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Fragmentation, Outsourcing and the Service Sector*

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Résumé / Abstract

On montre que la croissance du secteur des services facilite la fragmentation de la production. Les services relient les blocs de production et permettent la dispersion de la production intégrée. Un pays possédant un grand nombre de services spécialisés a tendance à exporter les pièces dont la production utilise intensément les services. Avec la libéralisation de l'échange des services, les pays possédant un secteur de services avancé tendent à impartir la fabrication des pièces. Par conséquent, la libéralisation du commerce augmente la fragmentation. Par contre, si les coûts de transport sont élevés pour les services les plus complexes, le libre échange des services spécialisés peut réduire la fragmentation.

We show that the growth of the service sector facilitates outsourcing, or fragmentation of production. Services link production blocks, and allows the breaking up of integrated production. The cost of aggregate service decreases as the number of specialized services increases. A country with a greater number of specialized services tends to export components that are service-intensive. When international trade in specialized services are permitted, the country with an advanced service sector will outsource most of the manufacturing activities. Thus free trade in specialized services tends to increase fragmentation. On the other hand, if there are high transport costs with a bias against complex specialized services, then free trade in specialized services may work against fragmentation.

Mots Clés : Fragmentation, impartition, secteur des services

Keywords: Fragmentation, outsourcing, service sector

JEL : L23, F12

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1 Introduction

There has been a marked increase in the fragmentation of production in recent years. A given final good (for example, a personal computer, a car) may include components that are produced at many different parts of the world. The emergence of contract manufacturers of chips, such as Taiwan's UMC (United Microelectronics Corporation) and TSMC(Taiwan Semiconductor Manufacturing Company), and Singapore's CSM (Chartered Semiconductor Manufacturing) is a spectacular illustration of such fragmentation. It was Morris Chang, founder and chairman of TSMC, who pointed out to the world that the semiconductor industry was in fact not one but two industries, and that it would be best to separate them out[1]. "One industry is about designing chips, which requires lots of talent but little capital. The other is about making chips, which requires more capital than talent"(The Economist, May 19, 2001, p 62). Another well known example of fragmentation concerns the famous camera, Leica, with lenses produced in Germany, and other parts produced in Canada, Spain, and the Far East.

To explain the tendency for increased fragmentation, economists have cited factors such as low labor costs in developing countries that have opened up and welcome foreign investment, and reduced tranport costs. These factors alone do not explain why computer chips are made in Taiwan and Singapore, and car parts are made in Mexico, but these are not made in, say, Nepal, Vietnam, or Bangladesh. To answer this question, one must take into account the fact that components are not just "manufactured" by manufacturing labor. They have to be marketed, their transportation have to speedy, and insured, deliveries must be timely, communications with head office or customers must be efficient, contracts must be reliable, etc.All these factors point to the importance of a service industry that supports and facilitates manufacturing. An important point is that it is not economical to produce components in a low wage economy that does not have an efficient service sector.

In this paper, we develop a general equilibrium model with a manufacturing sector, and a service sector. We show how the growth of the service sector enables the economy to manufacture and export components. The

[1]In 1987, Mr Chang founded TSMC, the world's first "fab", or fabrication plan. Many "fabless" designers (among which are university-based research centers) have bought capacity from TSMC. Integrated design manufacturers (IDMS) such as Intel still maintain that chip design and manufacture go hand in hand.

range of components that a country can export is shown to depend on the price of service. We also show how international trade in services may affect the trade in components, and the degree of fragmentation.

Our story may be summarised as follows. There are two countries, and advanced country, and a developing country. There are two final goods, say bananas and cars. Bananas are produced by labor, and no fragmentation is possible in banana production. Cars are produced by assembling components, such as spark plugs, seat belts, tyres, gear box, transmission, engine, and so on. To produce these components and connect them with other "production blocks", an economy needs both manufacturing labor, and services. A manufacturer of a given component hires manufacturing labor and buys and combines services from "service providers", such as an accounting firm, a marketing firm, a security firm, a bank, a delivery firm, a cleaning contractor, and so on. These service firms have a constant variable cost, and a fixed cost. Thus their average cost falls as their volume of service output rises. Decreasing average cost is not compatible with price-taking behavior. Therefore we assume that the service industry is characterized by monopolistic competition: each service firm faces a downward sloping demand curve, and sets its price, taking as given the prices of imperfect substitutes set by other service firms.

