The Spread of Industry: spatial agglomeration in economic development*

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ABSTRACT: This paper describes the spread of industry from country to country as a region grows. All industrial sectors are initially agglomerated in one country, tied together by input-output links between firms. Growth expands industry more than other sectors, bidding up wages in the country in which industry is clustered. At some point firms start to move away, and when a critical mass is reached industry expands in another country, raising wages there. We establish the circumstances in which industry spills over, which sectors move out first, and which are more important in triggering a critical mass.

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1. Introduction

During the last three decades industry has spread from Japan to several of its East Asian neighbours. In 1965 manufacturing absorbed nearly one of every four workers in Japan, against one in six in Taiwan, one in eight in the Philippines, or one in eleven in South Korea. Japanese manufacturing workers then earned over one and a half times as much as their Philippine colleagues, and three times as much as manufacturing workers in South Korea and Taiwan, measured on a purchasing power parity (PPP) basis.

Figure 1a and 1b show, respectively, what has happened since then to the ratio of manufacturing to total employment in Japan, the Philippines, South Korea and Taiwan, and the evolution of manufacturing earnings relative to the average for the four economies. Between 1965 and 1993, manufacturing grew much faster than any other sector in South Korea and Taiwan, absorbing large transfers of labour from agriculture and incorporations into the labour force. In 1993 both economies had a larger fraction of workers employed in manufacturing than Japan did, while in the Philippines the share of manufacturing in employment remained roughly unchanged relative to 1965.

The real earnings of manufacturing workers grew in all four economies in absolute terms. In relative terms, however, Japan increased its gap with the other three until 1973. Since that year, South Korean and Taiwanese manufacturing workers have caught up and currently earn nearly as much (at PPP) as their Japanese colleagues, while the earnings of Philippine workers have fallen relative to the average for the four economies.[1]

The spread of industry from country to country is usually viewed primarily as the consequence of changes within each country — policy reform enabling specialisation according to comparative advantage, government interventions targeted at solving investment coordination failures, or rapid factor accumulation starting from low initial levels. Such changes have received particular attention in studies of the rapid growth

[1] See appendix for data sources. Japan had in turn caught up with the United States during previous years, with the ratio of earnings between US and Japanese manufacturing workers (at PPP) falling from 2.7 to 1.3 between 1965 and 1975.

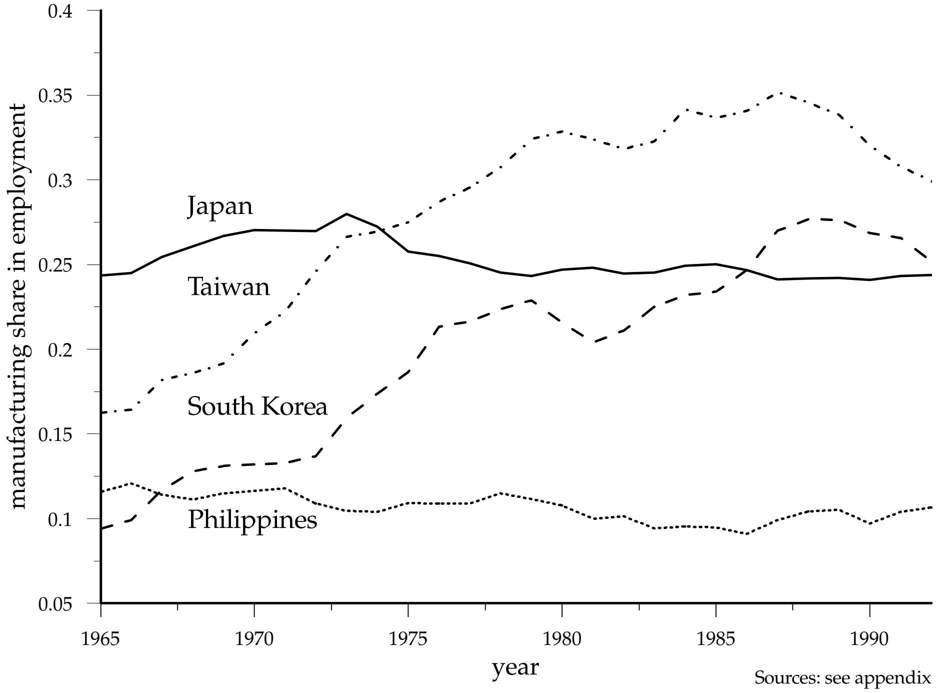

FIGURE 1a
Manufacturing employment relative to total employment

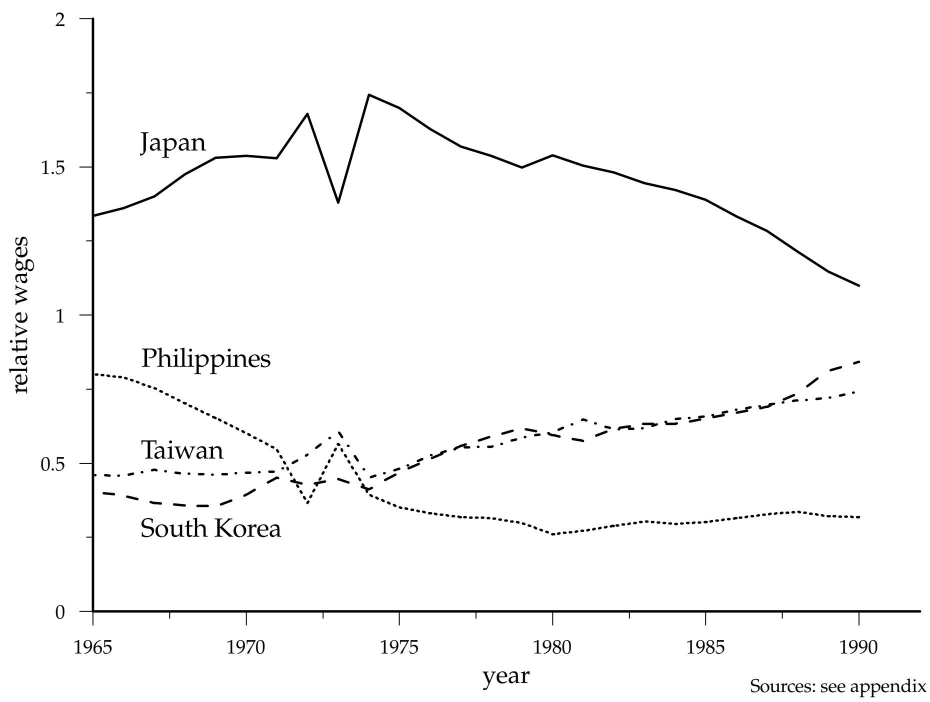

FIGURE 1b
Monthly manufacturing earnings relative to the average for the four economies (at PPP)

of manufacturing production across the newly industrialising countries (NICs) of East Asia (see, e.g, Little, 1994; Rodrik, 1995; and Young, 1995).

While not denying the importance of these considerations, in this paper we seek to develop an alternative approach to the way in which industry spreads between countries. We suppose that all countries are similar, or even identical, in underlying structure, yet show that the distribution of industry may not be uniform across countries and that industrialisation may spread in a series of waves from country to country. The approach is based on a tension between agglomeration forces, which tend to hold industry in a few locations, and wage differences (or more generally, factor supply considerations) which encourage the dispersion of industry.

The basic idea runs as follows. Suppose that countries have identical technology and endowments, and may contain two sectors, agriculture and industry. Firms in the industrial sector are imperfectly competitive and are linked by an input-output structure, which —as in Krugman and Venables (1995), and Venables (1996)— creates forward and backward linkages. If there are some trade or transport costs, then proximity to firms supplying intermediates reduces costs and gives rise to cost (or forward) linkages. The presence of firms using intermediate goods raises sales and profits of intermediate goods suppliers, and creates demand (or backward) linkages. The interaction of these forces creates pecuniary externalities, encouraging the agglomeration of industry so that, if these forces are strong enough, industry will be concentrated in a single country (label it country 1). Wages in this country will be higher than elsewhere, but the positive pecuniary externalities will compensate for the higher wage costs.

Now suppose that some (exogenous) force increases the size of the industrial sector relative to agriculture. This bids up wages in country 1 relative to wages elsewhere, and there comes a point at which it becomes profitable for some industrial firms to move out of country 1 to another country, say 2. As this process continues so firms in 2 begin to benefit from the forward and backward linkages to other firms, and a 'critical mass' is reached. At this point there is rapid —although not necessarily discontinuous— expansion of country 2 industry, accompanied by an increase in the country 2 wage. The equilibrium now involves countries 1 and 2 industrialised and with higher wages than elsewhere.

