

Relocating the value chain: off-shoring and agglomeration in the global economy*

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Abstract

Fragmentation of stages of the production process is determined by international cost differences and by the benefits of co-location of related stages. The interaction between these forces depends on the technological relationships between these stages. This paper looks at both cost minimising and equilibrium fragmentation under different technological configurations. Reductions in shipping costs beyond a threshold can result in discontinuous changes in location, with relocation of a wide range of production stages. There can be overshooting (off-shoring that is reversed as costs fall further) and equilibrium may involve less off-shoring than is efficient.

Keywords: fragmentation, off-shoring, parts and components, assembly, vertical linkages, agglomeration.

JEL classification: F1, F23, R3

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1. Introduction:

An ever finer division of labour, at all levels from the individual to the international, has been a continuing aspect of economic progress. Its pace has varied, and some authors speak of the industrial revolution as the first spatial unbundling (factories unbundled from consumers), and current globalisation as the second unbundling (production stages unbundled across nations). The second unbundling has been driven by falls in transport costs and advances in information and communications technology (ICT) which cut the cost of organising complex activities over distances. Cheap and reliable telecommunications combined with information management transformed the organisation of group-work across space. Stages of production that had to be performed in close proximity – within walking distance to facilitate face-to-face coordination of innumerable small glitches – can now be dispersed without an enormous drop in efficiency or timeliness. Working methods and product designs have been shifted in reaction to the spatial separation, typically in ways that make production more modular. The second unbundling has spread from factories to offices, the result being the outsourcing and offshoring of service-sector jobs.

Many of the international supply chains that developed are regional, not global. The cost and unpredictable delays involved in intercontinental shipping still matter. Moreover, coordination in the same time zone is easier and more reliable. Electronic meetings are easier to arrange, and face-to-face meetings incur less time lost in travel. The first large-scale production unbundling started in the mid 1980s and took place over very short distances. The Maquiladora programme created ‘twin plants’, one on the US side of the border and one on the Mexican side. Although the programme existed since 1965, it only boomed in the 1980s with employment growing at 20% annually from 1982-89 (Dallas Fed 2002, Feenstra and Hanson 1996). Another unbundling started in East Asia at about the same time (and for the same reasons). In this region distances are short compared to the vast wage differences (Tokyo and Beijing are about 90 minutes apart by plane, yet in the 1980s the average Japanese income was 40 times the Chinese average). In Europe, the unbundling was stimulated first by the EU accession of Spain and Portugal in 1986, and then by the emergence of Central and Eastern European nations.

Numerous examples serve to illustrate the pervasiveness of unbundling. The “Swedish” Volvo S40 has navigation control and screen made in Japan, the side mirror and fuel tank in Germany, the air conditioner in France, the headlights in the US and Canada, the fuel and brake lines in England, the hood latch cable in Germany, and so on. Some parts are

even made in Sweden (airbag and seat belts). These ‘parts’ are themselves made up of many parts and components, whose production is likely to be equally dispersed. For example, the air conditioner has a compressor, motor and a control centre, each of which may be made by a different company in a different nation. Manufacturing stages that used to be done by the same company in the same factory are now dispersed around the world. Sometimes these are owned or controlled by the original manufacturer, but often they are owned by independent suppliers.

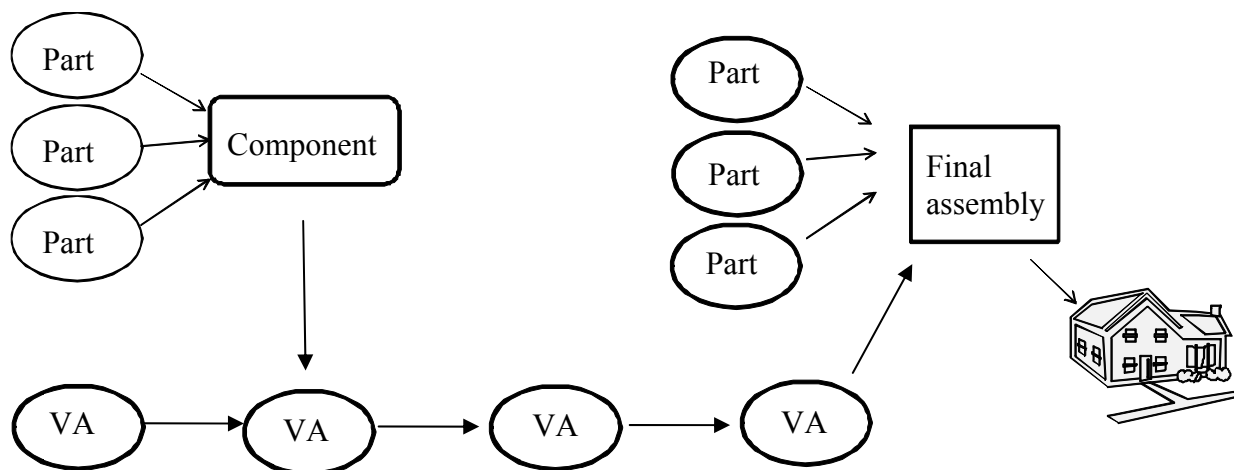
Unbundling has been centre stage in much recent international trade research. There have been important empirical studies charting the rise of trade in parts and components. However, formal measurement has been problematic since trade data does not make clear what goods are input to other goods, and analyses based on standard techniques – input-output tables – are at too high a level of aggregation to capture the level of detail suggested by industry examples.

Analytical work has taken a variety of approaches. Much of the focus has been on taking simple characterisations of the technology of unbundling and drawing out the general equilibrium implications for trade and particularly for wages (Yi 2003, Grossman and Rossi-Hansburg 2006, Markusen and Venables 2007). Others have linked it multinational activity (Helpman 1984) and have looked at transactions cost issues (Helpman et al).

This paper focuses on quite different aspects. We take seriously the fact that technology – the engineering of the product – dictates the way in which different stages of production fit together. Possibilities are illustrated in fig. 1. Each cell is a stage at which value is added to a good that ends up as final consumption, and each arrow is a physical movement of a part, component, or the good itself. They may be movements within a factory, or may be unbundled movements between plants or between countries. There are two quite different configurations. One we refer to as the spider: multiple limbs (parts) coming together to form a body (assembly), which may be a component or the final product itself. The other is the snake: the good moving in a linear manner from upstream to downstream with value added at each stage.¹ Most production processes are complex mixtures of the two. Cotton to yarn to fabric to shirts is a snake like process, but adding the buttons is a spider. Silicon to chips to computers is snake like, but much of value added in producing a computer is spider-like final assembly of parts from different sources.

¹ Dixit and Grossman (1982) undertake a general equilibrium analysis of the snake.

Figure 1: Snakes and spiders



In production processes like those illustrated in fig. 1 the location of any one element depends on the location of others. There are centripetal forces binding activities together, these including the costs of coordination with and transport to other stages in the production process.² Co-location matters, as firms seek to be close to other firms with which they transact, and the form of this depends on the engineering of the product; it is different for spiders than for snakes. But there are also centrifugal forces that encourage dispersed production of different stages; for example, different cells have different factor intensities which create international cost differences and incentives to disperse. There is therefore a tension between comparative costs creating the incentive to unbundle, and co-location or agglomeration forces binding parts of the process together.

Our objective is to analyse the interaction of these forces and show how they determine the location of different parts of a value chain. We look at the efficient location of these stages when decisions are taken by a single cost-minimising agent, and also at outcomes when stages are controlled by independent decision takers. Co-location and agglomeration forces mean that equilibrium is not necessarily cost minimising as coordination failures obstruct moves towards efficiency. There will be multiple equilibria

² And costs associated with length and variability of time in transit, Hummels (2001), Harrigan and Venables (2006)

and locational hysteresis. We show that the form this takes depends on engineering detail – snakes or spiders. This moves the paper significantly beyond earlier investigations of these issues which have often worked with highly symmetric and stylised (eg Dixit-Stiglitz) structures.³

The remainder of the paper develops models of the spider and the snake, looking at each in turn. While they give rise to quite different outcomes there are a number of general implications that we draw out in concluding comments. Throughout, the setting is a world of two countries, N and S.⁴ Production costs differ in the two countries because of factor price or productivity differences. We will assume that all demand for the final product is in N and that, initially, all stages of production take place in N. The question is: under what circumstances do what parts of the production process relocate to S?

2. The spider:

We look first at a ‘spider’, that is a production process in which parts are produced separately and come together for assembly.⁵ Three sorts of cost are incurred in the process of getting a unit of final assembled product to the consumer; the cost of producing parts, shipping costs, and costs of assembly.

Parts are indexed by type $y \in Y$, and the unit production cost of an individual part produced in S is $b(y)$. If the part is produced in N its production cost is normalised to unity (for all y). Minimum and maximum values of $b(y)$ are \underline{b} and \bar{b} respectively and we assume that $\underline{b} < 1 < \bar{b}$, so low b parts can be produced more cheaply in S, and high b parts more cheaply in N. We will refer to low b parts as ‘labour-intensive’ (and high b parts as capital intensive) although we are not explicit about the extent to which international cost differences are due to productivity or factor price differences. Parts come together for assembly, which requires $\psi(y)$ units of part y , for each $y \in Y$. Assembly also uses primary factors, and the units costs of these are a_N, a_S , according as assembly is in N or in S.

When a part’s production is spatially separated from assembly a per unit off-shoring costs of $t\theta(y)$ is incurred, this representing shipping costs and a wider set of communication,

³ For example Venables (1996) and Fujita et al (1999).

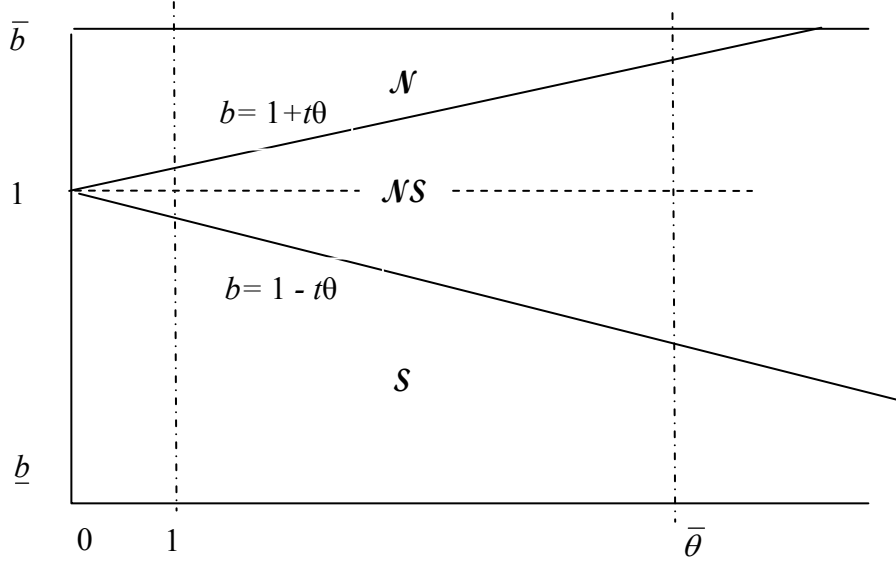
⁴ This could be easily generalised for the spider, but is more difficult for the snake.

