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A MULTIREGIONAL LOCATION MODEL OF MONOPOLISTICALLY-COMPETITIVE FIRMS

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We build a multiregional location choice model for monopolistic competitors, which accommodates two types of assemblers and two classes of vertically-linked parts suppliers. By revealing the changes in potential profits of the firms in each region, the partial equilibrium model can help us identify the best location to set up a business when trade barriers are reduced.

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I. INTRODUCTION

Many of the attempts to predict the impacts of regional trade liberalization such as NAFTA (e.g., Brown, 1993; Markusen and Rutherford, 1993) rely on the general equilibrium analysis. A general equilibrium model with few sectors and regions can provide a big picture, but it is not suitable for studying the impacts upon a specific sector because it often fails to reflect idiosyncrasies of the industry in question. Considering that both lower tariffs and relaxed regulations constitute a reduction of price-inflating factors, it seems possible to produce a more objective scenario by quantifying the effects introduced by free trade. The task can be accomplished by simulating the changes in relative attractiveness of regions and subsequent locational behavior of manufacturing firms, for it ultimately dictates regional production, employment, and trade flows.

The factors influencing manufacturing firms' choice of location may be divided into situation costs (transportation of raw material and finished products) and site costs (wages, amenities and taxes). Employing Chamberlin's (1933) concept of slightly differentiated products manufactured by many firms, Fujita et al. (1995) lays out a basic analytical framework in which these factors make up

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a profit profile for a firm. The model uses monopolistically competitive industries, where a potential manufacturer of a given product would identify the best location by comparing the profit levels of existing firms in each region when all goods-markets are cleared.

However, the said model is not so useful when it comes to vertically-integrated industries such as automobile assembly because first-tier suppliers and second-tier suppliers display markedly distinct production/location pattern. Namely, second-tier firms produce labor-intensive parts and chase low wage. Since presence of many second-tier suppliers does not necessarily help assemblers, it would be erroneous to treat the two groups of suppliers equally. The model presented below builds upon the Fujita et al.'s by considering multiple manufacturing sectors and a more complex industrial structure with two different layers of intermediate input suppliers.

II. MODEL FRAMEWORK

Fig. 1 illustrates the basic structure of the model. There are two different types of good A; A_1 and A_2. They are deemed to have different input-intensity of production and substitutability among competing brands. The A-goods are produced using various intermediate inputs (F-goods) furnished by first-tier suppliers who, in turn, use basic components (S-goods) from second-tier suppliers. Consumers' demand for finished goods creates subsequent demands for inputs, and there exist J regions serving as market and production sites.[1]

A representative consumer is assumed to consume a numeraire good (Q) and the two groups of differentiated A-goods:

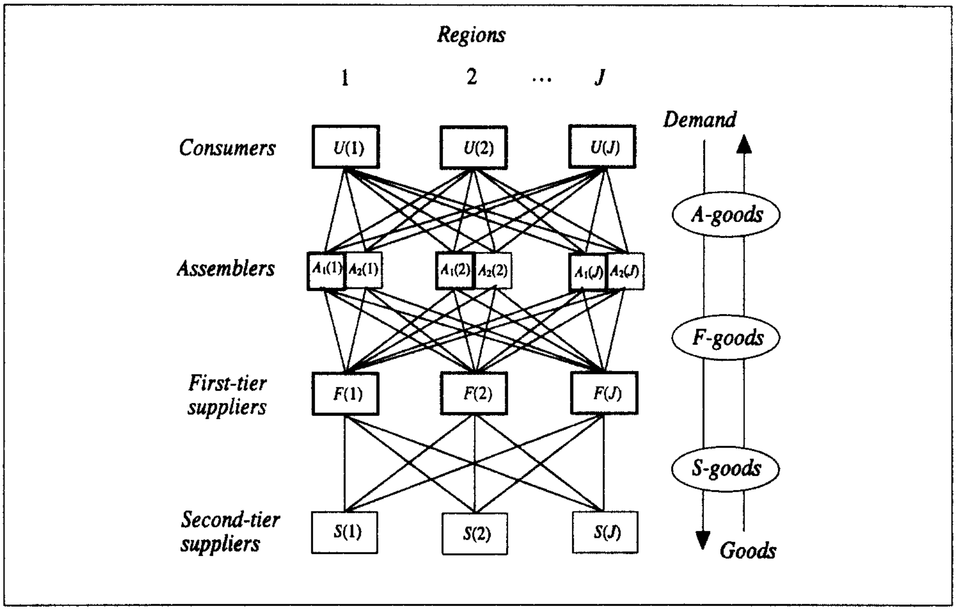
$$U = Q^{1-\alpha_1-\alpha_2} C_{A_1}^{\alpha_1} C_{A_2}^{\alpha_2}$$