Further growth in the industrial sector raises wages in 1 and 2 relative to wages in other countries, and at some point industry spills over into a third country, eventually reaching critical mass, and so on. The story is therefore one of industry spilling over, in a series of waves, from one country to another.

The objective of this paper is to study this process, establishing circumstances in which industrialisation takes this form. Sections 2 and 3 of the paper set out the model and describe the forces at work. Forward and backward linkages are central to our story, and the model we develop contains many different industries, which may differ in the strength and type of linkages that they enjoy and that they bestow on other industries, and also in their relative factor intensities. In section 4 we pay attention to the industrial structure of the economies during their development. This allows us to characterise which industries are the first to move out from industrialised countries, and which are most important in triggering 'critical mass'. Section V concludes.

2. The model

The structure of this model is closely related to that in Krugman and Venables (1995), and makes use of the same sorts of technical tricks, involving the combination of Dixit and Stiglitz (1977) monopolistic competition and 'iceberg' transport costs that have figured in many recent papers in economic geography. We will therefore be brief in describing its formal structure.

We consider a world in which there are N countries, the ith of which is endowed with quantities L_i and K_i of labour and arable land, for $i = 1,...,N$. We shall usually assume that all countries are identical, so have the same endowments, L and K. Each country can produce both manufacturing and agricultural output.

Agriculture

Agriculture is perfectly competitive. It produces under constant returns to scale a homogenous output, which we choose as *numéraire*, and assume costlessly tradeable. The agricultural production function is Cobb-Douglas in land and labour, with labour share θ. If manufacturing employment in country i is denoted m_i and the labour market clears, agricultural output is $(L_i - m_i)^{\theta} K_i^{(1-\theta)}$, and the wage in the economy is

$$w_i = \theta (L_i - m_i)^{(\theta - 1)} K_i^{(1-\theta)}, \qquad i = 1,\ldots,N \ . \tag{1}$$

Manufacturing

Manufacturing is composed of S different sectors or industries, each of which is assumed to be monopolistically competitive. The number of industry s firms operating in country i is denoted n_i^s and endogenously determined. Firms enter and exit in response to positive and negative profits respectively, so at equilibrium profits are exhausted. In each industry, a large number of differentiated goods can be produced under increasing returns to scale. All potential varieties are symmetric, so at equilibrium each firm produces a different one and charges a producer price p_i^s. Shipments of industrial goods are subject to 'iceberg' transportation costs —that is, a fraction of any shipment melts away in transit. The number of units that must be shipped from country i in order that one unit arrives at j is denoted $\tau_{i,j}$, which we assume to be same for all industries.

Each industry's products can be aggregated via a CES function to yield a composite that is used both as a consumption good and as an intermediate input. These CES functions may be represented indirectly by CES price indices, q_i^s. In each country each industry's price index is defined over products supplied from all sources, so takes the form:

$$q_i^s = \left[\sum_{j=1}^{N} n_j^s (p_j^s \tau_{j,i})^{(1-\sigma)} \right]^{1/(1-\sigma)} , \tag{2}$$

where σ (> 1) is a measure of product differentiation.

The cost function of a single industry s firm in location i is:

$$C_i^s = (\alpha + \beta x_i^s)\, 1^{\eta^s}\, w_i^{(1-\eta^s - \sum_{r=1}^{S} \mu^{r,s})} \prod_{r=1}^{S} (q_i^r)^{\mu^{r,s}} \ . \tag{3}$$

We assume a fixed input requirement of α and a constant marginal input requirement β. The input is a Cobb-Douglas aggregate of labour, agricultural and manufactured products. The share of agriculture in the s industry is η^s, and agriculture has price 1. The share of industry r in the s industry is $\mu^{r,s}$, and q_i^r is the price index of industry r in country i, where all industry r varieties enter the composite intermediate and are appropriately aggregated by the CES form of expression (2). Shares sum to unity, so the labour coefficient is as given, and its price is the local wage, w_i.

Preferences

The representative consumer in each nation has quasi-homothetic preferences over agriculture (the *numéraire)* and the S CES aggregates of industrial goods. The indirect utility of the representative consumer in country i is

$$V_i = 1^{-(1-\sum_{s=1}^{S}\gamma^s)} \prod_{s=1}^{S} (q_i^s)^{-\gamma^s} (y_i - e^0) \ , \tag{4}$$

where y_i is income, and e^0 is the subsistence level of agricultural consumption.

General equilibrium

Expenditure on each manufacturing industry in each country can be derived from (3) and (4) as

$$e_i^s = \gamma^s \Big[w_i m_i + (L_i - m_i)^{\theta} K_i^{(1-\theta)} - e^0 \Big] + \sum_{r=1}^{S} \mu^{s,r} n_i^r p_i^r x_i^r \ . \tag{5}$$

The first term is the value of consumer expenditure, and the second the value of intermediate demand. Consumers have a linear expenditure system (indirect utility function given by (4)), so devote the first e^0 of their income to agriculture, and proportion γ^s of their income above this level to expenditure on industry s products. In the square brackets, the first term is wage income in manufacturing, and the second is income generated in agriculture —agricultural rent is distributed across the population to equalise per capita incomes. The final term is intermediate demand, generated as industry r firms spend fraction $\mu^{s,r}$ of their costs (and, with zero profits, of their revenue) on the output of industry s.

The division of consumers' and producers' expenditure on each industry between individual varieties of industrial goods can be found by differentiation of the price index with respect to the price of the variety. Demand in j for a single s industry variety produced in i, $x_{i,j}^s$, is

$$x_{i,j}^s = (p_i^s)^{-\sigma} \left(\frac{\tau_{i,j}}{q_j^s} \right)^{(1-\sigma)} e_j^s , \tag{6}$$

and each firm's total output is $x_i^s = \sum_{j=1}^{N} x_{i,j}^s$.

Since the producer of an individual good faces an elasticity of demand σ, firms mark up price over marginal cost by the factor $\sigma/(\sigma-1)$. We choose units of measurement such that $\beta\sigma = \sigma - 1$, so that the price is

$$p_i^s = w_i^{(1-\eta^s-\sum_{r=1}^{S}\mu^{r,s})} \prod_{r=1}^{S} (q_i^r)^{\mu^{r,s}} . \tag{7}$$

Firms are scaled such that they earn zero profits at size 1, achieved by choosing units such that $\alpha = 1/\sigma$. In equilibrium the number of firms has adjusted to give zero profits, so

$$x_i^s \le 1, \quad n_i^s \ge 0, \quad \text{complementary slack, for all } i = 1,...,N, \; s = 1,...,S. \tag{8}$$

The manufacturing wage bill in country i, $m_i w_i$, is:

$$m_i w_i = \sum_{s=1}^{S} \left(1 - \eta^s - \sum_{r=1}^{S} \mu^{r,s} \right) n_i^s p_i^s x_i^s . \tag{9}$$

Equations (1)–(9) characterise equilibrium. To understand the forces at work in the model it is helpful to consider the following thought experiment: if we add one more firm to a country, what are the mechanisms through which this affects the profits of firms in that country?

The first two mechanisms are through competition in the factor and goods markets, and have the effect of reducing profits of existing firms. The extra firm increases labour demand and raises the wage, expressions (1) and (9). It also lowers the price index, expression (2), reducing sales, expression (6), and hence profits.

The presence of linkages creates two forces pulling in the opposite direction. The lower price index reduces the cost of firms using the firm's product as an intermediate, equation (3), this creating a cost or forward linkage. The presence of an additional firm also raises expenditure in the country, expression (5), this increasing sales, expression (6), and hence profitability, so creating a demand or backward linkage.

The analysis of the paper is centred on the tension between these forces. The first two forces encourage geographical dispersion of industry, as firms seek low wages and markets with little supply from competing firms. The second two encourage agglomeration in a single location, as firms gain from being close to other firms which are their customers and their suppliers.