The number of different services that an economy can offer depends on its stage of development and the size of the economy. For example, a matured economy such as the US has more specialized services than less matured ones, such as Indonesia. A large economy, such as Germany, can offer more services than a small economy, such as New Zealand, even if the two economies have the same level of human capital per person.

We argue that the greater is the range of services, the more efficient is the production of components. On the other hand, a country that has a greater range of services may have a more expensive service price, perhaps due to higher labor cost. For example, a computer programmer in the US earns more than his couterpart working in India. The trade-off between range of services and costs of individual services determine what types of components will be produced in which country. We expect that a component that has a high ratio of service to manufacturing labor will be produced in the country that has a greater range of services.

In writing our paper, we have benefited from the the insightful discussions on fragmentation, contained in Jones and Kierzkowski. (1990, 2001a,b).Jones and Kierzkowski (1990) proposed a distinction between integrated and fragmented technologies.Under the integrated technology, the manufacturing of a good takes place within a single production block, and the role of services is rather limited. Fragmented technology requires that service links connect individual production blocks. “These links can be best thought of as consisting of bundles of activities- coordination, transportation, telecommunication, administration, insurance, financial services, and so on.” (2001a, p 368). However, Jones and Kierzkowski (2001a) did not model the service sector. They focussed attention on the case in which one integrated production activity gets segmented into two components as a result of an exogenous reduction in the cost of international service links.Jones and Kierzkowski (2001b) devoted a short section to the role of services in fragmentation. They mentioned two stylized facts about the costs of service links: “First, purely domestic service links are less costly than those required to connect production blocks located in more than one country...Second, production of services displays strong increasing returns to scale.” The second stylized fact seems to call for a departure from a model based on perfect competition. Our paper is attempt to move in that direction.

Various aspects of fragmentation have been studied by a number of authors. Arndt (1997) showed that intra-product specializationcan be a source of gains from trade. harris (1993, 1995) focussed on the role of telecommunications. Hanson (1996) mentioned fragmentation in the context of trade between Mexico and the United States. Feenstra (1998) linked the integration of trade with the disintegration of production.Raff (2001) discussed the role of direct foreign investment in services. Deardorff (1998, 2001) provided insightful discussions of the role of services in coordinating the fragments.

This paper is organized as follows. In section 2, we develop a simple model of a closed economy with a service sector. In section 3, we characterize the autarkic equilibrium. Section 4 considers two economies with different numbers of specialized service firms, and shows how the pattern of trade in components is determined, given that there is no trade in services. Section 5 allows trade in services. Section 6 discusses some generalisations of the basic model.

2 A model of a closed economy with a service sector

2.1 The service sector

An aggregate service is produced using specialised services as inputs. There are n specialised services (e.g., accounting, marketing, legal service, auditing, security...). We let S denote the number of units of aggregate service produced, and m_i denote the units of specialised service i, used as input in the production of the aggregate. We assume the following production function:

$$S = [m_1^{\alpha} + ... + m_n^{\alpha}]^{1/\alpha} \tag{1}$$

where $0 < \alpha < 1$. For example, if $\alpha = 1/2$ and $n = 2$, then using 4 units of specialized service 1 and zero unit of specialized service 2 will result in 4 units of aggregate service, while using 2 units of each specialized service will result in 8 units of aggregate service. (This idea of gains from specialization was forcefully put forwards by Adam Smith: 4 brick layers can build 4 houses in one year, but two brick layers and two carpenters can build 8 houses in one year.)

Let p_i be the price of a unit of specialised service i. The cost of producing one unit of aggregate service is the solution of the cost minimization problem

$$P_S = \min_{m_i} \sum_{i=1}^{n} p_i m_i$$

subject to

$$\left[\sum_i m_i^{\alpha}\right]^{1/\alpha} = 1$$

The solution yields

$$P_S = \left[\sum_{i=1}^{n} p_i^{\alpha/(\alpha-1)}\right]^{(\alpha-1)/\alpha} \tag{2}$$

From Shephard's lemma, the conditional factor demand function (here, for the specialised service i) given that we must produce one unit of the aggregate service is

$$m_i^d(p, S=1) = \frac{\partial P_S}{\partial p_i} = Ap_i^{1/(\alpha-1)}$$

where

$$A \equiv \left[\sum_{j=1}^{n} p_j^{\alpha/(\alpha-1)}\right]^{-1/\alpha}$$

If S units of the aggregate service is to be produced, the conditional factor demand is

$$m_i^d(p, S) = ASp_i^{1/(\alpha-1)} \tag{3}$$

It does not matter in our model whether aggregate services are produced by "aggregate service firms" that buy specialialized services, and sell aggregate services in the market, or whether aggregate services are produced by users of the aggregate service (such as a manufacturer of a car component.) In the latter case, P_S is the cost (rather than the price) of a unit of aggregate service.

