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Research and Development, Regional Spillovers, and the Location of Economic Activities

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RESEARCH AND DEVELOPMENT, REGIONAL SPILLOVERS, AND THE LOCATION OF ECONOMIC ACTIVITIES

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Abstract

Many empirical studies have found both inter-industry and intra-industry externalities in the form of local knowledge spillovers in research. This paper makes some assumptions reflecting these empirical regularities in order to analyse their implications for the allocation of economic activities between two regions. The two main assumptions are that R&D guarantees a positive equilibrium rate of growth in the volume of output by increasing the marginal productivity of labour, and that it is characterised by geographically bounded intra-industry as well as inter-industry knowledge spillovers. The existence of an iceberg type cost in transporting consumption goods from one region to the other, together with increasing returns to scale in production, introduces a centripetal force; this is opposed by a centrifugal force associated with congestion costs: agents living in crowded areas suffer a reduction in their level of utility. In equilibrium, different locations of research and manufacturing firms can result. Where transport costs are higher (congestion costs lower), centripetal forces dominate and all economic activities end up concentrated in one region. As transport costs decrease (congestion costs increase), an equilibrium with activities in both regions becomes more likely.

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1. Introduction[1]

Since the beginning of the decade there has been a revival of interest in the study of economic geography, fostered by the application of new theoretical results in the analysis of economies with static and dynamic increasing returns to scale, (e.g. Dixit and Stiglitz, 1977; Romer, 1986).[2] The main feature shared by the majority of models of the so called "new economic geography" literature is the joint assumption Dixit-Stiglitz monopolistic competition among firms offering differentiated goods and transport costs for transferring goods from one location to another. As it has first been shown by Krugman (1991a, 1991b), within this framework two centripetal forces emerge: backward linkages, inducing firms to locate production where the demand for their products is largest, and forward linkages, urging workers to live where real wages, which are a decreasing function of transport costs, are higher.[3]

The contribution of this paper to the literature is to model explicitly the interaction between increasing returns in manufacturing and local externalities in research, in a framework characterised by perfect labour mobility. The existence of positive knowledge spillovers in R&D is a well accepted result of empirical research (e.g. Jaffe, 1986, 1989;

1 I would like to thank Keith Blackburn, Victor Hung, Andrew Mountford, Gianmarco Ottaviano, Morten Ravn and Oreste Tristani for their suggestions and comments on earlier versions of this paper, and seminar participants at the University of Southampton, at the Bank of Italy and at the 1997 European Meeting of the Econometric Society. All remaining errors are my own. The opinions expressed do not necessarily reflect those of the Bank of Italy.

2 The origins of theoretical thinking on location of economic activities can be attributed to von Thünen's book The Isolated State, first published in Germany in 1826. Among other early contributions are Christaller (1933), Lösch (1940), Mills (1967, 1972) and Jacobs (1969).

3 Hirschmann (1958) was the first author to analyse this aspect.

Caballero and Lyon, 1990, 1992; Nadiri, 1993). More recently, the geographic dimension of this phenomenon has been confirmed by the studies of Jaffe, Trajtenberg and Henderson (1993), Feldman (1994), Henderson (1994), Audretsch and Feldman (1996). Glaeser et al. (1992), Shea (1995, 1996), Henderson, Kuncoro and Turner (1995), although not attributing them explicitly to R&D activity, have found evidence of the existence of both inter-industry and intra-industry geographically bounded positive spillovers in manufacturing. This paper shows that when such externalities are present different patterns of location can result, depending on the interaction between transport and congestion costs.