⁵ We will think of this as assembly of the final product although it could be assembly of a component that is sold in N.

coordination and trade costs. The cost is the product of a parameter t capturing the overall level of off-shoring costs, and a type specific element $\theta(y)$, the support of which is $[1, \bar{\theta}]$. We will generally refer to $t\theta(y)$ as shipping costs, so high θ parts can be thought of as ‘heavy’ to ship and low θ parts as being ‘light’. A final element of costs is incurred if assembly takes place in S; since the final market is in N, a further shipping cost of $t\alpha$ is paid. This is the product of parameter t measuring the overall level of transport costs and constant α measuring the cost of shipping the final product relative to the cost of shipping parts; we assume $\alpha > 0$, and if $\alpha < \int_Y \theta(y)\psi(y)dy$ then it is cheaper to ship the assembled product than to ship all parts separately.

The combination of cost differences and shipping costs is illustrated on fig. 2 which has relative costs, b , on the vertical axis and the part specific element of shipping costs, θ , on the horizontal. The set Y is the area $[1, \bar{\theta}] \times [\underline{b}, \bar{b}]$ and each part can be represented as a pair $\{b(y), \theta(y)\}$ in the set. The lines $b = 1 + t\theta$ and $b = 1 - t\theta$ divide the space into three sets according to the cost of reaching assembly. Parts in the upper region, \mathcal{N} , are more cheaply supplied from N, regardless of whether assembly is in N or S; even if assembly is in S so shipping costs are incurred, the cost of production in N plus shipping cost, $1 + t\theta$, is less than the cost of production in S, which is b . In the bottom region, \mathcal{S} , the converse is true: these are parts which are relatively labour-intensive and light, so are most cheaply supplied from S regardless of where assembly is; even if assembly is in N and shipping cost are incurred, supply from S is cheaper than supply from N, $b + t\theta < 1$. For parts in region \mathcal{NS} , assembly in S is most cheaply supplied from S ($b < 1 + t\theta$) and assembly in N most cheaply supplied by production in N ($1 < b + t\theta$).

Figure 2: Production and shipping costs of parts



With this as set up, we now determine the location of assembly and associated location of parts. We do this first in fairly general terms, and then in sections 2.1 and 2.2 move to particular distributions of parts over the space Y in order to get more specific results.

Single agent cost minimisation:

Under what circumstances will the assembler choose to locate in N or in S , given that she is controlling the location of all parts producers? The answer is given by comparison of total costs in each situation, knowing that the assembler will locate production of each part to achieve the lowest delivered costs to the assembly plant. The two sides of the inequality below give total costs (assembly, parts, and shipping) when assembly is in N (left-hand side) and in S (right-hand side); it is cost minimising to assemble in S if the inequality is satisfied.

$$\begin{aligned}
 & a_N + \int_{y \in \mathcal{N} \cup \mathcal{NS}} \psi(y) dy + \int_{y \in \mathcal{S}} [b(y) + t\theta(y)] \psi(y) dy \\
 & > a_S + \alpha t + \int_{y \in \mathcal{N}} [1 + t\theta(y)] \psi(y) dy + \int_{y \in \mathcal{S} \cup \mathcal{NS}} b(y) \psi(y) dy.
 \end{aligned} \tag{1}$$

The left hand side of the inequality gives assembly costs in N (a_N) plus the costs of parts; types in sets \mathcal{N} and \mathcal{NS} are produced in N at unit cost 1, whilst those in set \mathcal{S} are produced in

S at unit cost $b(y)$ and also incur shipping costs $t\theta(y)$ to reach the assembler. The second line has the assembler operating in S at primary factor cost a_S with parts in sets \mathcal{NS} and \mathcal{S} produced in S and those in set \mathcal{N} produced in N. Shipping costs are incurred on parts in set \mathcal{N} and also on the assembled product that has to be shipped to the market in N.

Inequality (1) can be rearranged as

$$a_N - a_S + \int_{y \in \mathcal{NS}} [1 - b(y)] \psi(y) dy > t \left[\alpha + \int_{y \in \mathcal{N}} \theta(y) \psi(y) dy - \int_{y \in \mathcal{S}} \theta(y) \psi(y) dy \right]. \quad (2)$$

The left hand side is the difference in production costs when assembly is in N rather than S, consisting of differences in assembly costs and in the production costs of parts in set \mathcal{NS} which co-locate with assembly. Terms on the right hand side give the difference in shipping costs if assembly is in N compared to S; assembly in S incurs $t\alpha$ plus the costs of shipping parts from set \mathcal{N} , while saving shipping costs on parts from set \mathcal{S} .

By inspection of fig. 2 and equation (2) we see that as $t \rightarrow \infty$ assembly and production of all parts take place in N, where final demand is. The sets \mathcal{N} and \mathcal{S} disappear (see fig. 2) as all parts co-locate with assembly, and costs of shipping the assembled product, $t\alpha$, come to dominate inequality (2). At the other extreme, as $t \rightarrow 0$ all activities locate where their primary factor costs are lowest. The set \mathcal{NS} disappears, so parts locate according to the value of $b(y)$ relative to unity, and assembly locates in S if $a_S < a_N$ and in N if $a_S > a_N$.

At intermediate values of t there is tension between three forces. Relative production costs, as determined by the comparative advantage of N and S and given by the left-hand side of (2); the benefits of locating assembly with final consumption in N, $t\alpha$; and the benefits of co-locating parts and assembly, the remaining terms on the right-hand side of (2).

Consider first the case in which assembly is relatively cheap in S, $a_S < a_N$. We know from the preceding discussion that assembly is in N at high t and in S at low t . As t falls relocation of the industry takes the following form. Falling shipping costs enlarge the set \mathcal{S} (flattening $b = 1 - t\theta$ on fig. 2) so there is steady migration of parts from N to S, in line with their comparative costs. At some point it becomes cost minimising to relocate assembly to S and as assembly relocates so too do parts in set \mathcal{NS} , just leaving parts in \mathcal{N} to be produced in N. However, further reductions in t enlarge set \mathcal{N} (flattening $b = 1 + t\theta$) so some parts move back from S to N; lower shipping costs weakens the benefit of co-location relative to

comparative production cost.

In the case in which assembly is relatively cheap in N, $a_S > a_N$, we know that assembly occurs in N at both very high and very low shipping costs. It may stay in N at all intermediate values, but it is also possible that as t is reduced it moves to S and then moves back, relocating parts in set \mathcal{NS} as it does so. This happens if a high proportion of parts are labour intensive, with significantly lower production costs in S than in N; it is then efficient to move these parts and assembly to S, even though $a_S > a_N$. As t falls further the benefits of locating assembly with parts diminishes, and assembly moves back to N in line with its comparative costs. We work this out explicitly in section 2.1 using a particular distribution of parts across set Y .

Nash equilibrium:

What difference does it make if individual parts producers and the assembler all take independent location decisions? Cost savings from co-location mean that there are potential coordination problems and, to set out the simplest case, we look at the simultaneous move Nash equilibrium.

Each parts' producer takes the location of the assembler (and all other parts' producers) as given, and locates where the unit cost of supplying the assembler is lowest. This gives location of parts as described by sets \mathcal{N} , \mathcal{NS} and \mathcal{S} on fig.2. We assume that parts' producers supply the assembler at cost.⁶ The assembler takes as given the location of parts' producers and chooses N or S to minimise its costs.

Suppose first that assembly is in N, and that parts in sets \mathcal{N} and \mathcal{NS} are produced in N while those in set \mathcal{S} are produced in S. There is no incentive for any parts producer to move, as each is in the country with the least cost of supplying the assembler in N. If the assembler switches location from N to S the location of parts producers is taken as unchanged, so the move is unprofitable (and assembly in N is an equilibrium) if

$$a_N - a_S < t \left[\alpha + \int_{y \in \mathcal{N} \cup \mathcal{NS}} \theta(y) \psi(y) dy - \int_{y \in \mathcal{S}} \theta(y) \psi(y) dy \right]. \quad (3)$$

The left hand side is the change in the assembler's own primary factor costs. On the right

⁶ This can be rationalised by a contestability assumption ensuring that parts' producers make zero profits.

hand side, the assembler now has to pay shipping costs on the assembled product and on parts in sets \mathcal{N} and \mathcal{NS} , while saving those in set \mathcal{S} .

Conversely, suppose that assembly is in \mathcal{S} . In this case parts in set \mathcal{N} will be produced in \mathcal{N} while those in sets \mathcal{S} and \mathcal{NS} are produced in \mathcal{S} . If the assembler switches location from \mathcal{S} to \mathcal{N} (given location of parts producer) the deviation is unprofitable if

$$a_N - a_S > t \left[\alpha + \int_{y \in \mathcal{N}} \theta(y) \psi(y) dy - \int_{y \in \mathcal{S} \cup \mathcal{NS}} \theta(y) \psi(y) dy \right] \quad (4)$$

i.e. the primary cost change exceeds shipping cost savings on the final product and on parts in \mathcal{N} , net of shipping costs incurred on products in sets \mathcal{S} and \mathcal{NS} .

Two points follow immediately from these inequalities. First, equilibria do not necessarily deliver global cost minimisation; inequalities (3) and (4) are different from (2). And second, there may be multiple equilibria; it is possible that, for some parameters, inequalities (3) and (4) are both satisfied. The reason is simply that the location of production of parts in set \mathcal{NS} is now taken as given instead of being directly controlled by the assembler. We draw out the implications in more detail in the section 2.2.

