Vertical FDI

This version: October 19, 2017

In this note, we construct a model to study vertical foreign direct investment (FDI). The motivation for undertaking vertical FDI is to save on production costs. To keep things simple, we consider a model with two stages of production, two factor inputs, and two countries. Extending the model to more stages of production or more types of production inputs is straightforward.

Two-stage model of production

Our goal is to understand the firm's decision over where to undertake different parts of the production process. The good produced by the firm — the *final good* — is made up of two distinct stages, a and b. Each stage requires two factors of production, skilled and unskilled labor. The production stages differ in the relative amounts of skilled and unskilled labor needed. We assume that stage a is unskilled-labor intensive and stage b is skilled-labor intensive.

Assumption 1. The stage a production function is unskilled-labor intensive. The stage b production function is skilled-labor intensive.

Production of the final good requires one unit of good a and one unit of good b. Production of goods a and b follow a fixed-proportions technology, with cost functions,

$$c_a(w_u, w_s) = \theta_{au} w_u + \theta_{as} w_s \quad (1)$$
$$c_b(w_u, w_s) = \theta_{bu} w_u + \theta_{bs} w_s, \quad (2)$$

where the θ parameters are the unit requirements of skilled and unskilled labor, w_u is the wage paid to unskilled workers, and w_s is the wage paid to skilled workers.[1] Since the final good requires one unit each of a and b, the cost of producing the final good is

$$c(w_u, w_s) = c_a(w_u, w_s) + c_b(w_u, w_s). \quad (3)$$

To fix ideas, assume that the firm is producing calculators. First, the component parts must be made. Call these parts b for circuit boards. Second, the component parts are assembled to create the calculator. Call assembly a. The cost of producing one calculator is given by (3), the cost of one unit of components and one unit of assembly.

Trade costs and firm structure

The model is made up of two countries, $i = 1, 2$. Countries differ by their wages. Unskilled labor is more expensive in country 1 and skilled labor is more expensive in country 2.

Assumption 2. Skilled labor is more expensive in country 2, $w_s^1 < w_s^2$. Unskilled labor is more expensive in country 1, $w_u^1 > w_u^2$.

[1] For more information about the fixed-proportions technology and its associated cost functions, see the "Note on Leontief production" on the course web site.

The firm must decide how to organize production: Where should it produce goods a and b?

If the firm chooses to ship component parts between the countries, it pays an ad valorem cost τ_b to do so. Shipping the final good across countries requires paying the ad valorem cost τ. These transport costs are symmetric: It costs the same to ship from country 1 to country 2 as to ship from country 2 to country 1. Without any costs of transport, it would always be optimal to produce each stage in the country in which it is cheapest. When there are transport costs, this is not always the case.

We need to make one further assumption. It must be that one country will have the comparative advantage in producing calculators. We assume that this is country 1.

Assumption 3. If the final good is made completely within a single country, it is cheaper to do so in country 1.

We study the decision of a firm in country 1 that needs to produce both stages of production and deliver the final good to each market. The firm chooses between four firm structures:

1. **Horizontal FDI.** Produce a and b in each country.
2. **Export.** Produce a and b in country 1, export the final good to country 2.
3. **Partial fragmentation.** Produce b in country 1, ship some of good b to country 2. Both countries produce a.
4. **Complete fragmentation.** Produce b in country 1, ship all of good b to country 2. Produce a in country 2 and ship some of the final good to country 1.

In the first structure, the firm replicates itself in country 2. In the second structure, the firm produces in its home country and exports the final good. These two firm structures were at the center of the horizontal FDI model we have studied earlier. In both of these cases, production is carried out entirely in one country.

In structures three and four, components are only produced in country 1 — this is the country with lower skilled-labor wages and components are skilled-labor intensive. In structure three, each country assembles the components into calculators to sell in their own market. In structure four, country 2 assembles all of the calculators and ships some back to country 1.

Our assumptions have ruled out two other firm structures. Since country 1 is the low-cost country if the entire calculator is produced in a single country (assumption 3), we will never have the reverse of structure two, where the calculator is made completely in country 2 and exported to country 1. Since country 1 is the low-cost producer of components (assumptions 1 and 2), and components are costly to ship, we will never have the reverse of structure four, where country 2 produces components and assembly is done in country 1.

Final good cost

The firm will choose the production structure that minimizes the cost of the final good in each market. We now compute the firm's cost of delivering a calculator to each country under each firm structure. Let c^1 be the cost of the calculator in country 1 and c^2 be the cost of the calculator in country 2.