Concerning the industry that produces the n specialised services, we assume it consists of service firms that operate under monopolistic competition.We assume that service firm i produces the specialised service i. Service firm i takes the function (3) as the demand function that it faces. It takes S as given, and even though it can influence p_i, we assume it takes A as a constant. (This is the the assumption made by Dixit and Stiglitz). Inverting (3), we get the inverse demand function

$$p_i = \left[\frac{m_i}{AS}\right]^{\alpha-1} = p_i(m_i)$$

The marginal revenue is

$$MR_i = p_i\left[1 - \frac{1}{\epsilon}\right] = \alpha p_i$$

where ϵ is the elasticity of demand

$$\epsilon \equiv -\frac{d\ln m_i}{d\ln p_i} = \frac{1}{1-\alpha} > 1$$

We now turn to the production of specialised service i. We assume that to produce m_i units of specialised service i, the service firm i must incur fixed cost and variable cost. Assume the fixed cost is $F = wf$ and the variable cost is cwm_i, where c is a positive constant representing the amount of units of labor required per unit of service output, and w is the wage rate, which the firm takes as given.Since the firm equates marginal revenue with marginal cost, we have

$$\alpha p_i = cw$$

Non-negative profit requires

$$p_i \geq \frac{F}{m_i} - cw \tag{4}$$

and profit is

$$r_i = pm_i - cwm_i - wf = \left[\left(\frac{1-\alpha}{\alpha} \right) cm_i - f \right] w \tag{5}$$

In a symmetric equilibrium, $p_i = p_j = p$, so (2) gives

$$P_S = n^{(\alpha-1)/\alpha} p = n^{(\alpha-1)/\alpha} \left(\frac{cw}{\alpha} \right) \tag{6}$$

This equation says that the greater is the number of specialised services, the lower is the price (=cost) of a unit of aggregate service.

The sum of profits in the service industry is

$$R = nr_i = n \left[\left(\frac{1-\alpha}{\alpha} \right) cm_i - f \right] w \tag{7}$$

2.2 The goods sector

The goods sector is perfectly competitive. The economy produces two final goods, denoted by X and Y. To produce one unit of good Y, the input requirement is a_Y units of labor. Thus

$$P_Y = wa_Y$$

To produce one unit of good X (say a car), k components must be assembled: e.g., spark plugs, seat belts, tyres, gear box, engine, etc. Define units of measurement so that each car needs exactly one unit of each of the k components. We assume that assembling a car requires g units of labor and θ_X units of services. Then the price of a car is the sum of the prices (denoted by π_j) of the k components and the cost of assembling:

$$P_X = \pi_1 + \pi_2 + ... + \pi_k + gw + P_S\theta_X$$

To produce one unit of component j, two inputs are required: one unit of labor and θ_j units of aggregate service. The price of component j is therefore

$$\pi_j = w + \theta_j P_S$$

The price of good X is then

$$P_X = (k+g)w + \Theta P_S = (k+g)w + \Theta n^{(\alpha-1)/\alpha}\left(\frac{cw}{\alpha}\right)$$

where

$$\Theta \equiv \theta_X + \sum \theta_i$$

denotes the number of units of aggregate service required per unit of good X.

It follows that, for given n, the economy has the following property of a Ricardian model: the prices P_X, P_S, and P_Y are determined only by technology.

2.3 Consumers

In this economy, the profits of the service firms are in general positive in equilibrium. So national income is the sum of labor income and profit

$$M = wL + n\left[\left(\frac{1-\alpha}{\alpha}\right)cm_i - f\right]w \tag{8}$$

Assume that the labor supply L is fixed. The representative consumer solves

$$\max_{X,Y} U(X,Y)$$

subject to

$$P_X X + P_Y Y = M$$

where $P_Y = 1$ and M is his income Assume that $U(X,Y)$ is homothetic. Then the demand functions takes the form

$$X^d = \Phi_X(P_X, P_Y)M \tag{9}$$

and

$$Y^d = \Phi_Y(P_X, P_Y)M \tag{10}$$

where, in view of the budget constraint,

$$P_X \Phi_X(P_X, P_Y) + P_Y \Phi_Y(P_X, P_Y) = 1 \tag{11}$$

3 Autarkic equilibrium

3.1 Equilibrium conditions

In equilibrium,

$$m_i = n^{-1/\alpha} S = n^{-1/\alpha} \Theta X^d = n^{-1/\alpha} \Theta \Phi_X(P_X, P_Y)M \tag{12}$$