The experiment

In the remainder of the paper we study how exogenous changes in the economy change the relative strengths of the forces for dispersion of industry and for agglomeration, and thereby trigger the spread of industry between countries. The exogenous changes we study are economic growth which increases the share of manufacturing relative to agriculture in the countries under study. We capture the process of growth in a very simple way, by assuming an exogenous increase in the labour endowment (in efficiency units). We assume this increase is the same at all locations, and hold the stock of land (in efficiency units) constant. This could be interpreted as growth in participation rates and as improvements in the educational attainments of the labour force. On this respect, Young (1995) documents the fundamental role played by factor accumulation in explaining the extraordinary postwar growth of Hong Kong, Singapore, South Korea and Taiwan:

> Participation rates, educational levels, and (excepting Hong Kong) investment rates have risen rapidly in all four economies. In addition, in most cases there has been a large intersectoral transfer of labor into manufacturing, which has helped fuel growth in that sector.

> [R]ising participation rates remove an average of 1 percent per annum from the per capita growth rate of Hong Kong, 1.2 and 1.3 percent per annum from South Korea and Taiwan, respectively and a stunning 2.6 percent per annum (for 24 years!) from the growth rate of Singapore. [...] Human capital accumulation in the East Asian NICs has also been quite rapid. [...] I have found that the improving educational attainment of the workforce contributes to about 1 percent per annum additional growth in labor input in each of these economies.

However, given our assumption that the representative consumer has quasi-homothetic preferences, we prefer to think of this exogenous growth in the efficiency units of labour mainly as a process of technical change, raising the productivity of labour in both manufacturing and agriculture. In practice, of course, technical change does differ across countries and across sectors (and to explain why, one ought to treat it endogenously). We treat it this way in order to focus on our primary concern, the tension between agglomeration forces and factor price differences. Since we assume an income elasticity of consumer demand for manufactures larger than unity, the effect of an increase in the endowment of labour (in efficiency units) is to increase demand for manufacturing relative to agriculture, and thereby induce a transfer of labour from agriculture to manufacturing. As we show in the next section, this raises wages wherever industry clusters relative to wages elsewhere, and can lead industry to spill from country to country.

3. The agglomeration of industry

The forces at work are most easily illustrated in an example with two countries and one manufacturing industry. Figure 2 illustrates such a case.

The axes on the figure are the number of firms in each country, and the curves are zero profit loci for firms in countries 1 and in 2, i.e. the locus of points along which $x_1 = 1$ and $x_2 = 1$ (we drop the industry superscripts in this section). Above the curves there are many firms so profits are negative, suggesting exit as illustrated by the arrows, and conversely below. By symmetry of the two economies, the curves intersect at the point U where $n_1 = n_2$. We assume that linkages are strong enough that this equilibrium is unstable (moving a firm from country 1 to 2 raises profits in 1 and reduces them in 2); parameter values under which this is so are discussed in

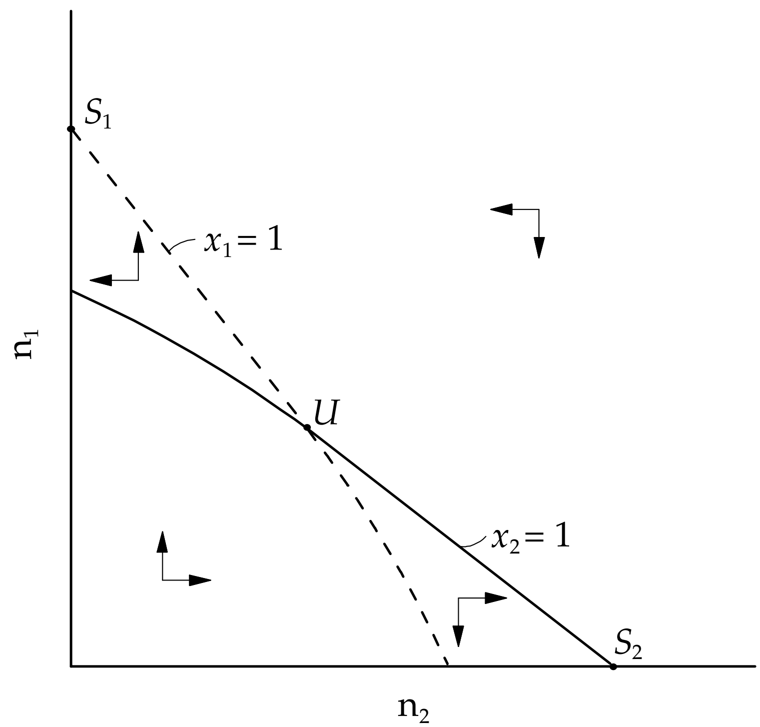

FIGURE 2
Initial configuration: industrial agglomeration in country 1

Krugman and Venables (1995). Stable equilibria are illustrated by the points S_1 and S_2, at which industry is agglomerated in country 1 (respectively 2) and entry in the other country is unprofitable.

We assume that the initial equilibrium is at S_1, so has $n_2 = 0$. Suppose now that there is growth in the labour force (in efficiency units) in both countries, while the land stock remains constant. How does this affect the equilibrium?

To answer this question, let us look first at what happens to relative wages. At S_1 country 1 meets world demand for manufactures, so

$$n_1 p_1 x_1 = e_1 + e_2 \ , \tag{10}$$

where expenditures on manufactures in each country are, from (5),

$$e_1 = \gamma\left[w_1 m_1 + (L - m_1)^\theta - e^0\right] + \mu n_1 p_1 x_1 \ , \qquad e_2 = \gamma(L^\theta - e^0) \ , \tag{11}$$

(the land stock in each country has been set at unity). Expression (1) gives wages as

$$w_1 = \theta(L - m_1)^{(\theta-1)} , \qquad w_2 = \theta L^{(\theta-1)} . \tag{12}$$

The country 1 manufacturing wage bill, $w_1 m_1$ is a fraction $(1-\mu)$ of the value of output, $e_1 + e_2$, so, using (10)–(12),

$$m_1 \theta (L - m_1)^{(\theta-1)} = \frac{\gamma}{1-\gamma}\left[(L - m_1)^{\theta} + L^{\theta} - 2e^0\right] . \tag{13}$$

This equation gives country 1 manufacturing employment, m_1, as a function of parameters. Notice that if e^0 is zero then the equation is homogenous of degree θ in L and m_1. However, if e^0 is positive, then raising L raises m_1 more than proportionately, this increasing w_1/w_2:

$$\frac{\mathrm{d}(w_1/w_2)}{\mathrm{d}L} = \frac{\gamma\, 2e^0(1-\theta)}{L^{\theta}[(1-\gamma)(L - \theta m_1) + \gamma(L - m_1)]} > 0 . \tag{14}$$

Turning to industry, at equilibrium S_1 the price indices of expression (2) reduce to

$$q_1 = n_1^{1/(1-\sigma)} p_1 , \qquad q_2 = n_1^{1/(1-\sigma)} p_1 \tau . \tag{15}$$

Demand for the output of each firm in country 1, and for a potential deviant locating in 2 are, by (6) and (15),

$$x_1 = \frac{e_1 + e_2}{n_1 p_1} = 1, \qquad x_2 = \left(\frac{p_2}{p_1}\right)^{-\sigma}\left[\frac{e_1 \tau^{(1-\sigma)} + e_2 \tau^{(\sigma-1)}}{n_1 p_1}\right], \tag{16}$$

and relative prices can be derived from (7) and (15) as

$$\left(\frac{p_2}{p_1}\right) = \tau^{\mu}\left(\frac{w_2}{w_1}\right)^{(1-\mu)} . \tag{17}$$

We have so far assumed that industry is agglomerated in country 1. Is this an equilibrium? Yes, if the sales of a potential deviant locating in country 2 are less than the level required to break even, i.e., if $x_2 < 1$ at equilibrium S_1. Substituting (17) in (16) and eliminating $n_1 p_1$, we can express x_2 as

$$x_2 = \left(\frac{w_1}{w_2}\right)^{\sigma(1-\mu)} \tau^{1-\sigma-\sigma\mu}\left[1 + \frac{e_2}{e_1+e_2}\left(\tau^{2(\sigma-1)} - 1\right)\right], \tag{18}$$

where the share of country 2 in expenditure, derived from expressions (10)–(12), is

$$\frac{e_2}{e_1+e_2} = \frac{\gamma(1-\mu)(L^\theta - e^0)}{w_1 m_1}. \tag{19}$$

If L is close to $(e^0)^{1/\theta}$ then total demand for manufactures is very low, wages in the two countries are very close, and x_2 is less than unity. There is then an equilibrium at S_1, as we illustrated it on figure 2. As L grows the forces at work can be seen from equations (14), (18) and (19). Growth of L raises manufacturing employment in country 1 and raises relative wages, equation (14), this increasing x_2 through the first term on the right hand side of (18). Pulling in the opposite direction, growth of L reduces the share of country 2 in world expenditure for the product, because wage differences mean that country 1's consumer expenditure on manufactures is rising relative to country 2's. This means that the demand linkage is being strengthened, and has the effect of reducing x_2 (see equation (18), in which $\tau^{2(\sigma-1)} - 1 > 0$). The net effect is to increase x_2, although it is not necessarily the case that $\lim_{L\to\infty}(x_2) > 1$. Possibilities are illustrated in figure 3.

