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Modularity and the Organization of International Production

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Modularity and the Organization of International Production

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October 30, 2003

Abstract

In many globalized industries, vertical outsourcing seems to co-evolve with horizontal integration in the component sector. In order to account for this phenomenon, I incorporate modularity into an industry-equilibrium model with monopolistic competition and perfect contracts that allows the organization of the firm to be endogenous in both the vertical and horizontal dimensions of production. The model illustrates that the co-evolution is most likely to occur in industries with modular product architectures and high increasing returns to scale in the intermediate good sector. This paper also provides a theoretical legitimation of Stigler's contentious conjecture that firm production structures become vertically disintegrated as an industry expands.

JEL classification: F23, F12, L22

Keywords: vertical outsourcing, horizontal integration, standardization, product modularity

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Introduction

The last few decades have seen an unprecedented reorganization of international production. In many industries, production has become increasingly disintegrated as multinational firms have fragmented their production process and set up subsidiaries across borders (Feenstra and Hanson 1996; Campa and Goldberg 1997; Feenstra 1998; Hummels, Ishii and Yi 2001). At the same time, the boundaries of the multinational firms have been changing, with cross-border vertical outsourcing (Antras and Helpman, 2003) and horizontal mergers and acquisitions on the rise (Evenett, 2003).

Case studies from a variety of industries have indicated that the trend of vertical outsourcing and horizontal integration in international production might be related. Sturgeon (2001) and Sturgeon and Lee (2001), for example, document that the recent trend by brand-name electronics firms to replace in-house manufacturing with outsourced manufacturing has co-evolved with a consolidation of market shares by the five largest firms in the contract manufacturing industry. Similar trends have been found in other global industries such as semiconductors (Langlois and Steinmueller 1999), telecommunications (Li and Whalley 2002), automobiles (Sturgeon and Florida 2000) and pharmaceuticals (Arora, Fosfuri and Gambardella 2001).

A detailed review of the existing literature reveals that, to date, no theoretical studies have addressed the co-evolution of vertical outsourcing and horizontal integration. As Sturgeon (2001) indicates, to neglect this link might lead to the erroneous characterization of the vertical outsourcing process as one where industries necessarily evolve toward smaller firms. The goal of this paper is to fill the gap in the existing literature by providing a theoretical framework that can explain the co-evolution.

In order to do so, I build on two separate streams of literature - international trade and management - that focus on the relative prevalence of vertical integration versus outsourcing. An emerging international trade literature has studied the impact of *market characteristics* on the boundaries of the firm by incorporating transaction costs and imperfect competition into industry-equilibrium models. Among them, Konan (2000) developed a perfect-contract model with two imperfectly competitive vertical layers of production. In her model, a firm's decision to internationally outsource is determined by the trade-off between the high fixed cost of vertical integration and the high marginal cost of trading at arm's length due to double marginalization. Konan finds that a decrease in market power in the intermediate goods sector reduces the double marginalization cost of arm's length trade and thus induces outsourcing. McLaren (2000) and Grossman and Helpman (2002a, 2002b) focus on the importance of contracts on the organization of international production. In their models, firms face a trade-off between the friction of incomplete contracts in arm's length relationships and excess governance costs in integrated companies. McLaren finds that a "thicker" intermediate good market reduces the hold-up problem that intermediate good firms face and thus induces outsourcing. Grossman and Helpman find that an increase in industry size and a better contracting environment favor outsourcing. The impact of competition on the vertical boundaries of the firm was ambiguous however.

Unlike the trade literature, the management literature has focused more on the role of *product characteristics* on the organization of production. In particular, a large number of studies have analyzed the link between modularity in product design and the boundaries of the firm. Sanchez and Mahoney (1996), for example, argue that modularity in product design induces outsourcing, because the standardized component interfaces in a modular product architecture reduce the coordination cost of trading at arm's length. Sturgeon (2002) adds that modularity is even more likely to induce outsourcing if the outsourced production stages face increasing returns. This is because component producers can then move down their average cost curve by applying the same set of standard production routines for various clients. Schilling (2000), finally, links industry standards to the boundaries of the firm. She argues that industry-wide standardization - *de facto* as well as regulatory - makes the interrelation between components less specific, thus increasing modularity and providing incentives to firms to outsource.

In this paper, I incorporate modularity into an industry-equilibrium model with monopolistic competition and perfect contracts to explain the co-evolution of vertical outsourcing and horizontal integration in international production. The paper is organized as follows. Section 1 defines modularity and explains how the concept is incorporated into the model. The model is then formalized in Section 2 and the two basic cost trade-offs that determine the equilibrium organization of production are identified. In the remaining sections, the model is solved and concluding remarks are provided.

1 Product Modularity

A final product can be seen as a set of components that interact with one another according to the rules of its product architecture (Ulrich, 1995). Product architectures can vary on a continuum from integral to modular (Schilling, 2000; Gawer and Cusumano, 2002). When a product has an integral architecture, components are specifically adjusted to each other to fully elicit the potential performance of the final product. As a result of this specificity, replacement of a component by another variety significantly reduces the functionality of the final product. In contrast, components in a modular architecture are designed to interact with each other according to codified architectural standards. As a result, components can be substituted with little loss of functionality as long as their substitutes are compatible with these standards.