2.1. The spider: cost minimisation.

We can derive more explicit results by restricting attention to the case in which all parts have the same transport intensity (or ‘weight’). We therefore replace $t\theta(y)$ by t , the same for all parts, collapsing the set Y down to one dimension. Since parts now vary in a single dimension the index y can simply be replaced by parts’ b values (i.e. $y \equiv b$). Cost minimisation means that parts will be produced in \mathcal{N} if b , their production costs in \mathcal{S} , exceeds some critical value b^* . This ‘offshoring’ threshold value depends on t and on the location of assembly, and we denote it b_N^* when assembly is in \mathcal{N} , b_S^* when assembly is in \mathcal{S} . Total costs when assembly is in \mathcal{N} (respectively \mathcal{S}) are $C(b_N^* : \mathcal{N})$, $C(b_S^* : \mathcal{S})$, given by

$$C(b_N^* : \mathcal{N}) = a_N + \int_{b_N^*}^{\bar{b}} \psi(b) db + \int_b^{b_N^*} (b+t) \psi(b) db \quad (5)$$

$$C(b_S^* : \mathcal{S}) = a_S + \alpha t + \int_{b_S^*}^{\bar{b}} (1+t) \psi(b) db + \int_b^{b_S^*} b \psi(b) db.$$

These equations are analogous to the two sides of inequality (1). The off-shoring thresholds minimise the costs of supplying each location, and are therefore implicitly defined by first order conditions

$$\partial C(b_N^* : N) / \partial b_N^* = \psi(b_N^*) [b_N^* + t - 1] = 0, \quad \partial C(b_S^* : S) / \partial b_S^* = \psi(b_S^*) [b_S^* - (1+t)] = 0. \quad (6)$$

These are illustrated on figs. 3a and 3b, analogous to fig. 2, but whereas fig. 2 was constructed for a given value of the shipping cost parameter, figs. 3 have t on the horizontal axis and the set of parts Y is simply a vertical line on the figure. The off-shoring thresholds are functions of t given by the first order conditions (6), but constrained to lie in the support of b , so $b_S^* = \min[1+t, \bar{b}]$, $b_N^* = \max[1-t, \underline{b}]$. Thus, given t , parts on a vertical line in the interval $[\underline{b}, b_N^*]$ form the set \mathcal{S} ; those in $[b_N^*, b_S^*]$ form the set \mathcal{NS} ; and those in $[b_S^*, \bar{b}]$ form the set \mathcal{N} .

Under what circumstances will the assembler choose to locate in N or in S, given that she is controlling the location of all parts producers? The answer comes from comparison of total costs so, subtracting equations (5),

$$C(b_N^* : N) - C(b_S^* : S) = a_N - a_S + \int_{b_N^*}^{b_S^*} (1-b)\psi(b)db - t \left[\alpha - \int_{\underline{b}}^{b_N^*} \psi(b)db + \int_{b_S^*}^{\bar{b}} \psi(b)db \right] \quad (7)$$

If we further assume that each part in $[\underline{b}, \bar{b}]$ is used in the same quantity, $\psi(b) = 1$, this can be evaluated as

$$\begin{aligned} C(b_N^* : N) - C(b_S^* : S) &= a_N - a_S + (b_S^* - b_N^*) \left(1 - \frac{b_S^* + b_N^*}{2} \right) - t [\alpha + \bar{b} + \underline{b} - b_S^* - b_N^*] \\ &= 2t [R(t) - A(t)] \end{aligned} \quad (8)$$

where the functions $R(t)$ and $A(t)$ are constructed as

$$R(t) \equiv \left[b_S^* + b_N^* + \left(\frac{b_S^* - b_N^*}{t} \right) \left(1 - \frac{b_S^* + b_N^*}{2} \right) \right] \frac{1}{2} \quad (9)$$

$$R(t) = 1 \quad \text{if} \quad t < \min[1 - \underline{b}, \bar{b} - 1]$$

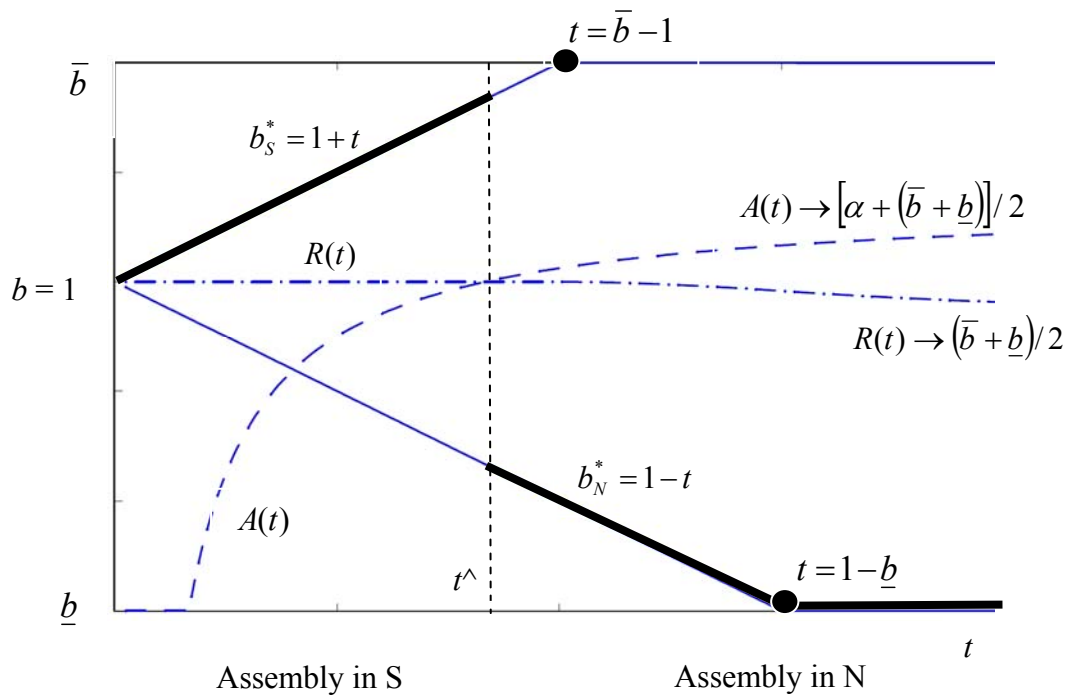
$$A(t) \equiv \left[\frac{a_S - a_N}{t} + \alpha + \bar{b} + \underline{b} \right] \frac{1}{2}. \quad (10)$$

These two functions are shown on fig. 3; it is cost minimising to locate assembly in S (equation (8) is positive) if $R(t)$ lies above $A(t)$.

Notice that $R(t) = 1$ for the range $t < \min[1 - \underline{b}, \bar{b} - 1]$ since in this range $b_S^* = 1 + t < \bar{b}$ and $b_N^* = 1 - t > \underline{b}$, and hence $b_S^* + b_N^* = 2$. Once t exceeds $\bar{b} - 1$, $1 - \underline{b}$, b_S^* and b_N^* become respectively \bar{b} and \underline{b} ; $R(t)$ is then monotonically decreasing in t if $(\bar{b} + \underline{b})/2 < 1$ and increasing if $(\bar{b} + \underline{b})/2 > 1$ with asymptotic value as $t \rightarrow \infty$, $R(t) \rightarrow (\bar{b} + \underline{b})/2$. The dependence of $A(t)$ on shipping costs t is clear from equation (10). As $t \rightarrow \infty$ its asymptotic value is $[\alpha(\bar{b} - \underline{b}) + (\bar{b} + \underline{b})]/2$ which is, in all cases, greater than the asymptotic value of $R(t)$. If assembly is low cost in S, $a_S < a_N$, then $A(t)$ is increasing in t from minus infinity to its asymptotic value; if assembly in S is high cost, $a_S > a_N$, it is decreasing from plus infinity.

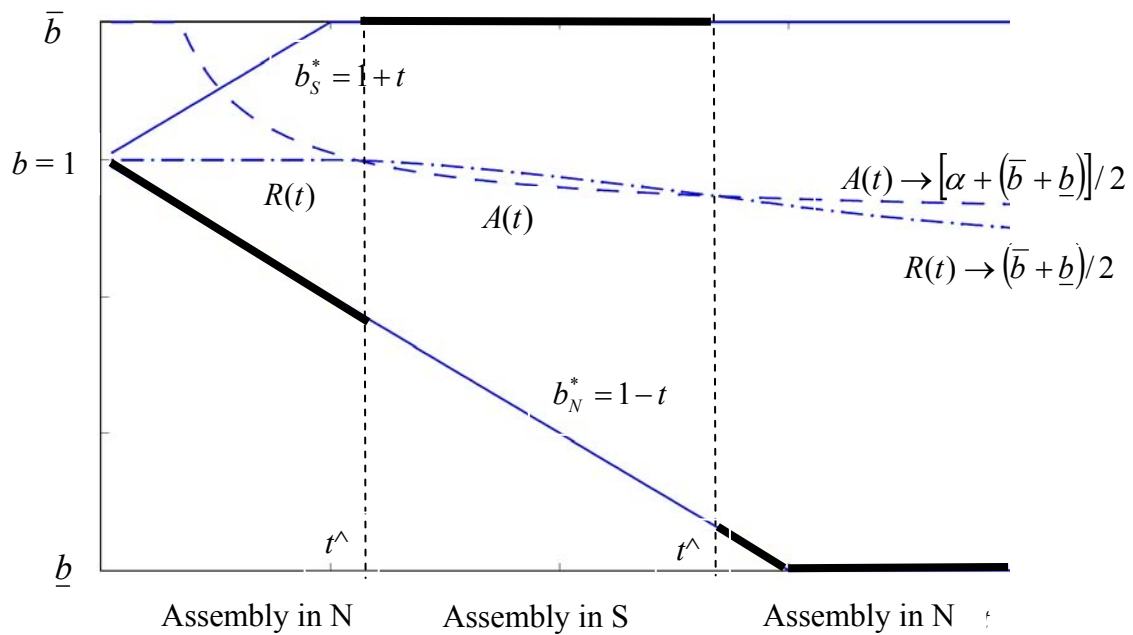
For $a_S < a_N$, the case illustrated in fig. 3a, there must be a single intersection of curves $R(t)$ and $A(t)$, as illustrated at t^* ; to the right of this assembly is in N and to the left it is in S. The bold lines map out the location of parts as a function of t . Thus, if shipping costs fall through time location of the industry follows the pattern indicated by the heavy lines. Initially all production is in N, then declining t is associated with a slow migration of low b parts (labour intensive and below b_N^*) to S. At point t^* it becomes worthwhile to relocate assembly and a broad range of parts, $b_S^* - b_N^*$, from N to S. Some of these parts have higher costs in S than in N, but it is efficient to locate them close to the assembly plant in S; as t falls further, these parts move back from S to N as comparative factor costs becomes more important relative to shipping costs.

