose to locate near each other. I follow an approach given on p. 11 of Head and Mayer (2002) in measuring internal distance of a province or state as $0.67 \times \sqrt{area/\pi}$. The resulting number for Canada is close to the result obtained in a very detailed calculation by Helliwell and Verdier (2001).

[24] In addition, AvW's estimates of trade costs due to distance could be biased upwards for the following reason. For measuring within U.S. trade flows, they relied on the 1993 Commodity Flow Survey (CFS). These flows include both merchandise and wholesale shipments. Often, the wholesale shipments are shipments from the warehouse to the retailer, and hence, should not be counted. Unfortunately, it is not possible to separate these data out. Consequently, AvW apply an aggregate shrinkage factor to the total commodity flows to match that number with U.S. gross output in merchandise. However, wholesale shipments tend to be short distance, while merchandise shipments tend to be long distance. This means that the short-distance shipments are reduced too little and the long-distance shipments are reduced too much, leading to an upward bias in the (absolute) magnitude of the distance/trade relationship. I thank David Hummels for pointing this out to me.

model will generate an implied international trade cost τ.Because $(1 + \tau) = (1 + d)(1 + b)$, the larger is d, the smaller will be b. In other words, the more of the (normalized) intra-national to international trade ratio that can be attributed to distance, the less that can be attributed to the border barrier.

Consequently, I adopt what I think is a conservative approach. In the baseline analysis, I set the international (relative to intra-national) distance cost to be 5 percent. This number is considerably smaller than the AvW number and the number that would be implied by other papers based on the U.S. and Canada intra-national and international distances. To the extent this is an underestimate of the true U.S.-Canada distance cost, I will overestimate the border barrier, the border effect, and the increase in trade that will result if the border barriers are eliminated. In some sensitivity analyses, I examine the consequences of a 10 percent distance cost.

In the second and third simulations, I introduce heterogeneous trade costs across goods by specifying that some of the goods face low trade barriers, while the remainder face high trade barriers. There are two main motivations for introducing this heterogeneity. First, much of the empirical research that estimates industry-level border effects finds considerable variation in these border effects across industries. See, for example, Helliwell (1998) and Hillberry (2002). Second, the data show that at least half of U.S.-Canada trade is mediated by multinationals; in particular, trade involving Canadian affiliates of U.S. parents accounted for 45 percent of U.S. (merchandise) imports from Canada and 48 percent of U.S. merchandise exports to Canada in 1990. In addition, another 10 percent of U.S. trade involves U.S. affiliates of Canadian parents. It is plausible that multinational-mediated trade faces lower trade costs than arms length trade.

Five key industries – motor vehicles, primary metals, fabricated metals, non-electrical machinery, and electrical machinery (including electronics) – account for most of the multinational trade. For example, in 1990, they accounted for 84.5 percent of all U.S. imports from Canadian affiliates.[25] These industries accounted for 39 percent of all Canadian manufacturing shipments in 1990. Manufacturing, in turn, accounts for about 80 percent of all merchandise shipments. In addition, the mining industry, which for years has consisted primarily of petroleum production and export to the United States, does not appear to face large trade costs. Taken together, the evidence suggests that at least one-third of the goods that Canada produces face low barriers. That is the number I

[25] These industries also appear to be playing a key role in vertical specialization, as they accounted for 85 percent of U.S. manufactured exports to Canada "shipped for further manufacture." This provides more support for the presumption that these industries face low trade costs.

use. In the simulation involving OQ and ROC, I use this number for each province. The five above-mentioned manufacturing industries are dominant in OQ, accounting for 88 percent of Canada's shipments, while mining is dominant in ROC.[26]

4.1.2 Variables Used to Calibrate Trade Costs and Productivities

Wages

According to EK, Canada's manufacturing wage was 0.88 of the U.S. wage in 1990. In the third simulation, in which I divide Canada into OQ and ROC, I assume that both regions have the same wage.

Trade shares

The average of Canada's export share of merchandise GDP in 1990 from the OECD input-output tables and from the most recent vintage of the OECD's STAN database for Canada is 0.91.[27] In the simulation with OQ and ROC, I use the most recent OECD STAN data for Canada, and the Statistics Canada publications "Interprovincial Trade in Canada, 1984-1996," and "Provincial Gross Domestic Product by Industry, 1984-1999" to impute the OQ and ROC share of merchandise GDP. I calculate that the OQ export share is 0.962, and the ROC export share is 0.796.

Vertical specialization

According to HIY, the vertical specialization share of merchandise exports for Canada in 1990 was 0.27. I calculated the OQ and ROC vertical specialization shares as follows: I use the 1990 industry-level vertical specialization numbers from the working paper version of HIY. From "Interprovincial Trade in Canada, 1984-1996" I calculate OQ's share of Canada's exports industry by industry. I then multiply the former by the latter to get a measure of total OQ vertical specialization, which I normalize by dividing by OQ's total merchandise exports. I follow the same procedure for the ROC. OQ's vertical specialization share is 0.333; the ROC vertical specialization share is 0.144. The OQ VS share of exports is larger than for ROC, because it is where almost all auto production occurs; auto production accounts for about half of all of Canada's vertical specialization.

[26] The parameterization and calibration do not focus on matching intra-national trade. In the third simulation, it would be possible to either calibrate the transport cost between Ontario-Quebec and the Rest of Canada to match trade between these two regions, or take a stand on the distance costs between these two regions, and assess if the model's implication for trade between these two regions matches the data.

[27] This seems like a high number, but note that gross output, of which exports are a part, is about 2.5 times larger than value-added or GDP.

