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ABSTRACT

Equilibrium Locations of Vertically Linked Industries*

This paper considers the locational choice of firms in an upstream and a downstream industry. Both industries are imperfectly competitive, with firms subject to increasing returns. There are transport costs between the two locations. Depending on the level of these costs there may be a single equilibrium with production diversified between locations, or multiple equilibria, some of which involve agglomeration at a single location. Typically the forces for agglomeration are greatest at intermediate levels of transport costs. Reducing these costs from a high to an intermediate level will cause agglomeration and consequent divergence of economic structure and income levels; reducing them to a low level may cause the industries to operate in both locations, bringing convergence of structure and income.

JEL classification: F1, F10, F12, R3
Keywords: industrial location, international trade, imperfect competition

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NON-TECHNICAL SUMMARY

The paper considers the locational choice of firms in an upstream and a downstream industry. There are two locations and trade between locations is costly. Both industries are imperfectly competitive. containing firms which operate with increasing returns to scale. The questions addressed are, what are the forces for one or both industries to agglomerate at a single location? Does production take place at a single location or at both? How does the equilibrium depend on parameters. and in particular how does economic integration effect agglomeration and the equilibrium location of the industries?

The incentive to agglomerate comes from the vertical relationship between the industries. There is a demand linkage. as firms in the upstream industry benefit from being close to their market. the downstream firms. There is also a cost linkage. as firms in the downstream industry benefit from being close to suppliers upstream. (These are market linkages. and we assume that there are no direct technological externalities between firms.) If either industry is perfectly competitive these demand and cost linkages would create no special incentives to agglomerate – the division of the perfectly competitive industry between locations would have no bearing on the location decisions of firms in the imperfectly competitive industry. If both industries are imperfectly competitive. however. downstream firms want to locate where there are many upstream firms and *vice versa*. thus potentially creating agglomeration.

Operating against agglomeration is the fact that final consumer demand and labour supply are tied to locations. The interaction between these forces creates the following pattern of equilibria:

- if trade costs are very high. both industries will be divided between the two locations in order to meet final consumer demand.
- at intermediate levels of trade costs there are multiple equilibria: agglomeration creates an equilibrium in which both industries produce in a single country (it could be either). Division of production between locations remains an equilibrium. although it may be unstable.
- at low levels of trade costs both industries will be divided between the two locations. This is because at low enough trade costs location decisions become extremely sensitive to labour cost differences. This rules out equilibria in which the concentration of production in a single location leads to wage differences between locations.

The paper illustrates the fundamental ambiguity of the effects of economic integration on the location of industry. In a move from high to intermediate trade

costs clustering forces come to dominate, and we see geographical concentration of industry and divergence of regional economic structure and wage rates. But at very low trade costs such wage differentials are not sustainable; there may be increased geographical dispersion of industry with convergence of economic structure and wages.

The paper also provides the basis for making precise the idea of a location's industrial base. Location decisions of firms in one industry depend on those in other industries. This gives equilibrium locations a certain inherent stability and is what creates the multiple equilibria we see in the model. It also means that changes in one industry will affect other industries, however, possibly 'catastrophically'. If damage to just one part of the chain is sufficiently severe, the whole vertical structure of production may be affected, and a set of vertically related industries may switch to another location.

1. Introduction. Firms' location decisions depend on the interaction between production costs and ease of access to markets. If trade costs -- the costs associated with supplying different locations -- are low, then firms are highly sensitive to production cost differences, and industries are 'footloose'. With high trade costs firms become tied to markets and their location decisions are much less sensitive to differences in production costs. When production is subject to increasing returns to scale, then at intermediate levels of trade costs location becomes skewed towards (although not completely concentrated in) locations with easy market access. Such locations can therefore support higher real wages than can less well placed locations (see for example Krugman (1980), Krugman and Venables (1990)).

This observation is of rather modest interest until combined with the actions of other decision makers. Krugman (1991 a,b) has added labour mobility to the story. Locations close to large markets pay higher real wages than do locations in which firms have higher costs of reaching customers. They consequently attract labour inflow, this further enlarging the market and causing a concentration of economic activity. The forces for concentration depend on the level of trade costs and the proportion of the population that is mobile in response to wage differences.

Labour mobility is not the only reason for the size of the market at different locations to be endogenous. If industries are vertically linked then movement of the downstream industry affects the market for the upstream. The simultaneous location decisions of firms in two imperfectly competitive and vertically related industries are the subject of this paper[1]. Firms in the upstream industry will be drawn towards locations where there are relatively many downstream firms -- the market access effect. But the proximity of many upstream firms reduces the costs of downstream firms, confirming their location. This interaction creates a force for the clustering of vertically linked industries in one location. Operating in the opposite direction are factor market considerations and the distribution of final consumption. We do not allow labour to move, so, if labour supply and final demand are spread across locations, this will offset the incentive for clustering. The relative strengths of these forces depend on characteristics of the industry under study, most notably the strength of vertical linkages and the importance of trade costs. Depending on these characteristics there may be unique or multiple equilibria, these involving either diversified production, or the concentration of production (in one or both industries) in a single location. It is worth emphasising that all the linkages and consequent forces for clustering of industries that we study are derived only from *market* interactions between firms; no technological externalities are considered.

Since the number, type, and stability of equilibria depend on parameters, it is possible that changes in these parameters may have radical effects. A cluster of industrial activity will be quite robust to small parameter changes -- firms are located where they are because of the presence of firms in the other industry, so parameter changes may only induce a marginal change in the equilibrium. However, other parameter changes may move the system to a different configuration of equilibria, having 'catastrophic' effects. Thus, parameter changes can change the equilibrium from being diversified to concentrated, or *vice versa*.

Several practical and policy implications follow from the analysis of this paper. First, the paper creates a framework for the analysis of the effects of economic integration on the geographical concentration of production. A key parameter in the analysis is the cost of trade between locations. If economic integration reduces this cost, then it will affect the incentives for an industry to cluster, and hence the location of industry. As we shall see, the direction of relocation depends on characteristics of the industry and of other vertically related industries. For some vertical groupings of industries integration might lead to clustering in a single location; for others relocation could be in the opposite direction in response to wage differences.

Second, by focusing on vertical linkages between industries, this paper captures the idea of a region's 'industrial base'. Location decisions of firms in one industry depend on those in other industries. This gives equilibrium locations a certain inherent stability, and is what creates the multiple equilibria we see in the model. But it also means that changes in one industry will affect other industries, possibly 'catastrophically'. If damage to just one part of the chain is severe enough, then the whole vertical structure of production may be affected, and the equilibrium may switch to another location.