Figure 3a: Cost minimising location, low cost assembly in S ($a_S < a_N$)



Parameter values: $a_S = 0.2, a_N = 0.3, \underline{b} = 0.4, \bar{b} = 1.4$, implying $t^\wedge = 0.332$

Figure 3b: Cost minimising location, low cost assembly in N ($a_S > a_N$)



Parameter values: $a_S = 0.25, a_N = 0.2, \underline{b} = 0.4, \bar{b} = 1.2$, implying $t^\wedge = 0.224, 0.536$

Fig. 3b illustrates a case where N is the lower cost assembly location, $a_S > a_N$, and $(\bar{b} + \underline{b})/2 < 1$. High assembly costs in S mean that assembly takes place in N when t is very low, as well as when it is high; the function $A(t)$ is now decreasing in t , from plus infinity to its asymptotic value. If the cost advantage of S in parts is small, then $A(t)$ will lie above $R(t)$ everywhere and assembly will stay in N for all t . However, a large cost advantage for S means a lower value of \underline{b} and \bar{b} , shifting $A(t)$ down relative to $R(t)$ (see equations (9), (10)). There may then be two intersections of $A(t)$ and $R(t)$, as illustrated. It is then cost minimising, for an intermediate range of t , to move assembly and a substantial fraction (in fig 3b, all) parts production to S. The three phases can be summarised as follows: when t is high assembly stays close to the market because of costs of shipping the final product; at intermediate t it is cost minimising to use low cost parts producers in S and also to co-locate assembly in S with these parts producers; at low t all elements – parts and assembly – locate according to their comparative production costs. The condition on parameters required for this double intersection and relocation of assembly is given in appendix 1.

Production costs and shipping costs:

What if there is a correlation between production costs and shipping costs? This can be captured most simply by having the distribution of parts lie on a sloping line on the set Y . Thus, continuing to index parts by b , shipping costs may take the form $tf(b)$, where $f(b) > 0$ for all b . (In the preceding sub-section shipping costs were the same for all b so the line was vertical, $f(b) = 1$). If $f'(b) > 0$ then labour intensive parts are light, i.e. parts with cost advantage in S have lower shipping costs. Equations (5) giving total costs when assembly is in N, S now become

$$C(b_N^* : N) = a_N + \int_{b_N^*}^{\bar{b}} \psi(b)db + \int_{\underline{b}}^{b_N^*} (b + tf(b))\psi(b)db \quad (11)$$

$$C(b_S^* : S) = a_S + \alpha t + \int_{b_S^*}^{\bar{b}} (1 + tf(b))\psi(b)db + \int_{\underline{b}}^{b_S^*} b\psi(b)db .$$

The off-shoring thresholds minimise the costs of supplying each location, so become

$$\partial C(b_N^* : N) / \partial b^* = \psi(b_N^*) [b_N^* - (1 - tf(b_N^*))] = 0, \quad (12)$$

$$\partial C(b_S^* : S) / \partial b^* = \psi(b_S^*) [b_S^* - (1 + tf(b_S^*))] = 0$$

The gradients of off-shoring thresholds are $\frac{db_N^*}{dt} = \frac{-f(b_N^*)}{1 + tf'(b_N^*)}$, $\frac{db_S^*}{dt} = \frac{f(b_S^*)}{1 - tf'(b_S^*)}$ so are negative and positive respectively when t is close to zero, although need not be so everywhere. However, the qualitative configuration of the thresholds is as on figs. 3 since (subtracting the thresholds defined by (12)), $b_S^* - b_N^* = t[f(b_N^*) + f(b_S^*)] \geq 0$.

Appendix 2 sets out further detail, and here we simply illustrate the case where labour-intensive parts are heavy so f is decreasing in b . Fig 4.a has the same parameters as fig. 3b except that f is linearly decreasing in b . Off-shoring thresholds become concave and, importantly, the range of t for which it is cost minimising for assembly to take place in S becomes larger. Opposite to what might be expected, relatively *higher* trade costs on labour intensive parts has the effect of *increasing* off-shoring to S. The intuition is that it is more expensive to access S's comparative cost advantage through shipping parts (and less expensive to access N's), and consequently more efficient to move assembly to S. Assembly moves to S, and so then do parts in the interval $[b_N^*, b_S^*]$.

Conversely, if labour intensive parts have low shipping costs (f is linear and increasing) then off-shoring thresholds are convex, and it becomes more likely that assembly stays in N. Less off-shoring takes place, because it is efficient to keep assembly in N and just import the lowest cost parts from S.

Increasing returns to outsourcing:

A further possibility is that shipping costs are non-linear in the set of parts being shipped. In particular, we think that it is likely that costs of outsourcing are an increasing but concave function of the number of parts outsourced. There are two possible reasons for strict concavity. One is that there are economies of scope in coordination and communication costs; coordinating the remote supply of two parts costs less than twice the cost of coordinating a single one. The other arises from the possibility of disruption in supply of parts that are outsourced. For example, assembly might require that all parts are delivered on time, and is disrupted by a single part arriving late (see Harrigan and Venables 2006). The probability of all parts arriving on time is decreasing but convex in the number of parts outsourced, so overall costs are increasing and concave.

To capture this we add a further element to shipping costs, $tD(\cdot)$. t is the usual trade cost parameter and $D(\cdot)$ is an increasing and concave function of the set of parts that are shipped to the assembler in each case. Costs are then,

$$\begin{aligned}
C(b_N^* : N) &= a_N + \int_{b_N^*}^{\bar{b}} \psi(b)db + \int_{\underline{b}}^{b_N^*} (b+t)\psi(b)db + tD((b_N^* - \underline{b})\psi(b)) \\
C(b_S^* : S) &= a_S + \alpha t + \int_{b_S^*}^{\bar{b}} (1+t)\psi(b)db + \int_{\underline{b}}^{b_S^*} b\psi(b)db + tD((\bar{b} - b_S^*)\psi(b))
\end{aligned} \tag{13}$$

The off-shoring thresholds minimise the costs of supplying each location, and are defined by first order conditions

$$\begin{aligned}
\partial C(b_N^* : N) / \partial b_N^* &= \psi(b_N^*) [b_N^* - (1-t) + tD'((b_N^* - \underline{b})\psi(b))] = 0, \\
\partial C(b_S^* : S) / \partial b_S^* &= \psi(b_S^*) [b_S^* - (1+t) - tD'((\bar{b} - b_S^*)\psi(b))] = 0,
\end{aligned} \tag{14}$$

providing that second order condition $tD'' > -1$ is satisfied.

The additional cost has the effect of rotating off-shoring threshold b_S^* upwards and b_N^* down, as illustrated in fig. 4b (with same parameter values as fig. 3b). As in the previous case, over a range of shipping costs it increases off-shoring, and for similar reasons. Selective off-shoring of some parts is less attractive, so to benefit from the comparative advantage the whole sector – all parts and assembly – are moved from N to S.

Figure 4.a: $a_S > a_N$ and labour intensive parts have high shipping costs

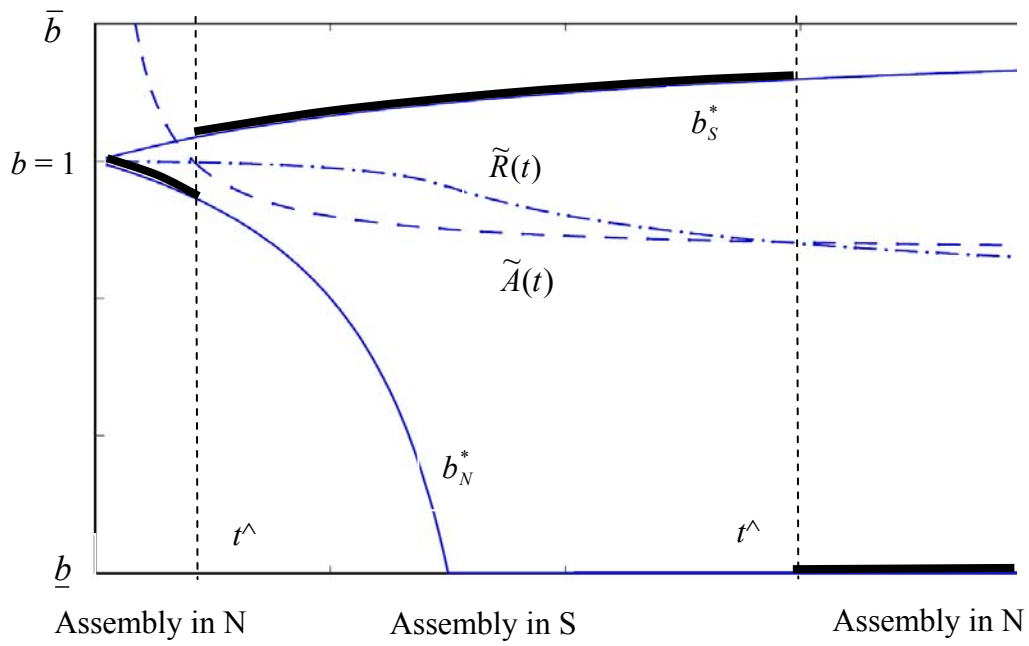
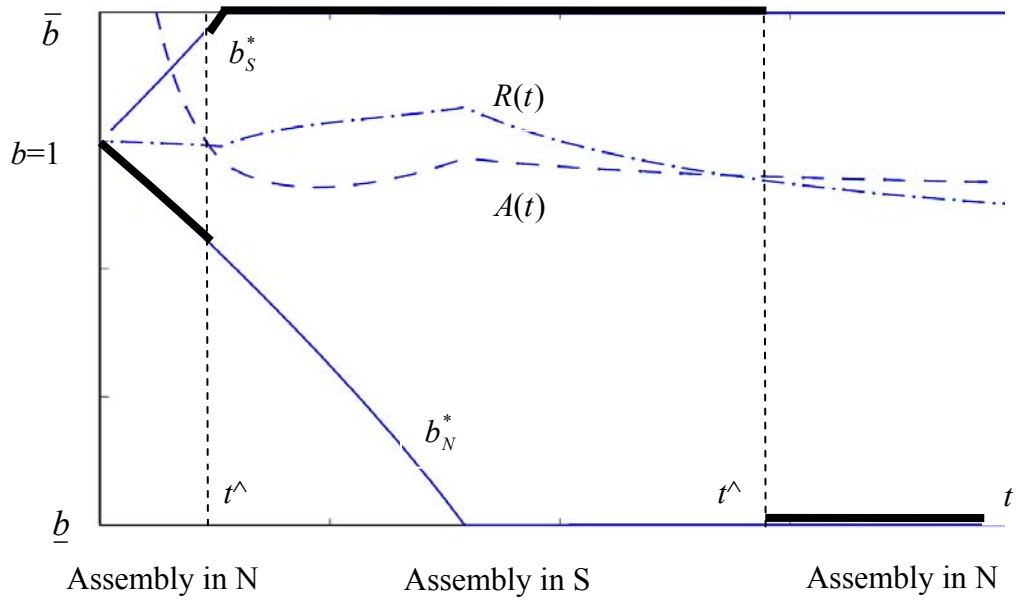


Figure 4.b: $a_S > a_N$ and increasing returns to outsourcing



2.2. The spider: equilibrium.

We now turn from overall cost minimisation to the Nash equilibrium in which each firm's location choice is made taking as given the location of all others. Inequalities (3) and (4) give the conditions under which a deviation by the assembler is not profitable, and we now apply these to the case in which shipping costs are the same for all parts. The location of parts producers is given by the sets \mathcal{N} , \mathcal{NS} and \mathcal{S} as characterised by off-shoring thresholds b_S^* , b_N^* . Inequality (3), the condition for assembly to be in N, becomes

$$a_N - a_S < t[\alpha + \bar{b} + \underline{b} - 2b_N^*] \quad \text{or} \quad A(t) > b_N^* \quad (15)$$

While that for assembly in S is

$$a_N - a_S > t[\alpha + \bar{b} + \underline{b} - 2b_S^*] \quad \text{or} \quad A(t) < b_S^*. \quad (16)$$

Equilibria can therefore be identified by comparison of $A(t)$ with the off-shoring thresholds, and are shown on Figs. 5, constructed with the same parameter values as figs. 3. Thus, the lower bold line on each figure gives equilibria with assembly in N; inequality (15) is satisfied so it is cost minimising to put assembly in N, and most parts (all those in interval $[b_N^*, \bar{b}]$) are produced in N. The upper bold line gives equilibria with assembly in S; most parts (those in interval $[\underline{b}, b_S^*]$) are produced in S and it is consequently cost minimising to put assembly in S (inequality (16) is satisfied). Since the underlying parameters and relationships on these figures are identical to 3a and 3b, we represent the cost-minimising switch-points by the small circles.