4.2 Solution

Solving the model is complicated, even when employing the Frechét distribution. Unlike in the EK model, in which the exact solution can be found, in my vertical specialization model, I must find an approximate solution. To do so, I approximate the $[0, 1]$ continuum with 1,000,000 equally spaced intervals, with each interval corresponding to one good.[28] For each good and region, I draw a stage-one productivity and a stage-two productivity from the Frechét distribution. Because there are four regions and two stages of production, there are 16 possible production methods for each good. Given a candidate vector of regional wages, I calculate for each region's consumer the cheapest production method (i.e., the locations of stage-1 and stage-2 production) for each of the 1,000,000 goods. I then calculate whether the resulting pattern of specialization and trade is consistent with labor market equilibrium (or, equivalently, balanced trade). The model uses a simple Gauss-Newton algorithm to adjust wages until labor market equilibrium in each of the regions is achieved.

As described above, I solve for the trade barriers and productivities that enable the model to match the data on Canada's wages, trade shares, and/or vertical specialization. With the trade barriers and productivities, and with the distance costs assumption, the border barrier can be inferred. I solve the model again under no border barriers, and then use the two solutions to calculate Canada's 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.

5 Results

I present the key results from each simulation.[29] In the first simulation, I solve for the productivity parameter T and trade barrier τ that allows the model to match Canada's relative (to the U.S.) wage rate and Canada's export share of GDP. These values are listed in Table 3. An international trade cost of just 15.3 percent is needed to capture the two facts. By contrast AvW estimate international trade costs to be 91 percent. From the difference in trade costs, it would not be

[28] An alternative approach is to set up the model to handle an integer number of goods and apply programming techniques to solve for it exactly.

[29] I focus on international trade and vertical specialization. There are implications for intra-national vertical specialization, of course. In all three simulations, the model-implied intra-national vertical specialization exceeds international vertical specialization under border barriers, consistent with the data.

surprising to see a much smaller border effect. Table 3 shows that this is the case. The border effect is just 2.7. When distance costs are 10 percent instead of the benchmark 5 percent, the border effect is even smaller.

I also examine a simulation in which the elasticity is 10. The model-implied trade cost is now only about 7 percent. The higher elasticity implies that the impact of distance costs on trade is now approximately twice as large. To offset this, I set distance costs to be just 2.5 percent. In this scenario, the border effect is 2.6, virtually the same as when the elasticity is five. AvW noted that the border effect estimates were essentially invariant to the assumption about the elasticity. This result apparently carries over to my framework.

A large source of the difference between my border effect number and those of AvW, EK, and others is the magnification effect from the vertical specialization in my model. To see this, it is constructive to calibrate the EK model to match the same two facts. The EK model links the work of AvW and others with my work, because it is a Ricardian trade model, because I use the same Frechét distribution that they use, and because it allows for intermediate goods trade. Using the same elasticity, labor force size, and the share of intermediates in production, I solve the EK model for the T and τ that match the relative wage rate and export share. I find that the international trade cost is 69.2 percent, more than four times larger than in my model.[30]

When distance costs are 5 percent, the border effect from the EK model is 9.4, close to the AvW estimate. A large fraction of the border effect "gap" between my model and the EK model is simply because the implied border barrier is smaller in my model, so much so that despite the magnification effect, the border effect in my model is also smaller. The appendix shows analytically for the vertical specialization special case discussed above that for a *given trade share*, my model will deliver a lower border barrier and border effect than the EK model.

In the above simulation, the implication for Canada's international vertical specialization is counterfactual. The model implies that it is about 9 percent, which is only one-third of its actual value. For the model to imply greater vertical specialization, two possible adjustments are to increase the heterogeneity in productivities, i.e., lower the elasticity, or to lower trade costs. Both of these would help increase the number of goods for which internationally vertically specialized production is the most efficient process. However, changing these specifications would also raise

[30] This number is actually very close to the EK trade cost measure for an elasticity of 5 when the distance between the two countries is on the interval [375,750] miles, the two countries share a border and a language, and in which the destination is the United States. With these characteristics, the implied barrier is about 58 percent.

the model's implication for the export share of GDP to counterfactually high levels.

Consequently, in order to match both the vertical specialization and the export share data, an alternative adjustment is introduced – heterogeneity in trade costs – so that some goods face low enough trade costs that vertical specialization will occur, while other goods face high enough trade costs to preclude much trade. This is what I do in the second simulation. It can be justified on two empirical grounds. First, as mentioned above, industry-level estimates generate a wide range of border effects – from one to 100, roughly – which suggests the presence of differential trade costs across types of goods.[31] Second, for the case of Canada, motor vehicles account for almost one-half of total vertical specialization. Hummels, Rapoport, and Yi (1998) suggest that this resulted from the U.S.-Canada Auto Pact of 1965, which eliminated all tariffs on motor vehicle trade by U.S. and Canadian manufacturers.

As discussed in the previous section, I specify one-third of the goods to be low trade cost goods, while the remainder are high trade cost goods. I solve for these two trade costs, as well as the relative mean productivities, to match Canada's vertical specialization, trade share, and relative wage. Table 4 presents the results. Note the extreme variation in the trade costs across the two sets of goods. The low cost goods face a trade barrier of just 1.2 percent, while the high cost goods face a trade barrier of 56.2 percent. Put simply, the low cost barrier is what helps generate vertical specialization, and the high cost barrier is what helps ensure that Canada's trade share is not too high. Because two-thirds of the goods face the high barrier, the goods-weighted average of these two costs is 37.9 percent. However, the model implies that about 61 percent of Canada's trade is in the low cost goods; an import-weighted average of these two trade costs is just 22.5 percent.