The vertical axis of figure 3 measures L relative to $(e^0)^{1/\theta}$; the economy moves up this axis through time. The horizontal gives trade costs, τ, and lines give the critical value of L, denoted L^*, at which $x_2 = 1$. Below these contours the equilibrium is as at S_1 in figure 2, with industry concentrated in country 1. As L reaches L^* so entry of a firm in country 2 becomes profitable. Several points can be learnt from the figure.

First, a low level of linkages (a low value of μ) is associated with quite rapid spread of industry. This is as would be expected —in the limiting case when $\mu = 0$ there are no agglomeration forces and industry is always spread between locations. All the curves are drawn for the same value of γ, the share of manufacturing in consumption; lower γ shifts the curves upwards, as it reduces the share of manufacturing in the economy, and hence the rate of wage increase associated with manufacturing expansion.

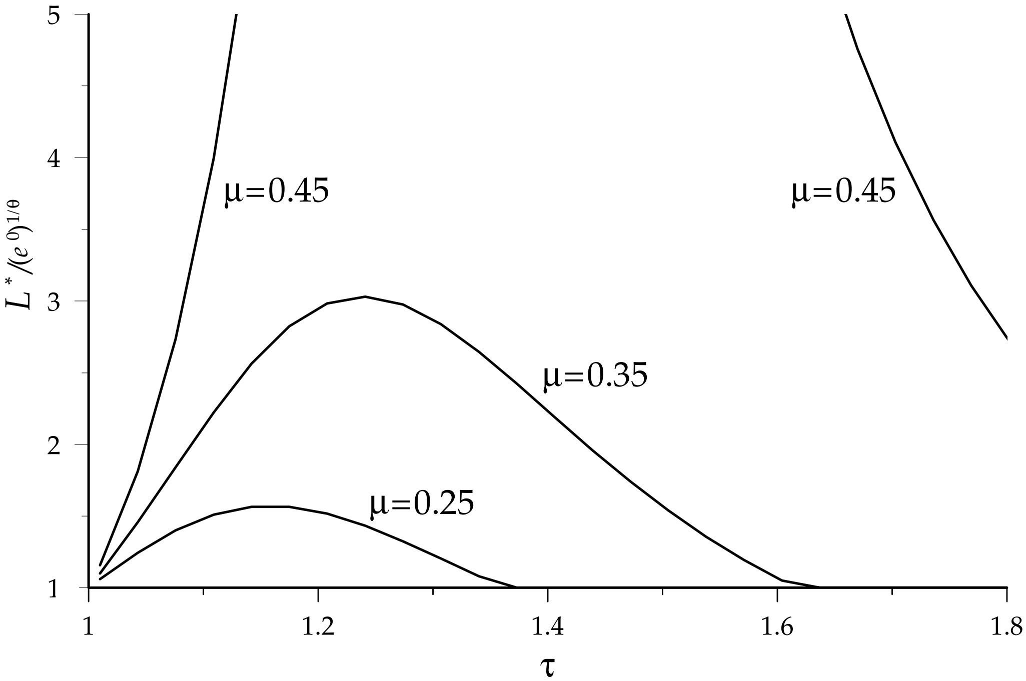

FIGURE 3
Values of L at which industrial production in country 2 becomes profitable

Second, the spread of industry is faster at high or low levels of trade barriers, τ, than at intermediate levels. This is because when trade barriers are very high industry must be divided between locations to meet final consumer demand. At the other extreme, when barriers are very low, it only takes very small factor price differences to induce relocation. It is a general property of models of this type that agglomeration forces are strongest at intermediate barriers (see for examples Venables, 1996), and this is what we see in the bell shape of the curves in figure 3.

Third, it is possible that as L goes to infinity industry remains concentrated in location 1 (this occurring in this example if μ exceeds 0.48). Agglomeration may therefore remain an equilibrium if μ is high, τ takes an intermediate value, and there is a low share of manufactures in demand, γ.

We have demonstrated that when L reaches L^* entry of a manufacturing firm in country 2 is profitable. What then happens as L increases further?

In terms of figure 2, the spread of industry comes as follows. Growth in L shifts both the zero profit contours upwards, but the $x_2 = 1$ locus shifts faster, coming to

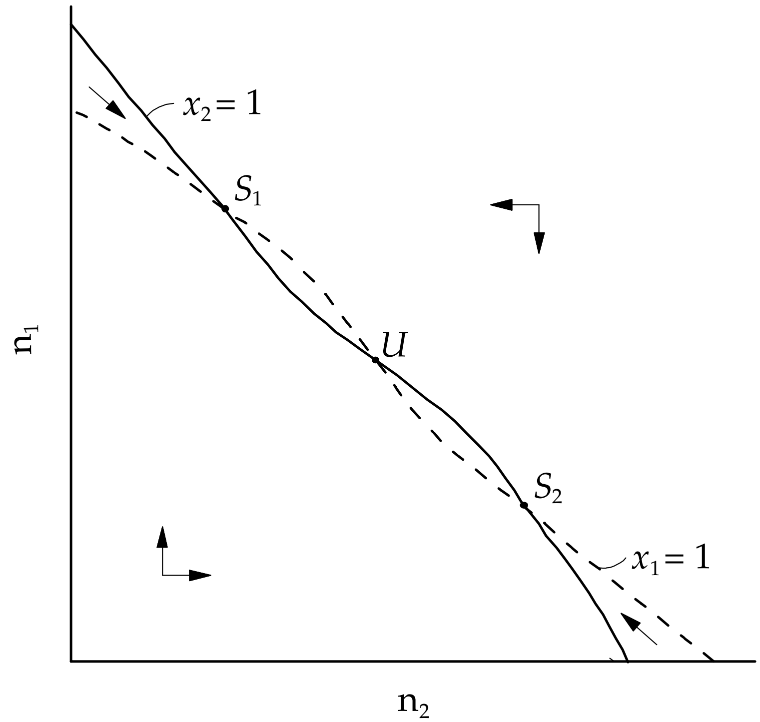

FIGURE 4
The spread of industry to country 2

intersect the $x_1 = 1$ locus on the vertical axis. The equilibrium S_1 then moves into the interior of the figure, as illustrated in figure 4. Further growth in L continues to move S_1 to the right, and at a high enough value the three equilibria may (but do not always) merge into a single stable equilibrium at $n_1 = n_2$.

Figure 5 illustrates wages in each economy (expressed relative to the average for both economies together) as L increases. We see divergence while production is concentrated in country 1. Once manufacturing production occurs in both countries (S_1 starts to move into the interior of figure 4), further increases in L cause wage convergence, to the point of equality.

The process described in figures 2, 4 and 5 is one of continuous change —there are no discontinuous jumps, although there are kinks as catch up begins and ends. This continuous change will occur if linkages are moderate or transport costs low. Stronger linkages or higher transport costs— which make linkages more important —will create considerably larger wage gaps between countries, and may also generate discontinuous change.