As in Schilling (2000), industry-wide standardization (both *de facto* standardization and regulatory standardization) of architectural rules increases the degree of modularity of a product. This is because standardization of component interlinkages reduces the specificity of the relationship between components as they are now required to interact through stricter industry-wide rules. As a consequence, substitution of components leads to a smaller loss in overall functionality and the product becomes more modular.

An important contribution of this paper is the incorporation of modularity into an industry equilibrium model of international production. To capture input specificity, I associate each final product with an ideal component (Grossman and Helpman, 2002). If a component is ideal, then the final good producer can incorporate the intermediate good in final good production without bearing mismatch costs. However, if the intermediate is not fully specialized (i.e. not fully compatible), mismatch costs arise. The final good producer must then pay additional units of labor to make the intermediate good compatible to the final good.

For simplicity, I assume that intermediate and final goods are located on two separate concentric circles. In particular, all final goods are symmetrically and uniformly distributed along the circumference of a unit circle. All intermediate goods, on the other hand, are arrayed along the circumference of a concentric circle of length γ, with γ ranging from 0 to ∞. As we shall elaborate on below, γ determines the degree of modularity in an industry.

An intermediate good is ideal for a final good if they both lie on the same ray. If they do not lie on the same ray, then mismatch cost $s\delta$ arises, where s equals the wage rate and δ equals the intermediate good circle's arc distance between the actual position of the intermediary good and the position of the ideal intermediary good. An example is considered in figure 1. For illustration, γ is smaller than one, implying that the intermediate good circle is smaller than the final good circle. There are four final good firms x_1 to x_4. The ideal intermediate good for x_1 is z_1, and the ideal intermediate good for x_2 is z_2. Suppose that final good firm x_1 decides to use the non-ideal intermediate good z_3 to produce the final good. In that case, the final good firm faces mismatch cost $s\delta$, where δ equals the arc distance between z_1 and z_3.

While final good producers are uniformly distributed along the circumference of the unit circle, intermediate good producers can choose where to position themselves on the intermediate good circle. As a result, mismatch costs are endogenous in the model. Final good firms will only bear the mis-

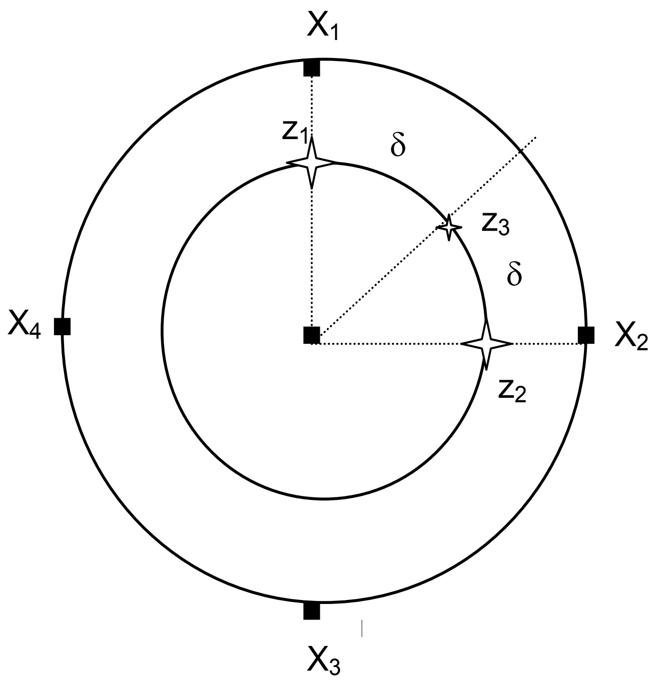

Figure 1: Locations of final and intermediate good suppliers

match cost of using a non-ideal component if the price of that component after adjustment for mismatch costs is cheaper than that of its ideal component. Under constant returns to scale in the intermediate good sector, this cannot occur in this model. If intermediate good firms face increasing returns to scale, however, mismatch costs can endogenously arise as the intermediate good firms can move down their average cost curves by selling a standardized component to multiple final good producers. For symmetry purposes, I take on the strong assumption that an intermediate good firm can sell a standardized component to at most two final good producers. This implies that the mismatch cost that each final good firm faces in industry equilibrium will take on one of two values:

$$s\delta = \begin{cases} 0 & \text{if} \quad \text{all firms use ideal components} \\ \frac{s\gamma}{2n} & \text{if} \quad \text{all firms use standardized components} \end{cases}$$

The amount of mismatch costs that a final good firm faces if it uses standardized components thus depends on three factors: (1) the number of final good firms n, (2) the wages that the final good firm faces s and (3) the degree of modularity γ.[1]

I have defined γ as the degree of modularity for the following reason. If, all else equal, γ decreases, then the distance between component varieties becomes smaller, thus making the varieties closer substitutes to each other. This characteristic of γ strongly resembles that of modularity. Once again, take figure 1 as an example. Suppose the intermediate good circle becomes smaller due to an increase in γ. In that case, the final good producers x_1 and x_2 would need to pay less mismatch costs to use z_1 in their final good production.

2 Model Setup

Consider a world with two regions, Home and Foreign, and one industry that produces differentiated consumer goods. The industry in both regions is assumed to be sufficiently small in relation to the rest of the economy, so that the industry can hire as much labor as it wishes at fixed wages. Wages at home s are higher than wages abroad w^*. The production structure in the industry consists of two vertical layers of production that are fragmented across borders. The intermediate good sector z is concentrated abroad, while the final good sector x is concentrated at home.