$$\text{where } C_{A_h} = \left(\sum_{k=1}^{J} m_h(k) A_h(k)^{\mu_h} \right)^{\frac{1}{\mu_h}} \text{ and } h = 1, 2. \tag{1}$$

Here, $m_h(k)$ is the number of the variety of type-h good produced in region $k (k = 1, \cdots, J)$, while $A_h(k)$ indicates the quantity of each variant of type-h good produced in region k for consumption. The fact that higher $m_h(k)$ improves utility can be interpreted, as in Helpman and Krugman (1985, p. 116), to represent a taste for variety in the population at large, while each individual may have his/her most preferred variant. The μ_h is a substitutability parameter $(0 < \mu_h < 1)$ for each pair of brands within a group. If μ_h is close to 0, A-goods can be substituted with unit elasticity, while when it is close to 1, the goods are almost perfect substitutes.[2]

[1] For reference purposes, markets are indexed by g. Locations for second-tier suppliers, first-tier suppliers, and assemblers are indexed by i, j, and k, respectively.

[Figure 1] Model framework



Note: Highlighted cells indicate the original specification by Fujita et al. (1994).

The production function for the assemblers has a Cobb-Douglas form for the two input categories, labor (L) and intermediate inputs $\{F(j)\}$:

$$A_h(k) = L_{A_h(k)}^{1-\beta_h} C_F^{\beta_h} \text{ where } C_F = \left(\sum_{j=1}^{J} n(j)F(j)^{\eta}\right)^{\frac{1}{\eta}} \text{ and } h = 1, 2 \tag{2}$$

Here, L denotes variable labor inputs. The $n(j)$ is the number of the variety of F-goods produced in region j, while $F(j)$ is the quantity of each variant of F-goods produced in region j which is demanded by an assembler of type-h A-good in region k. The η is the assembler's substitution parameter for a pair of modules ($0< \eta <1$). Thus, C_F represents the subproduction function in terms of the differentiated inputs available and the degree of substitution among them.[3] The two types of A-goods differ in two aspects: (*a*) their factor intensity and (*b*) the degree of substitutability between a pair of brands. We assume that *both types of assemblers share a common substitutability parameter*, η, for F-goods.

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[2] $\mu_h = 1 - \frac{1}{\sigma_h}$ where σ_h is the elasticity of substitution. If μ_h approaches $-\infty$, A-goods are quite distinct and consumed in fixed proportions. However, the σ_h (and the price elasticity of demand) should be greater than 1, making μ_h greater than 0, in order for the firms to be monopolists.

[3] The model can be easily extended to include other factors of production such as capital.

This greatly simplifies the pricing decision of first-tier suppliers, as we will see in equation (24).

All firms possess increasing-returns-to-scale technology due to fixed input requirements. This allows each firm to specialize in production of one and only one variant, making the firm a monopolist. The total labor requirements for the assembler k, producing $A_h(k)$ units of goods, are

$$TL_{A_h(k)} = f_{AL} + L_A[A_h(k)] \qquad \text{where } h = 1, 2. \tag{3}$$

Here, f_{AL} is fixed labor requirements, while $L_A[A_h(k)]$ is variable labor requirements.