Substituting (12) into (8), we get

$$M = wL + w\left(\frac{1-\alpha}{\alpha}\right) cn^{(\alpha-1)/\alpha} \Theta \Phi_X(P_X, P_Y)M - wfn$$

hence

$$M = \frac{(L - fn)w}{1 - w\left(\frac{1-\alpha}{\alpha}\right) cn^{(\alpha-1)/\alpha} \Theta \Phi_X(P_X, P_Y)}$$

The equilibrium output of X is then

$$\widehat{X} = \frac{(L - fn)w \Phi_X(P_X, P_Y)}{1 - w\left(\frac{1-\alpha}{\alpha}\right) cn^{(\alpha-1)/\alpha} \Theta \Phi_X(P_X, P_Y)} \tag{13}$$

Remark: Note that, in view of (11),

$$w\left(\frac{1-\alpha}{\alpha}\right) cn^{(\alpha-1)/\alpha} \Theta \Phi_X(P_X, P_Y) = (1-\alpha) P_S \Theta \Phi_X(P_X, P_Y)$$

$$< (1-\alpha)P_X\Phi_X(P_X, P_Y) < 1-\alpha$$

Example: With Cobb-Douglas utility, $U = X^\beta Y^{1-\beta}$

$$P_X X^d = \beta M$$

that is

$$P_X\Phi_X(P_X, P_Y)M = \beta M$$

or

$$\Phi_X(P_X, P_Y) = \frac{\beta}{P_X} \tag{14}$$

Substituting (14) into (13), we get

$$\widehat{X} = \frac{w\beta(L-fn)}{P_X - w\beta\Theta\left(\frac{1-\alpha}{\alpha}\right)cn^{(\alpha-1)/\alpha}}$$

$$\widehat{X} = \frac{\beta(L-fn)}{(k+g)w + \Theta n^{(\alpha-1)/\alpha}\left(\frac{cw}{\alpha}\right)[1-(1-\alpha)\beta]} > 0$$

3.2 A modified version of the model

From this point onwards, for convenience, we assume that there is a continuum of components, represented by the interval $[0, k]$. Let τ be the index for the component. The price of component τ is $\pi(\tau)$, and the price of the car is

$$P_X = \theta_X P_S + \int_0^k \pi(\tau)d\tau$$

where

$$\pi(\tau) = w + \theta(\tau)P_S$$

Assume for simplicity that

$$\theta(\tau) = b\tau$$

Then we can draw the graph of $\pi(\tau)$ as a function of τ

$$\pi(\tau) = w + \tau b P_S$$

This graph is a straight line with slope bP_S. In autarkic equilibrium,

$$\pi(\tau) = w + \tau b n^{(\alpha-1)/\alpha}\left(\frac{cw}{\alpha}\right)$$

4 Trade in goods, and fragmentation

4.1 Assumptions

Now consider a two country world. The home country is the US, the foreign country is Mexico. All consumers have identical preferences. The endowments of labor are L and L^*. There are n service firms in the US, and n^* service firms in Mexico, where $n^* < n$. We assume, in this section, that SERVICES ARE NOT INTERNATIONALLY TRADED, while components can be traded. Mexico has the component price curve

$$\pi^*(\tau) = w^* + \tau b^* (n^*)^{(\alpha-1)/\alpha} \left(\frac{c^* w^*}{\alpha}\right)$$

We assume $a_Y^* > a_Y$. Then Mexico's wage is lower than US wage:

$$w^* < w.$$

If the slope $b^* \widehat{P}_S^* > b\widehat{P}_S$, then the two curves $\pi^*(\tau)$ and $\pi(\tau)$ will intersect at a point τ_I. Mexico will export those components with index $\tau < \tau_I$ and the US will export (if Mexico also assembles cars at the new equillibrium) those components with $\tau > \tau_I$.

One may assume that

$$g^* > g$$

and $g^* - g$ is so great that Mexico does not[2] assemble cars when it can buy cars from the US.