In the intermediate goods sector z, firms face increasing returns to scale and produce differentiated inputs. In the final goods sector x, firms compete in a Dixit-Stiglitz monopolistic competition market and produce differentiated final goods. As in Konan (2000), this setup of successive stages of production with increasing returns to scale technologies creates a first *cost trade-off that endogenizes the vertical boundaries of the firm* in industry equilibrium. If final good firms outsource, they face a high marginal cost due to

[1]Since our model applies largely to industry or economy-wide phenomena and not to the firm, ignoring the integer problem will not be important issue here.

"double marginalization" (Spengler, 1950) but do not need to pay the fixed cost of setting up an international subsidiary. If the final good firms decide to set up a subsidiary, they internalize the double marginalization distortion, but need to spend the additional fixed cost to set up the subsidiary. The trade-off will determine whether firms will be vertically integrated or will outsource in industry equilibrium.

The assumptions of increasing returns to scale in the intermediate good sector and input specificity create a second *cost trade-off that endogenizes the horizontal boundaries of the intermediate good firms* under outsourcing. In particular, it determines whether an intermediate good firm provides an ideal component to one final good producer or whether it consolidates its market share by providing a non-ideal standardized component to two final good producers. Ideal Outsourcing eliminates mismatch costs, but leaves the intermediate good firms with a high average cost. Standardized Outsourcing allows the intermediate good firm to move down its average cost curve, but leads to mismatch costs.

The two cost-tradeoffs allow me to distinguish three production structure regimes (see figure 2). Under *Vertical Integration*, vertically integrated firms produce both the intermediate good and the final good. Under *Ideal Outsourcing*, production of intermediate goods is outsourced to external firms that produce ideal components. Under *Standardized Outsourcing*, production of intermediate goods is outsourced to external firms that provide a standardized component to multiple final good producers.

The equilibrium production structure is determined by a two-step procedure. In step one, firms in both markets choose from the three production structures to produce consumer goods. As shown in figure 3, they do so in a non-cooperative game with ordered moves and perfect information. At decision node h.1, each domestic final goods firm take the existing industry structure as given and decides whether to commit to x production. If a home firm chooses not to produce x, then the game is over and both the home firm and the foreign firm that links itself to the home firm receive zero profits. If

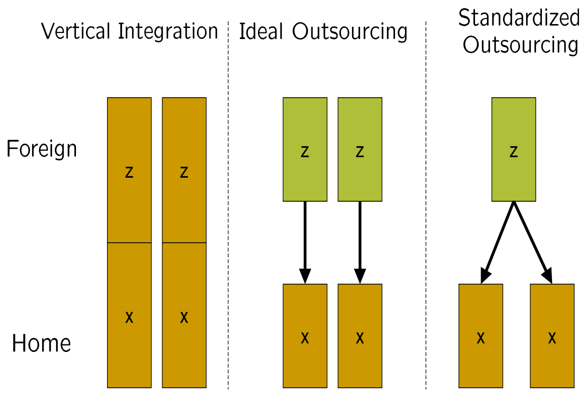

Figure 2: Three Production Structures

the final goods producer commits to x production, then it needs to decide at node h.2 whether to produce intermediate good z itself (vertical integration) or to purchase z at arm's length from a foreign firm (outsourcing). If *Vertical Integration* is chosen, then the home firm receives monopoly profits π_x^{VI} and the foreign firm that links itself to that home firm receives zero profits. If instead at node h.2, the home firm decides to import z at arm's length, then the foreign firm enters the game. At node f.1, the foreign firm decides whether to produce intermediate good z. Without foreign z production the game ends with the home firm's loss of its fixed cost (-F) and a zero foreign firm profit. If the foreign firm decide to produce z, it needs to decide at node f.2 which variety of the final good to supply. *Ideal Outsourcing* will be the outcome if the intermediate good producer decides to produce an ideal variety for a domestic final good producer. *Standardized Outsourcing* will be the outcome if he chooses to supply a standardized variety. Home and foreign firms choose the production structure that maximizes their profits given the existing industry structure.

In step two, the firms select the profit maximizing price and quantity given the production regime chosen. The problem is solved through backward induction.

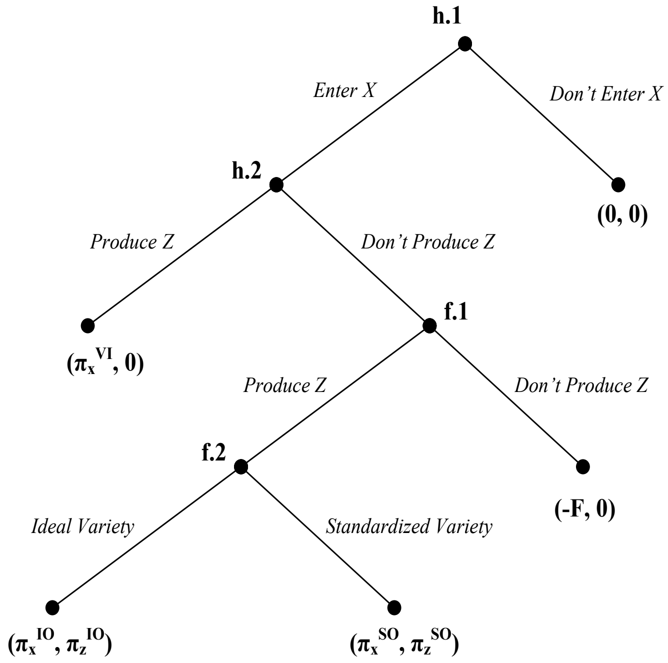

Figure 3: Three Production Structures

3 Monopolistic Competition Model

The final good producers act in a Dixit-Stiglitz monopolistic competition setting. Consumers spend a constant fraction β of their income on output from the industry. They view the varieties produced by the industry as symmetrically differentiated and perceive a constant elasticity of substitution between every pair of goods. A standard result in this kind of setting is that the demand for any differentiated product is given by