Structure 1: HFDI. In this structure, calculators in each country are produced using only local labor. Since nothing is shipped, no trade costs are incurred.

$$c^1 = c_a(w_s^1, w_u^1) + c_b(w_s^1, w_u^1) \tag{4}$$
$$c^2 = c_a(w_s^2, w_u^2) + c_b(w_s^2, w_u^2) \tag{5}$$

Structure 2: Exporting. In this structure, calculators are produced using only country-1 labor. The calculators exported to country 2 are subject to τ.

$$c^1 = c_a(w_s^1, w_u^1) + c_b(w_s^1, w_u^1) \tag{6}$$
$$c^2 = \left[c_a(w_s^1, w_u^1) + c_b(w_s^1, w_u^1)\right](1+\tau) = c^1 \times (1+\tau) \tag{7}$$

Structure 3: Partial fragmentation. In this structure, components are only made in country 1, but both countries assemble. The components exported to country 2 are subject to τ_b.

$$c^1 = c_a(w_s^1, w_u^1) + c_b(w_s^1, w_u^1) \tag{8}$$
$$c^2 = c_a(w_s^2, w_u^2) + c_b(w_s^1, w_u^1)(1+\tau_b) \tag{9}$$

Structure 4: Complete fragmentation. In this structure, components are only made in country 1, and assembly happens only in country 2. The components exported to country 2 are subject to τ_b and the calculators exported to country 1 are subject to τ.

$$c^1 = \left[c_a(w_s^2, w_u^2) + c_b(w_s^1, w_u^1)(1+\tau_b)\right](1+\tau) \tag{10}$$
$$c^2 = c_a(w_s^2, w_u^2) + c_b(w_s^1, w_u^1)(1+\tau_b) \tag{11}$$

Even in this simple model, the wage differences across countries and the costs of trading goods shape the structure of the firm in complex ways. We will study how each of these factors influences the firm structure, holding fixed the others.

Component-part trade costs

We begin by studying how the optimal firm structure changes as the cost of trading component parts, τ_b, changes. The simplest way to do so is to consider a numerical example.

Let $\theta_{ua} = 5$, $\theta_{sa} = 1$, $\theta_{ub} = 1$, $\theta_{sb} = 10$, $w_u^1 = 10$, $w_s^1 = 20$, $w_u^2 = 2$, $w_s^2 = 30$, $\tau_b = 0.05$, and $\tau = 0.05$.[2] What are the final good costs in each country under each firm structure? Which firm structure delivers the lowest costs in each country?

In Table 1, we report the final good costs in each country under the four structures (columns 2 and 3). For these combinations of wages and trade costs, the optimal firm structure is complete fragmentation. This firm structure generates the lowest-cost final good in each country.

[2] Note that the final good trade cost, τ, is small. Later, we will study the interaction of τ and τ_b.

Table 1: Final good costs, varying τ_b

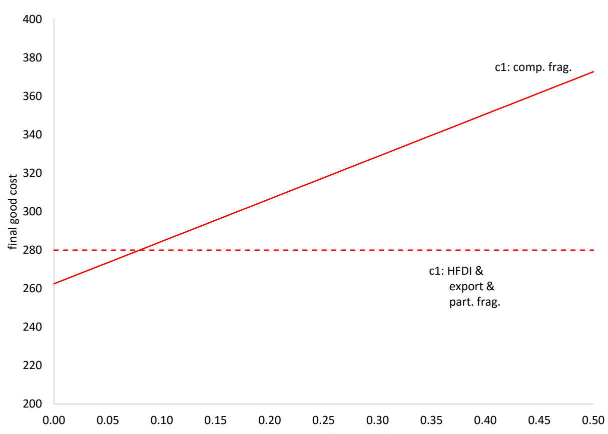
	$\tau_b = 0.05$		$\tau_b = 0.15$		$\tau_b = 0.30$	
	c^1	c^2	c^1	c^2	c^1	c^2
Horizontal FDI	280.0	342.0	280.0	342.0	280.0	342.0
Exporting	280.0	294.0	280.0	294.0	280.0	294.0
Partial fragmentation	280.0	260.5	280.0	281.5	280.0	313.0
Complete fragmentation	273.5	260.5	295.6	281.5	328.7	313.0

What happens as the cost of trading the component parts increases? If we leave the other parameters unchanged, but increase the cost of shipping the components to 0.15, we find that complete specialization is no longer optimal. As we see in Table 1 (columns 4 and 5), partial fragmentation now delivers the lowest costs. The cost savings from the low wages in country 2 are no longer enough to make it worth the cost of shipping components for assembly and the resulting calculators shipped back to country 1.