The basic framework of Dixit-Stiglitz monopolistic competition interacting with transport costs has been applied to the study of many aspects of the optimal location of economic activities: the effects of trade liberalisation on the size of third world metropolises (Elizondo and Krugman, 1992), the relationship between geography and trade (Asilis and Rivera-Batiz, 1994; Puga and Venables, 1998), the effects of the reduction of transport costs on income convergence across countries and on the patterns of geographical specialisation (Krugman and Venables, 1995, 1996), the consequences of vertical and horizontal integration at the industry level (Venables, 1996; Ekholm and Forslid, 1997), the role of services (de Vaal and van den Berg, 1997) and the dynamics of urbanisation (Puga, 1996a).[4]

All these models consider the effects of static economies of scale and are characterised by the existence of a steady-state equilibrium with a constant level of production. A more recent strand of the literature, to which this paper is

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[4] A stimulating framework that includes many earlier models as subcases has been proposed by Puga (1996b). Two recent comprehensive surveys are those by Fujita and Thisse (1996) and by Ottaviano and Puga (1997).

more closely related, has studied the relationship between the location of economic activities and the equilibrium rate of growth of the economy. Bertola (1993) analyses the effects of integration between two regions within an AK model of growth extended to allow for labour as a factor of production; his main conclusion is that integration does not necessarily lead to a better allocation of resources, or to a higher rate of growth. Walz (1995), using the theoretical framework of Romer’s (1990) model of R&D and growth, studies the optimal location of research firms in a two-country economy. In his model knowledge spillovers are not geographically bounded and therefore there is no correlation between the equilibrium rate of growth and alternative patterns of location of the economic activities. In Martin and Ottaviano (1996), who also adopted Romer’s framework, this correlation is present: with no labour mobility, higher concentration fosters growth by making the inputs for R&D activity less expensive.

The theoretical framework adopted in this paper is partly different from that of the model just mentioned. The two main assumptions are that R&D guarantees a positive equilibrium rate of growth in the volume of output by increasing the marginal productivity of labour, and that it is characterised by geographically bounded intra-industry as well as inter-industry knowledge spillovers. The existence of an iceberg-type cost in transporting consumption goods from one region to the other, together with increasing returns to scale in production, introduces a centripetal force; this is opposed by a centrifugal force: agents living in crowded areas suffer a reduction in their level of utility owing to congestion costs (for example higher house prices). The model is characterised by both backward and forward linkages (although of a slightly different kind from those emerging from Krugman-type models): workers prefer to live where the majority of firms are located, as the prices of consumption goods are lower, but thus suffer from higher congestion costs, which can be sustained only if more firms are attracted to the region.

In equilibrium, which is achieved when all workers share the same level of utility, different locations of research and manufacturing firms can result. For higher transport costs (lower congestion costs), centripetal forces dominate and all economic activities end up concentrated in one region. As transport costs decrease (congestion costs increase), an equilibrium with activities in both regions becomes more likely.[5] Moreover, when production is not necessarily located in the same region as research (i.e., R&D and manufacturing firms are not vertically integrated), research firms concentrate in just one region and, by internalising all the geographically bounded spillovers that characterise this activity, achieve a higher equilibrium rate of growth of the level of technology.

The rest of the paper is organised in five parts. The next section describes the basic structure of the model. Section 3 derives the long-run equilibrium and the optimal allocation of economic activities between the two regions. Section 4 makes some considerations on the effects of integration on welfare and income distribution. The final section concludes.

2. The model

The model adapts the quality-ladder model of Grossman and Helpman (1991) to the case where there are two regions and where there are regional knowledge spillovers. The two regions are populated by a continuum of infinitely-lived agents (normalised to lie in the [0,1] interval) who maximise their

[5] This result is similar to Helpman (1995); for an empirical justification see, for example, Krugman (1991b), p. 81, Table 3.4.

utility over a fixed set of consumption goods. The supply side of the economy is composed of a fixed number of industries, each producing a differentiated consumption good, and an endogenous number of R&D firms, one in each industry, which compete to become, in the next period, the technology leader and the only producer of that industry's consumption good. There are only two factors of production, unskilled and skilled labour. The former is employed only in manufacturing, the latter only in the research sector. Each worker offers inelastically a fixed amount of labour and uses the revenues from his activity to maximise an intertemporal utility function over the amount of goods consumed. The share of workers in each group is exogenous. The solution of the model is a dynamic competitive equilibrium in which the location of economic activities and the rate of growth in the volume of output are endogenously determined.