Next, the production function for first-tier suppliers producing F-goods is

$$F(j) = L_{F(j)}^{1-\delta} C_S^{\delta} \text{ where } C_S = \left(\sum_{i=1}^{J} r(i) S(i)^{\rho} \right)^{\frac{1}{\rho}}. \tag{4}$$

The $r(i)$ denotes the number of the variety of S-goods shipped from second-tier suppliers in region i, and $S(i)$ indicates the quantity of each variant of S-goods produced in region i which is demanded by a first-tier supplier in region j. The ρ is a substitution parameter for the S-goods $(0<\rho<1)$ which, again, is assumed to be common to all first-tier suppliers.

Analogous to equation (3), total labor requirements for a first-tier supplier y, producing F_y units, are the sum of fixed and variable labor requirements:

$$TL_{F_y} = f_{FL} + L_F(F_y) \tag{5}$$

As for second-tier suppliers, they are assumed to use only labor to produce S-goods. The total labor requirement for a second-tier supplier x, producing S_x units, is

$$TL_{S_x} = f_{SL} + a_{SL} S_x \tag{6}$$

Physical movement of goods incurs additional expenses in the multiplicative form (i.e., on an *ad valorem* basis). Thus, the delivered price in region g for A-goods assembled in region k becomes

$$P_A(k, g) = P_A(k) T_A(k, g) \tag{7}$$

where $P_A(k)$ is the mill price and $T_A(k, g)$ is the transport markup (plus one) for A-goods produced in region k and consumed in region g. Similarly, the delivered price for F-goods and that for S-goods are, respectively,

$$P_F(j,\ k)=P_F(j)T_F(j,\ k) \text{ and } P_S(i,\ j)=P_S(i)T_S(i,\ j)\ . \tag{8}$$

The transport markups are aggregate indicators representing all forms of spatial friction such as freight costs, tariffs, and non-tariff barriers. Region-specific factor prices and different transport markup rates between each pair of regions give rise to regional differences in the profitability of firms.

Ⅲ. DEMAND FOR FINAL GOODS AND PARTS

As indicated in Fig. 1, the demand for final goods generates subsequent demands for intermediate inputs produced in each region. In this section, demand and price for each class of goods are derived according to the optimization behavior of the economic agent involved.

3.1. Consumer behavior

A consumer in region g is assumed to maximize his or her utility shown in equation (1) by consuming the numeraire good and two types of A-goods subject to a budget constraint:

$$\begin{aligned} &Max\ U \\ &s.t.\ \ I(g)=P_Q(g)Q+\sum_{h=1}^{2}\sum_{k=1}^{J} m_h(k)P_{A_h}(k)T_{A_h}(k,\ g)A_h(k) \end{aligned} \tag{9}$$

Since the budget shares (a_h) are fixed, we can examine consumption of each product group in isolation, as suggested by Dixit and Stiglitz (1977, p. 298):

$$\begin{aligned} &Max\ \left(\sum_{k=1}^{J} m_h(k)A_h(k)^{\mu_h}\right)^{\frac{1}{\mu_h}} \\ &s.t.\ \ a_hI(g)=\sum_{k=1}^{J} m_h(k)P_{A_h}(k)T_{A_h}(k,\ g)A_h(k) \text{ where } h=1,2. \end{aligned} \tag{10}$$

Then, the quantity of a variant of type-h good, assembled in region x and demanded by consumers in region g, is as shown below.[4]

$$A_h(x,\ g)=\frac{a_hI(g)\{P_{A_h}(x)T_{A_h}(x,\ g)\}^{-(\omega_h+1)}}{\sum_{k=1}^{J} m_h(k)\{P_{A_h}(k)T_{A_h}(k,\ g)\}^{-\omega_h}} \text{ where } \omega_h=\frac{\mu_h}{1-\mu_h}. \tag{11}$$

[4] See Appendix B.