As the cost of trading component parts continues to increase, the firm stops shipping components. In Table 1, we compute the final good costs when $\tau_b = 0.3$ in columns 6 and 7. When the costs of component shipments are this high, the firm produces the entire good in country 1 and exports the final good to country 2.

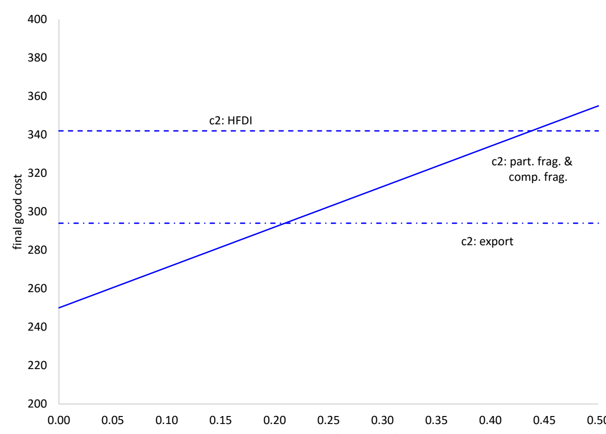
That the firm chooses to export, rather than use horizontal FDI, when τ_b is large, is greatly influenced by the value of τ. If the cost of shipping the final good was large, the firm would choose to replicate production in country 2 rather than export.

Figure 1: Costs in country 1.



Notes: For $\tau \leq 0.07$, complete fragmentation delivers the lowest-cost final good to country 1. For $\tau > 0.07$, horizontal FDI, exporting, or partial fragmentation deliver the same, lowest-cost final good to country 1.

Figure 2: Costs in country 2.



Notes: For $\tau \leq 0.21$, partial and complete fragmentation both deliver the lowest-cost final good to country 2. For $\tau > 0.21$, exporting delivers the lowest-cost final good to country 2.

We can analyze the firm's choice graphically by plotting the costs of the final good in country 1 and country 2 under the different firm structures. In Figure 1, we plot the costs in country 1, c^1.

While there are four firm structures, the cost of the good in country 1 is the same under horizontal FDI, exporting, and partial fragmentation. In each of these cases, the final good in country 1 is produced completely in country 1. Note, also, that in these three cases the final good cost does not depend on τ_b, so the line corresponding to c^1 in these cases is flat.

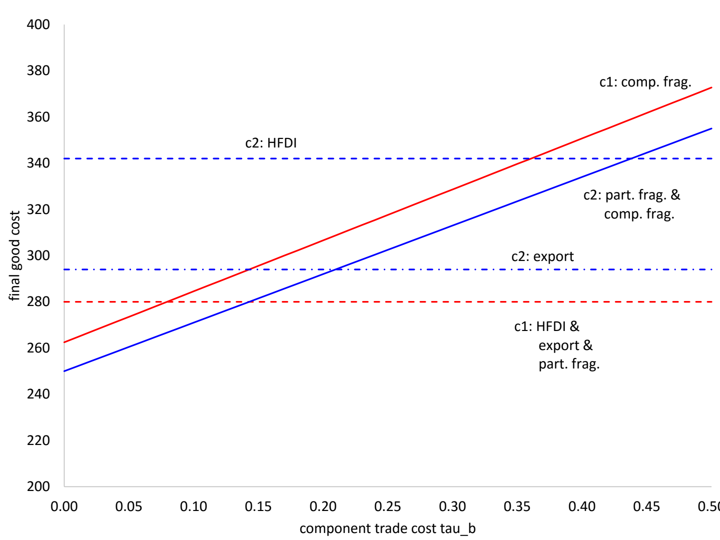
In Figure 2, we plot the costs in country 2, c^2. In country 2, the final good costs under exporting or horizontal FDI are both flat, as neither of these structures involves shipping component parts. Under both partial and complete fragmentation, the final good price is identical, as both firm structures have components made in country 1 and assembled in country 2.

We combine Figures 1 and 2 in Figure 3. From this figure we can determine the values of τ_b for which each firm structure will be optimal. Complete fragmentation is optimal from $\tau_b = 0$ until $\tau_b = 0.07$. Over this interval, complete fragmentation is the lowest cost way to provide the good to country 1. This cutoff value of τ_b is determined where c^1 under complete fragmentation and c^1 under the other structures intersect. For any $\tau_b > 0.07$, country 1 is indifferent between horizontal FDI, exporting, and complete fragmentation.