To assess the border effect from this simulation, I assume that the low cost goods face no border barriers; these goods are already essentially traded in a free-trade zone. For the high cost goods, I continue to assume that distance costs are 5 percent. These assumptions imply a (import-weighted) border barrier of 19.0 percent. Table 4 shows that the border effect is 5.03. This is about half of the AvW estimate and of my estimate from the EK model. If distance costs are 10 percent, the implied border effect is 3.6.

How much of an increase in international trade would occur if border barriers were eliminated? The model implies that United States-Canada trade would rise by 44 percent, a significant amount, but, again, about one-half of what AvW obtain for their multi-country model, an increase of 79

[31] See Hillberry (2002), for example.

percent.[32]

I also examine the consequences of the assumption that one-third of the goods are low trade cost goods by conducting two further simulations, one with one-half of the goods and one with one-fourth of the goods treated as low trade cost goods. The implications in terms of import-weighted trade costs and border effects are essentially the same, with the former delivering a trade cost of 20.2 percent and a border effect of 4.8, and the latter yielding a trade cost of 22.5 percent and a border effect of 5.1.

The two preceding simulations treated regions within Canada as symmetric. Ontario and Quebec are the manufacturing centers of Canada, accounting for 77 percent of manufacturing shipments in 1990. In the five key industries mentioned before, the two provinces account for almost 90 percent of shipments. By contrast, the rest of Canada is focused more on fishing, forestry, mining, and agriculture. These differences in production are captured in the fact that OQ have a higher trade share of GDP and a considerably higher vertical specialization share – again, mainly owing to the presence of the motor vehicle industry in Ontario.

In the last simulation, the goal is to match the trade share and international vertical specialization share of OQ and ROC. To do so, I allow for the two regions to have different mean productivities and a different pair of high and low trade costs. Now, there are six equations to nail down six parameters. Table 2 presents the values of the variables to be matched, and Table 5 presents the model-calibrated parameters. The trade cost numbers are broadly similar to those in the previous simulation. Note that the low trade cost for OQ is slightly negative. This means that for one-third of the goods, the combination of the border barrier and distance costs to the United States is less than distance cost to the rest of OQ and to the rest of Canada. Given the concentration of Ontario's auto manufacturing industry near Windsor, Canada, this outcome does not seem too surprising. The low cost trade barrier for the ROC is about 8 percent. In both regions, the high cost barrier continues to be on the order of about 60 percent. In OQ, more than two-thirds of imports are of the low-cost goods, while less than half of imports are of low cost goods in the ROC. Consequently, the import-weighted trade costs are 17.3 percent and 33.5 percent, respectively. Because OQ accounts for about 2/3 of total Canada imports, the overall model-implied import-weighted trade cost for Canada is 22.6 percent.

Turning to border effects, I again assume that the low cost goods are essentially in a free trade zone and that the high cost goods face distance costs of 5 percent. This implies a U.S.-Canada

[32] AvW's two-country model would imply an increase in U.S.-Canada trade of about 150 percent.

border barrier of 19.3 percent. In this environment, Table 5 shows that the border effect is 5.2, similar to the value in the previous simulation. If border barriers were eliminated, U.S.-Canada trade would rise 46 percent.

Focusing on the second two calibrated simulations, the main lessons are: Trade costs between the U.S. and Canada are about 23 percent. The Canada border effect in 1990 is about five, less than half of AvW's estimates, and closer to the estimates that take into account heterogeneity in border barriers across goods. In addition, the predicted increase in U.S.-Canada trade resulting from the elimination of border barriers is about 45 percent, a significant, but not earth-shattering, amount. Why is this? A key part of the model-based calibration is that is that it must explain existing vertical specialization. Given the elasticity, the only way the model can generate a large vertical specialization share for Canada is if the international trade costs facing some goods is low. But if these costs are low, then the further trade increases from eliminating border barriers are limited, as well.

6 Conclusion

The main quantitative result of this paper is that a model of international and intra-national trade with endogenous vertical specialization, calibrated so that it matches the 1990 data on Canada's relative wage with the United States, as well as Canada's exports and vertical specialization, generates trade barrier and border effect estimates that are about half of the numbers estimated in the literature. For an elasticity of five, the import-weighted U.S.-Canada trade cost is about 23 percent, (the border barrier is about 19 percent) and Canada's border effect is about five. These numbers go a long way toward resolving the border effect puzzle. Among studies that have examined the U.S.-Canada border effect, only Hillberry (2002) has obtained numbers this small, and his approach emphasizes heterogeneity in barriers across goods, as I do here.

Vertical specialization plays a key role in this result. The presence or possibility of vertically specialized production magnifies the costs of border barriers. This is due to two complementary mechanisms, each of which magnifies the effect of a border barrier. First, the "back and forth" trade associated with vertical specialization means that at least some stages of production bear multiple border costs. Second, because different stages can be produced in different countries, sometimes the last stage of production is the "marginal" production process. Then 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. Because the costs of border barriers are magnified, and because Canada had a significant amount of international vertical specialization – 27 percent of exports – in 1990, then it must be the case that some goods face very small trade barriers (relative to intra-national trade barriers). I parameterize the fraction of goods facing small trade barriers to be one-third. For these goods, the model implies that the value of the barrier is close to zero, and they account for about three-fifths of Canada's imports.