Following sections of the paper are organised as follows. The next section sets up the basic industry model that we use and does some routine but necessary algebra. Section 3 analyses a single industry in partial equilibrium; this illustrates some of the forces at work in the model. Section 4 turns to two vertically linked industries and is the core the paper, demonstrating the multiplicity of locational equilibria that exist. Section 5 goes to general equilibrium, endogenising consumer income and factor prices. This increases the set of equilibria still further.

2. The industry model. We work with a standard model of monopolistic competition with product differentiation, as developed by Dixit and Stiglitz (1977) and applied to international trade by Krugman (1980) and others. There are two vertically linked industries, both taking this form; each industry may contain firms at two locations and all firms supply demand at each location. Locations are referred to by subscripts; industries are indexed by superscripts. This section describes the model for a single industry, leaving inter-industry interactions and general equilibrium for later sections.

We denote the expenditure at location i on the output of industry k by e_i^k [2]. With CES aggregators over varieties, demand for a particular variety is given by,

$$x_{ii}^k = (p_i^k)^{-\epsilon^k}(P_i^k)^{\epsilon^k-1}e_i^k, \qquad x_{ij}^k = (p_i^k t^k)^{-\epsilon^k}(P_j^k)^{\epsilon^k-1}e_j^k, \qquad i \neq j \tag{1}$$

x_{ij}^k is the quantity of a particular variety of industry k output produced in i and sold in j, and p_i^k is the price of a product produced in i. ϵ^k is the elasticity of demand for a single variety, and $\epsilon^k > 1$. We assume iceberg transport costs, so $p_i^k t^k$ is the effective price of a product exported from i, $t^k \geq 1$. The price indices at each location, P_1^k and P_2^k are defined by

$$\begin{aligned}(P_1^k)^{1-\epsilon^k} &= (p_1^k)^{1-\epsilon^k} n_1^k + (p_2^k t^k)^{1-\epsilon^k} n_2^k,\\ (P_2^k)^{1-\epsilon^k} &= (p_1^k t^k)^{1-\epsilon^k} n_1^k + (p_2^k)^{1-\epsilon^k} n_2^k.\end{aligned} \tag{2}$$

where n_i^k is the number of industry k firms producing at location i. Notice that if trade costs are positive ($t^k > 1$), then relocation of a firm from one location to the other (say, 2 to 1) reduces 1's relative price index ($dn_1^k = - dn_2^k > 0 \Rightarrow d(P_1^k/P_2^k) < 0$). This reduction in 1's relative price index comes from saving trade costs as another variety is produced in location 1.

Turning to the supply side, the profits of a single location i firm, denoted π_i^k, are

$$\pi_i^k = \left(p_i^k - c_i^k\right)\left(x_{ii}^k + x_{ij}^k\right) - c_i^k f^k. \tag{3}$$

where c_i^k is marginal cost, and $c_i^k f^k$ is fixed cost. The first order condition for profit maximisation is

$$p_i^k\left(1 - \frac{1}{\epsilon^k}\right) = c_i^k. \tag{4}$$

The zero profit condition has the effect of determining firm scale independently of the level of costs and implies (using (4) in (3)),

$$x_{ii}^k + x_{ij}^k = f^k(\epsilon^k - 1) \tag{5}$$

In the full model expenditure levels and costs will be endogenous. But looking at a single industry equations (1) - (5) determine equilibrium prices, quantities, price indices, and numbers of firms, conditional upon expenditure and costs.

Algebra is much simplified by definition of variables z_i^k and ρ^k.

$$z_i^k \equiv \left(p_i^k\right)^{\epsilon^k}\left(P_i^k\right)^{1-\epsilon^k}, \qquad \rho^k \equiv c_2^k/c_1^k = p_2^k/p_1^k. \tag{6}$$

$1/z_i^k$ is the demand for a single variety at its home location, per unit expenditure. It summarises information about the price of the product and about the prices and numbers of competing varieties, as given by the price index. ρ^k is the relative costs (and from (4) also relative prices) of suppliers in the two locations. Using (1) in (5) with (6) zero profits can be expressed as,

$$\frac{e_1^k}{z_1^k} + \frac{e_2^k}{z_2^k}\left(\frac{t^k}{\rho^k}\right)^{-\epsilon^k} = \phi^k, \qquad \frac{e_1^k}{z_1^k}(t^k\rho^k)^{-\epsilon^k} + \frac{e_2^k}{z_2^k} = \phi^k. \tag{7}$$

where $\phi^k \equiv f^k(\epsilon^k-1)$. These equations say that each firm has to reach output level ϕ^k to break even. Sales at the home location depend on expenditure and demand per unit expenditure; at the other location, this term is adjusted by a term measuring the relative (dis)advantage of the firm relative to local firms, this made up of any cost difference, ρ^k, and transport costs, t^k. We can solve for z_i^k to give

$$z_1^k = \frac{e_1^k\left[1 - (t^k)^{-2\epsilon^k}\right]}{\phi^k\left[1 - (t^k/\rho^k)^{-\epsilon^k}\right]}, \qquad z_2^k = \frac{e_2^k\left[1 - (t^k)^{-2\epsilon^k}\right]}{\phi^k\left[1 - (t^k\rho^k)^{-\epsilon^k}\right]}. \tag{8}$$

Replacing P_i^k by z_i^k the equations defining the price indices take the form,

$$z_1^k = p_1^k n_1^k + p_2^k n_2^k(\rho^k)^{-\epsilon^k}(t^k)^{1-\epsilon^k}, \qquad z_2^k = p_1^k n_1^k(\rho^k)^{\epsilon^k}(t^k)^{1-\epsilon^k} + p_2^k n_2^k. \tag{9}$$

from which

$$p_1^k n_1^k = \frac{z_1^k - z_2^k(\rho^k)^{-\epsilon^k}(t^k)^{1-\epsilon^k}}{1 - (t^k)^{2(1-\epsilon^k)}}, \qquad p_2^k n_2^k = \frac{z_2^k - z_1^k(\rho^k)^{\epsilon^k}(t^k)^{1-\epsilon^k}}{1 - (t^k)^{2(1-\epsilon^k)}}. \tag{10}$$

Equations (10) and (8) can be used to find the equilibrium location of an industry as a function of relative costs and demands. These equations hold for each industry -- although additional information is needed if industries are vertically linked.

3. A single industry. In order to illustrate the forces at work we look first at a single industry (dropping superscripts throughout this section). We continue to work with partial equilibrium so hold expenditures e_1 and e_2 constant; there are no intermediate inputs so costs and relative prices, ρ, are exogenous. Defining the relative expenditure levels by $\sigma \equiv e_2/e_1$, dividing the two equations (10) and using (8) we obtain,

$$\frac{n_2}{n_1}\rho = \frac{\sigma t^{\epsilon} + t^{1-\epsilon} - \rho^{\epsilon}(\sigma + t)}{t^{\epsilon} + \sigma t^{1-\epsilon} - \rho^{-\epsilon}(1 + \sigma t)} \qquad (11)$$

This equation gives the division of the industry between the two locations as a function of relative expenditure at the locations, σ, transport costs, t, and relative production costs, ρ.