Since the country-1 final cost is identical regardless of the firm's structure for $\tau_b > 0.07$, the next cutoff is determined where c^2 under fragmentation intersects c^2 under exporting. For $0.07 < \tau_b \leq 0.21$, the best firm structure is partial fragmentation, and, for $\tau_b > 0.21$, the best firm structure is exporting. The relationship between the optimal firm structure and the component transportation cost, τ_b is summarized in the first row of Table 2.

Notice that the best firm structures we derived in Table 1 could have been read off of Figure 3. Both of these methods solve the same problem—how best to structure the firm under different assumptions about component-part trade costs.

Figure 3: Costs in country 1 and 2, $\tau = 0.05$.



Notes: For $\tau_b \leq 0.07$, complete fragmentation delivers the lowest-cost final good to both countries. For $0.07 < \tau_b \leq 0.21$, partial fragmentation delivers the lowest-cost final good to both countries, and for $0.21 < \tau_b$, exporting delivers the lowest-cost final good to both countries.

Table 2: τ_b cutoff values

	Complete frag.	Partial frag.	Export	HFDI
$\tau = 0.05$	[0, 0.07]	(0.07, 0.21]	(0.21, ∞)	—
$\tau = 0.15$	—	[0.00, 0.34]	(0.34, ∞)	
$\tau = 0.25$	—	[0.00, 0.43]	—	(0.43, ∞)

Final good trade costs

In the previous section, we varied the cost of trading the component parts, but held everything else, including the cost of trading the final good, constant. How does the optimal firm structure change as τ, the final-good trade cost, changes?

We first turn to Figures 4 and 5. In each figure we repeat the analysis in Figure 3, but we have increased the cost of trading the final good. In Figure 4, we have raised the final good trade cost to 0.15. The line corresponding to the cost of the final good in country 1 under complete fragmentation is shifted up in comparison to that in Figure 3. Even when $\tau_b = 0$, it is not cost-minimizing to use complete fragmentation. In this economy, the firm chooses partial fragmentation for $\tau_b \leq 0.34$ and exporting when $0.34 < \tau_b$. Notice that, when $\tau = 0.05$, the firm chose exporting once $0.21 < \tau_b$, but, when $\tau = 0.15$, the component trade cost must be 0.34 or larger to make exporting the best structure. Raising the final good trade cost has made exporting more costly.

We increase the cost of trading final goods to $\tau = 0.25$ in Figure 5. In this case, the firm never exports. The increase in the cost of shipping the final good means that the best firm structure is partial fragmentation for $\tau_b \leq 0.43$ and horizontal FDI when $0.43 < \tau_b$. The switch from exporting to horizontal FDI is the proximity motive that we studied in our models of horizontal FDI.

Figure 4: Costs when $\tau = 0.15$.

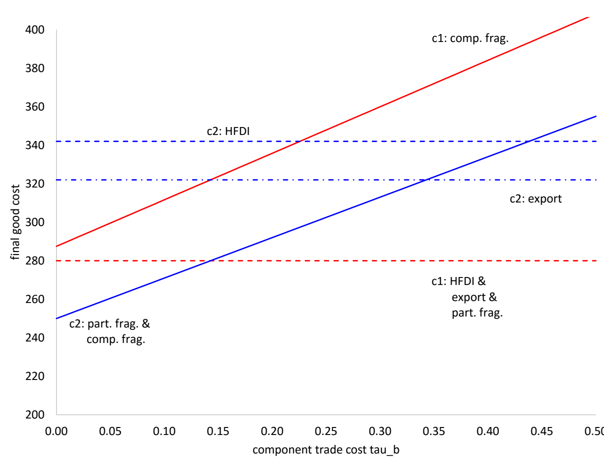
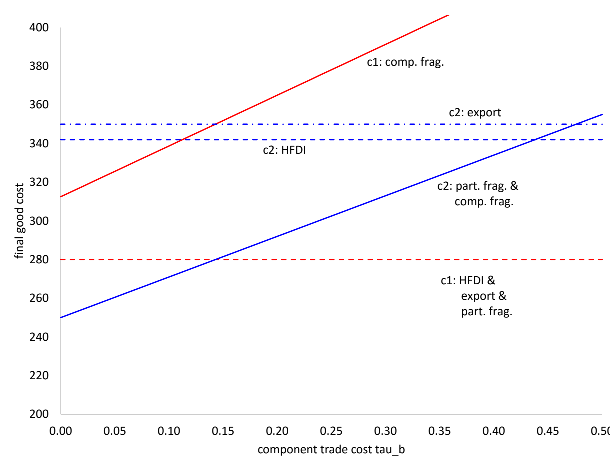


Figure 5: Costs when $\tau = 0.25$.