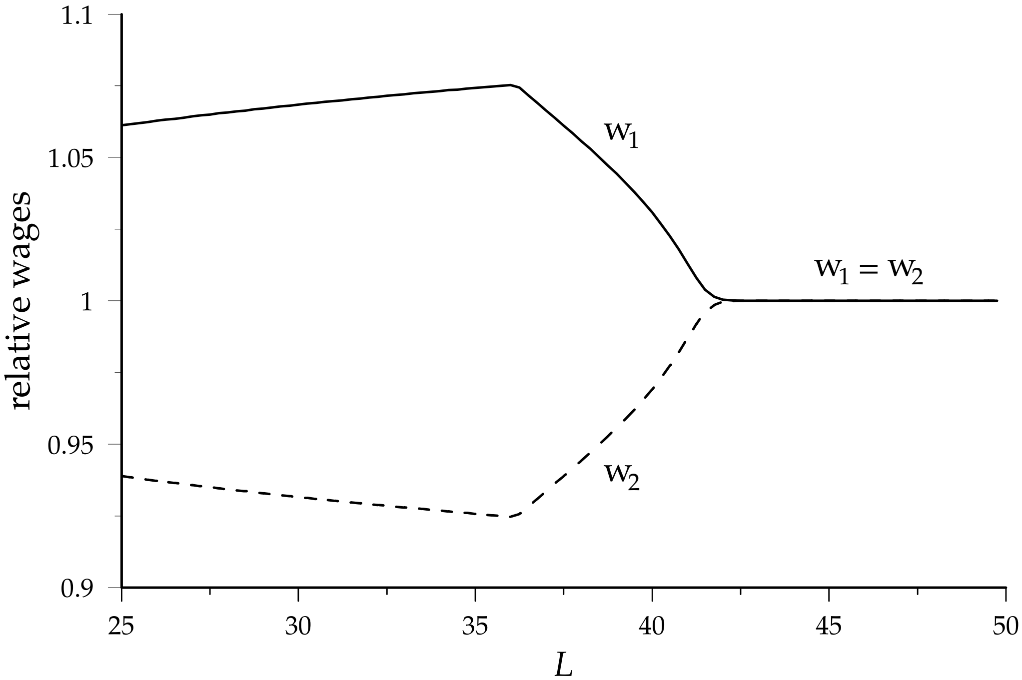

FIGURE 5
Wages relative to the average for the two economies

Figure 6 illustrates such a case. It is analogous to figure 2, but represents the zero profit loci when transport costs are higher. At low L there is an equilibrium at S_1, as in figure 2, but here the symmetric equilibrium labelled S, where $n_1 = n_2$, is also stable. Growth in L shifts $x_2 = 1$ upwards relative to $x_1 = 1$ as before, but now when the two loci cross at S_1 the equilibrium disappears. At high τ (or μ), when the first firm enters in 2, the linkages it creates to subsequent entrants raise the incentives for other firms to relocate. Profits are only exhausted again after a discontinuous jump to the equilibrium at S. In the results discussed below we concentrate on low trade costs and moderate linkages, and therefore on continuous change.

4. The spread of industry

We now look more closely at the process of spreading industrialisation, and in particular ask which industries move first, and how industrial structure evolves in each country. The answer to these questions depends on the factor intensities of

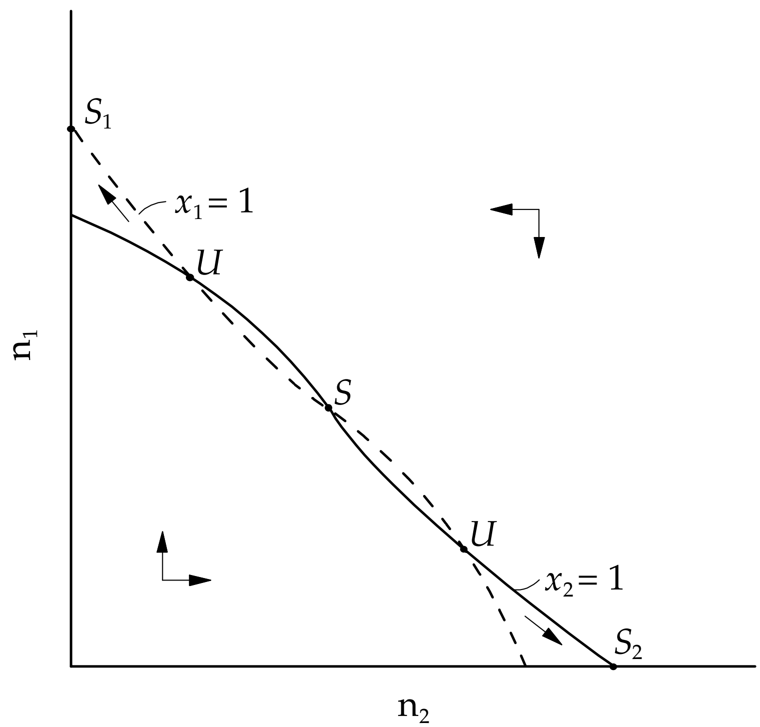

FIGURE 6
Initial configuration with higher trade costs

different sectors, and on the strength of linkages between industries which, in general, involves the full structure of the input-output matrix.

In order to illustrate forces at work, we restrict attention to three cases in which the input-output matrix takes simple and, we hope, interpretable forms. The first is where linkages are the same for all industries, but industries differ in labour intensities. The second is where we can rank industries in an order from upstream to downstream. The third is where some sectors are weakly linked and others are strongly linked to the rest of the economy, both forwards and backwards.

Our techniques in this section are entirely numerical. We shall work with a 3 country and 9 manufacturing sector version of the model outlined above, parameter details of which are given in the appendix. We start with an initial equilibrium with all industry agglomerated in country 1 and show how, as we increase countries' stock of efficiency units of labour, industry spreads.

Labour intensity

For the first experiment we assume that all elements of the intermanufacturing transactions section of the input-output matrix are equal, i.e, $\mu^{r,s}$ is the same, for all r, s = 1,...,9, so that every industry has the same forward and backward linkages to every other industry (including itself). Industries differ in their labour intensity, and we set the share of labour in costs equal to 2/3 in industry 1, declining in equal steps down to 1/3 in industry 9.

The columns of the input-output matrix (in value shares) must sum to unity, and we set the share of agricultural input in each industry, η^s, so that this is so. Since agriculture is perfectly competitive it creates no pecuniary externalities, and setting η^s in this way is done purely so that equal interindustry linkages can be compatible with differing labour inputs.

The overall pattern of the spread of industry can best be summarised by looking at wages in each country, and these are given in figure 7. The vertical axis is the wage in each country, expressed relative to the average for all three economies, and the horizontal axis is the labour endowment of each country in efficiency units. The solid line is country 1, the dashed country 2, and the dots country 3, where labels will always correspond to the order in which industry spreads. Wages are expressed the relative to the *numéraire* —real wage differences are larger because of differences in the price index in each country.

Starting from low L, the economies go through the following phases of development. In phase A all industry is in country 1, and growth in L causes divergence of wages. This reaches a point at which production in countries 2 and 3 becomes profitable, and in phase B there is a process of relocation of production from country 1 to countries 2 and 3.

Recall that all countries are symmetrical in underlying endowments, technology and preferences, and in phase B countries 2 and 3 are also symmetrical in industrial structure. As the volume of manufacturing in countries 2 and 3 increases, so do the associated linkages and pecuniary externalities. A critical mass of industry is approached, at which a (hypothetical) relocation of a firm from 3 to 2 raises profits of firms in 2 and reduces profits of firms in 3. The industrial structures of these economies must then diverge, and this is what we observe in the interval C.

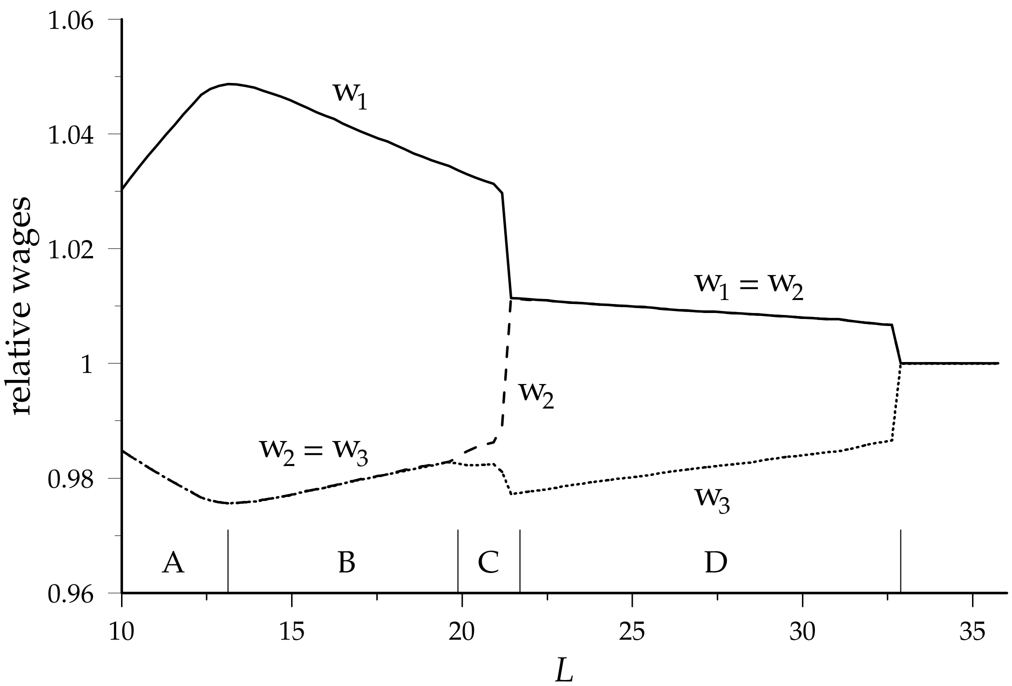

FIGURE 7

Different labour shares: wages relative to the average for the three economies

In interval *C* economy 2 undergoes very rapid industrialisation as firms in 2 reap the benefits of agglomeration. Country 2's industrialisation comes at the expense of both economies 1 and 3, as illustrated by the declining relative wages in these countries. In phase *D* economies 1 and 2 have become identical. However, continued growth of *L* causes growth of industry in 3, this narrowing the wage gap. Beyond some point country 3 reaches 'critical mass', and converges to symmetry with 1 and 2.