4.2 Free-trade equilibrium (without trade in services)

Assume that services are not internationally traded. To find a free-trade equilibrium, let us at first consider the simple case where the assembling of components does not require services, that is, $\theta_X = \theta_X^* = 0$. Assume that g^* is much greater than g, so that car assembling takes place only in the US. Let P_X $(= P_X^*)$ denote the world price of good 1 (cars) under free trade, and $P_Y = P_Y^* = 1$.

[2]Alternatively, one may assume that the cost of assembly is zero, and service is not needed for assembly. Then consumers do not buy cars, they buy components and assemble the cars themselves.

World income, in terms of good Y, is the sum of labor income and profits

$$Z \equiv wL + w^*L^* + n\left[\left(\frac{1-\alpha}{\alpha}\right)cm - f\right]w + n^*\left[\left(\frac{1-\alpha}{\alpha}\right)cm^* - f^*\right]w^* \tag{15}$$

where

$$w = \frac{1}{a_Y}$$

if good 2 is produce in the home country, otherwise

$$w > \frac{1}{a_Y}$$

similarly,

$$w^* = \frac{1}{a_Y^*}$$

if good 2 is produce in the foreign country, otherwise

$$w^* > \frac{1}{a_Y^*}$$

World demands for good 1 and good 2 are

$$X^\omega = \Phi_X(P_X, 1)Z = \Phi_X(P_X, 1)Z \tag{16}$$

$$Y^\omega = \Phi_Y(P_X, 1)Z = \left[1 - P_X\Phi_X(P_X, 1)\right]Z \tag{17}$$

Suppose that in equilibrium, the foreign country exports components with index τ in the range $[0, \tau_I]$ and the home country exports components with index τ in the range $[\tau_I, k]$. Then the total quantity of aggregate services supplied by the foreign country is

$$S^* = \left[\int_0^{\tau_I} b^*\tau d\tau\right] X^\omega = \frac{1}{2}b^*\tau_I^2 X^\omega \tag{18}$$

Similarly, for the home country,

$$S = \left[\int_{\tau_I}^{k} b\tau d\tau\right] X^\omega = \frac{1}{2}b\left[k^2 - \tau_I^2\right] X^\omega \tag{19}$$

We also have

$$m = n^{-1/\alpha} S$$

$$m^* = (n^*)^{-1/\alpha} S^*$$

Since τ_I is the intersection of the two component-price curves, it must be the case that for component τ_I the production costs in both countries are equal:

$$w^* + b^* P_S^* \tau_I = w + b P_S \tau_I \tag{20}$$

That is,

$$w^* + \tau_I b^* (n^*)^{(\alpha-1)/\alpha} \left(\frac{c^* w^*}{\alpha} \right) =$$

$$w + \tau_I b n^{(\alpha-1)/\alpha} \left(\frac{cw}{\alpha} \right) \tag{21}$$

Equation (21) determines τ_I as a function of n, n^* , w and w^*. We assume $n > n^*$. Then

$$\tau_I = \tau_I(n, n^*, w, w^*) = \frac{w - w^*}{\Delta} > 0 \tag{22}$$

where

$$\Delta \equiv b^* (n^*)^{(\alpha-1)/\alpha} \left(\frac{c^* w^*}{\alpha} \right) - b n^{(\alpha-1)/\alpha} \left(\frac{cw}{\alpha} \right) > 0$$

provided that n is sufficiently great relative to n^*.

Lemma: $\tau_I(n, n^*, w, w^*)$ is an ncreasing function of with w and n^*, and is a decreasing function of w^* and n.

Proposition 1

(i) The foreign country exports components in the range $[0,\tau_I]$ (i.e., component that are less service-intensive) and the home country exports components that are more service-intensive).

(ii) An increase in n^* or a decrease in c^* will result in a greater range of components exported by the foreign country. (In other words, it will increase "fragmentation", or "outsourcing" by the home country's car industry.)

(iii) An increase in w^* will result in a decrease in the range of components exported by the foreign country.