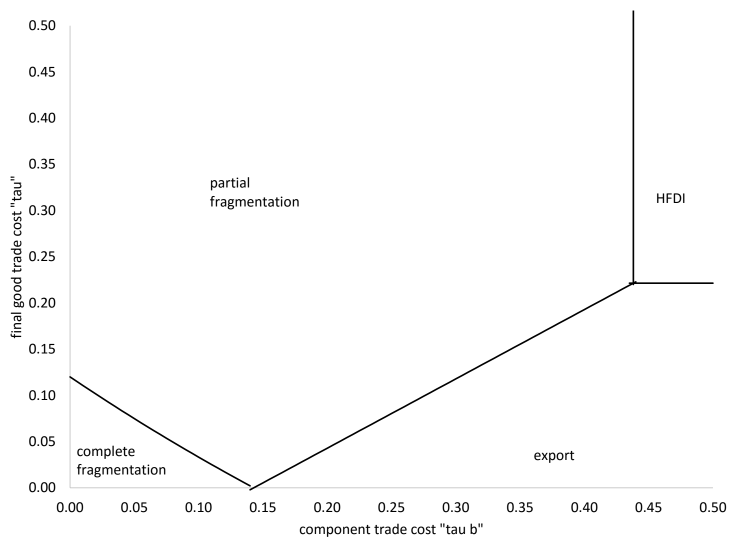


We can summarize the relationship between the final good trade cost, the component good trade cost, and the best firm structure using Figure 6. This figure shows the optimal firm structure for each pair of trade costs, (τ_b, τ). If we read across the figure when $\tau = 0.05$, we see that complete fragmentation is optimal until $\tau_b = 0.07$, after which partial fragmentation is optimal. Once we reach $\tau_b = 0.21$, exporting is optimal.

Inspecting Figure 6, we see some broad patterns emerge.

1. When both trade costs are low, complete fragmentation is optimal. Since trading both goods is easy, the firm would like to take advantage of the lower low-skilled wage in country 2.
2. When both trade costs are high, it is expensive to trade both the final good and its components, so horizontal FDI is best.
3. When final good trade costs are low, but component trade costs are high, exporting is optimal. The final goods are traded, but the components are not.
4. When final good trade costs are high, but component trade costs are low, partial fragmentation is optimal. The the components are traded, but the final goods are not.

Figure 6: Trade costs and the optimal firm structure.



Trade policy and firm structure

How does trade policy affect firm structure, foreign direct investment, trade, and output? Figure 6 helps us think through these questions. Suppose we begin with $\tau_b = 0.25$ and $\tau = 0.05$. If a trade agreement lowers τ_b to 0.15, what happens?

Initially, firms in country 1 are organizing as exporters. When τ_b falls to 0.15, firms would like to partially fragment. This implies that firms in country 1 are making foreign direct investments in country 2 to set up assembly plants. The types of goods being traded change. Firms in country 1 were exporting the final good to country 2, but now they export intermediate goods. Some of the assembly that was being done in country 1 is now being done in country 2, so assembly output (and employment) falls in country 1. In country 2, an assembly industry is born!

Multinationals and the 2016 presidential campaign

We can use this model to understand the decision made by U.S. multinational United Technologies to move the manufacture of Carrier air conditioners from Indiana to Mexico.

Initially, Carrier designed and produced air conditioners in the United States and served other countries by exporting. In Figure 6, Carrier was operating in the lower right quadrant. When the United States and Mexico liberalized trade, tariffs between the two countries fell to zero. This moved Carrier into the lower left corner of Figure 6, where complete fragmentation is optimal: The skilled-labor intensive design takes place in the United States, but assembly happens in Mexico, where production wages are lower.

Presidential candidate Donald J. Trump had suggested that air conditioners imported into the United States would be subject to a 35 percent tax. In our analysis, this would increase the cost of trading final goods, τ. This could potentially lead to partial fragmentation: Carrier would produce air conditioners for the U.S. market in the United States and air conditioners for the rest of the world in Mexico.