Some, although perhaps not all, of the properties of this relationship are as would be expected. If locations have the same size and costs ($\sigma = \rho = 1$) then the industry is equally divided between the two locations, regardless of t. In all other cases the division of the industry depends on t. As $t \to \infty$ we have $\rho n_2/n_1 \to \sigma$; the relative values of output equal the relative values of expenditure, as they must with autarky. If $t = 1$ then

$$\frac{n_2}{n_1}\rho = \frac{1 - \rho^{\epsilon}}{1 - \rho^{-\epsilon}}.$$

The division of the industry is now independent of each location's expenditure, but infinitely sensitive to cost differences; only for $\rho = 1$ can we have a positive number of firms in both locations.

Figure 1 illustrates how ρ and t together determine n_2/n_1 when expenditures in the two locations are not equal. The figure is constructed with consumer expenditure at location 1 five times greater than at location 2 ($\sigma = 0.2$). The line $n_2/n_1 = \sigma$ gives combinations of ρ and t for which production is divided proportionately to expenditure. Higher lines give lower values of n_2/n_1, until $n_2 = 0$. Evidently, if $\rho \geq 1$, then reductions in t bring steady reductions in n_2/n_1 until specialisation occurs, the specialised equilibrium involving production only at the location with the large expenditure. But if the location with small market has a cost advantage ($\rho < 1$), then the reallocation of production as t falls is not

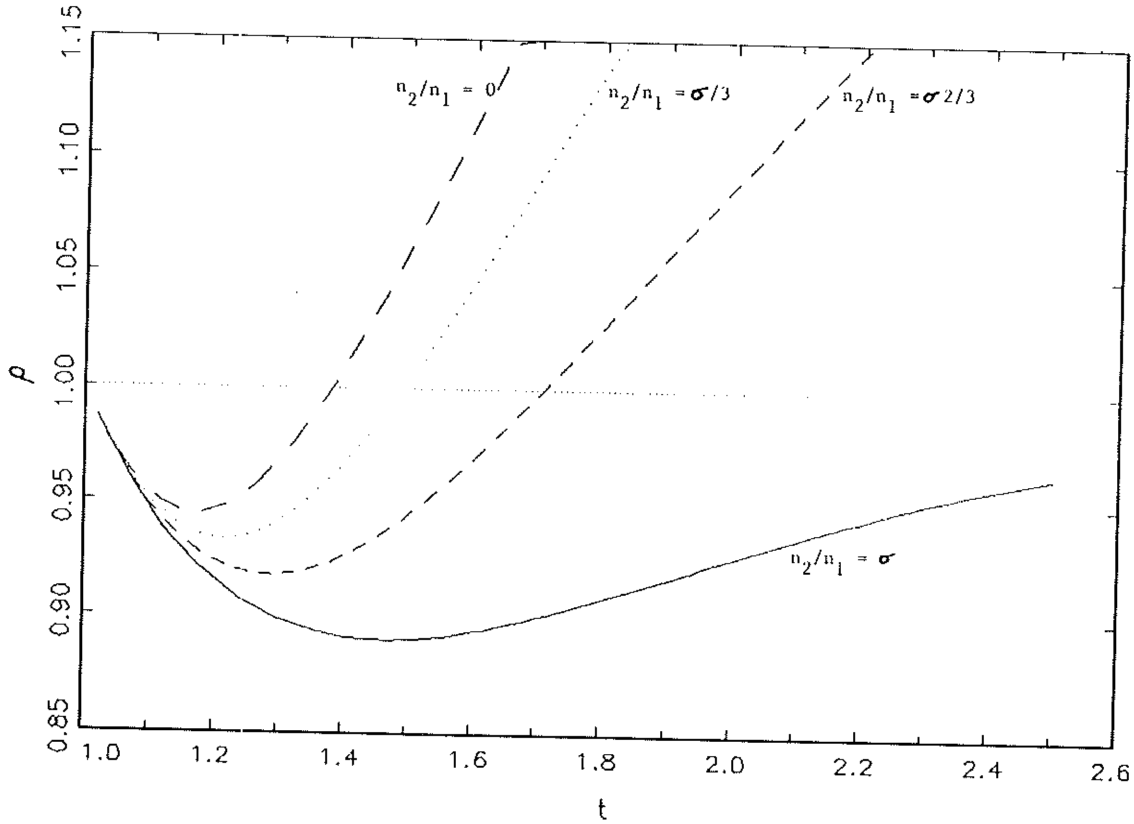

ρ
1.15
1.10
1.05
1.00
0.95
0.90
0.85
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
t
n2/n1 = 0
n2/n1 = σ/3
n2/n1 = σ 2/3
n2/n1 = σ

Fig. 1.

monotonic. This is because there are two forces at work. Firms want to produce at the location with the larger expenditure, this force increasing the lower are trade costs. But the lower are trade costs, the more sensitive are firm's location decisions to cost differences. The combination of these forces gives the U shape of the curves in figure 2.

Figure 1 is constructed for given σ and ϵ. Reducing either of these parameters has the effect of pushing the curves downwards, requiring larger cost differences to maintain production relative to market size. Figure 1 also lends itself to a simple general equilibrium interpretation. If each location has a perfectly inelastic supply of labour to the industrial sector and the relative endowment of this is equal to $K\sigma$ (some positive constant K), then full employment is achieved by $n_2/n_1 = K\sigma$. Wages adjust to bring this about, so the general equilibrium dependence of relative wages on t is given by the curve $n_2/n_1 = K\sigma$.

<u>4. Vertically linked industries.</u> We now turn to our central case in which there are two industries, upstream industry *a* which supplies downstream industry *b* which supplies consumption. The structure of each industry is as above, but demand for industry *a* comes from industry *b*, and the costs of industry *b* depend on industry *a*. To capture these linkages we must elaborate on both the cost side and the demand side of the model.