Proof: obvious ■

Now, since the price of good 1 must equal the cost of production, in a free trade equilibrium, we must have

$$P_X^* = P_X = \widehat{P}_X = \left[\int_0^{\tau_I} (w^* + b^*\tau P_S^*) d\tau\right] + \left[\int_{\tau_I}^{k} (w + b\tau P_S) d\tau\right] \tag{23}$$

More precisely

$$\begin{aligned} P_X^* &= P_X = \widehat{P}_X \\ &= \left[\int_0^{\tau_I} (w^* + b^*\tau P_S^*(n^*, w^*)) d\tau\right] + \\ & \left[\int_{\tau_I}^{k} (w + b\tau P_S(n, w)) d\tau\right] \end{aligned}$$

Observation 1: Since $\widehat{P}_X$ is the area under the kinked curve defined by the lower bound of the two curves $\pi^*(\tau)$ and $\pi(\tau)$, we may write this as

$$\widehat{P}_X = \int_0^k \min\left[\pi^*(\tau), \pi(\tau)\right] d\tau \equiv \widehat{P}_X(w, w^*, n, n^*) \tag{24}$$

(An explicit expression for $\widehat{P}_X$ is given in the Appendix.) Notice that, if we assume that good Y are produced in both countries, then $w = 1/a_Y$ and $w^* = 1/a_Y^*$, and the equilibrium price $\widehat{P}_X$ is independent of demand.

Using **Observation 1**, we can state

Proposition 2: $\widehat{P}_X$ is an increasing function of w and w^* and is a decreasing function of n and n^*.

Proof: obvious from Observation 1.For a more formal proof, see Appendix 2 ■

Let us now compute the equilibrium output of cars. First, we must calculate world's income, Z. From (15),

$$Z = wL + w^*L^* - wnf - w^*n^*f + \xi$$

where

$$\xi \equiv \left(\frac{1-\alpha}{\alpha}\right)\left[cwnm + c^*w^*n^*m^*\right]$$

Using

$$m = n^{-1/\alpha} S = n^{-1/\alpha} b[k^2 - \tau_I^2] X^\omega \text{ and } m^* = (n^*)^{-1/\alpha} S^* = (n^*)^{-1/\alpha} b^* \tau_I^2 X^\omega$$

we get

$$\xi = qX^\omega$$

where

$$q \equiv (1-\alpha)\left[\frac{(w-w^*)^2}{\Delta}\right] + \left(\frac{1-\alpha}{\alpha}\right) bcwk^2 n^{(\alpha-1/\alpha)} b$$

Thus (16) gives

$$X^\omega = \Phi_X(\widehat{P}_X, 1)\left[wL + w^*L^* - wnf - w^*n^*f + qX^\omega\right] \tag{25}$$

Since $\widehat{P}_X$ has been deterinined in (24), equation (24) determines the equilibrium X^ω:

$$\widehat{X}^\omega = \frac{\Phi_X(\widehat{P}_X, 1)\left[wL + w^*L^* - wnf - w^*n^*f\right]}{1 - q\Phi_X(\widehat{P}_X, 1)} > 0$$

Note that since $1 - P_X\Phi(P_X, 1) = \Phi_Y(P_X, 1) > 0$ and since $P_X > q$, we have $1 - q\Phi_X(\widehat{P}_X, 1) > 0$. ($qX^\omega < P_X X^\omega$ because the value of output of X must exceed the value of profits to the service industry, by the accounting identity that revenue equals the sum of payments to inputs.)

5 Trade in services

Now suppose that services are internationally tradable. We consider two cases: (i) complete free trade in services, which equalizes the prices of services, and (iii) trade in services with transport costs (e.g. the "iceberg transportation cost" model.)

We assume that, before the opening of trade in services, the n^* services produced in the foreign country have their exact counterparts in the home country. (The home country has $n - n^*$ services that are not produced in the foreign country. We number services so that the first n^* services are produceable in both countries, and the last $n-n^*$ services cannot be produced in the foreign country. With trade in specialized services, the production function of aggregate services in the home country is

$$S = \left[\sum_i (m_i + m_i^*)^\alpha \right]^{1/\alpha}$$

and thus the price is

$$P_S = \left[\sum_{i=1}^{n} [\min(p_i, p_i^*)]^{\alpha/(\alpha-1)} \right]^{(\alpha-1)/\alpha}$$

if there is no transportation cost. If the transport cost is positive, and is of the iceberg type, then

$$P_S = \left[\sum_{i=1}^{n} [\min(p_i, \delta_i p_i^*)]^{\alpha/(\alpha-1)} \right]^{(\alpha-1)/\alpha}$$

where $\delta_i > 1$.Here, $1/\delta_i$ is the fraction of one unit of service i that remains after being transported. By convention, if the foreign country cannot produce service $n - j$, then p_{n-j}^* is any number greater than p_{n-j} $(j \leq n - n^*)$.