The flip side of relatively small trade costs, border barriers, and border effects is a relatively small increase in trade if the border barriers were eliminated. The model indicates that U.S.-Canada trade would increase about 45 percent. My numbers may even be overestimates, because they are based on an international distance cost (relative to intra-national distance costs) of just 5 percent. If the international distance cost was 10 percent, then the Canada border effect is less than four and the implied growth in trade if border barriers were eliminated is about 35 percent. Last, it is likely that since the full implementation of the U.S.-Canada free trade agreement and NAFTA, border barriers are smaller today than in 1990. All of this suggests that the United States and Canada are fairly highly integrated with one another, and that there may not be enormous gains from trade if remaining border barriers were eliminated.

Vertical specialization 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 a special case of the model, I demonstrate that 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 stage-2 production. This suggests that there may be an upward bias in estimates of the substitution elasticity that do not control for vertical specialization. Chaney (2005) also presents a model that breaks the link between the elasticity of trade with respect to barriers and the elasticity of substitition.

The fact that the border barrier implied by my model is on the order of 20 percent or less surely must make the task of identifying and measuring these barriers – whether they are currency, regulatory, cultural, or other costs – easier. This is an important task for future research.

In my framework, the trade and distance costs enter in an *ad valorem* way. Recent empirical research suggests the importance of fixed or sunk costs in international trade costs.[33] It would be

[33] See Roberts and Tybout (1997), Anderson and van Wincoop (2004), and Helpman, Melitz, and Yeaple (2004),

useful to extend the framework to include fixed costs of exporting, as in Chaney (2005) and Melitz (2003). If fixed costs are increasing in the number of border crossings, it seems plausible that vertical specialization can generate magnification effects along the lines obtained with *ad valorem* costs.

A Appendix

A.1 Solution for $\underline{z}^h$ in standard model

For each good consumed in the home country, there are two production methods: it can be produced at home or abroad. Following DFS by ordering the continuum of goods according to declining home country comparative advantage, there is a cutoff $\underline{z}^h$ for which goods on the interval $[0, \underline{z}^h]$ are produced by the home country, and goods on the interval $[\underline{z}^h, 1]$ are produced by the foreign country. 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:

$$p^H(\underline{z}^h) \equiv \frac{w^h}{A^h(\underline{z}^h)} = (1+b)\frac{w^f}{A^f(\underline{z}^h)} \equiv (1+b)p^F(\underline{z}^h) \tag{24}$$

Simplifying yields:

$$\omega = \left(\frac{A^h(\underline{z}^h)}{A^f(\underline{z}^h)}\right)(1+b) \tag{25}$$

where $\omega = w^h/w^f$. Using the result from (16), yields:

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

Solving for $\underline{z}^h$ yields (17).

A.2 Solution for $\underline{z}^h$ in vertical specialization model special case

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

$$p_2^{HH}(\underline{z}^h) \equiv \frac{Bw^h}{A_1^h(\underline{z}^h)^{\theta}A_2^h(\underline{z}^h)^{1-\theta}} = (1+b)\frac{B(1+b)^{\theta}w^{h\theta}w^{f(1-\theta)}}{A_1^h(\underline{z}^h)^{\theta}A_2^f(\underline{z}^h)^{1-\theta}} \equiv (1+b)p_2^{HF}(\underline{z}^h) \tag{27}$$

for example.

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

$$\omega^{1-\theta} = \left(\frac{A_2^h(\underline{z}^h)}{A_2^f(\underline{z}^h)}\right)^{1-\theta} (1+b)^{(1+\theta)} \tag{28}$$

which leads to:

$$\omega^{1-\theta} = \left(\frac{1-\underline{z}^h}{\underline{z}^h}\right)^{\frac{1-\theta}{n}} (1+b)^{(1+\theta)} \tag{29}$$

Solving for $\underline{z}^h$ yields (21).

A.3 Border effect with vertical specialization when barriers are value-added

When border barriers such as tariffs are applied only to the value-added that occurred in the exporting country, then (27) now becomes:

$$p_2^{HH}(\underline{z}^h) \equiv (1+b(1-\theta))p_2^{HF}(\underline{z}^h) \tag{30}$$

Solving for $\underline{z}^h$ as before, and then plugging it into the expression for the border effect yields:

$$\left[(1+b)^{\theta}(1+b(1-\theta))\right]^{\frac{n}{1-\theta}} \tag{31}$$

When $\theta \geq 1/2$, (31) is clearly greater than $(1+b)^n$. When $0 < \theta < 1/2$, it can be shown that $f(\theta) = \left[(1+b)^{\theta}(1+b(1-\theta))\right]^{\frac{1}{1-\theta}} - (1+b)$, for which $f(0) = 0$ and $f(0.5) > 0$, is concave. This implies that for this range of θ, (31) exceeds $(1+b)^n$. Hence, the magnification effect still holds.

When $b(1-\theta)$ is small, $1+b(1-\theta)$ can be approximated by $(1+b)^{1-\theta}$; hence, the border effect is:

$$(1+b)^{\frac{n}{1-\theta}} \tag{32}$$

With this approximation, it can be seen that the $\frac{1+\theta}{1-\theta}$ term from the "gross" barrier case is replaced by $\frac{1}{1-\theta}$. This is intuitive, because θ is the stage-1 portion that is taxed twice in the gross case.

A.4 Comparing the vertical specialization special case to the EK model

In this exercise, I ask the following question. For a *given trade share*, and under the same assumptions as in sections 3.4.1 and 3.4.2, what are the border barrier and border effect implications of the vertical specialization model relative to the EK model? In the vertical specialization model, the export share of GDP is given by $(1+\theta)(1-\underline{z}_v^h)$. In the EK model for the case in which all goods are tradable, the export share of GDP is given by $\frac{1-\underline{z}^h_{ek}}{1-\theta}$. In both models, θ is the share of intermediates in production. Setting these two expressions equal to each other yields:

$$\underline{z}^h_v = \frac{\underline{z}^h_{ek} - \theta^2}{1-\theta^2} \tag{33}$$

Now substitute in (17) and (21); this yields:

$$(1+b_v)^{n\left(\frac{1+\theta}{1-\theta}\right)} = (1+b_{ek})^n(1-\theta^2) - \theta^2 \tag{34}$$

It is easy to see then that the border effect in the vertical specialization model is less than the border effect in the EK model, $(1+b_{ek})^n$. It can also be shown that the border barrier b_v in the vertical specialization model is less than the barrier b_{ek} in the EK model.