We notice first that the equilibrium division of the downstream industry *b* is (from (11) with superscripts)

$$\frac{n_2^b p_2^b}{n_1^b p_1^b} = \frac{\sigma^b(t^b)^{\epsilon^b} + (t^b)^{1-\epsilon^b} - (\rho^b)^{\epsilon^b}(\sigma^b + t^b)}{(t^b)^{\epsilon^b} + \sigma^b(t^b)^{1-\epsilon^b} - (\rho^b)^{-\epsilon^b}(1 + \sigma^b t^b)} \tag{12}$$

Relative costs, ρ^b, are now endogenous. We model costs by assuming that there is a single primary factor, labour, at each location. There is no inter-locational labour mobility, and the wage at location i is w_i with relative wages $\omega \equiv w_2/w_1$. In this section we remain in partial equilibrium, so ω is exogenous. Industry a uses labour alone, so relative costs and hence relative prices are

$$\rho^a = \omega. \tag{13}$$

Industry b uses labour and industry a output. This is aggregated according to a CES aggregator (equation (2)), so has price index in location i P_i^a. We assume a Cobb-Douglas technology between labour and the industry a composite output, with labour share μ. The industry b cost function and relative costs and prices between locations are

$$c_i^b = w_i^\mu (P_i^a)^{1-\mu}, \quad i=1,2; \qquad \rho^b = \omega^\mu \left(\frac{P_2^a}{P_1^a}\right)^{1-\mu}. \tag{14}$$

As is clear from this equation relative costs in industry b depend on ω, and on industry a price indices, which in turn depend on industry a costs and the numbers of firms in industry a. From the definition of z_i^k, (equation (6)),

$$\left(\frac{P_2^a}{P_1^a}\right)^{1-\epsilon^a} = \left(\frac{z_2^a}{z_1^a}\right)(\rho^a)^{\epsilon^a} \tag{15}$$

Values of z_i^k are given by equations (8), so

$$\left(\frac{z_2^a}{z_1^a}\right) = \left(\frac{e_2^a}{e_1^a}\right) \frac{[1 - (t^a/\omega)^{-\epsilon^a}]}{[1 - (t^a\omega)^{-\epsilon^a}]}. \tag{16}$$

and hence (using (16) and (15) in (14))

$$\rho^b = \omega^{\frac{\mu-\epsilon^a}{1-\epsilon^a}} \left(\frac{e_2^a}{e_1^a} \frac{\left[1 - (t^a/\omega)^{-\epsilon^a}\right]}{\left[1 - (t^a\omega)^{-\epsilon^a}\right]} \right)^{\frac{1-\mu}{1-\epsilon^a}} \tag{17}$$

This gives the equation we need for ρ^b, and may be interpreted as follows. Suppose we know e_2^a/e_1^a and ω. Then from zero profits in industry a we know the relative numbers of firms in industry a, n_2^a/n_1^a, and hence the industry a price indices, P_2^a/P_1^a. This, together with relative wages, ω, determines the relative cost levels in industry b, ρ^b.

Turning to the demand side, industry b demand comes from consumer expenditure alone. We continue to treat this as exogenous, so have $\sigma^b \equiv e_2^b/e_1^b$. Demands for industry a output, e_i^a, are now endogenous, coming from industry b, and we assume for the moment that the *only* source of demand for a's output is in b. Intermediates account for share $1-\mu$ of b's costs, so the absolute and relative values of demand for a output are,

$$e_i^a = (1-\mu) n_i^b c_i^b (x_{ii}^b + x_{ij}^b + f^b) = (1-\mu) n_i^b p_i^b \phi^b, \quad i=1,2;$$

$$\left(\frac{e_2^a}{e_1^a}\right) = \frac{n_2^b p_2^b}{n_1^b p_1^b}. \tag{18}$$

This says simply that expenditure on industry a output at each location is proportional to industry b production at that location.

Using the demand linkage (equation (18)) and the cost linkage (equation (17)) in the relationship determining the location of industry b (equation (12)) gives the following equilibrium condition:

$$\frac{\left[1 - (t^a\omega)^{-\epsilon^a}\right]}{\left[1 - (t^a/\omega)^{-\epsilon^a}\right]}(\rho^b)^{\frac{1-\epsilon^a}{1-\mu}}\ \omega^{\frac{\epsilon^a-\mu}{1-\mu}} = \frac{\sigma^b(t^b)^{\epsilon^b} + (t^b)^{1-\epsilon^b} - (\rho^b)^{\epsilon^b}(\sigma^b + t^b)}{(t^b)^{\epsilon^b} + \sigma^b(t^b)^{1-\epsilon^b} - (\rho^b)^{-\epsilon^b}(1 + \sigma^b t^b)}. \tag{19}$$

As we have noted, in partial equilibrium relative consumer demands, σ^b and wage rates ω, are exogenous. This equation therefore gives the equilibrium value of ρ^b as a function of parameters. Having found ρ^b from this equation equilibrium values of all other variables can be derived. In particular, in each industry the relative numbers of firms in each location, n_2^a/n_1^a and n_2^b/n_1^b, are decreasing functions of ρ^b, (as we saw for a single industry in figure 1).

Equation (19) characterises equilibrium only if numbers of firms are non-negative, this requirement setting the following four bounds:

For industry b, (12) gives the condition:

$$\left(\frac{\sigma^b(t^b)^{\epsilon^b} + (t^b)^{1-\epsilon^b}}{\sigma^b + t^b}\right)^{\frac{1}{\epsilon^b}} > \rho^b > \left(\frac{(t^b)^{\epsilon^b} + \sigma^b(t^b)^{1-\epsilon^b}}{1 + \sigma^b t^b}\right)^{-\frac{1}{\epsilon^b}} \tag{20}$$

The left hand inequality gives $n_2^b > 0$, and the right $n_1^b > 0$.

For industry a, (using (10) with (16) and (17)),

$$(t^a)^{1-\mu}\omega^{\mu} > \rho^b > (t^a)^{\mu-1}\omega^{\mu}. \tag{21}$$

The left inequality gives $n_2^a > 0$ and the right $n_1^a > 0$.

We now have all the information necessary to analyse the equilibrium. Suppose first that wages are the same in both countries, so $\omega = 1$. Equation (19) becomes

$$(\rho^b)^{\frac{1-\epsilon^a}{1-\mu}} = \frac{\sigma^b (t^b)^{\epsilon^b} + (t^b)^{1-\epsilon^b} - (\rho^b)^{\epsilon^b}(\sigma^b + t^b)}{(t^b)^{\epsilon^b} + \sigma^b (t^b)^{1-\epsilon^b} - (\rho^b)^{-\epsilon^b}(1 + \sigma^b t^b)} \qquad (22)$$

This bears a strong resemblance to equation (11), derived for a single industry. The left hand side of (11) gives the location of firms in the industry. But now, for the downstream industry b, this feeds back through intermediate demand to the relative number of firms in the a industry (demand linkage (18)). This in turn determines the industry a price indices and hence the costs of the b industry, ρ^b (through cost linkage (17)).

Evidently this equation is highly non-linear, and its behaviour is plotted in each box in figure 2, the boxes corresponding to different values of t^b. The horizontal axis in each of these boxes is ρ^b, (the endogenous variable) and the vertical axis gives relative demand for good b, σ^b. The figure is drawn for $\epsilon^a = \epsilon^b = 6$, $\mu = 0.5$, and $t^a = t^b$ ($\equiv$t). The solid curve plots out the locus of ρ^b and σ^b satisfying equation (22). The dashed lines on the figures give values of ρ^b and σ^b for which the inequalities (20) and (21) hold with equality. Along these lines the equilibrium number of one of the sorts of firms is zero, as labelled on the diagram. In the central region between them, all the n_i^k are positive.