It follows that the total economy-wide demand for a variant of type-h A-good assembled in region x is

$$A_h^D(x) = \sum_{g=1}^{J} A_h(x,g)$$
$$= P_{A_h}(x)^{-(\omega_h+1)} \sum_{g=1}^{J} \frac{\alpha_h I(g) T_{A_h}(x,g)^{-(\omega_h+1)}}{\sum_{k=1}^{J} m_h(k)\{P_{A_h}(k) T_{A_h}(k,g)\}^{-\omega_h}} . \tag{12}$$

Since $\omega_h > 0$, we can see that the demand for this particular brand of A-good increases with a lower price and delivery cost, with a higher income and expenditure share of the consumers, and with higher transport costs that the competitors face.[5]

3.2. Behavior of assemblers

An assembler in region x producing a variant of type-h good would minimize the total cost, given the required production level as shown in equation (2):

$$Min \ W(x) TL_{A_h^D(x)} + \sum_{j=1}^{J} n(j) P_F(j) T(j,x) F(j)$$
$$s.t. \ A_h^D(x) = L_{A_h(x)}^{1-\beta_h} C_F^{\beta_h} \tag{13}$$

Solving this problem gives the labor requirements for this firm as

$$L_{A_h(x)} = \frac{(1-\beta_h) A_h^D(x)}{W(x)} b_h(x), \tag{14}$$

where $b_h(x)$ is the region-specific Lagrange multiplier. Furthermore, we can obtain

$$C_F = \left(\frac{b_h(x) \beta_h A_h^D(x)}{P_F(j) T_F(j,x)} \right)^{\frac{1}{\eta}} F(j)^{-\frac{1}{\varepsilon}} \text{ where } \varepsilon = \frac{\eta}{1-\eta}. \tag{15}$$

Substitution of these input requirements into the constraint yields the Lagrange multiplier for this problem, which is binding and thus equal to the marginal cost:

[5] The magnitude of the impact brought about by changes in price or transport cost would depend on the substitutability of final goods. If μ_h is close to 1, meaning the good is not very different from other brands, then the price elasticity of demand, as well as ω_h, will be quite high. Thus, a small reduction in the price or transport cost will cause a big increase in demand.

$$b_h(x) = \beta_h^{-\beta_h}(1-\beta_h)^{-(1-\beta_h)} W(x)^{1-\beta_h}\left[\sum_{j=1}^{J} n(J)\{P_F(j)T_F(j, x)\}^{-\varepsilon}\right]^{-\frac{\beta_h}{\varepsilon}}. \quad (16)$$

In addition, the amount of a variant of F-good produced in region y and demanded by an assembler (type-h) in region x producing $A_h^D(x)$ is

$$F(y, x) = b_h(x)^{\frac{\varepsilon}{\beta_h}+1}\left\{\frac{1-\beta_h}{W(x)}\right\}^{\frac{1-\beta_h}{\beta_h}\varepsilon}\left\{\frac{\beta_h}{P_F(y)T_F(y, x)}\right\}^{\varepsilon+1} A_h^D(x). \quad (17)$$

Noting that first-tier suppliers serve all assemblers of both types across all regions, it follows that the total demand for a variant of module produced in region y is

$$\begin{aligned} F^D(y) = & \sum_{k=1}^{J}\sum_{h=1}^{2} m_h(k)F(y, k) = \beta_h^{1-\beta_h}(1-\beta_h)^{-(1-\beta_h)} \\ & \times \sum_{k=1}^{J}\sum_{h=1}^{2}\left\{m_h(k)\, W(k)^{1-\beta_h}\left[\sum_{j=1}^{J} n(j)\{P_F(j)T_F(j, k)\}^{-\varepsilon}\right]^{-\left(\frac{\beta_h}{\varepsilon}+1\right)}\right. \\ & \left.[P_F(y)\, T_F(y, k)]^{-(\varepsilon+1)} A_h^D(k)\right\} \end{aligned} \quad (18)$$

One can say that the demand for F-goods increases, *ceteris paribus*, with a higher level of A-good production, and with lower price and transportation charge. It also increases when wages at region k increase (due to the factor substitution effect) or when price and transport cost for competing products go up.