5.1 Complete free trade in services

Recall that the autarkic price of the aggregate service in the foreign country is $P_S^* = (n^*)^{(\alpha-1)/\alpha}(c^* w^*/\alpha)$ and that of the home country is $P_S = (n)^{(\alpha-1)/\alpha}(cw/\alpha)$. By assumption $P_S^* > P_S$ (because n is much greater than n^*), complete free trade in services will result in the export of specialised services(indexed $\geq n$) from the home country to the foreign country, and the equalization of service prices. The home country will stop producing specialized services $\tau \leq n$. The equalization of the price of aggregage services means that, under free trade in services, the costs of producing components are lower in the foreign country. The home country will therefore stop producing all components: all the car components are produced in Mexico, and the cars are assembled in the US (recall our assumption that g^* is much greater than g.)

Proposition 3: Free trade in services results in complete outsourcing of component manufacturing to the foreign country.

5.2 Incomplete free trade in services

This occurs when there is an "iceberg transportation cost" of services. Then service prices are not equalized. Still, the effect of the incomplete free trade in services is the narrowing of the gap between P_S^* and P_S. The foreign country imports the last $n - n^*$ services from the home country, and the home country may import the first n^* services from the foreign country, but the price of aggregate service in the foreign country may remain higher than in the home country. In this case, the curve $\pi^*(\tau)$ is rotated downwards, leading to an increase in τ_I.

Proposition 4: Incomplete free trade in services may result in an increase in the range of components exported by the foreign country.

6 Generalisation: services with increasing complexity

We now relax the assumption that all services cost the same. We introduce the idea that some services are more complex than others. It is convenient to have a continuum of services, indexed by ρ in $[0, n]$ .The greater is ρ, the higher is the variable cost $c(\rho)$.

6.1 Assumptions for a closed economy

The production function of the aggregate service is

$$S = \left[\int_0^n [m(\rho)]^\alpha d\rho \right]^{1/\alpha}$$

Let $p(\rho)$ be the price of the specialised service ρ. Then

$$P_S = \left[\int_0^n [p(\rho)]^{\alpha/(\alpha-1)} d\rho \right]^{(\alpha-1)/\alpha} \tag{26}$$

The conditional demand for service ρ is

$$m(\rho) = AS[p(\rho)]^{\alpha/(\alpha-1)}$$

where

$$A = \left[\int_0^n [p(\rho)]^{\alpha/(\alpha-1)} d\rho \right]^{-1/\alpha}$$

Each specialised service firm equates maginal revenue to marginal cost. This gives

$$p(\rho) = \frac{wc(\rho)}{\alpha} \tag{27}$$

Substituting (27) into (26), we get

$$P_S = \frac{w}{\alpha}\left[\int_0^n [c(\rho)]^{\alpha/(\alpha-1)} d\rho\right]^{(\alpha-1)/\alpha}$$

For concreteness, let

$$c(\rho) = c_0\rho^{\gamma}$$

where $\gamma \geq 0$; then

$$\left[\int_0^n [c(\rho)]^{\alpha/(\alpha-1)} d\rho\right]^{(\alpha-1)/\alpha} = \frac{c_0}{K}[n]^{(\alpha\gamma+\alpha-1)/\alpha}$$

where we assume that

$$K = \frac{\alpha\gamma + \alpha - 1}{\alpha - 1} > 0$$

Then

$$P_S = \frac{wc_0}{\alpha K}[n]^{(\alpha\gamma+\alpha-1)/\alpha}$$

(If $\gamma = 0$, we have the result in the main text)

6.2 The two-country case

With two countries, the range $[0, n]$ overlaps with the range $[0, n^*]$ where $n^* < n$. The cost of producing specialised service ρ in the home country is

$$p(\rho) = \frac{wc_0\rho^{\gamma}}{\alpha}$$

and that of the foreign country is

$$p^*(\rho) = \frac{w^*c_0^*}{\alpha}\left[\rho^{\gamma^*}\right]$$

where we assume

$$\gamma^* > \gamma > 0$$

Define the cost ratio

$$v(\rho) = \frac{p(\rho)}{p^*(\rho)}$$

Assume $w^* c_0^* < w c_0$. Then $v(0) = .(w c_0 / w^* c_0^*) > 1$, and there exists a unique $\widetilde{\rho}$ such that

$$v(\widetilde{\rho}) = 1 \text{ and } v(\rho) < 1 \text{ for all } \rho > \widetilde{\rho}$$

We assume that $\widetilde{\rho} < n^* < n$. Then the home country has comparative advantage in producing complex services.