For the case in which final demands are of equal size, $\sigma^b = 1$, stable and unstable equilibria are marked on the diagrams by points labelled S and U respectively. Looking at the first box, (t=1.23) the central point U is a diversified equilibrium in which both industries are equally divided between locations. However, the equilibrium is unstable, in the sense that profits π_i^k are increasing in n_i^k. To see this suppose that n_1^a, n_2^a, n_2^b adjust to hold respective profits at zero, but we are above the solid curve; it must then be the case that $\pi_2^b > 0$, since larger location 2 market size unambiguously raises profitability in country 2.

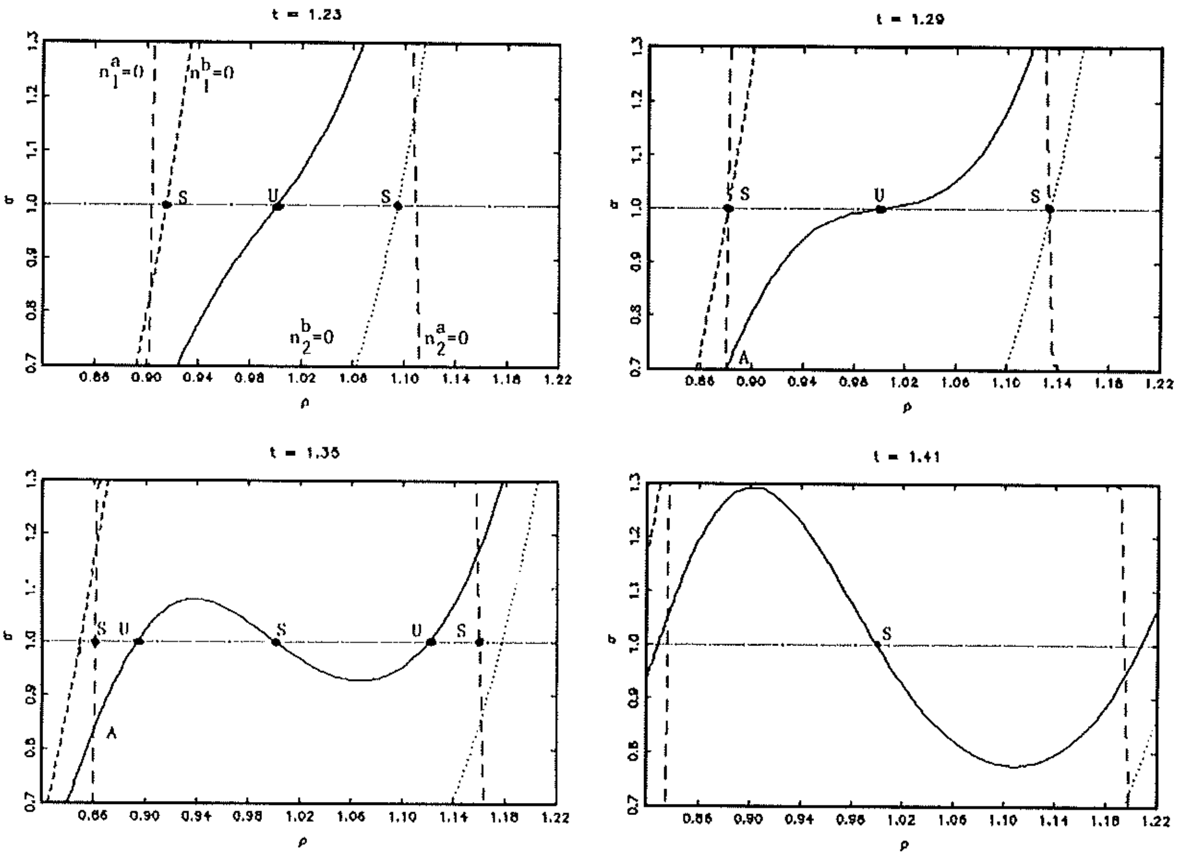


Fig. 2.

Now consider an increase in n_2^b at the point U; this raises demand for the intermediate, increasing n_2^a, and hence reducing ρ^b; but this puts us above the solid curve, implying that $\pi_2^b > 0$. If the curve is downward sloping then the argument is reversed, and equilibrium is stable.

The points labelled S in the first box are specialised equilibria in which the number of firms of one type is zero. At the right hand point S n_1^a and n_1^b adjust to hold respective profits at zero, but n_2^a and n_2^b are zero. This point is below the solid curve so we know that profits of firms in location 2 are negative, as they must be for the point to be an equilibrium. The left hand S is symmetric, with no production occurring in location 1.

The four boxes in figure 2 illustrate the 4 qualitative types of equilibrium that may occur. Continue to suppose that $\sigma^b = 1$. If trade costs are high (t=1.41, bottom right) then production is diversified, with the industry split (symmetrically) between the two locations; this is as we would expect -- we know it must be so under autarky. (Intersections of the solid curve with $n_i^a = 0$ are not equilibria as $\pi_i^a > 0$). If trade costs are a little lower (t=1.35, bottom left) then the diversified outcome is still a stable equilibrium, but there are also two stable equilibria in which production is unevenly divided between locations; industry *a* produces in only one location, although industry *b* continues to produce in both, albeit with the number of firms strongly skewed towards the location where *a* production is taking place. Unstable equilibria lie between the stable equilibria. At lower trade costs again (t=1.29, top right) the diversified equilibrium becomes unstable. At the lowest trade costs presented (t=1.23, top left) we see that the pair of stable equilibria become totally specialised; at each equilibrium industry *b* produces in a single location -- and therefore so must industry *a*.

Figure 3 presents similar information in a different form, in order to emphasise the dependence of the equilibrium on trade costs. In it we plot numbers of firms in industry *b* in each of the locations holding $\sigma^b = 1$ and $t^a = t^b$ ($\equiv$ t). The central line along which $n_1^b = n_2^b$ is the diversified equilibrium which is stable where solid, and unstable below point C. The upper and lower lines give the (stable) equilibria in which production is unevenly divided between locations, with additional unstable equilibria illustrated by dashed lines. Notice that labels on the upper and lower lines could be interchanged (there are symmetric pairs of equilibria). Along these lines industry *a* production is concentrated in one location, and, if t is small enough, then *b* production is similarly concentrated (see figure 2).