Fig 5a deals with the case where assembly is cheaper in S than in N. It illustrates that at high or medium shipping costs there are two equilibria. Assembly in S implies that a high share of parts production is in S, this supporting the choice of the assembler to locate in S. Similarly, assembly in N is supported by the presence of many parts producers in N. Starting from a high value of t and with all production in N, reductions in t move the equilibrium along the lower heavy line until point Ω at which the equilibrium with assembly in N ceases to exist, and assembly jumps to S. The jump relocates a set of parts producers some of which move back to N as further reductions in t make co-location with the assembler less important.

Figure 5a: Equilibrium locations, low cost assembly in S ($a_S < a_N$)

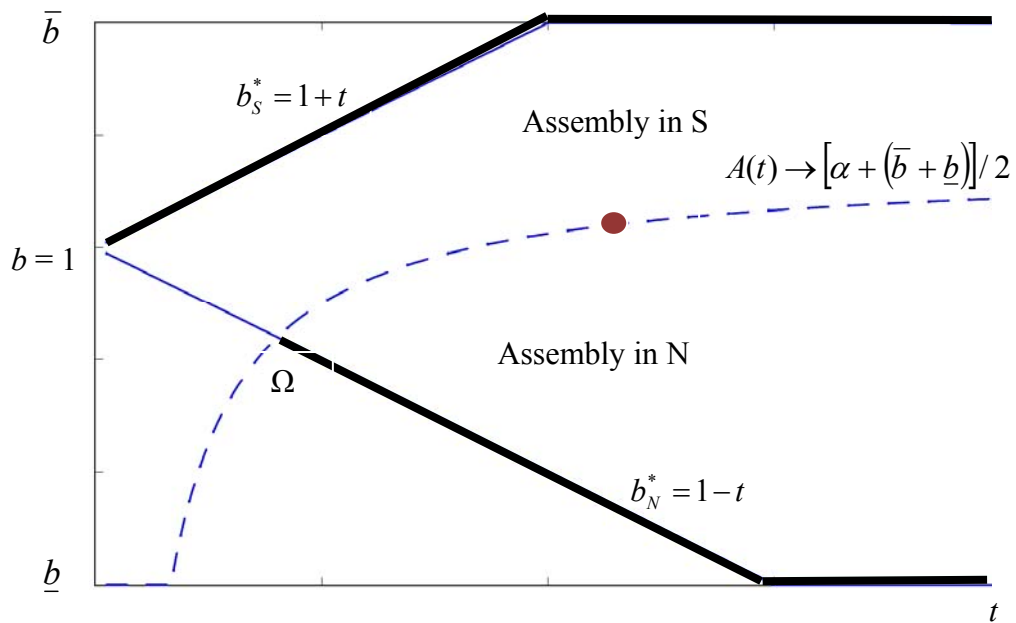


Figure 5b: Equilibrium locations, low cost assembly in N ($a_S > a_N$)

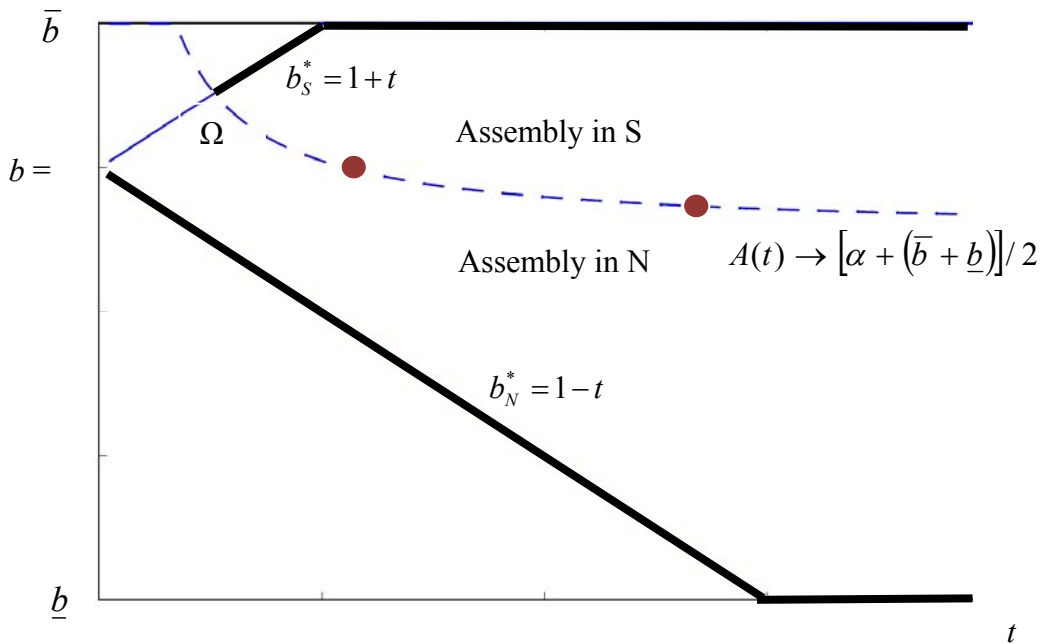


Fig 5b gives the case where primary factor costs of assembly are higher in N than in S. In the case illustrated assembly in N is an equilibrium at all values of t ; starting from this position, offshoring of parts takes place in a continuous manner but assembly never moves.

However, there is, for t greater than Ω , an alternative equilibrium in which assembly in S is supported by location of a high share of parts production in S. Notice that fig 4b has the same parameters as 4a, so we know that it is efficient for assembly to locate in S in the interval between the circles. However, inertia due to co-location effects means that this does not occur. It is possible to make an example in which there is an interval of t in which the equilibrium with assembly in N does not exist, ($A(t)$ intersects $b_N^* = 1 - t$ twice), this requiring parameters that shift $A(t)$ downwards (e.g. a lower value of α or lower support $[b, \bar{b}]$)

Cost minimisation and Nash equilibrium:

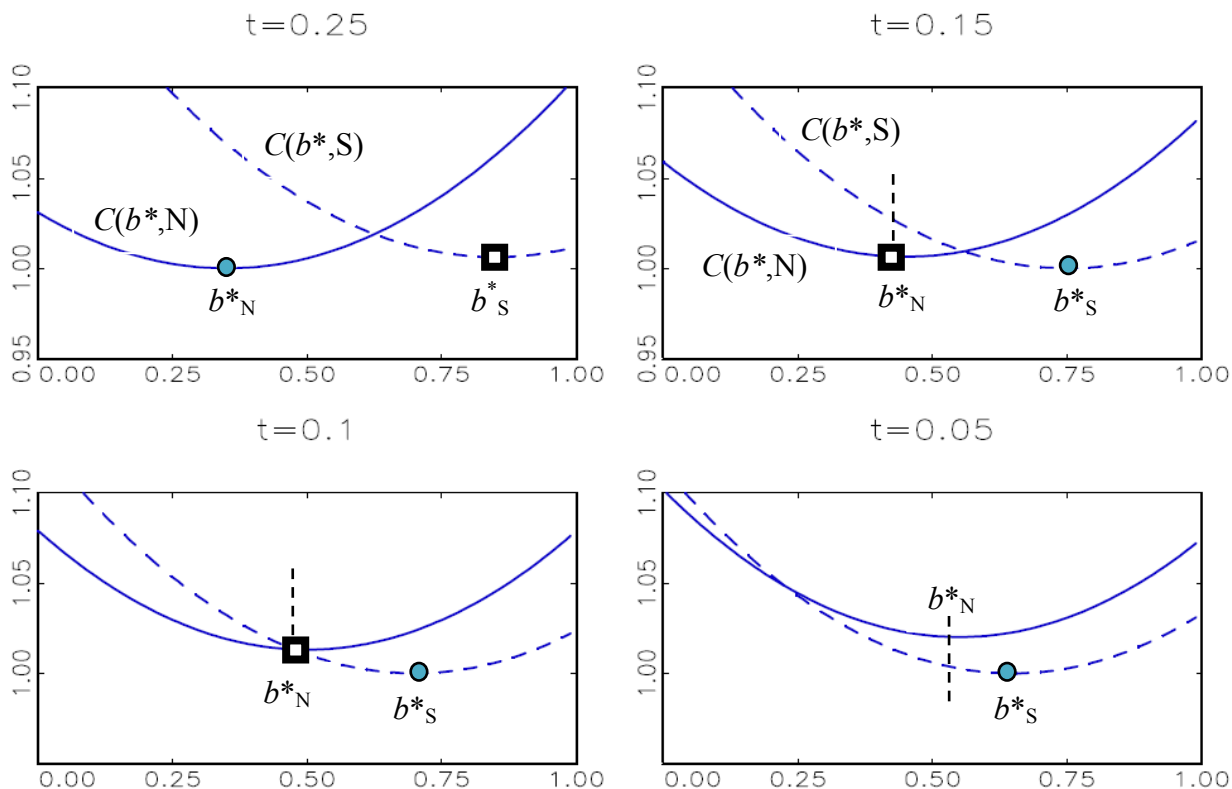
Why does the Nash equilibrium fail – in some cases – to achieve global cost minimisation? A helpful, if informal, way to think about this is to identify ‘coordination blockages’. Starting from high t and all activity in N there may be key decision takers whose payoffs are such that they stall relocation of the spider to its cost minimising configuration.