$$x = Ap_x^{-\sigma} \tag{1}$$

where σ is the exogenously fixed elasticity of substitution and

$$A \equiv \frac{\beta E}{np_x^{1-\sigma}} \tag{2}$$

As firms are assumed to be symmetric, each firm faces the same demand

$$x = \frac{\beta E}{n p_x} \tag{3}$$

On the supply side, firms make decisions in two steps. In the first step, firms decide on their production structure. Vertically, final good producers x decide between vertical integration and outsourcing and, horizontally, intermediate good producers z decide between producing standardized or idealized components. In the second step, firms maximize their profits given the production structure chosen in stage one. The model is solved through backward induction.

3.1 Vertical Integration

In stage 2, firms maximize their profits given the production structure chosen in stage 1. I start off by assuming that all firms are *vertically integrated* (VI). In that case, each final good producer chooses to produce the intermediate good z himself. He naturally chooses to produce the ideal component because he does not want to bear a self-imposed mismatch cost. The final goods producer thus faces the following profit function:

$$\pi_x^{VI} = [p_x(X) - s - w^* - \tau_z]x - (F + G_x) \tag{4}$$

where the marginal cost of production includes domestic wages s induced during final good production, foreign wages w^* induced during component production, and transportation costs and/or tariffs τ_z induced during the transportation of the intermediate good from foreign to home. The fixed cost of VI production includes the fixed cost of setting up a final good firm at home F and the fixed cost of setting up a subsidiary for component production G_x abroad.

The corresponding first-order condition of optimization provides the standard Dixit-Stiglitz result that the price-marginal-cost mark-up depends only on the elasticity of substitution σ:

$$\tilde{p}_x^{VI} = \left(\frac{\sigma}{\sigma - 1}\right)(s + w^* + \tau_z) \tag{5}$$

By plugging the pricing equation (**??**) and the demand function (**??**) into the profit function (**??**), the expected profit function of a vertically integrated firm can be derived:

$$\tilde{\pi}_x^{VI} = A^{VI}\sigma^{-\sigma}(\sigma - 1)^{\sigma-1}(s + w^* + \tau_z)^{1-\sigma} - (F + G_x) \tag{6}$$

The zero-profit condition now allows the determination of the equilibrium number of firms and the level of firm output:

$$\tilde{n}^{VI} = \frac{\sigma^{-1}\beta E}{F + G_x} \tag{7}$$

which implies that the number of final good firms is increasing in βE, decreasing in σ and decreasing in fixed costs.

$$\tilde{x}^{VI} = \frac{(F + G_x)(\sigma - 1)}{s + w^* + \tau_z} \tag{8}$$

This implies that the scale of firm output is increasing in the ratio of fixed to marginal cost, and increasing in the elasticity of substitution between varieties. Changes in any other demand side parameters such as β and E lead to adjustments in industry output via changes in the number of firms only.

3.2 Ideal Outsourcing

If the equilibrium production structure is *Ideal Outsourcing* (IO), the production of the intermediate component is outsourced to an external firm that produces the ideal component. Because the model does not allow for economies of scope, the intermediate good firm can only provide ideal intermediate goods to one final good firm. As a result, in an IO equilibrium there are an equal number of intermediate and final good firms and no final good firm bears mismatch costs. In this production structure, the profit maximization conditions need to be solved for both the intermediate good producer and the final good producer.

I start with the optimization decision of intermediate good producers. The profit function for the IO intermediate good producer is:

$$\pi_z = P_z(Z)z - w^* z - G_z \tag{9}$$

where G_z is the fixed cost of setting up an intermediate good firm z. The profit-maximizing intermediate good producer sets marginal revenue equal to marginal cost:

$$P_z(Z) = \mu_z^{IO} w^* \tag{10}$$

where μ_z^{IO} is the intermediate good markup under ideal outsourcing.

The final good producer faces the following profit function:

$$\pi_x^{IO} = [p_x(X) - s - P_z - \tau_z]x - F \tag{11}$$

By plugging the pricing equation (**??**) into (**??**)

$$\pi_x^{IO} = [p_x(X) - s - \mu_z^{IO} w^* - \tau_z]x - F \tag{12}$$

The profit function for the final good producer under ideal outsourcing differs from the profit function under vertical integration in two important ways. On the one hand, the IO final good producer now faces a lower fixed cost than under VI as he does not incur the fixed cost G_x of setting up a subsidiary. On the other hand, the IO final good producer faces a higher marginal cost than under VI as he has to pay an extra markup μ_z^{IO} to purchase the intermediate good. As mentioned above, this is the crucial tradeoff that determines the vertical boundaries of the firm in this model.