The intuition underlying figure 2 and 3 is straightforward. At sufficiently high values of t^b production must be divided between locations in order to meet final consumer demand. At low t downstream firms become very sensitive to cost differences; the location with more upstream firms has lower costs, so attracts the downstream industry. Presence of the downstream industry creates a large market for the upstream industry, so confirming its location, and giving the pair of specialized equilibria. For intermediate values of t trade costs are high enough for the diversified equilibrium to be stable. But if production were specialised, then no firm has an incentive to move, because of the presence of firms in the *other* industry.

We have assumed so far that both σ^b and ω are unity. If location 2 final demand is relatively small ($\sigma^b < 1$), then the equilibrium can be found by referring back to figure 2 and

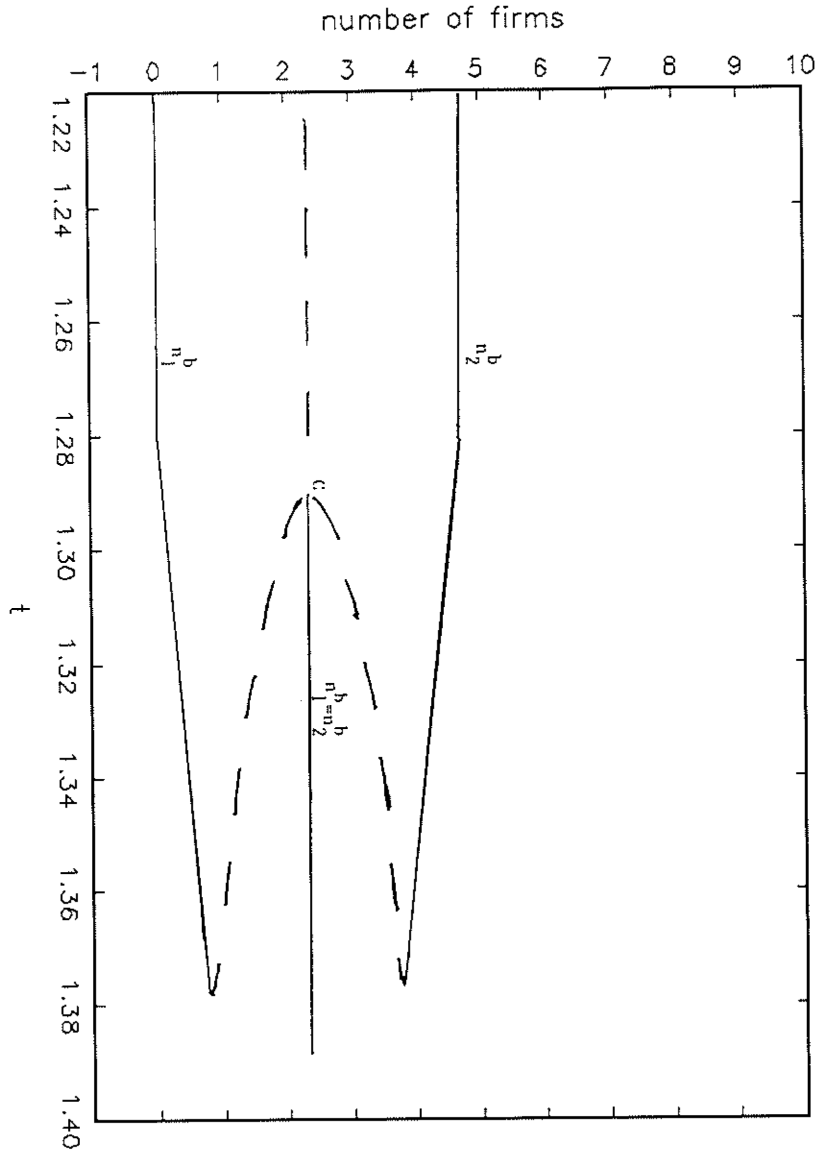

number of firms
-1
0
1
2
3
4
5
6
7
8
9
10
t
1.22
1.24
1.26
1.28
1.30
1.32
1.34
1.36
1.38
1.40
n_1^b
n_2^b
c
$n_1^b=n_2^b$

Fig. 3.

reading off a horizontal value of $\sigma^b < 1$. A few remarks are in order. First, the 'central' equilibrium is pulled to the right if it is stable; higher ρ^b corresponds to relatively less production in location 2, as would be expected. Second, the equilibrium in which production in (at least one of) the industries is concentrated in the small location will not exist if σ is small enough. This occurs if σ^b is below point A in the two panels of figure 2 on which A is marked.

Figures 2 and 3 are based on a numerical example, but the qualitative form of the equilibrium described is more general, depending on there being a bifurcation in the equilibrium condition (22). The bifurcation set (point C on figure 3) is where $d\sigma^b/d\rho^b = 0$. If we restrict ourselves to symmetric locations ($\sigma^b = 1$, $\omega = 1$) this condition gives a bifurcation set defined by

$$\frac{(t^b)^{\epsilon^b} + (t^b)^{1-\epsilon^b}}{1+t^b} = 1 + \left(\frac{2(1-\mu)\epsilon^b}{\epsilon^a - 1}\right) \tag{23}$$

The left hand side of this equation equals 1 when $t^b = 1$, is strictly increasing in t^b, and tends to ∞ as $t^b \to \infty$. The equation has a solution with $t^b > 1$ if and only if $1 - \mu > 0$ and ϵ^a, ϵ^b are finite; the solution is unique. A linkage between industries ($1 - \mu > 0$) and imperfect competition (finite elasticities) in both industries are therefore jointly necessary and sufficient for the existence of a single bifurcation point at some positive level of transport costs, and hence for the equilibrium to be qualitatively as described in figures 2 and 3.

Inspection of equation (23) is not very revealing about the exact location of the bifurcation point; values of t^b solving this equation are given in table 1. From this table we see that the critical value of t is lower the higher are the elasticities of demand, and the greater is 1-μ, the share of intermediates in industry b.

Table 1. *Critical values of trade costs.*

	$1-\mu = 0.25$			$1-\mu = 0.5$			$1-\mu = 0.7$		
ϵ^b / ϵ^a	3	5	7	3	5	7	3	5	7
3	2.16	1.66	1.48	1.91	1.54	1.40	1.61	1.9	1.29
5	1.77	1.47	1.36	1.61	1.38	1.29	1.41	1.27	1.21
7	1.61	1.38	1.29	1.48	1.31	1.24	1.33	1.22	1.17

Finally, we may note that when there are multiple equilibria their welfare ranking, from the point of view of each location, is unambiguous. Since there are no profits or government revenues, relative wages are (for the moment) exogenous, and consumers only purchase good b, relative utilities are determined by relative industry b price indices. Industry is concentrated in location 2 if ρ^b is low, and low ρ^b implies low P_2^b/P_1^b and hence relatively high location 2 welfare. As would be expected, the location with industry is better off as consumers are served more cheaply.