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Figure 1

Vertical Specialization

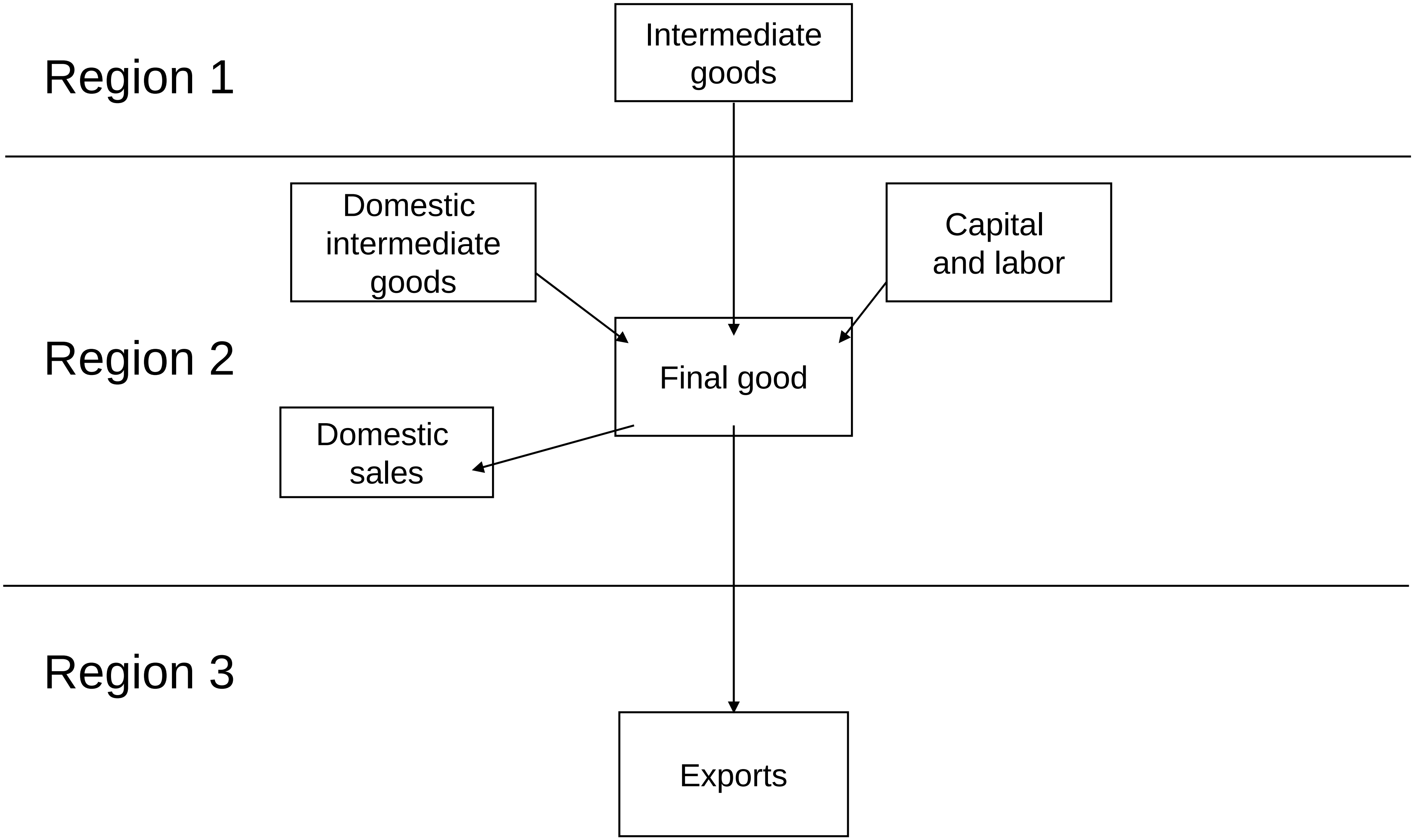
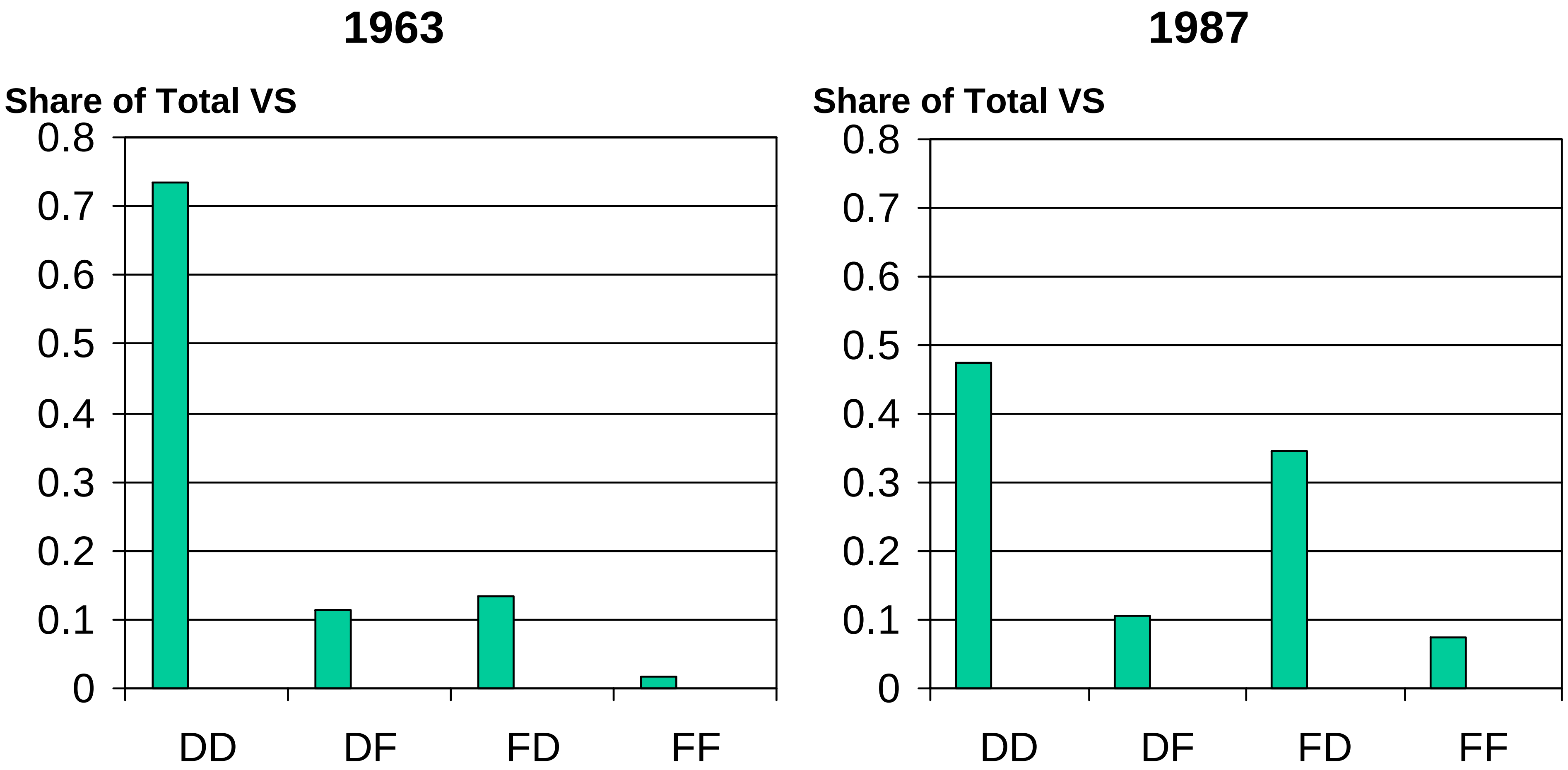