The rest of the analysis is similar to vertical integration. If I set the marginal revenue equal to marginal cost and make use of Dixit-Stiglitz preferences:

$$\tilde{p}_x^{IO} = \left(\frac{\sigma}{\sigma - 1}\right)(s + \mu_z^{IO} w^* + \tau_z) \tag{13}$$

By plugging the pricing equation (**??**) and the demand function (**??**) into the profit function (**??**), the expected profit of the *IO* final good firm is obtained.

$$\tilde{\pi}_x^{IO} = A^{IO}\sigma^{-\sigma}(\sigma - 1)^{\sigma-1}(s + \mu_z^{IO} w^* + \tau_z)^{1-\sigma} - F \tag{14}$$

With free entry, total profits amount to zero. Thus the break-even condition together with (**??**) implies:

$$\tilde{n}^{IO} = \frac{\sigma^{-1}\beta E}{F} \tag{15}$$

Finally, sales per brand amount to (**??**), or using the price equation and the zero profit condition:

$$\tilde{x}^{IO} = \frac{F(\sigma - 1)}{s + \mu_z^{IO} w^* + \tau_z} \tag{16}$$

3.3 Standardized Outsourcing

Under *standardized outsourcing* (*SO*), intermediate good firms sell a standardized intermediate good z to multiple final good producers. In order to preserve symmetry in the final goods sector, I assume that the intermediate good producer can sell a standardized component to maximum two final good producers. This implies that, in a *SO* equilibrium, there are twice as many final good firms than intermediate good firms and each final good firm bears mismatch costs $s\delta$ equal to $\frac{s\gamma}{2n}$.

Intermediate good producers face the same profit function as under Ideal Outsourcing and the profit maximization condition (**??**) also continues to hold. The profit function for the *SO* final goods producer is:

$$\pi_x^{SO} = [p_x(X) - s(1 + \frac{s\gamma}{2n}) - \mu_z^{SO} w^* - \tau_z]x - F \tag{17}$$

The profit function of the final good producer under SO bears a lot of similarities with the profit function under IO: the final good producer faces no subsidiary setup cost G_x, but faces a markup μ_z^{SO} above w^*. An important difference is that under standardized outsourcing the final good producer has to spend resources $\frac{s\gamma}{2n}$ to make the standardized input suitable for the final good. As mentioned above, this provides the second trade-off that determines the horizontal boundaries of the intermediate good firm under outsourcing. The final good producer will only prefer to bear the mismatch cost of purchasing standardized components if the marginal cost of SO is lower than the marginal cost of IO. This can only occur if the intermediate good markup μ_z^{SO} is sufficiently lower than the intermediate good markup μ_z^{IO}. Given the fact that the intermediate good firm operates under increasing returns to scale, this is plausible because the intermediate good firm can move down his average cost curve by selling his components to more final good producers.

The rest of this section is similar to above. If I set marginal revenue equal to marginal cost and make use of Dixit-Stiglitz preferences:

$$\tilde{p}_x^{SO} = \Big(\frac{\sigma}{\sigma-1}\Big)(s + \mu_z^{SO} w^* + \tau_z + \frac{s\gamma}{2n}) \tag{18}$$

By plugging the pricing equation (**??**) and the demand function (**??**) into the profit function (**??**), I obtain the expected profit of an SO final goods firm.

$$\tilde{\pi}_x^{SO} = A^{SO}\sigma^{-\sigma}(\sigma-1)^{\sigma-1}(s + \mu_z^{SO} w^* + \tau_z + \frac{s\gamma}{2n})^{1-\sigma} - F \tag{19}$$

With free entry, total profits amount to zero. Thus the break-even condition together with (**??**) implies:

$$\tilde{n}^{SO} = \frac{\sigma^{-1}\beta E}{F} \tag{20}$$

By plugging (20) into (18), the price equation becomes:

$$\tilde{p}_x^{SO} = \left(\frac{\sigma}{\sigma-1}\right)(s + \mu_z^{SO} w^* + \tau_z + \frac{s\gamma\sigma F}{2\beta E}) \tag{21}$$

Finally, sales per brand amount to (**??**), or using the price equation and the zero profit condition:

$$\tilde{x}^{SO} = \frac{F(\sigma-1)}{s + \mu_z^{SO} w^* + \tau_z + \frac{s\gamma\sigma F}{2\beta E}} \tag{22}$$

4 Industry Equilibrium Determination

In the previous section I have solved for the profit maximizing price and output in the three market structures. In stage one, I solve for the equilibrium production structure by using the following approach: production structure i is the equilibrium production structure if and only if it is unprofitable for firms with another production structure to enter the market.

4.1 Determination of Vertical Firm Boundaries

I start off with determining the vertical boundaries of the firm. In do so by focusing on the conditions under which vertical integration is the equilibrium production structure. Vertical integration acts as a stable equilibrium if and only if it is unprofitable for firms to enter with an *IO* or *SO* production structure.