5. General equilibrium. Until now we have treated ω and σ^b as parameters. If the industries are small relative to factor markets and total income this is appropriate. We now turn to the case where this is not so, and two new and opposing forces come into play. First, if a location has little industry then it has low labour demand and wage, this acting to attract industry; this force leads industry to be divided between the two locations. Second, little industry and a low wage reduce final expenditure, tending to amplify forces causing industry to concentrate at one location.

The first of these forces must be the more powerful at low levels of trade costs (from section 3 we know that the sensitivity of location to cost differences is very high for low t). Furthermore, in the limit as t^a, $t^b \rightarrow 1$, the equilibrium *must* be qualitatively different from that of the preceding section. To see this recall that when $t^a = t^b = 1$ industry locates where the wage is lowest. If the wage in each location is strictly increasing in industrial employment this implies that there is a unique equilibrium, which, since it is unique, is stable. And if the two economies are symmetric, then the equilibrium will be diversified, with equal division of industry between two locations. This argument suggests that the set of equilibrium configurations will be:

-- at low t, a unique diversified equilibrium:

-- at intermediate t, multiple equilibria in which the specialised equilibria are stable:

-- at high t, a unique diversified equilibrium.

This turns out to be so, subject to the qualification that if factor market forces are made strong enough, then it is possible that specialised equilibria do not exist for any value of t. This is because examples can be constructed in which concentration of production in a single location would imply arbitrarily large wage differences.

We have no analytical results on the dividing lines between these cases, but illustrate them by embedding the industry model in a simple general equilibrium structure. Suppose that in addition to the two monopolistically competitive industries there is a perfectly competitive sector which is tradable, and is the numeraire. It is described by a strictly concave technology and revenue function $\Pi_i(1, w_i)$. There are separate labour markets at each location -- we ignore migration or other labour market linkages -- and the endowment of labour at location i is L_i, so wages come from factor market clearing.

$$L_i = n_i^a c_i^a (x_{ii}^a + x_{ij}^a + f^a) + \mu n_i^b c_i^b (x_{ii}^b + x_{ij}^b + f^b) - \frac{\partial \Pi_w(1, w_i)}{\partial w_i}. \quad (24)$$

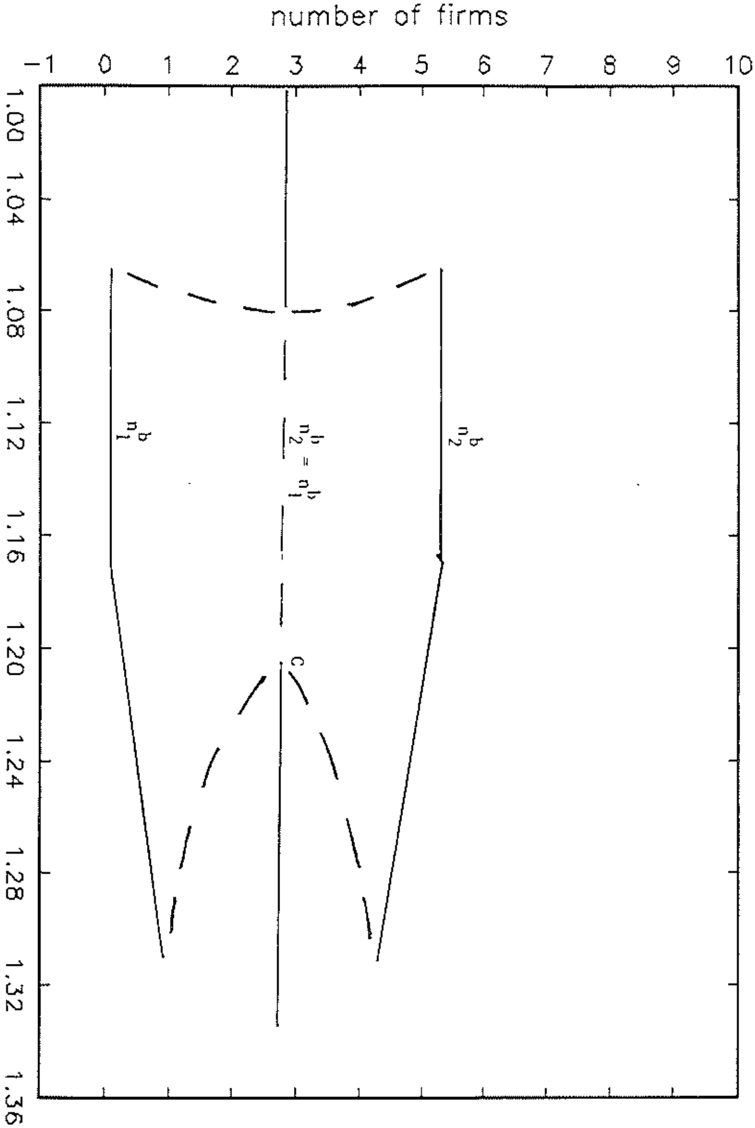
Income is given by

$$M_i = w_i L_i + \Pi_i(1, w_i) \quad (25)$$

If we assume Cobb-Douglas preferences with expenditure shares α, β, (and for the perfectly competitive sector $1 - \alpha - \beta$), then final consumer expenditure in each location on industries *a* and *b* is given by αM_i, βM_i; α has been set equal to zero until now.

Equilibrium configurations are illustrated in figure 4 which is constructed analogously to figure 3, and with the same parameters in the industry sectors. It differs from it in having upward sloping labour supply and endogenous income. Other parameters are given in the appendix and we need only note that, for the moment, we retain the assumption that $\alpha = 0$, so industry *a* only supplies intermediates.

Comparing figures 3 and 4 two features are apparent. First, in figure 3, for all t less than C, the diversified equilibrium is unstable, and specialised equilibria are stable. However, in figure 4 the specialised equilibria disappear for small enough t and the diversified equilibrium becomes stable. This is because asymmetric division of industry induces wage differences which, at low t, prevent industry from all clustering in a single location. The second point to note is that point C occurs at a lower value of t in figure 4 than in figure 3. The same forces are at work; wage flexibility tends towards equal division of the industry between locations. Figure 4 illustrates the fundamental ambiguity of the effects of economic integration on the location of industry. In a move from very high trade costs to intermediate ones clustering forces come to dominate, and we see industrial