All firms set their prices according to the monopolist's rule, equating the marginal cost to the marginal revenue: $MC = P\left(1-\frac{1}{e}\right) = MR$, where e is the price elasticity of demand. But we know that, for a CES-type subutility function with a substitutability parameter of μ_h, the $\left(1-\frac{1}{e}\right)$ term approximates μ_h when the number of the variants is large.[6] It can also be verified that e is greater than 1 in our case. Hence, the F.O.B. price of a unit of A-good produced in region x is derived as

$$P_{A_h}(x) = \frac{MC}{\left(1-\frac{1}{e}\right)} = \frac{b_h(x)}{\mu_h}. \quad (19)$$

3.3. Behavior of first-tier suppliers

Since they are functionally equivalent, first-tier suppliers face the same problem as assemblers. An F-good producer in region y minimizes the total cost, subject

[6] See Helpman and Krugman (1985), p. 119.

to the required production level of $F^D(y)$:

$$\begin{aligned} &Min\ \ W(y)\,TL_{F^D(y)} + \sum_{i=1}^{J} r(i)P_S(i)\,T(i,y)S(i) \\ &\quad s.t.\ \ F^D(y) = L_{F(y)}^{1-\delta} C_S^{\delta} \end{aligned} \tag{20}$$

The Lagrange multiplier (and marginal cost) for the first-tier supplier is

$$\begin{aligned} &q(y) = \delta^{-\delta}(1-\delta)^{-(1-\delta)}\,W(y)^{1-\delta}\Big[\sum_{i=1}^{J} r(i)\{P_S(i)\,T_S(i,y)\}^{-\theta}\Big]^{-\frac{\delta}{\theta}} \\ &\qquad \text{where } \theta = \frac{\rho}{1-\rho}. \end{aligned} \tag{21}$$

Repeating the same procedure as in an assembler's case yields the quantity of S-goods produced in region z, demanded by a firm in region y producing $F^D(y)$:

$$S(z,y) = q(y)^{\frac{\theta}{\delta}+1}\left\{\frac{1-\delta}{W(y)}\right\}^{\frac{1-\delta}{\delta}\theta}\left\{\frac{\delta}{P_S(z)\,T_S(z,y)}\right\}^{\theta+1} F^D(y). \tag{22}$$

It follows that the total demand for a variant of S-good produced in region z is

$$\begin{aligned} S^D(z) = &\sum_{j=1}^{J} n(j)S(z,j) = \delta^{1-\delta}(1-\delta)^{-(1-\delta)} \\ &\times \sum_{j=1}^{J} n(j)\,W(j)^{1-\delta}\Big[\sum_{i=1}^{J} r(i)\{P_S(i)\,T_S(i,j)\}^{-\theta}\Big]^{-\left(\frac{\delta}{\theta}+1\right)} \\ &\{P_S(z)\,T_S(z,j)\}^{-(\theta+1)}F^D(j)\ . \end{aligned} \tag{23}$$

In parallel with the demand for F-goods, the demand for S-goods increases, *ceteris paribus*, when F-good production and wages at region j go up, and when the price and transportation charge decrease. In addition, presence of competitors with lower price and transport costs is detrimental.

We can easily derive the F.O.B. price of an F-good produced in region y as

$$P_F(y) = \frac{q(y)}{\eta}. \tag{24}$$

3.4. Behavior of second-tier suppliers

Using labor as their sole input, second-tier suppliers produce $S^D(z)$ units of

S-goods that are priced according to the principle:

$$P_S(z) = \frac{a_{SL} W(z)}{\rho} \quad \text{where } W(z) \text{ is the prevailing wage level at region } z. \tag{25}$$

Ⅳ. PROFIT FUNCTIONS FOR THE FIRMS

Once demand functions are obtained, we can compare profit level for the firms to measure the attractiveness (or competitiveness) of the regions. Since the firms positioned higher in the production chain have more factors affecting their profit size, we examine profits of second-tier suppliers first, followed by those of first-tier suppliers and assemblers. As expected, anything that decreases the marginal cost of a firm is found to increase the firm's profit because the price elasticity of demand is always greater than 1 for monopolists.