Consider fig. 6 which has on the horizontal axis the range of parts actually produced in S, which we denote \tilde{b} , and on the vertical the associated levels of costs when assembly is in N, $C(\tilde{b}, N)$, and when it is in S, $C(\tilde{b}, S)$.⁷ The four panels correspond to progressively lower shipping costs, and the figures are constructed with $a_S < a_N$ so correspond to earlier figs. 3a and 5a. Values of \tilde{b} which minimise costs conditional on location of assembly are marked by circles and squares and are simply the off-shoring thresholds, b_N^* and b_S^* . Overall cost minimisation is the lower of these, marked by the circles; (as in fig. 2 this is assembly in N at high t and assembly in S at low t).

The figure illustrates payoffs to various decisions. A vertical movement from curve to curve, given \tilde{b} , is a relocation by the assembler, the move raising or lowering costs according to the height of the curves. A (small) move along a curve is a relocation by the marginal parts producer, given the location of assembly. Such moves will take place until the marginal parts producer is indifferent between locations, i.e. at the minimum of each of the curves. Thus, on both the upper panels there are two equilibria, the circle and the square. There is no incentive for movement either by any parts producer (minima of the curves) or by the assembler (a jump up to the higher cost curve).

⁷ As defined by equations (2); units on the vertical axis express costs relative to their minimum value.

Figure 6: Equilibrium moves



Looking at the top right hand panel ($t = 0.15$), the following thought experiment is useful. Suppose the initial position has all production in N (point $\tilde{b} = 0$ on the solid curve). Can the cost minimising point (the circle) be attained by independent moves? Relocation of parts producers moves to the square, but at this point relocation by the assembler would be cost increasing. The square and the circle are both equilibria, but the square is the only one that is ‘reached’ from initial location in N, since moves from the square are ‘blocked’ by the incentives faced by the assembler. There are two ways to remove the blockage. One is that the assembler controls parts producers in the interval $[b^*_S, b^*_N]$. Full control of the entire industry is unnecessary, as all is required is control of an interval of parts producers large enough for the move to be collectively profitable. The other is that the assembler acts at a prior stage of the game; the assembler’s move to N would then be made in anticipation of following relocation of parts producers in the interval $[b^*_S, b^*_N]$.

The lower panels give outcomes at lower shipping costs, illustrating how shipping costs that are sufficiently low shipping can remove the blockage. The third panel, $t = 0.1$, is

for parameter values at which the assembler is indifferent between locations, and the equilibrium with assembly in N is about to disappear. And in the final panel, $t = 0.05$, independent decisions (from initial point with all production in N) lead to b_N^* and thence to relocation by the assembler and to overall cost minimisation.

3. The snake:

We now turn to the case where the product moves through a vertical production process with value being added at each stage. The stages form a continuum indexed $z \in (0,1)$ with $z = 0$ the most upstream stage and $z = 1$ the final and most downstream. Every stage combines primary factors with the output of the previous stage. Techniques of production and shipping costs may vary across stages but, since the technology of production determines the ordering of stages, neither factor intensity nor shipping costs need vary continuously with z . Nevertheless, we think that considerable insight can be got by making these characteristics depend continuously (and in cases studied below, monotonically) on z . We will show how outcomes are quite different according to the comparative costs and shipping costs of upstream and downstream stages.

Primary factor costs incurred at stage z will be set equal to unity in N and denoted $c(z)$ in S, so a low c value denotes high labour intensity or productivity advantage in S. The full cost of the product at stage z is cumulative value added, the integral of primary costs over upstream stages. Thus, if all production is in N, full cost at stage z is simply equal to z .

Shipping costs are incurred where production switches location, with per unit cost denoted $\tau(z)t$. As before, t is a parameter common to all stages and capturing the overall technology of offshoring. Shipping costs also vary with z , and the function $\tau(z)$ can be thought of as capturing how the weight of the product varies along the production chain. An important criterion turns out to be whether ‘weight’ is added more or less fast than value added. All final consumption is in N, as before.

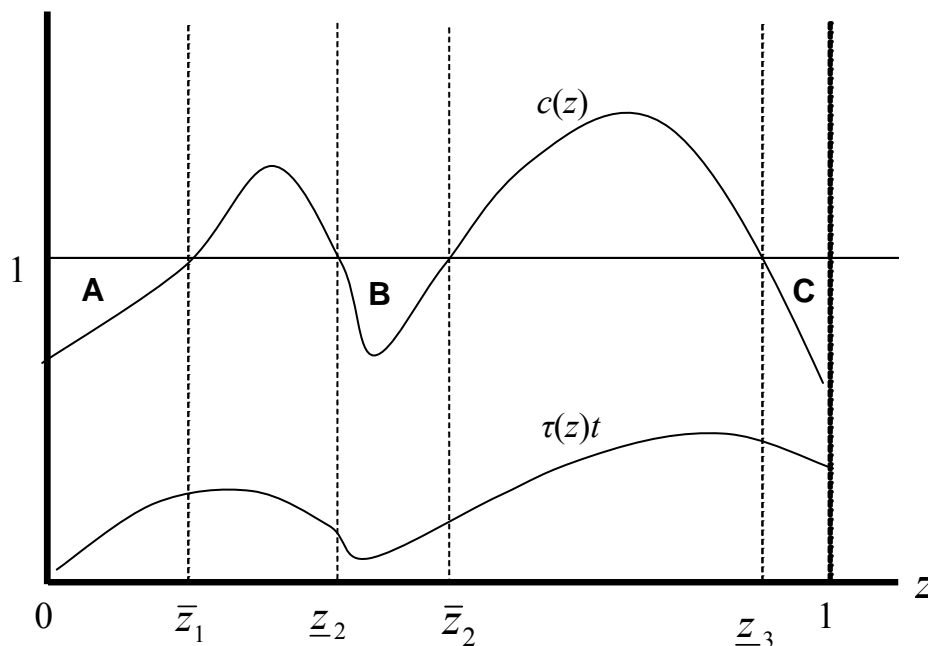
Fig. 7 illustrates costs along the snake, and we start with informal discussion of this example before moving to formal analysis. The horizontal axis is stages of production, and the horizontal line at unity is the value added of each stage if undertaken in N. Wiggly lines $c(z)$ and $\tau(z)t$ are unit costs in S and shipping costs respectively.⁸ As illustrated, stages in the

⁸ Not monotonic, but drawn to be continuous.

ranges marked A, B, C are ‘labour intensive’ with lower cost in S. Should they be undertaken in S? If the interval A is outsourced the production cost saving is given by the area A, while shipping costs $[\tau(0) + \tau(\bar{z}_1)]t$ are incurred. Here and through the remainder of the section, we assume that $\tau(0) = 0$; at this most upstream stage there is nothing physical to ship, although there could be coordination costs of other sorts. Costs $\tau(\bar{z}_1)t$ are incurred in shipping the output to next stage downstream in the chain, and decisions are based on comparison of production cost saving and shipping costs incurred. Interval B is a range of production cost saving, but if it is outsourced while stages on either side of B remain in N, shipping costs $[\tau(\underline{z}_2) + \tau(\bar{z}_2)]t$ are incurred. As illustrated, it is certainly not cost minimising to outsource the whole interval B; shifting \underline{z}_2 slightly to the right has no impact on production cost savings (around $c(\underline{z}_2) = 1$), and brings a finite saving in shipping costs. Finally, range C: the assumption that all final consumption is in N means that cost savings in C have to be weighed against shipping costs at both ends of the interval, \underline{z}_3 and 1. Outsourcing this range requires that \underline{z}_3 be a discrete distance below unity, so that the costs of shipping are offset by cost saving across a relatively wide range of stages.

With this as introduction, we now move to a more formal analysis comparing cases in which outsourcing commences from the upstream end of the snake, and where it starts downstream. These cases arise if cost differences are monotonic with, for example, S’s cost advantage steadily increasing or decreasing over the stages of production.

Figure 7: Costs along the snake



3.1 The snake: monotonic costs:

Cost minimisation

We start by looking at the cost minimisation problem of a single agent seeking an efficient location of the value chain. There are qualitatively different cases, depending on whether production in S is most valuable for upstream (case U) or for downstream stages (case D). It is easiest to set up these cases as two separate cost minimisation problems and then compare solutions. We will show that which configuration is overall cost minimising depends on parameters of the model in an intuitive way, with relocation starting upstream (case U) if upstream products are labour intensive and/or light, and the converse giving case D.

We start with case U, supposing that upstream stages $z \leq \hat{z}$ take place in S, downstream stages $z > \hat{z}$ take place in N, and the firm's problem is to choose \hat{z} to minimise total costs, which we denote $U(\hat{z})$, given by

$$U(\hat{z}) = \int_0^{\hat{z}} c(z) dz + \tau(\hat{z})t + \int_{\hat{z}}^1 dz. \quad (17)$$

The first integral is the cost of producing the range $z \leq \hat{z}$ in S; $\tau(\hat{z})t$ is the cost of shipping the product to N, and the final integral is the sum of the (unit) cost of producing remaining stages

in N. We assume that the functions $c(z)$ and $\tau(z)$ are twice differentiable, so first and second derivatives with respect to \hat{z} are

$$\frac{\partial U(\hat{z})}{\partial \hat{z}} = c(\hat{z}) + \tau'(\hat{z})t - 1. \quad (18)$$

$$\frac{\partial^2 U(\hat{z})}{\partial \hat{z}^2} = c'(\hat{z}) + \tau''(\hat{z})t. \quad (19)$$

Costs are reduced by *some* outsourcing if the first derivative is negative at $z = 0$, i.e. $c(0) + \tau'(0)t - 1 < 0$. The inequality is satisfied if upstream stages are labour intensive ($c(0) < 1$) and light, so shipping costs in the neighbourhood of the most upstream product are small. The gain to further outsourcing is diminishing if the second derivative is positive. If this is satisfied then an interior turning point (equation (18) equal to zero) is a cost minimum. Inspection of (19) indicates that this second order condition is satisfied if costs in S are monotonically increasing along the chain (labour intensity of stages monotonically declining) and shipping costs are convex. We call this case ‘upstream labour-intensive and light’ and illustrate it in the left hand panels of fig. 8a. The upper panel has z on the horizontal axis and unit costs on the vertical, and is drawn for a particular value of $t (= 0.05)$.⁹ $c(z)$ is linearly increasing in z and $\tau(z)$ is quadratic and convex over $z \in [0, 1]$; the first order condition is satisfied at $z = \hat{z}$ (equation (18)). We see that a range of upstream products, $[0, \hat{z}]$ is outsourced, and the range is less than suggested by looking at production costs alone because shipping costs are increasing, $\tau'(z) > 0$, as the product moves downstream. The bottom left panel takes the same case, but has t on the horizontal and z on the vertical, in order to illustrate the effects of shipping costs. As expected, lower t leads to more outsourcing.