Suppose first that a pair of firms with an *IO* production structure attempts to enter a market that is pervasively vertically integrated. In that case, the *IO* final good firm faces the same demand A^{VI} as the other vertically integrated firms with

$$\tilde{A}^{VI} = \sigma^\sigma(\sigma-1)^{1-\sigma}(F + G_x)(s + w^* + \tau_z)^{\sigma-1} \tag{23}$$

Facing VI demand, the *IO* final good firm then maximizes profits by setting its price according to (**??**). With this price, the *IO* final goods firm makes sales for:

$$\tilde{x}^{IO} = \tilde{A}^{VI}\tilde{p}_x^{IO\ -\sigma} = \frac{(\sigma-1)(F+G_x)(s+w^*+\tau_z)^{\sigma-1}}{(s+\mu_z^{IO}w^*+\tau_z)^{\sigma}} \tag{24}$$

His operating profits are:

$$\tilde{\pi}_x^{IO} = (F+G_x)\Big(\frac{s+w^*+\tau_z}{s+\mu_z^{IO}w^*+\tau_z}\Big)^{\sigma-1} - F \tag{25}$$

An IO final good firm will decide not to enter the market if its operating profits are negative. This implies that the first necessary condition for a vertical integration equilibrium is:

$$\Big(\frac{s+w^*+\tau_z}{s+\mu_z^{IO}w^*+\tau_z}\Big)^{\sigma-1}\frac{F+G_x}{F} \leq 1 \tag{26}$$

A parallel analysis show that firms with a SO production structure are deterred to enter if:

$$\Big(\frac{s+w^*+\tau_z}{s+\mu_z^{SO}w^*+\tau_z+\frac{s\gamma\sigma F}{2\beta E}}\Big)^{\sigma-1}\frac{F+G_x}{F} \leq 1 \tag{27}$$

The combination of (**??**) and (**??**) leads to the first proposition:

Proposition 1 *There exists an equilibrium with pervasive vertical integration if and only if*

$$\Big(RMC^{VI}\Big)^{\sigma-1} RFC^{VI} \leq 1$$

where RMC^{VI} is the relative marginal cost of vertical integration versus (both kinds of) outsourcing and RFC^{VI} is the relative fixed cost of vertical integration versus (both kinds of) outsourcing.

Proposition 1 provides the general condition that determines the vertical boundaries of the firm. It states that vertical integration becomes more likely if the marginal cost of vertical integration relative to that of both kinds of outsourcing decreases, if the fixed cost of vertical integration relative to that of outsourcing goes down, and if the weight of marginal costs relative to fixed costs, measured by scaling factor σ, goes up. The latter is because vertical integration is the low-marginal cost high-fixed cost production structure.

The proposition together with (**??**) and (**??**) also provides the specific market and product determinants of the vertical boundaries of the firm. First, it passes the two basic checks by showing that an increase in the fixed cost of setting up a subsidiary G_x induces outsourcing, while an increase in the intermediate good markups μ_z^{IO} and μ_z^{SO} induces vertical integration.

Second, it replicates Grossman and Helpman's (2002) result that the impact of competition on the production structure is ambiguous. The degree of competition is often measured with the elasticity of substitution σ. On the one hand, an increase in final good sector competition σ induces vertical integration because it increases the weight of relative marginal cost versus relative fixed cost. This is because an increase in σ increases the level of output of each firm. On the other hand, an increase in σ is likely to also lower the markup on the intermediate good μ_z because intermediate good firms also start producing more, thus moving down their average cost curves. The decrease in the intermediate good markup μ favors outsourcing. As a result, the impact of competition on the production structure is ambiguous.

An important question in economic theory is the impact of an increase in industry demand on the equilibrium production structure. In a seminal paper, Stigler (1951) argued that firm production structures become vertically disintegrated as an industry expands. The modern literature on outsourcing has not been very supportive to the Stigler conjecture however. As surveyed by Perry (1989), standard theory commonly asserts that firms become vertically integrated as the industry grows, not vertically disintegrated. By making a distinction between ideal outsourcing and standardized outsourcing, my model provides further insights into this puzzle. It shows that an increase in industry demand does not induce ideal outsourcing, but does induce standardized outsourcing. The reason is the following. Due to the assumption of Dixit-Stiglitz monopolistic competition in the final goods sector, the rise in industry demand βE leaves the firm level of output x unchanged while increasing the number of firms n. The increase in the number of firms in this model reduces the equilibrium mismatch cost because the symmetrically distributed firms move closer to one another on the circle. As a result, this reduces the SO marginal cost and induces standardized outsourcing.

An important contribution of this paper is that it allows me to study the impact of product characteristics on the equilibrium boundaries of the firm. In particular, my model shows that an increase in modularity induces standardized outsourcing. The reason is that, all else equal, a decrease in γ reduces the mismatch cost of adopting a non-ideal variety, thus favoring the adoption of a standardized component.

Finally, it is difficult to determine the impact of an increase in transportation costs (or tariffs) τ_z, domestic wages s, foreign wages w^* and fixed cost F on the relative costs of outsourcing because it is likely to alter the intermediate good markup μ_z. In order to determine the effect, I need to endogenize the intermediate good markup. I will do so in section 5.

4.2 Determinants of the Horizontal Firm Boundaries

I now determine when ideal outsourcing is the equilibrium production structure. Ideal outsourcing acts as a stable equilibrium if it is unprofitable for firms to enter with an SO or VI production structure. By using the same technique as above, I come up with the following results:

There exists an equilibrium with pervasive ideal outsourcing if and only if

$$\left(\frac{s+\mu_z^{IO}w^*+\tau_z}{s+w^*+\tau_z}\right)^{\sigma-1}\frac{Fs}{Fs+G_x w^*}\leq 1 \tag{28}$$

and

$$\left(\frac{s+\mu_z^{IO}w^*+\tau_z}{s+\mu_z^{SO}w^*+\tau_z+\frac{s\gamma\sigma F}{2\beta E}}\right)\leq 1 \tag{29}$$

Condition (**??**) is identical to (**??**), while condition (**??**) determines the prevalence of ideal outsourcing versus standardized outsourcing. This leads to the second proposition:

Proposition 2 *Ideal outsourcing is chosen over standardized outsourcing if and only if*

$$MC^{IO} \leq MC^{SO}$$

Proposition 2 provides the condition that determines the horizontal boundaries of the firm. It confirms that ideal outsourcing can only be an equilibrium if the final good producer perceives that the marginal cost of ideal outsourcing is lower than the marginal cost of standardized outsourcing. This will be the case if the intermediate good markup of standardized outsourcing μ_z^{SO} is not too much lower than the intermediate good markup of ideal outsourcing μ_z^{IO}, so that it does not dominate the mismatch cost.