2.1 *Demand side*

Every worker, whether skilled or unskilled, uses the revenues from his activity to maximise the following intertemporal utility function:[6]

(1) $$U = \sum_{t=0}^{\infty} \left(\frac{1}{1+\sigma} \right)^{t} u^{A}(t)$$

subject to the budget constraint:

$$\sum_{t=0}^{\infty} \prod_{v=0}^{t} \left(\frac{1}{1+r_v} \right) \left[\sum_{i=1}^{n^A} P_t^{A,A}(i) c_t^{IA}(i) + \sum_{i=1}^{n^B} P_t^{B,A}(i) c_t^{IB}(i) \right] \le \sum_{t=0}^{\infty} \prod_{v=0}^{t} \left(\frac{1}{1+r_v} \right) W_t^{IA} + a_0^I \ ,$$

[6] As the two regions are identical, for any equilibrium location of activities there also exists a perfectly symmetric alternative. In the following, unless stated otherwise, all choices are considered from the point of view of agents and firms located in region A.

where $u(t)^{IS} = \sum_{i=1}^{n^A} \ln\left[c_t^{IA}(i)\right] + \sum_{i=1}^{n^B} \ln\left[c_t^{IB}(i)\right] - \theta \ln\left(1 + Z_t^A\right)$ is the instantaneous utility function for a worker living in region *A*, $Z_t^A = L_t^A + H_t^A$ is the total population living in region *A*, $c_t^{SA}(i)$ is the consumption of the generic good *i* produced in region *S* (for *S=A,B*) and consumed in region *A*, σ is the subjective rate of time preference, $P_t^{A,A}(i)$ is the price of the generic good produced and consumed in *A*, $P_t^{B,A}(i)$ is the price in *A* of a good produced in *B*, W_t^{IA} is the nominal wage for labour of type *I* (*I=H,L*) in region *A*, r_t is the rate of interest on a safe asset and a_0 is the initial level of nominal wealth of each agent. The term $\vartheta \ln\left(1 + Z_t^A\right)$ represents the congestion costs associated with life in crowded areas (e.g. the cost of housing or the negative externalities of pollution).[7]

The solution of the maximisation problem in (1) gives the demand of the generic good *i* of each agent in each period, $c_t^{IA}(i) = \dfrac{\hat{E}_t^{IA}}{n^A P_t^{A,A}(i) + n^B P_t^{B,A}(i)}$, where $\hat{E}_t^{IA} = \left[\sum_{i=1}^{n^A} P_t^{A,A}(i) c_t^{IA}(i) + \sum_{i=1}^{n^B} P_t^{B,A}(i) c_t^{IB}(i)\right]$ is the nominal expenditure of a representative agent *I*. From the assumption of Cobb-Douglas preferences, it follows that agents devote a fixed share of their total expenditure to each good. Total demand for good *i* can be obtained by adding the quantities demanded by each agent in each region:

[7] This cost is similar to that introduced by Henderson (1974) and Gali (1994). Instead of assuming its existence, it could have been derived as, for example, it is done by Mills (1967), Elizondo and Krugman (1992) and Eaton and Eckstein (1994), who assume that the price of the land on which workers live decreases with the distance from the centre of each region. However, this would have had the effect of complicating the exposition of the basic features of the model, without adding any insight to the analysis.

(2) $$C_t^S(i) = \frac{E_t^A}{n^A P_t^{A,A}(i) + n^B P_t^{B,A}(i)} + \frac{E_t^B}{n^A P_t^{A,B}(i) + n^B P_t^{B,B}(i)}$$

where $E_t^S = L_t^S E_t^{LS} + H_t^S E_t^{HS}$ is the total expenditure in region *S* and H_t and L_t are respectively the total number of skilled and unskilled workers.

As in Grossman and Helpman (1991), there are no monetary variables in the model, so that any numeraire can be chosen. Their approach is follows and it is assumed that total nominal expenditure in each period is normalised to one: $E_t = E_t^A + E_t^B = 1$. With free capital mobility interest rates must be equalised. From the solution of the maximisation problem (1) the nominal interest rate is also constant, and equal to the subjective discount rate:

(3) $$\frac{\Delta \hat{E}_t^{IS}}{\hat{E}_t^{IS}} = \frac{\Delta P_t}{P_t} + \frac{\Delta c_t^{IS}}{c_t^{IS}} = r_{t+1} - \sigma = 0$$

As will be made clear later, in equilibrium nominal wages are also constant.