When industries differ only in the intensity with which they use labour, the sequence of industrialisation is unsurprising. The three panels of figure 8 give the shares of each country (country 1 solid, 2 dashed and 3 dotted, the three summing to unity) in the production of industries 2, 5, and 8. Industry 2, the top panel, is labour intensive, and we see that this industry is the first to relocate from country 1 (share of the industry falling from unity) to countries 2 and 3 during phase *B*. Industry 5 is of average labour intensity, and its relocation starts later. Industry 8 is labour unintensive, and moves only once linkages are strong enough, in phase *C*.

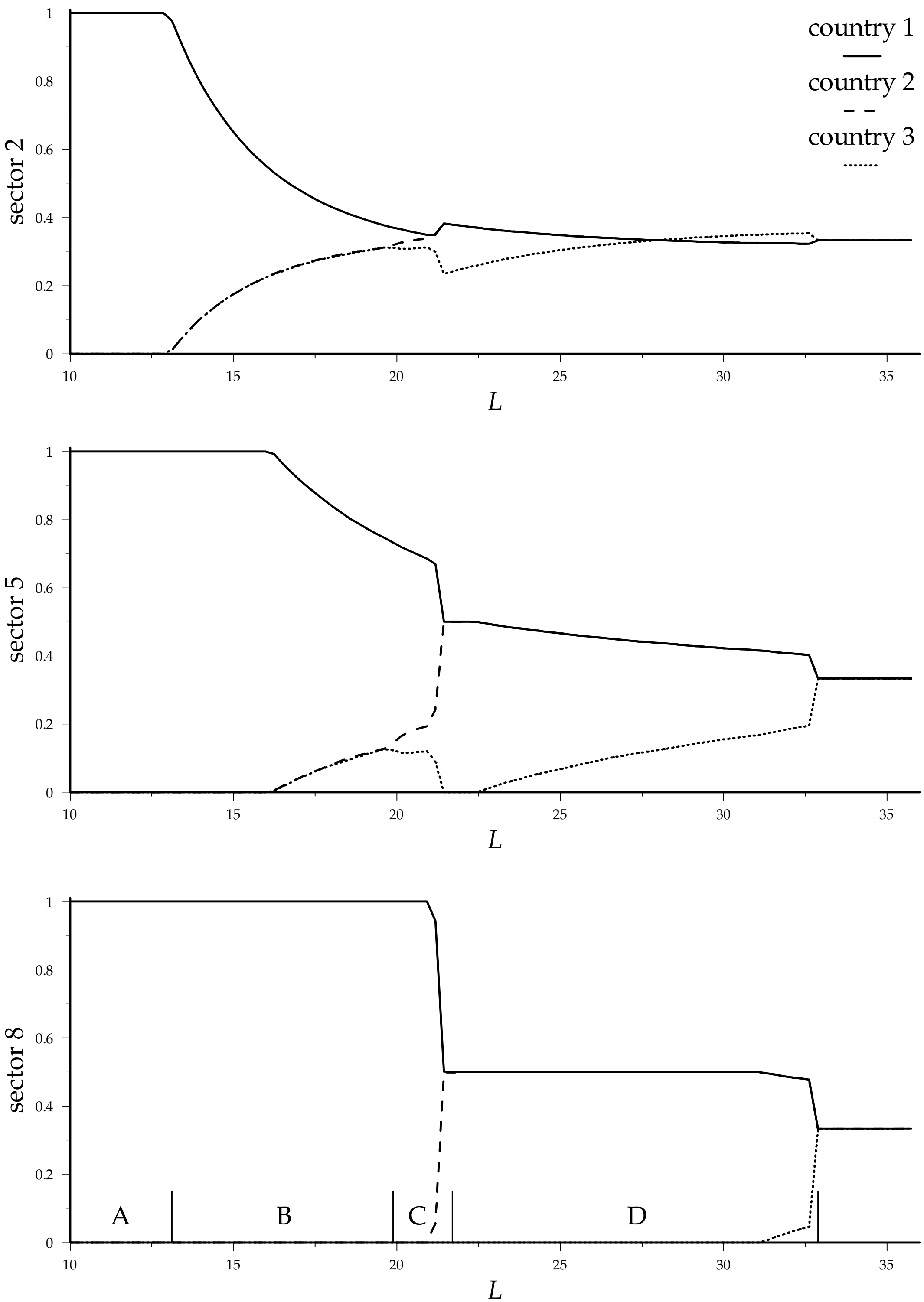

FIGURE 8

Different labour shares: share of industry in each country

(labour intensity decreases from top to bottom panels)

The process is therefore one of labour intensive industry leading the spread of industrialisation, and this creating linkages to attract less labour intensive activities. During phase *D* countries 1 and 2 have the same industrial structure, and there is industrial development in country 3, lead by labour intensive products. Country 3 becomes the largest producer in industries 1 and 2 (1 not illustrated), until there is eventual convergence of the industrial structure of all three countries.

How is this process altered if parameters of the model are changed? Larger inter-industry input-output coefficients or higher trade barriers both have the effect of delaying the spread of industry (as expected from figure 3), but make it occur more rapidly (i.e. over a shorter range of *L*) when it commences.

Upstream-downstream

The second experiment is one in which industries can be ranked in a hierarchy from upstream to downstream, in the following way. Industry 1 is upstream, using as an input no other manufacturing products than its own, but being used in all industries (including itself). Industry 2 uses as inputs the products of one other industry (industry 1), and is used in all industries except 1. This runs through to the last industry, industry 9, which is downstream, using all industries as inputs and being used by none but itself.

The structure this imposes is that the intermanufacturing transactions section of the input-output matrix has zeros below (to the left) of the main diagonal and positive elements on and above (to the right) of the main diagonal. We initially assume that all these positive elements are equal, so $\mu^{r,s} = 0$, for $r > s$, and $\mu^{r,s} = \mu$, for $r \leq s$ (two alternative configurations are discussed below). In order to abstract from labour intensity we assume that all sectors are equally intensive users of labour and, to ensure that columns of the input-output matrix sum to unity, we set the share of agriculture used in each industry, η^s, appropriately. Furthermore, we assume that downstream sectors receive a larger share of consumer expenditure than upstream sectors, so γ^s is lowest for industry 1 and then increases in steps of equal size, set so that all industries are of equal size (in value terms). The appendix gives the input-output matrix used in the simulations.

As in the previous case, growth of L causes spread of industry from country to country. The three panels of figure 9 give the location of industries 2, 5 and 8. Phases are labelled as before so in phase A all industry is in country 1, and in phase B both 2 and 3 develop a symmetrical industrial structure.

We see that upstream industry (low index, top panel) moves first. Because upstream sectors supply intermediates to downstream sectors, they bestow large costs linkages on them, and the relocation of upstream industries leads rapidly to phase C, in which there is fast relocation of more downstream industries from country 1 to country 2 (but not country 3). Compared with the case of different labour intensities, phase C is longer relative to phase B. This is because upstream industries create strong cost linkages, bringing forward the critical point at which industrialisation in country 2 takes off. The process then repeats itself, with the movement of upstream industries from 1 and 2 to country 3, these creating the cost linkages that spread other industries to 3.