Figure 2

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

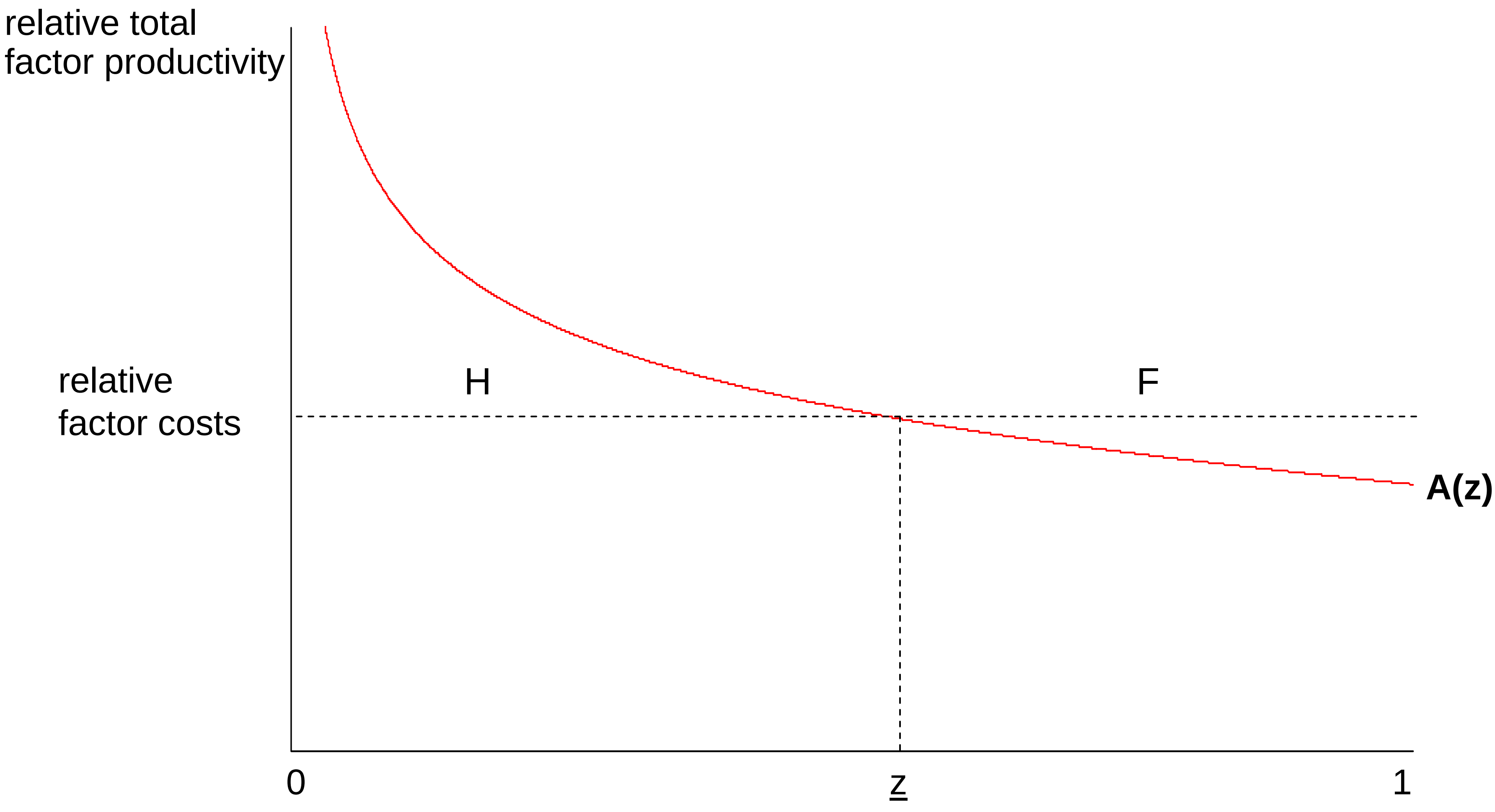
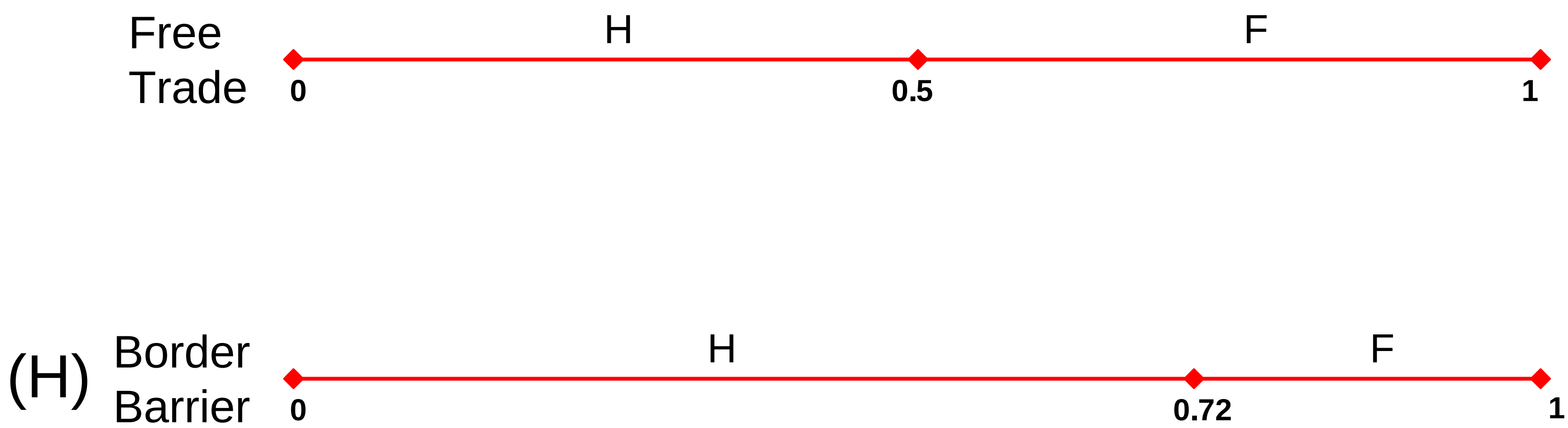