2.2 *Supply side*

The supply side of the economy is a simplified version of Grossman and Helpman's (1991) quality ladder model. In each period there exists a fixed number of industries producing a different, non-storable good *i* (for $=1,\ldots,n_t$). Within each industry a number $m_t(i)$ of R&D firms carry on a costly research activity aimed at improving the technology used in production. In each period only one research firm finds a profitable way of increasing productivity in manufacturing; as a result it becomes the technology leader. Having a technological advantage with respect to other potential manufacturers, this firm can set the price at a level at which it is the only one producing the industry's good with non-negative profits (i.e., as in Grossman and Helpman, Bertrand competition is assumed). Given free entry to research, for each industry *i*, the number $m_t(i)$ of firms in the R&D sector is endogenously determined. Every unit chooses the number of workers to employ in order to maximise profits, discounting it by the probability of becoming the technology leader. The number of firms in equilibrium is determined by the condition that no firms make positive profits. In each period there are thus *n* manufacturing firms producing final consumption goods and $\sum_{i=1}^{n} m_t(i)$ ($= m_t n_t$, by symmetry) R&D firms doing research with the objective of becoming the next period's technology leader.

2.2.1 *Manufacturing sector*

All goods are produced using a technology which is linear in its only input: unskilled labour. Starting production requires the payment of a fixed cost (κ) which can be expressed in labour units:

$$X_t^A(i) = \rho_t^A(i)\left[l_t^A(i) - \kappa\right] \tag{4}$$

where $X_t^A(i)$ is the output level of the generic industry *i* in region *A*, $\rho_t^A(i)$ is the marginal productivity of labour in region *A* (which reflects the level of technology reached in industry *i*) and $l_t^A(i)$ is the amount of unskilled labour used in the production of good *i* in region *A*.

Goods produced in A can be sold in B, but as is common in the new economic geography literature it is assumed that in order to do this a transport costs must be paid. This cost takes the iceberg form first introduced by Samuelson (1954):

for a quantity $X_t^B(i)$ of good *i* to be imported from B and consumed in A, a quantity $X_t^B(i)\tau$ must be produced (with $\tau \geq 1$).

The Cobb-Douglas form of our utility function implies that consumers spend a fixed amount of their total income on each good. Given Bertrand competition between manufacturers, the transport costs are therefore paid entirely by consumers. In equilibrium: $X_t^S(i) = \frac{E_t}{n^A P_t^A(i) + n^B P_t^B(i)}$.

2.2.2 *Research sector*

In the R&D sector firms carry on research with the objective of becoming the next period's technology leader. Their probability of success is an increasing function of the share of skilled labour employed:

(5) $$P\{j = winner\} = \left[\frac{h_t^A(i,j)}{\hat{H}_t(i)}\right]^{\varepsilon}$$

where $h_t^A(i,j)$ is the amount of skilled labour employed by research firm *j* of industry *i* in region *A*, $m_t(i)$ is the total number of R&D firms in industry *i* (which is determined endogenously), $\hat{H}_t(i) = \sum_{v=1}^{m_t(i)} h_t(i,v)$ is the total amount of skilled labour devoted to R&D in industry *i* and $\varepsilon \in (0,1)$ is a parameter measuring the elasticity of the probability of success with respect to the amount of skilled labour.

We assume that the technology used for production in previous periods is freely available in both regions. Its rate of improvement $g_{\rho^A,t}$ (which coincides with that of the marginal productivity of labour in manufacturing) is a positive function of the number of workers employed in the previous period by the winning firm, $h_t^A(i,j)$. As stated earlier, research is assumed to be characterised by both intra-industry regional externalities (proxied by the total number of R&D firms in the industry located in the same region, $m_t^A(i)$) and inter-industry regional externalities (proxied by the total number of industries that locate at least one R&D firm in the same region, n_t^{RA}).[8] The technology is therefore the following:

(6) $$\rho_{t+1}^A(i)=\rho_t(i)+\xi h_t^A(i,j)^{\alpha}\, m_t^A(i)^{\beta}\, n_t^{RA\gamma}\,\rho_{t-1}(i)$$

where $\alpha,\beta,\gamma>0$ are parameters describing the elasticity of the technological improvement relative, respectively, to the amount of skilled labour employed, intra-industry spillovers and inter-industry spillovers, and ξ is a positive constant.[9]

As for manufacturing, starting the R&D activity requires the payment of a fixed cost, μ, which is also expressed in labour units. The profit function for the generic firm *j* of industry *i*, located in region *S* and deciding to produce in *A* is therefore:

(7) $$\Pi_t^A(i,j)=\frac{P_{t+1}^A(i)X_{t+1}^A(i)-W_{t+1}^{LA}l_{t+1}^A(i)}{1+r_{t+1}}\frac{h_t^S(i,j)^{\varepsilon}}{\hat{H}_t^{\varepsilon}}-W_t^{HS}\left[h_t^S(i,j)+\mu\right]$$

2.2.3 *Supply side equilibrium*

With Bertrand competition, the assumption that the technology used in the previous period is freely available implies that the leading firm cannot set a price higher than

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[8] Assuming positive but limited spillovers between the two regions would have made the analysis more cumbersome, without modifying the basic results.

[9] Although this function displays decreasing returns to scale in labour, it nevertheless guarantees a constant rate of growth because of its linearity in the level of knowledge.

the one at which non-winning firms could profitably start production:

(8) $$P_{t+1}^{A}(i) \leq \frac{W_{t+1}^{LA} l_{t+1}^{A}(i)}{\rho_{t}(i)\left[l_{t+1}^{A}(i) - \kappa\right]}$$

Profit-maximising firms will always set a price satisfying this condition as an equality. Substituting (8) into the profit function (7), together with the expressions for the probability of winning the R&D race (5) and the research technology (6), it is possible to obtain:

(9) $$\Pi_{t}^{A}(i,j) = \frac{W_{t+1}^{LA} l_{t+1}^{A}(i) h_{t}^{S}(i,j)^{\alpha+\varepsilon} \xi m_{t}^{S}(i)^{\beta} n_{t}^{RS\gamma}}{\left(1+r_{t+1}\right)\hat{H}_{t}^{\varepsilon}} - W_{t}^{HS}\left[h_{t}^{S}(i,j) + \mu\right]$$

Maximising this profit function with respect to the number of workers devoted to research and assuming free entry to the research sector of each industry, it is possible to solve for the number of workers employed in each R&D firm:

(10) $$h_{t}^{S}(i,j) = \frac{\mu(\varepsilon+\alpha)}{1-\varepsilon-\alpha} = \Delta$$

Substituting this expression into (5), it becomes evident that the probability of winning the technology race is the same for all firms within the same industry, and that the number of R&D firms, identical in all industries, depends on the parameters describing the technology for research and on the total amount of skilled labour in the economy: $m_t = \frac{H_t}{\Delta n_t}$. In particular, the higher the fixed cost that has to be paid to start research, the lower the number of R&D firms and, owing to fewer intra-industry spillovers, the lower the equilibrium rate of growth of total output.

3. Geographical equilibrium

3.1 *Workers' location*

In the two-region economy real wages would always be higher if activities were concentrated, as this would imply that no transport costs have to be paid. However, agents living in an area with a higher population density suffer a loss of utility, owing to the congestion costs. Given free labour mobility, in equilibrium the utility of agents living in the two regions must be equalised; moreover, such an equilibrium is stable only if agents moving to a different location do not increase their level utility.