Proposition 2 together with (**??**) show that standardized outsourcing is more likely to occur in industries with low mismatch costs and high increasing returns to scale in the intermediate goods sector.

5 Markup Endogenization

Many of the comparative statics in the previous section could not be derived because the impact of these variables on the intermediate good markup had not been determined. In this section, I endogenize the intermediate good markup by assuming contestable markets in the intermediate goods sector.

5.1 Ideal Outsourcing

In an ideal outsourcing equilibrium, the output of the intermediate good firm is identical to the output of the *IO* final goods firm. As a result:

$$\tilde{z}^{IO} = \frac{F(\sigma - 1)}{s + \mu_z^{IO} w^* + \tau_z} \tag{30}$$

If I combine the pricing equation (**??**) with the output equation (**??**) and the zero profit condition due to a contestable market setting, then I find the equilibrium markup:

$$\tilde{\mu}_z^{IO} = \frac{w^* F(\sigma - 1) + G_z(s + \tau_z)}{w^*[F(\sigma - 1) - G_z]} \tag{31}$$

Note that this provides the requirement that $F(\sigma - 1) - G_z > 0$. If that condition holds, then the markup is always larger than 1. If it does not hold, then intermediate good firms will not produce in equilibrium. As expected, the markup is unambiguously increasing in the fixed cost of setting up an intermediate good firm G_z. It is also increasing in s and τ_z while decreasing in w^*, F and σ. Except for w^*, this is entirely due to the output effect: if the level of output goes up, then the fixed cost is spread over more units of output and the markup declines. An increase in w^* decreases the intermediate good markup even though output goes down because the positive revenue effect of an increase in w^* is larger than the marginal cost effect.

The price of the final good then becomes:

$$\tilde{p}_x^{IO} = \frac{\sigma F(s + \tau_z + w^*)}{F(\sigma - 1) - G_z} \tag{32}$$

Sales per firm are then:

$$\tilde{x}^{IO} = \frac{F(\sigma - 1) - G_z}{s + w^* + \tau_z} \tag{33}$$

As before, this implies that the scale of final firm output is increasing in the ratio of the final good firm's fixed to marginal cost, and increasing in the elasticity of substitution between varieties. An addition to before is that an increase in the fixed costs of intermediate good production G_z now leads to a reduction in final good output. The mechanism through which this happens is a higher intermediate good markup.

5.2 Standardized Outsourcing

In a standardized outsourcing equilibrium, the output of the intermediate good firm is identical to twice the output of the SO final goods firm. As a result:

$$\tilde{z}^{SO} = 2\frac{F(\sigma-1)}{s+\mu_z^{SO}w^* + \tau_z + \frac{s\gamma\sigma F}{2\beta E}} \tag{34}$$

This equation states that output of the intermediate good firm in a standardized outsourcing equilibrium is increasing in F, σ and s. It is decreasing in μ_z, w^*, τ_z and δ . If I plug the pricing equation (**??**) and the output equation (**??**) into the profit function (**??**) and set profits equal to zero due to market contestability, then I find the SO intermediate good markup:

$$\tilde{\mu}_z^{SO} = \frac{2w^*F(\sigma-1) + G_z(s + \frac{s\gamma\sigma F}{2\beta E} + \tau_z)}{w^*(2F(\sigma-1) - G_z)} \tag{35}$$

Note that this provides the requirement that $2Fs(\sigma-1)-G_z > 0$. If that condition holds, then the markup is always larger than 1. Just like above, the markup is increasing in G_z, s and τ_z and decreasing in F, σ and w^* due to the output effect. In addition, an increase in industry demand βE reduces the intermediate good markup. Note that this provides an additional channel through which an increase in industry demand induces standardized outsourcing.

The price of the final good then becomes:

$$\tilde{p}_x^{SO} = \frac{2\sigma F(s + \tau_z + w^* + \frac{s\gamma\sigma F}{2\beta E})}{2F(\sigma-1) - G_z} \tag{36}$$

Sales per firm is then:

$$\tilde{x}^{SO} = \frac{2F(\sigma-1) - G_z}{2[s + w^* + \tau_z + \frac{s\gamma\sigma F}{2\beta E}]} \tag{37}$$

As before, this implies that the scale of final firm output is increasing in the ratio of fixed to marginal cost, and increasing in the elasticity of substitution between varieties. In addition to before, an increase in the fixed costs of intermediate good production G_z now leads to a reduction in final good output. Interestingly, an increase in βE increases output, while an increase in γ reduces output.