4.1. Profit for second-tier suppliers

Since the price is higher than the marginal cost, it pays to produce as much as demand dictates. The profit function for a second-tier supplier in region z, serving first-tier firms in all regions, is derived as the total revenue minus the total cost:

$$\begin{aligned} \Pi_{S(z)} &= P_{S(z)} S^D(Z) - a_{SL} W(z) S^D(z) - W(z) f_{SL} \\ &= a_{SL}^{\delta}(1-\rho)\rho^{-\delta}\delta^{-\delta}(1-\delta)^{-(1-\delta)} W(z)^{-\theta} \\ &\quad \times \sum_{j=1}^{J} \frac{n(j) F^D(j) W(j)^{1-\delta} T(z,j)^{-(\theta+1)}}{\left[\sum_{i=1}^{J} r(i)\{W(i) T_S(i,j)\}^{-\theta}\right]^{\frac{\delta}{\theta}+1}} - W(z) f_{SL} \end{aligned} \tag{26}$$

Other things held constant, the profit is positively related to the size of the markets, wages at the markets (because more S-goods are substituted for labor), and the transport cost faced by the competitors. It is inversely related to the wage level in region z, the transportation cost to the markets, and the degree of overall competition captured by $r(i)$.

4.2. Profit for first-tier suppliers

The profit function for a first-tier supplier in region y is derived in a similar fashion, albeit a little complicated by the fact that the firm caters to all types of assemblers across regions:

$$\begin{aligned} \Pi_{F(y)} &= P_F(y) F^D(y) - q(y) F^D(y) - W(y) f_{FL} \\ &= \frac{q(y)(1-\eta)}{\eta} F^D(y) - W(y) f_{FL} \end{aligned} \tag{27}$$

Substitution of $F^D(y)$ in equation (18) and $q(y)$ in equation (21) into the above yields

$$\Pi_{F(y)} = (1-\eta)\{W(y)^{1-\delta}\}^{-\varepsilon} \sum_{k=1}^{J} \sum_{h=1}^{2} \frac{B}{N^{\frac{\beta_h}{\varepsilon}+1}} - W(y) f_{FL} \tag{28}$$

where $B = \beta_h^{-\beta_h}(1-\beta_h)^{-(1-\beta_h)} \left\{ \eta^{-1} \left(\frac{a_{SL}}{\rho} \right)^{\delta} \delta^{-\delta}(1-\delta)^{-(1-\delta)} \right\}^{\beta_h}$

$$\times m_h(k) A_h^D(k) W(k)^{1-\beta_h} \left[\sum_{i=1}^{I} r(i)\{W(i) T_S(i, y)\}^{-\theta} \right]^{\frac{\delta}{\theta}\varepsilon} T_F(y, k)^{-(\varepsilon+1)}$$

and $N = \sum_{j=1}^{J} \left[n(j)\{W(j)^{1-\delta}\}^{-\varepsilon} \left[\sum_{i=1}^{I} r(i)\{W(i) T_S(i, j)\}^{-\theta} \right]^{\frac{\delta}{\theta}\varepsilon} T_F(j, k)^{-\varepsilon} \right]$.

This may be interpreted in the same way as in the second-tier suppliers' case, with a notable exception that the profitability also improves when there is a greater variety of easily-accessible S-goods.