What if we retain the assumption that upstream is labour-intensive ($c'(z) > 0$) but remove the assumption that it is ‘light’, so have $\tau''(z) < 0$? The second order condition (19) is then satisfied for small t , but fails at large t . The case is illustrated in the right hand panels of fig. 8a. The top panel is drawn for small t , so \hat{z} is a cost minimum. However, the bottom panel illustrates that as t increase the second order condition fails and, in the case illustrated, costs are minimised by not outsourcing at all.¹⁰

⁹ The bottom curve is $\tau(z)t$ on a scale five times larger for visibility.

¹⁰ It is possible that, for a large enough production cost advantage in S there is a further range of outsourcing.

Figure 8a: Upstream outsourcing

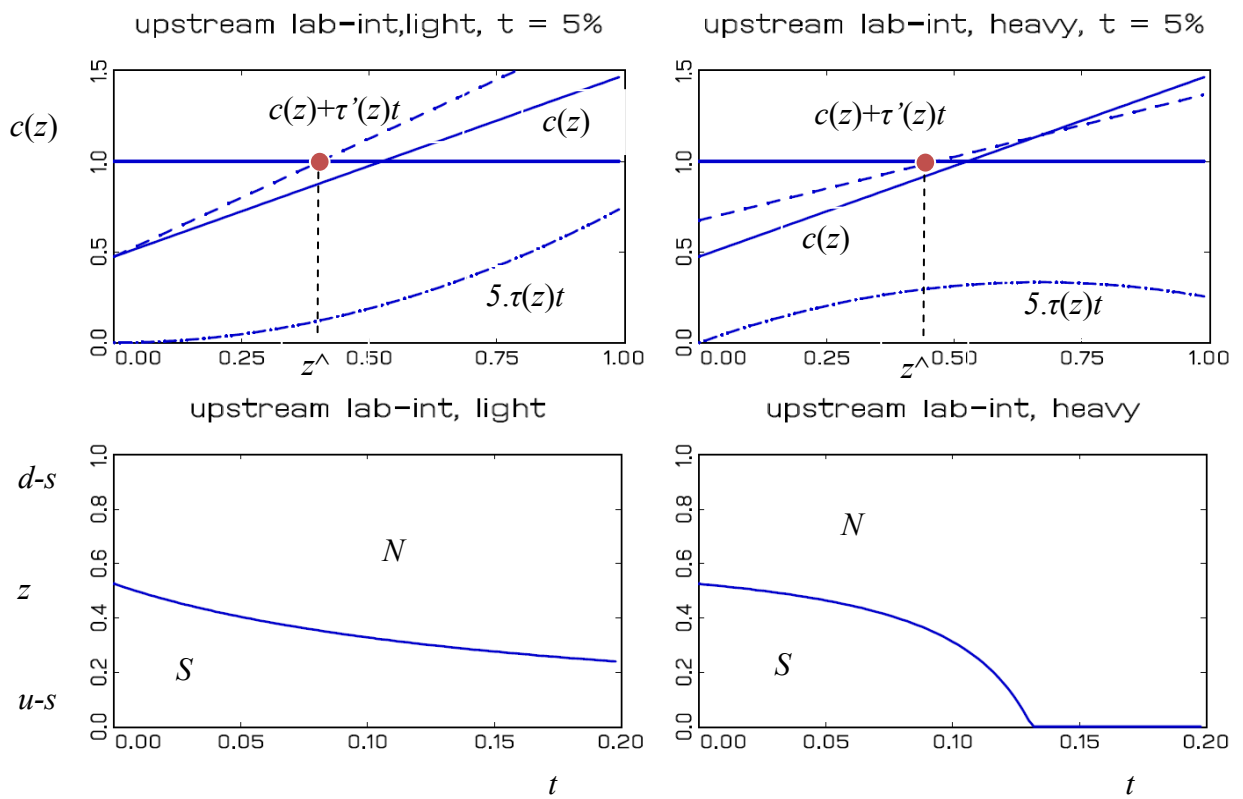
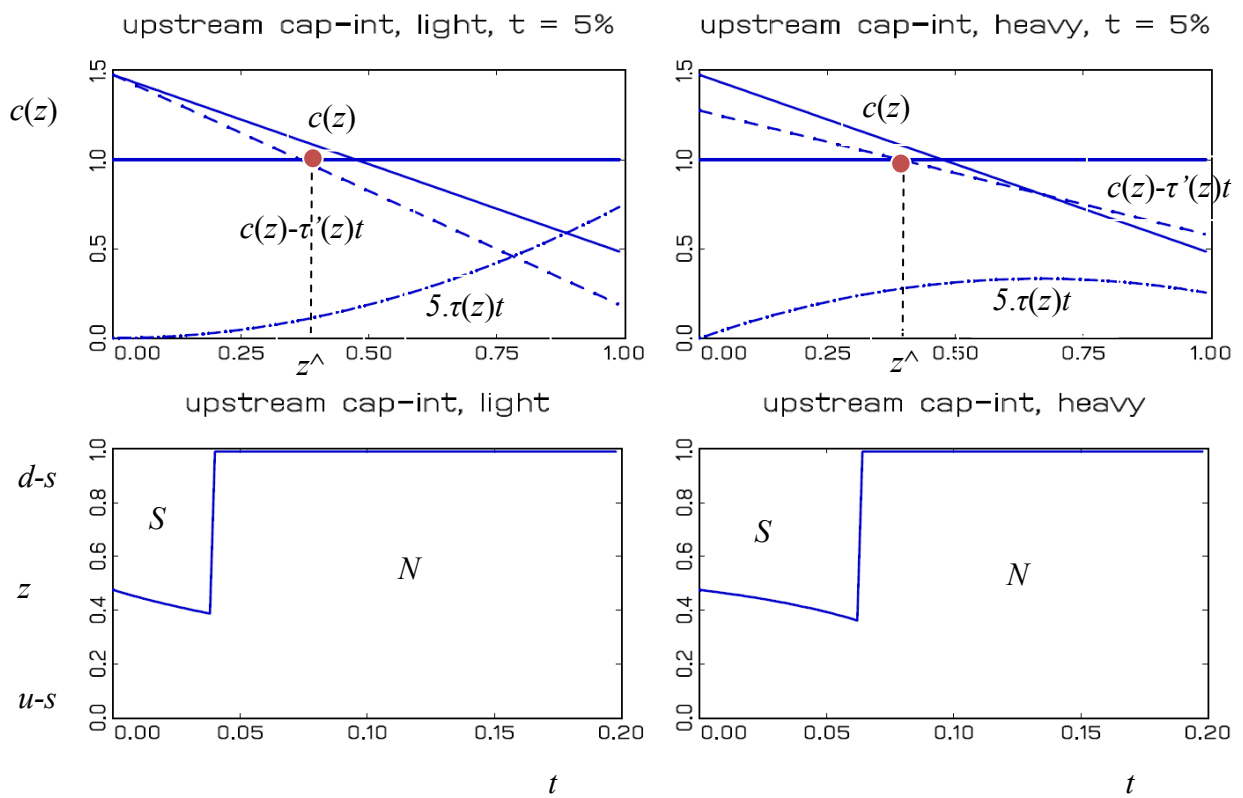


Figure 8b: Downstream outsourcing



Optimisation problem (17) *assumed* that if outsourcing occurred, it was upstream stages of the process that operated in S. We now look at the alternative, case D, in which outsourcing, if it occurs, involves moving downstream products to S. This case is quite different from the previous one because of the assumption that final consumption takes place entirely in N. Outsourcing a downstream range of parts (an interval $[z, 1]$, $z > 0$) therefore incurs *double* transport costs, $\tau(z)t$ plus $\tau(1)t$.

The firm's problem is now to minimise total costs $D(\tilde{z})$ where (opposite to case U) stages upstream of \tilde{z} ($z \leq \tilde{z}$) takes place in N and downstream of \tilde{z} ($z > \tilde{z}$) take place in S. $D(\tilde{z})$ takes the form:

$$\tilde{z} = 1: D(\tilde{z}) = \int_0^1 dz = 1 \quad (20)$$

$$\tilde{z} \in (0,1]: D(\tilde{z}) = \int_0^{\tilde{z}} dz + \tau(\tilde{z})t + \int_{\tilde{z}}^1 c(z)dz + \tau(1)t .$$

As indicated by (20), $D(\tilde{z})$ jumps upward as outsourcing commences and \tilde{z} goes below unity. Its gradient is then, for $\tilde{z} \in (0,1]$

$$\frac{\partial D(\tilde{z})}{\partial \tilde{z}} = 1 - c(\tilde{z}) + \tau'(\tilde{z})t . \quad (21)$$

and convexity requires

$$\frac{\partial^2 D(\tilde{z})}{\partial \tilde{z}^2} = -c'(\tilde{z}) + \tau''(\tilde{z})t > 0 . \quad (22)$$

The case of 'upstream capital intensive, light' ($c'(z) < 0$ and $\tau''(\hat{z}) > 0$) is in the left hand panels of fig. 8b. The second order condition holds and the upper panel illustrates a local cost minimum. However, off-shoring now incurs the cost penalty $\tau(1)t$, the cost of shipping the final product to market, so the local minimum at t^\wedge is a global minimum only if t is small. Outcomes are illustrated on the lower left panel of fig. 8b. Over a wide range of t there is no outsourcing, and when it commences it does so discontinuously, jumping to the cost minimum.

The final case of 'upstream capital intensive, heavy' ($c'(z) < 0$ and $\tau''(\hat{z}) < 0$) is illustrated in the right hand panels of fig 8b. There are now two distinct reasons why first

order condition (equation (21) equal to zero) may not give the cost minimising outcome; at high t the second order condition fails, and the fixed cost penalty $\tau(1)t$ means that no off-shoring is profitable.

Nash equilibrium

Parts of the chain are now controlled by independent firms, and we suppose that each controls a segment of length δ . This length can be interpreted as (approximately) the share of total value added in the chain¹¹. Once again, we look first at the case where upstream is labour-intensive/ light and ask: is it profitable for the most upstream producer who controls interval $[0, \delta]$ of the value chain to locate in N to S, and if so, is it profitable for others to follow?

The cost difference from producing the most upstream stages ($z \in [0, \delta]$) in S rather than N is

$$\Delta C(0, \delta) = \int_0^\delta [c(z) - 1] dz + \tau(\delta)t \quad (23)$$

i.e. the production cost difference plus transport costs incurred, given that downstream stages are in N. If this first move is profitable, do other firms follow? If the first z of the chain is located in S, then relocation from N to S by a firm occupying $[z, z + \delta]$ gives cost difference

$$\Delta C(z, z + \delta) = \int_z^{z+\delta} [c(z) - 1] dz + \tau(z + \delta)t - \tau(z)t \quad (24)$$

The shipping costs enter with opposite signs as relocation from N to S means that the firm no longer has to import its inputs, but does have to export its output.