Why do upstream industries move first? This is actually the outcome of two forces, working through differences in cost and in demand linkages respectively. Imagine an alternative characterisation in which all sectors have (in some sense) the same demand linkages and all receive the same share of consumer expenditure. To capture this we set all row sums equal in the intermanufacturing transactions section of the input-output matrix, allowing elements on or above the diagonal to differ across but not within rows. Column sums are not equal, so upstream sectors differ from downstream sectors in that they enjoy weaker cost linkages. Therefore upstream industries are the first to relocate.

Now imagine the reverse case, where cost linkage are (in some sense) the same for all sectors. We set all column sums equal (allowing elements on or above the diagonal to differ across but not within columns). Row sums differ, and we give downstream industries a larger share of consumer expenditure (such that all sectors produce the same value of output). In this case, downstream sectors differ from upstream sectors in that they have weaker demand linkages to other sectors. As opposed to the previous case, downstream industries are the first to relocate.

The experiment represented in figure 9 is a combination of the two just described, with intersectoral differences in cost and demand linkages working in opposite

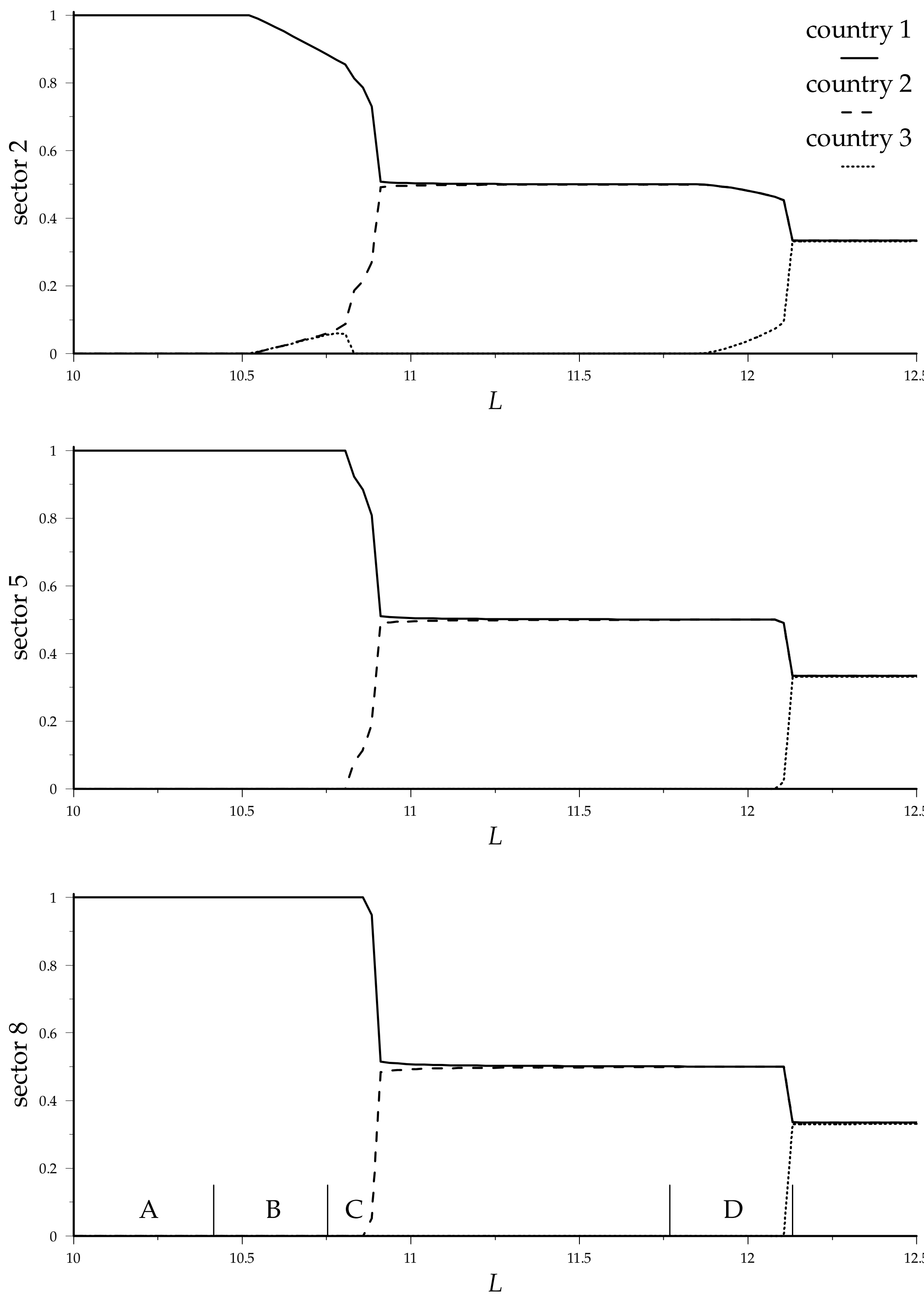

FIGURE 9

Upstream-downstream: share of industry in each country

(upstream to downstream from top to bottom panels) directions. The combined effect in the experiment is that cost linkages are more powerful than demand linkages, so upstream industries are the first to be detached from country 1's industrial complex, with downstream sectors rapidly following.

Strong vs. weak linkages

In this section we look at a case in which industries that have strong cost linkages also have strong demand linkages. Industry 1 is the least strongly linked and industry 9 the most strongly linked, both forwards and backwards. Higher indexed sectors therefore have stronger cost and demand linkages to any given sector than lower indexed sectors (and each sector has stronger demand and cost linkages to higher indexed sectors than to lower indexed sectors). Specifically, we assume that the intermanufacturing transactions section of the input-output matrix has $\mu^{r,s} = (r + s - 1)\mu$, for $r, s = 1,...,9$. The matrix is given in the appendix.

All sectors are equally intensive users of labour, and the share of agriculture used in each industry, η^s, is set so that column sums are unity. Values of γ^s are set so that all sectors are of equal size (in value terms).

Results are illustrated in figure 10. As in previous cases, industry spreads across countries as L grows. The top panel of figure 10 describes the location of industry 2, the least linked of those illustrated. Unsurprisingly, industries weakly linked to the rest of the economy are the first to be detached from the industrial complex of country 1. As weakly linked industries relocate to countries 2 and 3 they create linkages that pull from other sectors. A critical mass is reached where country 2 converges in industrial structure to 1 (phase C), attracting more strongly linked industries (5 and 8 illustrated in the middle and bottom panels of figure 10) and losing some presence in weakly linked ones, while country 3 specialises in the two most weakly linked sectors (2 illustrated in the top panel). During phase D country 3 attracts sectors in sequence from less to more strongly linked until the three countries converge in industrial structure and wages.

In all our examples the developing countries are —for a time— net exporters of the first industries they acquire. This is particularly pronounced in this case. For example, country 3 is the largest producer of weakly linked industries through the whole of phase D.