Figure 4

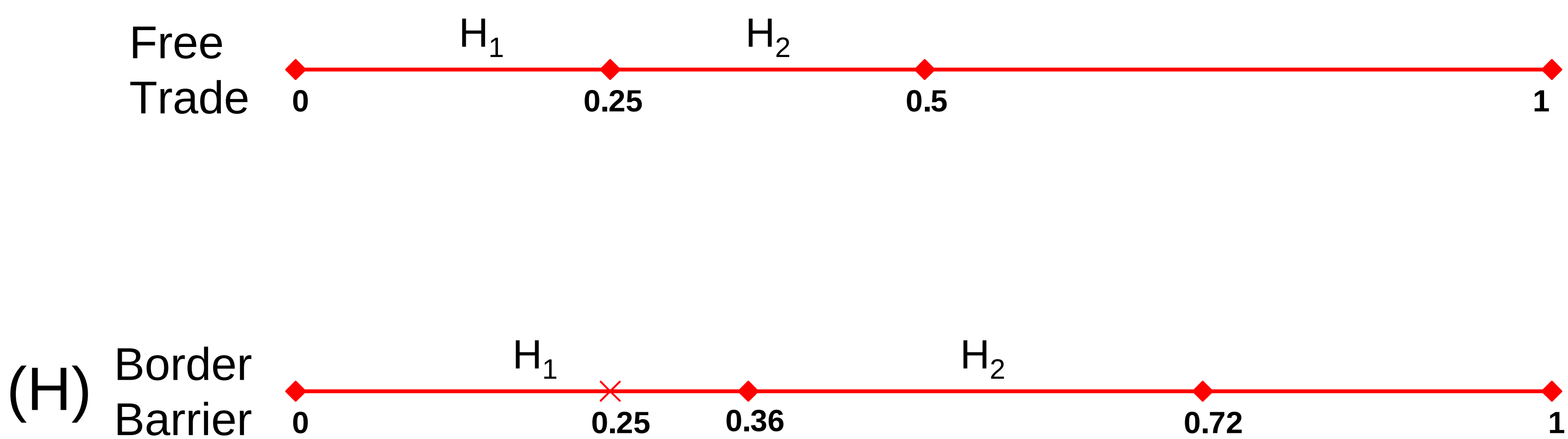
International Production Specialization: Standard model