If we let $\delta \rightarrow 0$ then, with $\tau(0) = 0$, the first move is cost reducing providing it saves primary factor costs. Linear approximation to the right hand side of (23) means that relocation is cost reducing so long as $c(z) - 1 + \tau'(z)t < 0$. This is just the gradient of total costs, $\partial U(z) / \partial z$ (equation (18)), so independent behaviour will cause relocation to occur so long as this derivative is negative. The Nash equilibrium and cost minimisation therefore coincide. There is no coordination failure and independent decision taking will secure overall cost minimisation.

¹¹ At N's factor prices any interval of length δ accounts for fraction δ of the total value added in the product.

What about deviations from the downstream end? The most downstream firm controls interval $[1-\delta, 1]$, and the cost difference from producing in S rather than N is

$$\Delta C(0, \delta) = \int_{1-\delta}^1 [c(z) - 1] dz + \tau(1 - \delta)t + \tau(1)t \quad (25)$$

i.e. the production cost difference plus transport costs incurred, given that both the market and upstream stages are in N. If this move by the most downstream firm is profitable, is it profitable for others to move from N to S? This is the decision of a firm in interval $z, z - \delta$, where upstream firms are in N and downstream firms are in S. The move would save production costs, save costs on shipping output downstream, and incur costs on importing inputs. The cost difference is therefore

$$\Delta C(z, z + \delta) = \int_{z-\delta}^z [c(z) - 1] dz - \tau(z)t + \tau(z - \delta)t \quad (26)$$

If $\delta \rightarrow 0$ then (26) is just the slope of $D(\tilde{z})$ in the open interval $(0, z)$. But (25) includes the jump in costs associated with incurring shipping costs on both inputs and outputs. It will be satisfied only if δ is large enough to yield cost savings on a relatively wide range of production stages. Failing this, the equilibrium will not achieve global cost minimisation, and will not involve any outsourcing of production. Relocation is ‘blocked’, because the most downstream firm faces the cost penalty of locating away from both the market and upstream suppliers. The blockage can be overcome only if a coordinated move of a sufficiently large number of stages can be achieved.

What this suggests is that, given some distribution of parameters across sectors of the economy, outsourcing is much more difficult to achieve in sectors where downstream activities are labour intensive and/or light, i.e. are the apparent candidates to benefit from outsourcing. Coordination failure may be acute for a downstream production stage sandwiched between a market in N and suppliers in N. Upstream stages can peel off more easily.

5. Concluding comments

It is a commonplace to say that globalization is associated with the fragmentation, unbundling, outsourcing and offshoring of production. But how does this occur given the complexity of actual production processes or ‘value chains’? No general results can be derived because of this complexity: a footloose (low communication or shipping cost task) might be capital intensive, or labour intensive tasks may be hard to manage from a distance: tasks with quite different characteristics may be ‘adjacent’ to each other in the value chain. Nevertheless, this paper makes a stab at establishing results that provide some insights.

The first distinction is between snakes and spiders. Snakes are production processes where a physical entity follows a linear process with value added at each stage. Spiders are many limbed, with parts from different sources coming together in one place for assembly. Of course, it need not be final assembly: spiders might be attached to any part of a snake.

How does activity in these two different models relocate from N to S (given a market in N and low labour costs in S) as trade and coordination costs fall? Production costs induce labour intensive (lower cost in S) parts to relocate, but this is moderated by the benefits of co-location with other stages of the production process. Discontinuous change and ‘overshooting’ can arise because of the role of node elements of production. In the spider, assembly is a nodal point, and when assembly relocates so do a wide range of parts. Some of these move against their comparative production costs in order to get the benefits of co-location, and then move back if shipping costs fall further. It is possible that assembly as a whole moves against its comparative production costs in order to get the benefits of co-location with labour intensive parts. If it is relatively capital intensive assembly may locate in N at very high and very low shipping costs, and in S at intermediate values of these costs. In the snake, the most downstream product is a node, as all upstream stages have to pass through this and thence to market. In the case where downstream is labour intensive this creates a barrier to off-shoring which, if it occurs at all, will be discontinuous, involving movement of a wide range of downstream activities together once a critical threshold is reached. Once again, co-location effects may induce overshooting, so stages move from N to S and then back again as shipping costs fall.

The comments above apply to the case when location decisions are made by a single agent seeking to minimise total costs. Equilibrium outcomes – where firms take decisions given the location of other firms – might not minimise total costs, as co-location forces

generate coordination failures. It is of course possible to think of ways to overcome coordination failure, such as acquisition of various stages by a single firm, or leadership in a multi-stage game. However, in the simplest case coordination failure creates multiple equilibria and has the effect of blocking relocation. Firms are reluctant to relocate if they are not sure that they will be followed, and this is a source of inefficiency. Off-shoring is likely to occur more slowly than is socially optimal.

The tension between factor costs and co-location is, we think, central to a micro-analysis of outsourcing. Combining spiders and snakes or working with less continuous technologies (e.g. one stage of the snake has a spike in its factor intensity) creates many more situations where off-shoring is 'blocked' by a key decision taker whose interest is not served by relocation. We have captured the benefits of co-location in the simplest possible way – costs saved in not having to ship the product to (or from) an adjacent stage. There are many other benefits of co-location such as information sharing and coordination over product specifications, design, quality, as well as the timeliness and reliability of production and delivery. All of these generate interactions with adjacent stages in the production process, and perhaps also with stages further up and down the value chain. There are also the wider benefits of agglomeration, such as shared labour skills and knowledge spillovers. The research challenge is to produce further regularities from the mass of possible cases in this rich and important topic.

Appendix 1

With $a_S > a_N$ the double intersection of then $A(t)$ and $R(t)$ can only occur if average parts' production costs in S are less than in N, $1 > (\bar{b} + \underline{b})/2$. Values of b_S^*, b_N^* are

$b_S^* = \min[1 + t, \bar{b}]$, $b_N^* = \max[1 - t, \underline{b}]$. Using these in equation (8) gives three regions for the expression for cost difference, equation (8):

$$1) \quad t < \bar{b} - 1: \quad b_S^* = 1 + t, \quad b_N^* = 1 - t$$

$$C(b_N^* : N) - C(b_S^* : S) = a_N - a_S + t[2 - (\alpha + \bar{b} + \underline{b})]$$

$$2) \quad \bar{b} - 1 < t < 1 - \underline{b}: \quad b_S^* = \bar{b}, \quad b_N^* = 1 - t$$

$$C(b_N^* : N) - C(b_S^* : S) = a_N - a_S - \frac{(1 - \bar{b})^2}{2} + t[1 - (\alpha + \underline{b})] - \frac{t^2}{2}$$

$$3) \quad \bar{b} - 1 < 1 - \underline{b} < t: \quad b_S^* = \bar{b}, \quad b_N^* = \underline{b}$$

$$C(b_N^* : N) - C(b_S^* : S) = a_N - a_S + (\bar{b} - \underline{b}) \left(1 - \frac{\bar{b} + \underline{b}}{2} \right) - t\alpha$$

The cost difference $C(b_N^* : N) - C(b_S^* : S)$ and its first derivative with respect to t are continuous in t . In regions 1 and 3 the expression is linear in t and in region 2 it is quadratic and concave. Evaluating the expression at its turning point (in region 3).

$$\text{Max}_t [C(b_N^* : N) - C(b_S^* : S)] = a_N - a_S + \frac{1}{2} [2 - (\alpha + \bar{b} + \underline{b})] [\bar{b} - \underline{b} - \alpha]$$

This expression being positive is necessary and sufficient for the double intersection. A

necessary condition is that $2 > (\alpha + \bar{b} + \underline{b})$, i.e. $\left(1 - \frac{\bar{b} + \underline{b}}{2} \right) > \frac{\alpha}{2}$ (this also implying that the

cost difference is increasing in t in region 1, and that $\bar{b} - \underline{b} - \alpha > 0$). The double intersection is more likely the smaller is S's cost disadvantage in assembly, $a_S > a_N$; the smaller is the cost of shipping the final product, α ; the lower its average costs in parts production $(\bar{b} + \underline{b})/2$; and, given this average, the greater is the range of costs, $\bar{b} - \underline{b}$.

Appendix 2.

Production costs and shipping costs:

Using (11) and (12) of the text

$$C(b_N^* : N) - C(b_S^* : S) =$$

$$a_N - a_S + \left(\frac{b_S^* - b_N^*}{\bar{b} - \underline{b}} \right) \left(1 - \frac{b_S^* + b_N^*}{2} \right) - t \left[\alpha + \frac{F(\bar{b}) + F(\underline{b}) - F(b_S^*) - F(b_N^*)}{\bar{b} - \underline{b}} \right]$$

Where F is the integral of f . Writing

$$\tilde{A}(t) \equiv \left[\left(\frac{a_S - a_N}{t} + \alpha \right) (\bar{b} - \underline{b}) + F(\bar{b}) + F(\underline{b}) \right] \frac{1}{2F(1)},$$

$$\tilde{R}(t) \equiv \left[F(b_S^*) + F(b_N^*) + \left(\frac{b_S^* - b_N^*}{t} \right) \left(1 - \frac{b_S^* + b_N^*}{2} \right) \right] \frac{1}{2F(1)}.$$

The conditions for assembly to be in N, respectively S are

$$A(t) > F(b_N^*)/F(1), \quad A(t) < F(b_S^*)/F(1).$$

Increasing returns to outsourcing:

Equations (13), (14), with uniform distribution, give cost comparison

$$\begin{aligned} C(b_N^* : N) - C(b_S^* : S) = & a_N - a_S + \left(\frac{b_S^* - b_N^*}{\bar{b} - \underline{b}} \right) \left(1 - \frac{b_S^* + b_N^*}{2} \right) - t \left[\alpha + \frac{\bar{b} + \underline{b} - b_S^* - b_N^*}{\bar{b} - \underline{b}} \right] \\ & + T\left(\frac{b_N^* - \underline{b}}{\bar{b} - \underline{b}} \right) - T\left(\frac{\bar{b} - b_S^*}{\bar{b} - \underline{b}} \right) \end{aligned}$$

To represent this on fig. 3 we define the functions $A(t)$ and $R(t)$ as

$$A(t) \equiv \left[\left(a_S + T\left(\frac{\bar{b} - b_S^*}{\bar{b} - \underline{b}} \right) - a_N - T\left(\frac{b_N^* - \underline{b}}{\bar{b} - \underline{b}} \right) + t\alpha \right) \frac{(\bar{b} - \underline{b})}{t} + (\bar{b} + \underline{b}) \right] \frac{1}{2}, \quad (9)$$

$$R(t) \equiv \left[b_S^* + b_N^* + \left(\frac{b_S^* - b_N^*}{t} \right) \left(1 - \frac{b_S^* + b_N^*}{2} \right) \right] \frac{1}{2}. \quad (10)$$

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