4.3. Profit for assemblers

The profit function of an assembler stationed in region x producing the maximum possible output is

$$\begin{aligned} \Pi_{A_h(x)} &= P_{A_h}(x) A_h^D(x) - b_h(x) A_h^D(x) - W(x) f_{AL} \\ &= \frac{b_h(x)(1-\mu_h)}{\mu_h} A_h^D(x) - W(x) f_{AL} \,. \end{aligned} \tag{29}$$

Substituting both $A_h^D(x)$ found in equation (12) and $b_h(x)$ in equation (16) into the equation above, we obtain

$$\begin{aligned} \Pi_{A_h(x)} &= (1-\mu)\{W(x)^{1-\beta_h}\}^{-\omega_h} \\ &\times \left[\sum_{j=1}^{J} \left[n(j)\{W(j)^{1-\delta}\}^{-\varepsilon} \left[\sum_{i=1}^{I} r(i)\{W(i) T_S(i, j)\}^{-\theta} \right]^{\frac{\delta}{\theta}\varepsilon} T_F(j, x)^{-\varepsilon} \right] \right]^{\frac{\beta_h}{\varepsilon}\omega_h} \\ &\times \sum_{g=1}^{J} \frac{a_h I(g) T_{A_h}(x, g)^{-(\omega_h+1)}}{\sum_{k=1}^{J} \left[m_h(k)\{W(k)^{1-\beta_h}\}^{-\omega_h} N^{\frac{\beta_h}{\varepsilon}\omega_h} T_{A_h}(k, g)^{-\omega_h} \right]} - W(x) f_{AL} \end{aligned}$$

where N remains the same as in equation (28). (30)

The firm's profitability at region x depends upon the region's wage level, accessibility to F-goods, the market size, ease of transportation to the consumption point, and the intensity of competition (m_h). It is worth noting that, although assemblers have no direct linkages to second-tier suppliers, they are still affected via first-tier suppliers. That is, a first-tier supplier's improved access to a greater variety of *S*-goods results in a reduced marginal cost (and hence lower *F*-good price) for that firm, which in turn benefits the assemblers as well. This relationship is not so explicit in the original specification proposed by Fujita et al. (1994) with a single class of parts suppliers.

V. CONCLUDING REMARKS

When a regional free-trading bloc is formed, it necessarily alters competitiveness of the member regions. Low wage alone cannot guarantee proliferation of manufacturing activities. A model based on monopolistic competition theory has been constructed to help assess the changes in potential profits for assemblers and parts suppliers operating in each region. By varying T, it can show impact of abolishing trade barriers upon the industry through the eyes of individual firms. As an outgrowth of the location theory, this model preserves the significance of intranational transport cost in addition to the increasing returns to scale and imperfect competition, two features that are rapidly gaining acceptance in the field of international economics as Krugman (1993) noted. Perhaps the biggest contribution made by this study is the proposal of a composite locational index *within a hierarchical industrial organization.*

APPENDIX A: List of parameters and variables

- Location-specific parameters

$m_h(k)$	number of variety of type-h A-goods assembled in region k
$n(j)$	number of variety of F-goods produced in region j
$r(i)$	number of variety of S-goods produced in region i
$T_A(k, g)$	transport markup for an A-good produced in k and delivered to g
$T_F(j, k)$	transport markup for an F-good produced in j and delivered to k
$T_S(i, j)$	transport markup for an S-good produced in i and delivered to j
$I(g)$	income of a representative consumer in region g
$W(g)$	prevailing wage rate in region g

- Location-dependent endogenous variables

$A_h^D(k)$	demand for a variant of type-h A-good assembled in region k
$F^D(j)$	demand for a variant of F-good produced in region j
$S^D(i)$	demand for a variant of S-good produced in region i
$P_{A_h}(k)$	F.O.B. price of a unit of type-h A-good assembled in region k
$P_F(j)$	F.O.B. price of a unit of F-good produced in region j
$P_S(i)$	F.O.B. price of a unit of S-good produced in region i