6.3 Free trade in services without transport costs

With free trade in services, the foreign country will import all services in the range $[\widetilde{\rho}, n]$, (and export the less complex services. if assembly needs services and can only be done in the home country). All components will be produced in the foreign country (because the prices of aggregate service P_S and P_S^* are equalised, and component production requires direct labor, which is cheaper in the foreign country) as well as aggregate services).

6.4 Free trade in services with transport costs

Assume instead that trade in services involves transport cost (of the iceberg type), and that the transport cost of specialised services from the foreign country to the home country is low (say zero), while the transport cost of complex specialised services (those with index greater than $\widetilde{\rho}$) is prohibitively expensive. Furthermore, we assume it is not possible to transport aggregate services. Then free trade will result in the foreign country exporting all the services with $\rho \leq \widetilde{\rho}$. The effects on the prices of aggregate service are: P_S becomes smaller, while P_S^* is unchanged. Under these circumstances, the range of components produced in the foreign country will contract. Thus trade in services can lead to less fragmentation when there are transportation costs that are biased against complexed services produced by the home country.

Proposition 5: Trade in services in the presence of transportation costs that are biased against the more complex specialised services supplied by the home country may lead to reduced fragmentation of manufacturing.

7 Concluding remarks

We have showed that the fragmentation of manufacturing depends on the level of development of the service industry in each country. Advanced economies have higher cost of supplying simple services, but they have a greater variety of services, so that their price of "aggregate service" tends to be lower than those of less developed economies. As a result, advanced economies tend to produce components that are service-intensive, and outsource the manufacturing of components that are less service-intensive to developing countries that have a basic service sector. Complete free trade in service will lead to complete outsourcing of components. Trade in services under non-negligible transport costs will result in partial fragmentation of manufacturing. If transport costs are biased against complex services, then a reduction in transport costs for less complexed services can reduce fragmentation.

We have assumed that the number of specialized services that a country can produce is given. This is a simplification that should eventually be relaxed. As countries grow, the number of services also tends to grow. It is tempting to endogenize n, the number of services, by allowing free entry and letting the "zero profit condition" determine the equilibrium n. In our model, we assume that each service firm must incur a fixed cost, in terms of labor. We should interpret "labor" in the sense of human capital. Then a country that invests in human capital will increase its "labor" force, and will be able to support a greater number of specialised service firms.

APPENDICES

Appendix 1: An explicit expression for $\widehat{P}_X$.

Denote the equilibrium value by $\widehat{P}_X$.Then

$$\widehat{P}_X. = w^*\tau_I(n,n^*,w,w^*) + w\left[k - \tau_I(n,n^*,w,w^*)\right] +$$

$$\left(\frac{1}{2}\right) b^* P_S^*(n^*,w^*)\left[\tau_I(n,n^*,w,w^*)\right]^2$$

$$+\left(\frac{1}{2}\right) bP_S(n,w)\left\{k^2 - \left[\tau_I(n,n^*,w,w^*)\right]^2\right\} \tag{28}$$

IF BOTH COUNTRIES PRODUCE GOOD 2 (bananas) THEN w and w^* are determined by $w = 1/a_Y$ and $w^* = 1/a_Y^*$. IN THAT CASE, equation (28) a determines the relative price of good 1 in terms of good 2 as functions of (a_Y,a_Y^*,, L,L^*). (recall that $P_X = P_X/P_Y$ because $P_Y = 1$).Then, after substituting (22) and (6) into (28) we get

$$\widehat{P}_X = \frac{3}{2}\left[\frac{(w-w^*)^2}{\Delta}\right] + wk + \frac{1}{2}bn^{(\alpha-1)/\alpha}\left(\frac{cw}{\alpha}\right)\left[k^2 - \frac{2k(w-w^*)}{\Delta}\right] \tag{29}$$

Appendix 2

Proof of Proposition 1

From (23),

$$\frac{\partial \widehat{P}_X}{\partial w^*} = \int_0^{\tau_I} \frac{\partial \pi^*(\tau)}{\partial w^*}d\tau + \pi^*(\tau_I)\frac{\partial \tau_I}{\partial w^*} - \pi(\tau_I)\frac{\partial \tau_I}{\partial w^*}$$

$$= \int_0^{\tau_I}(1 + b^*\tau\frac{\partial P_S^*}{\partial w^*})d\tau > 0$$

Other results can be established by a similar argument.

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