Substituting the level of consumption which maximises each worker's utility, $c_t^{IS,A}(i) = \frac{E_t^{IS}}{P_t^{A,S}(i)}$, into the instantaneous utility function, it is possible to obtain each worker's instantaneous level of utility:

(11) $$u^A(t) = n_t \ln\left(\frac{E_t^{IA}}{n_t \overline{P}_t^A}\right) - \vartheta \ln\left(1 + Z_t^A\right) = n_t \ln\left[\frac{E_t^{IA}}{n_t \overline{P}_t^A \left(1 + Z_t^A\right)^{\frac{\vartheta}{n_t}}}\right]$$

where $\overline{P}_t^A = P_t^{A,A}(i)^{\lambda_t} P_t^{B,A}(i)^{1-\lambda_t}$ is the price level in region *A*, $c_t^{IS,A}(i)$ is the consumption of the generic good *i* produced in region *A* by a worker of type *I* living in region *S*, $P_t^{A,S}(i)$ is the price in region *S* of the generic good *i* produced in region *A*[10] and $\lambda_t = \frac{n_t^A}{n_t}$ is the share of goods produced in region *A*.

The willingness of workers to move from one region to the other depends on the level of utility that they can achieve by living in the two places: it is therefore a

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10 $P_t^{A,S}(i) = P_t^{A,A}(i)$ for S=A and $P_t^{A,S}(i) = P_t^{A,A}(i)\tau$ for S=B.

function of the differences in the price level, congestion costs and nominal income. Appendix 1 shows that nominal wages can never differ too much between the two regions, as otherwise firms would prefer to change location; in the following, it is assumed that they are equalised (a possible justification could be that this results from collective bargaining). This assumption is almost irrelevant, however: in Appendix 2 it is shown that when nominal wages are not equalised only the parameter space for wich there are symmetric or asymmetric equalibria changes, while the number of possible equlibria is unchanged. From equation (11) it is possible to obtain the following function:

(12) $$\Delta L_t = g\left(\frac{u^A(t)}{u^B(t)} - 1\right) = g\left[\frac{\overline{P}_t^{\,B}\left(1+Z_t^B\right)^{\frac{\vartheta}{n_t}}}{\overline{P}_t^{\,A}\left(1+Z_t^A\right)^{\frac{\vartheta}{n_t}}} - 1\right]$$

where ΔL_t is the amount of unskilled labour wishing to move from A to B and $g(\bullet)$ is any well behaved, strictly increasing function such that $g(0)=0$ (in the following it is assumed that $g(x)=x$).

In equilibrium the utility of workers in the two regions must be equalised at each point in time. In fact, any equilibrium in which the overall utility is equalised but there are differences in the level reached at each point in time would not be time consistent.[11] Substituting the equilibrium price of goods (8) into (12), the condition under which workers do not have an incentive to move is given by the following expression, which makes it possible to solve

[11] Due to the absence of migration costs, workers would in fact find optimal to move to the region where they obtain the highest possible level of utility, even for just one period.

endogenously for the share of the population living in each region:

(13) $$\Delta L_t = \left(\frac{1+Z_t^B}{1+Z_t^A}\right)^{\frac{\vartheta}{n_t}} \tau^{2\lambda_t - 1} - 1 = 0$$

In order to solve the model it is only necessary to find a relationship between the number of manufacturing and research firms in each region and the number of workers.

3.2 *R&D and production location*

3.2.1 *Location of production independent of that of R&D*

Under the assumption that firms can choose where to locate production independently of where they have conducted the research activity, it is easier to solve the model by first determining the optimal location of research firms. Substituting the equilibrium number of workers in each research firm (10) into the profit function (9), it is possible to obtain:

(14) $$\Pi_t^A(i) = \frac{W_{t+1}^{LA} l_{t+1}^{A}(i)\Delta^{\alpha+\varepsilon}\xi m_t^S(i)^{\beta}\, {n_t^{RS}}^{\gamma}}{(1+r_{t+1})\hat{H}_t^{\varepsilon}} - W_t^{HS}[\Delta+\mu]$$

This expression clearly shows that profits increase both with the number of research firms within the same industry locating in the same region ($m_t^S(i)$), and with the number of industries locating at least one research firm in that region ($n_t^{R,S}$). Assuming that manufacturing can take place in either *A* or *B*, independently of where the research activity that led to success in the R&D race in the previous period was located, the only stable equilibrium such that all firms have the same expected profits is with the entire research sector located in the same region. All the other equilibria with profit equalisation and R&D firms in both regions are unstable. In the case of a symmetric equilibrium with the same number of industries locating research in each region, each firm has an incentive to change location, as this would increase the spillovers from which it could benefit.[12]