- Location-independent parameters

Q	demand for the numeraire good
f_{AL}	fixed labor requirement for an assembler
f_{FL}	fixed labor requirement for a first-tier supplier
f_{SL}	fixed labor requirement for a second-tier supplier
μ_h	substitutability of each pair of differentiated type-h A-goods
η	substitutability of each pair of differentiated F-goods
ρ	substitutability of each pair of differentiated S-goods
α	expenditure shares of consumers
β	expenditure shares of assemblers
δ	expenditure shares of first-tier suppliers

APPENDIX B: The consumer's utility maximization problem

$$Max \left(\sum_{k=1}^{J} m_h(k) A_h(k)^{\mu_h} \right)^{\frac{1}{\mu_h}}$$
$$s.t. \;\; \alpha_h I(g) = \sum_{k=1}^{J} m_h(k) P_{A_h}(k)\, T_{A_h}(k, g) A_h(k) \;\; \text{where} \;\; h = 1, 2. \tag{10}$$

$$\mathcal{L} = \left(\sum_{k=1}^{J} m_h(k) A_h(k)^{\mu_h} \right)^{\frac{1}{\mu_h}} + \lambda \left\{ \alpha_h I(g) - \sum_{k=1}^{J} m_h(k) P_{A_h}(k)\, T_{A_h}(k, g)\, A_h(k) \right\} \tag{10.1}$$

$$\frac{\partial \mathcal{L}}{\partial A_h(k)} = \frac{1}{\mu_h} \left(\sum_{k=1}^{J} m_h(k) A_h(k)^{\mu_h} \right)^{\frac{1}{\mu_h} - 1} m_h(k) \mu_h A_h(k)^{\mu_h - 1}$$
$$- \lambda m_h(k) P_{A_h}(k)\, T_{A_h}(k, g) = 0 \tag{10.2}$$

$$A_h(k)^{\mu_h - 1} = \frac{\lambda P_{A_h}(k)\, T_{A_h}(k, g)}{\left(\sum_{k=1}^{J} m_h(k) A_h(k)^{\mu_h} \right)^{\frac{1}{\mu_h} - 1}} \tag{10.3}$$

$$A_h(k) = \lambda^{\frac{1}{\mu_h - 1}} \{ P_{A_h}(k)\, T_{A_h}(k, g) \}^{\frac{1}{\mu_h - 1}} \left(\sum_{k=1}^{J} m_h(k) A_h(k)^{\mu_h} \right)^{\frac{1}{\mu_h}} \tag{10.4}$$

Then, plug this into the budget constraint in equation (10) to get rid of λ:

$$\alpha_h I(g) = \sum_{k=1}^{J} m_h(k) P_{A_h}(k)\, T_{A_h}(k, g)\, \lambda^{\frac{1}{\mu_h - 1}} \{ P_{A_h}(k)\, T_{A_h}(k, g) \}^{\frac{1}{\mu_h - 1}}$$
$$\times \left(\sum_{k=1}^{J} m_h(k) A_h(k)^{\mu_h} \right)^{\frac{1}{\mu_h}} \tag{10.5}$$

$$\lambda^{\frac{1}{\mu_h - 1}} = \frac{\alpha_h I(g)}{\sum_{k=1}^{J} m_h(k) \{ P_{A_h}(k)\, T_{A_h}(k, g) \}^{\frac{\mu_h}{\mu_h - 1}} \left(\sum_{k=1}^{J} m_h(k) A_h(k)^{\mu_h} \right)^{\frac{1}{\mu_h}}} \tag{10.6}$$

From equation (10.4), we obtain

$$A_h(x, g) = \frac{\alpha_h I(g) \{ P_{A_h}(x)\, T_{A_h}(x, g) \}^{-(\omega_h + 1)}}{\sum_{k=1}^{J} m_h(k) \{ P_{A_h}(k)\, T_{A_h}(k, g) \}^{-\omega_h}} \;\; \text{where} \;\; \omega_h = \frac{\mu_h}{1 - \mu_h}. \tag{11}$$

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