6 Industry Equilibrium Determination

6.1 Determinants of the Vertical Firm Boundaries

Vertical integration acts as a stable equilibrium if and only if it is unprofitable for firms to enter with an IO or SO production structure. Two conditions need to hold for vertical integration to be a stable equilibrium:

$$\left(\frac{F(\sigma-1)-G_z}{F(\sigma-1)}\right)^{\sigma-1}\left(\frac{F+G_x}{F}\right)\leq 1 \tag{38}$$

and

$$\left(\frac{(s+w^*+\tau_z)(2F(\sigma-1)-G_z)}{(s+\tau_z+w^*+\frac{s\gamma\sigma F}{2\beta E})2F(\sigma-1)}\right)^{\sigma-1}\left(\frac{F+G_x}{F}\right)\leq 1 \tag{39}$$

The two inequalities confirm the results from above. An increase in the fixed cost of setting up a subsidiary G_x induces outsourcing. The impact of competition σ on the vertical boundaries of the firm is ambiguous. An increase in industry demand βE and an increase in modularity through a decrease in γ favors standardized outsourcing.

The inequalities also provide new determinants of the vertical boundaries of the firm. First, an increase in the fixed cost of setting up an intermediate good firm G_z for obvious reasons induces vertical integration.

Second, an increase in the fixed cost of setting up a final good firm F has an ambiguous effect on the vertical boundaries of the firm. This is because an increase in F on the one hand reduces the relative fixed cost of of vertical integration. On the other hand, it increases the output of intermediate good firms, thus reducing their intermediate good markups and thus increasing the relative marginal cost of vertical integration.

Interestingly enough, a change of s, τ_z and w^* have no impact on the choice between vertical integration and ideal outsourcing, because the various effects exactly cancel each other out. They do have an impact on the choice between vertical integration and standardized outsourcing. An increase in τ_z and w^* reduces the relative marginal cost of standardized outsourcougn and thus induces standardized outsourcing. An increase in s, on the other hand, increases the mismatch cost for final good producers. As a result, the relative marginal cost of standardized outsourcing goes up, thus inducing vertical integration.

6.2 Determinants of the Horizontal Firm Boundaries

In order to determine the horizontal boundaries of the firm, I need to determine when ideal outsourcing is preferred to standardized outsourcing. The following condition determines when ideal outsourcing is preferred to standardized outsourcing:

$$\left(\frac{s + w^* + \tau_z}{s + w^* + \tau_z + \frac{s\gamma\sigma F}{2\beta E}}\right)\left(\frac{2F(\sigma-1) - G_z}{2(F(\sigma-1) - G_z)}\right) \leq 1 \tag{40}$$

The condition reiterates that an increase in modularity (decrease in γ) and an increase in industry demand βE induces standardized outsourcing. It also confirms that an increase in tariff τ_z and an increase in w^* reduces the relative marginal cost of standardized outsourcing, thus inducing standardized outsourcing. An increase in s, on the other hand, increases mismatch costs that final good producers need to pay, thus inducing ideal outsourcing.

An increase in the final good firm fixed cost F favors ideal outsourcing to standardized outsourcing. The reason is that an increase in F reduces the number of final good firms in industry equilibrium, thus increasing the mismatch cost of standardized outsourcing. An increase in intermediate good firm fixed cost G_z, on the other hand, induces standardized outsourcing, because it increases the intermediate good markup under standardized outsourcing less than that under ideal outsourcing. Finally, an increase in σ once again has an ambiguous impact on the horizontal boundaries of the firm.

7 Conclusion

This paper provides a theoretical framework to explain why in many globalized industries vertical outsourcing co-evolves with horizontal integration in the intermediate good sector. Specifically, I build an industry-equilibrium model with monopolistic competition and perfect contracts that allows the organization of the firm to be endogenous in both the vertical and horizontal dimensions of production. In this model, the vertical boundaries of the firm are determined by the trade-off between the high marginalization cost of outsourcing and the high fixed cost of vertical integration. The horizontal boundaries of the firm in the intermediate good sector are determined by the trade-off between the high average cost of ideal outsourcing and the high mismatch cost of standardized outsourcing. The two cost trade-offs allow to distinguish three production structure regimes. Under Vertical Integration, vertically integrated firms produce both the intermediate good and the final good. Under Ideal Outsourcing, production of intermediate goods is outsourced to external firms that produce ideal components. Under Standardized Outsourcing, production of intermediate goods is outsourced to external firms that provide a standardized component to multiple final good producers.

The equilibrium production structure depends endogenously on the parameters of the model. If an industry moves from Vertical Integration to Standardized Outsourcing, then a co-evolution in vertical outsourcing and horizontal integration occurs. The model illustrates that this is likely to occur in six circumstances: if products become more modular; if the fixed cost of setting up an intermediate good firm increases; if tariffs and/or transportation costs increase; if Southern wages increase; if Northern wages decrease; and if industry demand increases. A change in the degree of competition and in the fixed cost of setting up a final good firm, on the other hand, has an ambiguous impact on the organization of production.

The fact that an increase in industry demand induces standardized outsourcing is particularly noteworthy, as it provides a theoretical legitimation of Stiglers contentious conjecture that firm production structures become vertically disintegrated as an industry expands. This result is driven by the assumption of Dixit- Stiglitz monopolistic competition in the final goods sector. A rise in industry demand increases the number of final good firms while leaving firm output unchanged. The increase in the number of final good firms reduces the equilibrium mismatch cost of adapting standardized intermediate goods and thus induces standardized outsourcing.

In summary, the model helps to better appreciate the complexity of trade and investment in a world in which firms choose endogenously their organizational forms. Future extensions to the theoretical model are to allow intermediate good firms to produce standardized components to more than two final good producers and to introduce incomplete contracts.

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