In equilibrium a winning firm having to choose at time *t+1* where to locate production must be indifferent between *A* and *B*; therefore, from equation (14) it must follow that $W_{t+1}^{A} l_{t+1}^{A} = W_{t+1}^{B} l_{t+1}^{B}$. Under the assumption of equalisation of nominal wages between the two regions, manufacturing firms must all employ the same number of workers, $l_t = \frac{L_t}{n_t}$; in each region the number of unskilled workers is therefore proportional to the number of firms: $L_t^A = \lambda_t L_t$. Assuming that all the R&D firms locate in region *A* (as mentioned earlier, a perfectly symmetric equilibrium is possible with all the R&D firms located in region *B*) equation (13) becomes:

(15) $$\Delta L_t = \left[\frac{1 + (1 - \lambda_t) L_t}{1 + \lambda_t L_t + H_t} \right]^{\frac{\vartheta}{n_t}} \tau^{2\lambda_t - 1} - 1$$

The shape of equation (15) is studied in Appendix 2. It is demonstrated that a sufficient condition to have complete concentration of all economic activities in one region (Figure 1) is that the transport costs are high relative to the congestion costs, $\log(\tau) > \frac{\vartheta}{n_t} \log 2$, so that the centripetal force prevails. On the other hand, if the transport costs are sufficiently low with respect to the congestion costs, $\log(\tau) < \frac{\vartheta}{n_t} \log\left(\frac{1 + L_t}{1 + H_t} \right)$, the economy is split into two regions of

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12 This is also true in all cases of asymmetric equilibria, which are only possible if there are differences in the nominal wages of skilled workers between the two regions.

unequal size (Figure 2). This equilibrium must necessarily be asymmetric: for a given number of goods produced in region *A*, higher congestion costs must be paid by people living in that region, owing to the presence of workers employed in research firms; this utility loss must be compensated by a lower price level, which is possible only if more than half of the goods are produced in that region. On the other hand, consumers in region *B* will spend a larger share of their income on paying the transport costs on goods produced in *A*, but they will also benefit from lower congestion costs.

3.2.2 *Production in the region where the winning firm conducted R&D*

When the firm that won the technology race cannot locate production in a region different from where it conducted research (for example because close contacts must be kept between the research laboratories and the shop floor) the expected profit function for a firm in *A* becomes:

(16) $$\Pi_t^A(i) = \frac{W_{t+1}^{LA} l_{t+1}^A(i)\Delta^{\alpha+\varepsilon}\xi m_t^A(i)^{\beta} n_t^{RA\gamma}}{(1+r_{t+1})\hat{H}_t^{\varepsilon}} - W_t^{HA}[\Delta+\mu]$$

As before, profits are an increasing function of the number of research firms within the same industry locating in the same region; each industry’s research activity must therefore locate within the same region.[13]

From equation (16) it is clear that in equilibrium all manufacturing firms employ the same number of workers: $l_t = \frac{L_t}{n_t}$. In each region the number of unskilled workers is therefore

[13] Although profits also increase with the number of industries locating at least one research firm in that region, R&D firms cannot locate all in the same region because research and production in the same industry must locate within the same region.

proportional to the number of firms: $L_t^A = \lambda_t L_t$. Moreover, the number of skilled workers at time *t* must be proportional to that of industries at time *t-1*: $H_t^A = \lambda_{t-1} H_t$. Assuming that in equilibrium the location of production does not change from *t* to *t+1*, equation (13) becomes:

$$\Delta L_t = \left[\frac{1+(1-\lambda_t)}{1+\lambda_t}\right]^{\frac{\vartheta}{n_t}} \tau^{2\lambda_t - 1} - 1 \qquad (17)$$

As is shown in Appendix 2, there are three possible types of equilibria: complete concentration of economic activities in one region (Figure 1), asymmetric distribution of economic activities (Figure 3) and symmetric distribution of economic activities in the two regions. The condition for a polarised equilibrium is the same as in the case of separation between research and production, $\log(\tau) > \frac{\vartheta}{n_t}\log 2$; however, $\log(\tau) < \frac{2\vartheta}{3n_t}$ is a sufficient condition to have a symmetric distribution, which is never possible when firms are not vertically integrated.