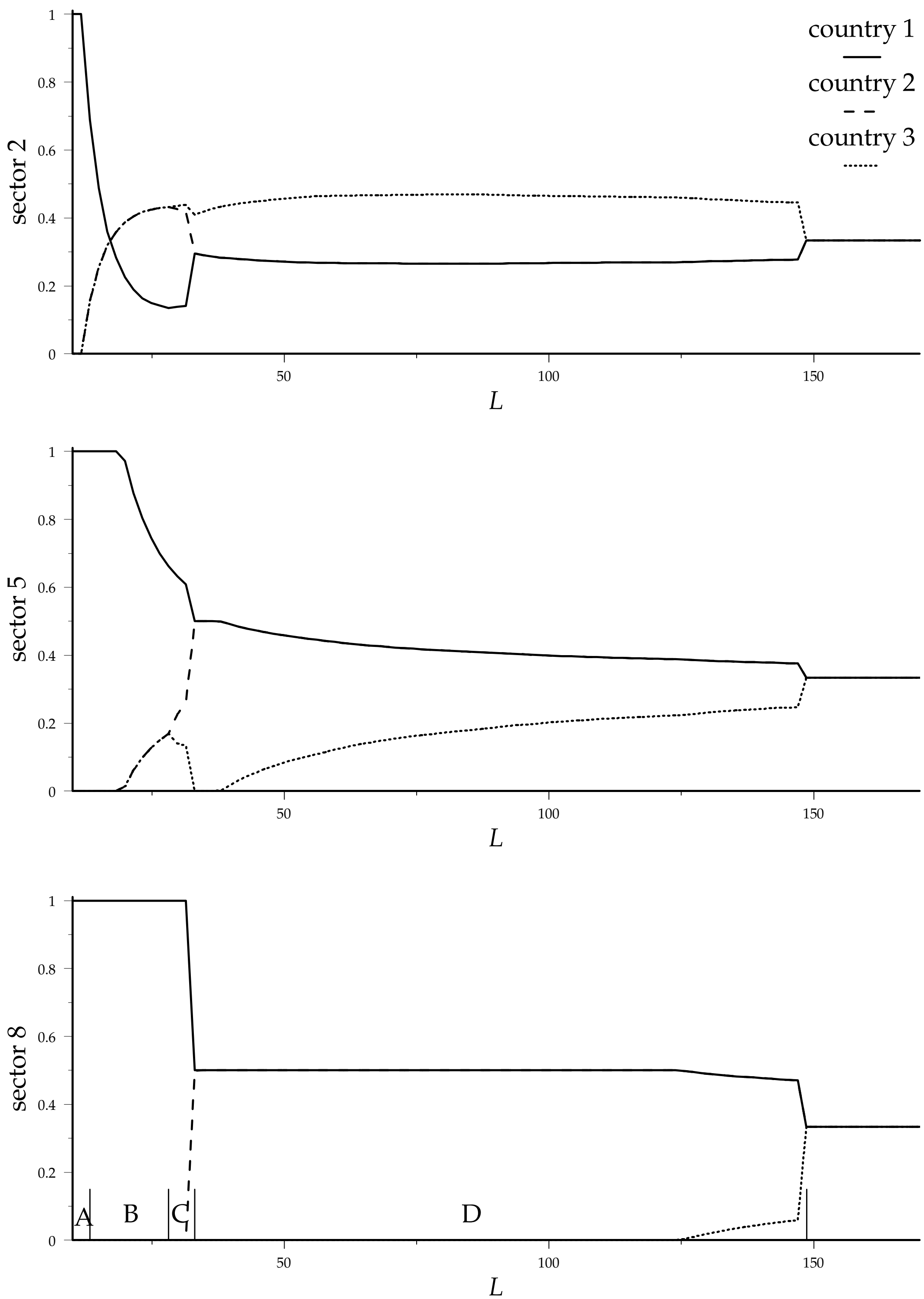

FIGURE 10

Strong vs. weak linkages: share of industry in each country

(linkage strength increases from top to bottom panels)

5. Concluding comments

This paper provides a radical way of thinking about the process of industrialisation. Interactions between imperfect competition, transport costs, and an input-output structure create incentives for firms to locate close to supplier and customer firms. Clustering of firms then occurs, so that even if countries are identical in underlying structure, only a few countries are industrialised. These countries have high wages, but the positive pecuniary externalities created by inter-firm linkages compensate for the higher wage costs. An increase in demand for manufactures raises wages in industrialised countries, leading to a point at which some firms choose to become established in a new country. Industrialisation then commences in this country, and takes place at a rapid rate as forward and backward linkages are created and a critical mass of industry attained. The process may then repeat itself, so industrialisation takes the form of a sequence of waves, with industry spreading from country to country.

The process we describe abstracts from many important aspects of industrial development. We have no capital accumulation (physical or human), no government, and no international differences in technology. Even within its framework the model we employ is simple; for example, firms are modelled as single plant operations, so multinationality and foreign direct investment are not considered. Nevertheless, we think the approach provides some new insights. It explains the rapid 'take-off' of newly industrialising economies, and highlights the way in which industrial structure may change during industrialisation.

The speed of the process, and which industries are the first to relocate, are determined by the input-output structure, establishing the strength of forward and backward linkages between industries as well as their factor intensity. So far we have only looked at hypothetical input-output structures, which sacrifice empirical foundations to isolate specific effects. We have learnt four things from them.

First, stronger linkages tie firms more tightly to existing agglomerations, and therefore postpone the spread of industry and cause it to happen in a more abrupt manner.

Second, labour intensive industries tend to leave first, as they are most affected by increases in industrialised countries' wages relative to the rest of the world. The development of labour intensive activities makes it profitable for labour unintensive sectors to follow, and when a critical mass is reached industrialisation can take off rapidly.

Third, upstream industries face higher costs of market access when they move away from an existing industrial cluster, but are not heavily dependent on proximity of suppliers of intermediate inputs. This suggests that upstream industries tend to leave early, and have a significant effect in pulling downstream industries along in their wake. However, different structures of the input-output matrix can create cases where demand is more important, and downstream industries move first.

Finally, weakly linked industries benefit less from being close to other industries (they neither sell a large fraction of their output to other industries nor spend a large share of their costs on intermediates produced by them). They are therefore the first to relocate in response to labour cost differentials, being gradually followed by more strongly linked industries.

Appendix

Parameter values

The simulations use the following parameter values:

In section 3: $\theta = 0.9$, $\sigma = 5$, $\tau = 1.1$, $S = 1$, $\gamma = 0.5$, $\mu = 0.5$, $\eta = 0$, $e^0 = 7$.

In section 4: $\theta = 0.9$, $\sigma = 5$, $\tau = 1.1$, $S = 9$, $e^0 = 7$.

Labour intensity:

The input output matrix takes the following form:

$\mu^{r,s}$		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
.		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
.		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
.		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
.	=	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
.		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
.		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
.		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
$\mu^{r,s}$		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
η^s		0.00	0.04	0.08	0.12	0.16	0.21	0.25	0.29	0.33
$1-\eta^s - \Sigma\, \mu^{r,s}$		0.67	0.63	0.59	0.55	0.51	0.46	0.42	0.38	0.34

Consumer expenditure shares are:

γ^s	=	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056

Upstream-downstream:

The input output matrix takes the following form:

$\mu^{r,s}$		0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044
.		0	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044
.		0	0	0.044	0.044	0.044	0.044	0.044	0.044	0.044
.		0	0	0	0.044	0.044	0.044	0.044	0.044	0.044
.	=	0	0	0	0	0.044	0.044	0.044	0.044	0.044
		0	0	0	0	0	0.044	0.044	0.044	0.044
.		0	0	0	0	0	0	0.044	0.044	0.044
.		0	0	0	0	0	0	0	0.044	0.044
$\mu^{r,s}$		0	0	0	0	0	0	0	0	0.044
η^s		0.36	0.31	0.27	0.22	0.18	0.13	0.089	0.044	0
$1-\eta^s - \Sigma\, \mu^{r,s}$		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

Consumer expenditure shares are:

γ^s	=	0.033	0.036	0.038	0.041	0.043	0.046	0.048	0.051	0.053

Strong vs. weak linkages:

The input output matrix takes the following form:

$\mu^{r,s}$	0.005	0.010	0.015	0.020	0.025	0.030	0.035	0.040	0.045
.	0.010	0.015	0.020	0.025	0.030	0.035	0.040	0.045	0.050
.	0.015	0.020	0.025	0.030	0.035	0.040	0.045	0.050	0.055
.	0.020	0.025	0.030	0.035	0.040	0.045	0.050	0.055	0.060
. =	0.025	0.030	0.035	0.040	0.045	0.050	0.055	0.060	0.065
	0.030	0.035	0.040	0.045	0.050	0.055	0.060	0.065	0.070
.	0.035	0.040	0.045	0.050	0.055	0.060	0.065	0.070	0.075
.	0.040	0.045	0.050	0.055	0.060	0.065	0.070	0.075	0.080
$\mu^{r,s}$	0.045	0.050	0.055	0.060	0.065	0.070	0.075	0.080	0.085
η^{s}	0.36	0.31	0.27	0.22	0.18	0.14	0.090	0.045	0
$1-\eta^{s} - \Sigma\ \mu^{r,s}$	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42

Consumer expenditure shares are:

γ^{s} =	0.10	0.098	0.092	0.086	0.080	0.074	0.068	0.062	0.056

Sources for figures 1a and 1b:

Total employment, manufacturing employment, and monthly earnings in manufacturing activities for Japan, Philippines, and the Republic of Korea:

International Labour Office. Annual issues. *Year Book of Labour Statistics*. Geneva: International Labour Office.

Total employment, manufacturing employment, and monthly earnings in manufacturing activities for Taiwan (Republic of China):

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Penn World Tables, Mark 5.6, (URL) `http://nber.harvard.edu/pwt56.html`.

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