number of firms
-1
0
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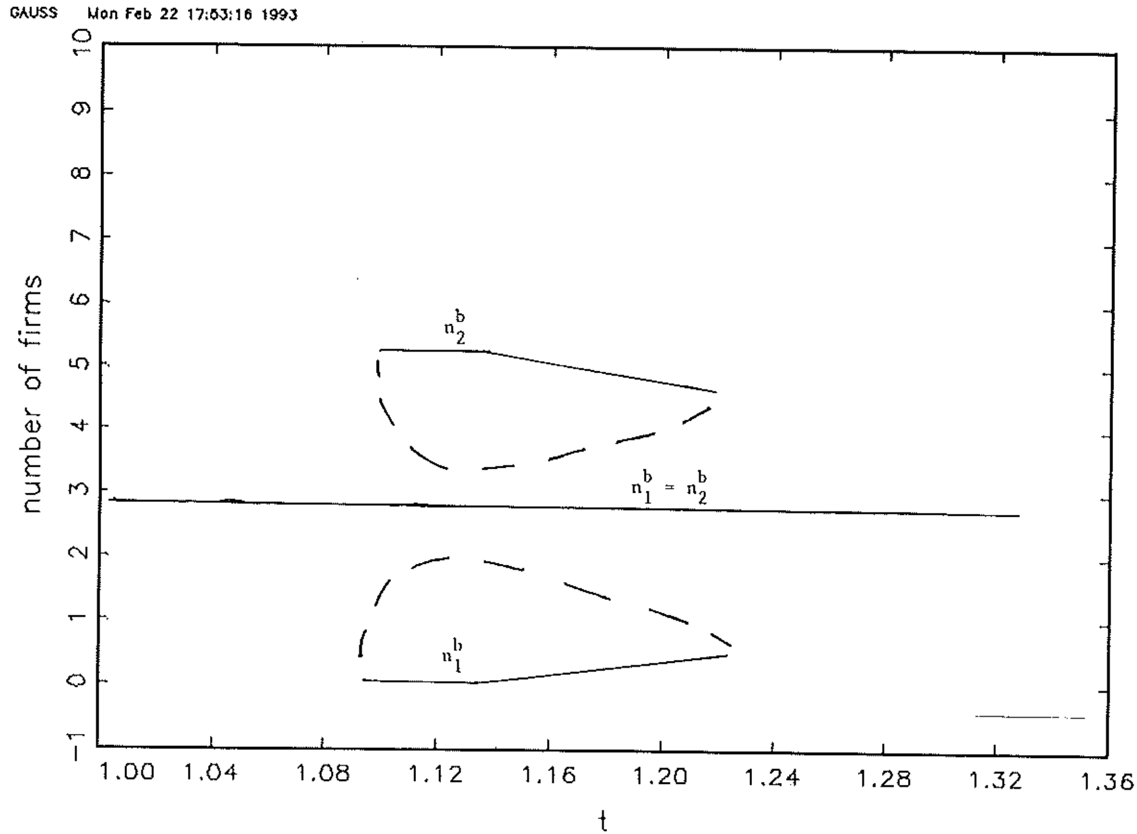
10
1.00
1.04
1.08
1.12
1.16
1.20
1.24
1.28
1.32
1.36
t
n_1^b
$n_2^b = n_1^b$
n_2^b
c

Fig. 4.



GAUSS Mon Feb 22 17:53:16 1993
number of firms
10
9
8
7
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2
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1.00 1.04 1.08 1.12 1.16 1.20 1.24 1.28 1.32 1.36
t
n_2^b
$n_1^b = n_2^b$
n_1^b

Fig. 5.

concentration, this giving rise to regional wage differentials. However, at very low trade costs such wage differentials are not sustainable. Industry relocates in response to wage differences so a diversified pattern of production re-emerges as the equilibrium. The precise point at which these changes occur depend on industry parameters -- as in the preceding section -- and on the supply curves of labour to industry.

If clustering forces are dominated either by wage differentials or by final demand, then it is possible that the diversified equilibrium is stable for all t. This is illustrated in figure 5, constructed for the same parameter values as figure 4, except that there is now some final demand for industry *a* output ($\alpha > 0$). This increases the tie between firms and final consumers and, together with wage flexibility, may mean that the diversified equilibrium is stable for all values of t. However, for intermediate values of t, there are five equilibria. A pair of stable, and a pair of unstable equilibria in which the industries are divided unequally between th: locations

<u>6. Concluding comments</u>. That linkages between industries create an incentive for agglomeration of activity seems unsurprising, but depends crucially on market imperfections. The linkages studied in this paper are purely market linkages, and they derive their effect from the interaction of trade costs with increasing returns to scale and imperfect competition. The importance of imperfect competition can be illustrated by considering what would happen if one the industries -- say the upstream -- were perfectly competitive. Then (if there are transport costs and the locations are sufficiently similar) part of the upstream industry will always locate wherever there are downstream firms. Downstream firms will use only the local supplier and the upstream industry will play a role no different from the supplier

of a primary factor. Imperfect competition changes this fundamentally as price in a location depends on the number of suppliers in that location, with more firms bringing lower price (unless offset by factor supply considerations). In this paper this works because product differentiation ensures all downstream firms use all upstream products. In a homogenous product oligopoly more suppliers in a location create more intense competition with an analogous price effect (see Venables (1985)). The fact that more upstream firms imply a lower price reduces costs for the downstream industry, bringing agglomeration.

The dependence of the equilibrium configuration on the level of trade costs raises interesting policy issues. The general equilibrium considerations of factor price flexibility and the characteristics of particular industries interact to determine whether a reduction in trade costs will be associated with clustering of industry and consequent divergence of economic structure and income level, or with dispersion of industry and convergence of incomes. In a multi-industry model this suggests that during a process of economic integration some industries might be expected to agglomerate, while other may spread out in response to factor price differences. Further work is needed to investigate and quantify the forces at work, and thereby be able to form judgements about which industries are likely to be dominated by centripetal or centrifugal forces.

The framework presented here also provides a way of making precise the idea of an industrial base. Some industries may be of particular importance in maintaining firms in other upstream and downstream industries; what are the characteristics of such industries? Clearly linkages to other industries are important, as are returns to scale, the extent of product differentiation, and the form of product market competition. Further research is needed to identify such 'strategic' industries. The paper is also suggestive of the possibly damaging effects of transient variability on long run economic structure. Full dynamic analysis is needed to investigate the effect of transient shocks and the possibility of hysteresis of industrial structure.

Appendix:

The revenue function takes the form:

$$\Pi_i(1, w) = K_i w_i^{-\gamma} \tag{26}$$

In figure 4: $\alpha = 0$, $\beta = 0.2$, $\gamma = 10$, $L_1 = L_2 = 20$, $K_1 = K_2 = 2$.
In figure 5: $\alpha = 0.02$, $\beta = 0.2$, $\gamma = 10$, $L_1 = L_2 = 20$, $K_1 = K_2 = 2$.

Notes:

1. The study of an imperfectly competitive upstream industry supplying perfectly competitive downstream industries has been undertaken by Ethier (1982), Rivera-Batiz (1988) and Markusen (1989) amongst others.

2. The reader may ignore superscripts in this section; they are needed in sections 4 and 5.

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