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

Figure 5

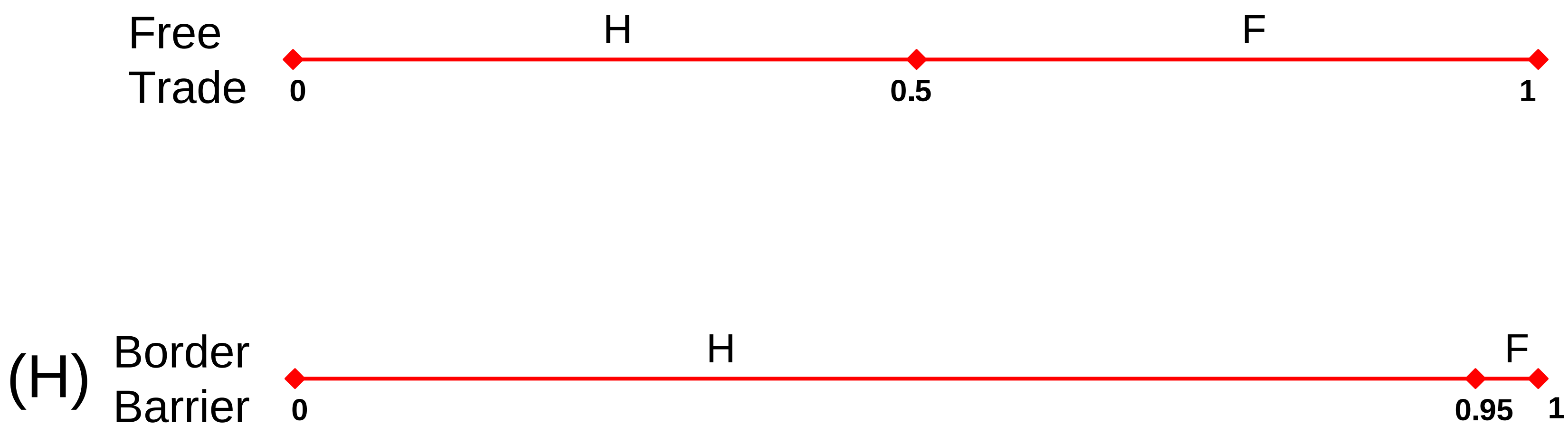
Intra-national Production Specialization: Standard model



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



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

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
CALIBRATION FOR U.S.-CANADA BORDER EFFECT SIMULATIONS

	SIMULATION		
	1	2	3
Elasticity (=n+1)	5	5	5
Stage 1 share in stage 2 production	0.62	0.62	0.62
Labor			
Ontario-Quebec	4.5	4.5	5.67
Rest of Canada	4.5	4.5	3.33
U.S.	100	100	100
Within country transport costs	0.0	0.0	0.0
Fraction of goods with low international transport costs		1/3	1/3
Values of Variables Used to Calibrate Productivity and Trade Costs			
Wage			
Canada wage relative to United States (manufacturing)	0.88	0.88	
Ontario-Quebec relative wage			0.88
Rest of Canada relative wage			0.88
Trade (merchandise export share of merchandise GDP)			
Canada	0.910	0.910	
Ontario-Quebec			0.962
Rest of Canada			0.796
Vertical Specialization (share of merchandise exports)			
Canada		0.270	
Ontario-Quebec			0.333
Rest of Canada			0.144

TABLE 3
Simulation One:
Symmetric Regions, Homogeneous Trade Costs

Mean Productivity (relative to U.S.)	1.08
International trade cost	**15.3%**
Border Effects:	
5 percent distance cost	**2.70**
Increase in U.S.-Canada trade if border barrier was eliminated	36.3%
10 percent distance cost	**1.57**
Increase in U.S.-Canada trade if border barrier was eliminated	16.0%
Elasticity =10 (2.5 percent distance costs)	2.58
EK model (5 percent distance costs)	9.40

Note: Productivity and trade cost solved to fit Canada export share of GDP and relative wage. Productivity is size-adjusted.
International trade cost is relative to intra-national trade cost

TABLE 4
Simulation Two:
Symmetric Regions, Heterogeneous Trade Costs

Mean Productivity (relative to U.S.)	0.99
Low International trade cost	1.21%
High International trade cost	56.18%
Import-weighted trade cost	**22.52%**
Border Effects:	
5 percent distance cost	**5.03**
Increase in U.S.-Canada trade if border barrier was eliminated	44.2%
10 percent distance cost	**3.62**
Increase in U.S.-Canada trade if border barrier was eliminated	33.6%

Note: Productivity and trade costs solved to match Canada's international vertical specialization share, trade share, and relative wage. Productivity is size-adjusted. International trade costs are relative to intra-national costs.

TABLE 5
Simulation Three:
Heterogeneous Regions, Heterogeneous Trade Costs

OQ Productivity (relative to U.S.)	0.88
OQ: Low international trade cost	-1.61%
OQ: High international trade cost	63.29%
OQ: Import-weighted trade cost	**17.29%**
ROC Productivity (relative to U.S.)	1.17
ROC: Low international trade cost	7.99%
ROC: High international trade cost	55.10%
ROC: Import-weighted trade cost	**33.47%**

Border Effects:

5 percent distance cost	**5.22**
Increase in U.S.-Canada trade if border barrier was eliminated	45.7%
10 percent distance cost	**3.72**
Increase in U.S.-Canada trade if border barrier was eliminated	35.6%

Note: Productivity and trade costs solved to match OQ's and ROC's international vertical specialization share, trade share and relative wage. Productivity is size-adjusted. International trade costs are relative to intranational costs.