4. Welfare, income distribution and integration

The welfare implications of the analysis are quite straightforward. Workers are utility maximisers, free to move from one region to the other: their choice is therefore always optimal. Analogously, firms are profit maximisers and they internalise the effects of spillovers on their location choices. Whatever the overall geographical equilibrium, it is therefore the result of an optimal choice for the given level of parameters.

On the other hand, the possibility of separating research and production has a significant impact on welfare, by making it possible to fully exploit the spillovers in R&D

activity, and therefore increasing the rate of growth in total output. This also has an impact on income distribution between the two regions. From the profit function in equations (14) and (16), under the assumption of nominal wage equalisation, it is possible to solve for the equilibrium relationship between the nominal wages of unskilled and skilled workers:[14]

(18) $$\frac{W_{t+1}^{L}}{W_{t}^{H}} = \frac{\Delta^{1-\alpha}(1+\sigma)n_{t+1}}{L_{t+1}(\alpha+\varepsilon)\xi n_{t}^{1-\beta}} \equiv \Omega_{t+1}$$

If, as is likely, the wage of skilled workers is higher than that of unskilled workers,[15] the concentration of research has the effect of making income distribution between the regions more uneven in per capita terms as well.[16]

Two effects that it is possible to expect from integration between two regions are the reduction of the needs for vertical integration between research and production (for example as information can be transmitted more quickly and efficiently) and the decrease of the transport costs. From the

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14 From equations (4), (6), (8) and (10), and the equilibrium condition between demand and supply, $X_t^S(i) = \frac{E_t}{n^A P_t^A(i) + n^B P_t^B(i)}$, it is the case that $W_t^L = \frac{L_t}{n_t}\left[1+\xi\Delta^{\alpha}\left(\frac{H_t}{n_t\Delta}\right)^{\beta} n_t^{\gamma}\right]$. From equation (18) it is also true that W_t^H is constant, as stated earlier. Finally, substituting into the budget constraint (1) it is possible to solve for the initial level of agents' wealth, a_0. A similar relationship could be derived for the case in which nominal wages are not equalised between regions.

15 This condition is satisfied when the share of unskilled workers and the number of industries are large, and when the number of research firms is small: $L_t > \frac{\Delta^{1-\alpha}(1+\sigma)n_t^{\beta}}{(\alpha+\varepsilon)\xi}$.

16 The ratio between per capita total expenditure in each region is $\frac{\tilde{E}_t^A}{\tilde{E}_t^B} = \frac{H_t + \lambda\Omega_t L_t}{(1-\lambda)\Omega_t L_t}$, where $\tilde{E}_t^S$ is the average expenditure of a worker in region S. Obviously, in absolute terms a larger region has a higher level of total consumption.

previous section it is clear that the possibility of separating research and production has the effect of increasing the asymmetries between the two regions, owing to the effect of feedback and feedforward mechanisms associated with the clustering of R&D. In fact, if an equilibrium with economic activities spread in both regions is preserved, it cannot be symmetric. On the other hand, the decrease of the transport costs reduces the centripetal forces and therefore makes it possible to sustain an equilibrium in which production is more evenly spread between the two regions. The final effect of integration depends on which of the two forces prevails.

5. Conclusions

Many empirical studies have found the existence of both inter-industry and intra-industry externalities in the form of local knowledge spillovers in research. This paper has made some assumptions reflecting these empirical regularities in order to analyse their implications for the allocation of economic activities between two regions.

The basic framework of the model is common to the new economic geography literature: the centripetal force is represented by the cost of transporting goods form one region to the other, which makes it more attractive for workers to locate where the larger share of consumption goods is produced (in order to minimise the payment of the transport costs). The centrifugal force is represented by congestion costs, which are assumed to increase with the number of workers living in a region. The existence of positive technological spillovers between research firms located in the same region is shown to affect the location of economic activities only when research and production can take place in different regions. However, when firms are not vertically integrated, the clustering of the R&D activity which results from the presence of spillovers introduces a centripetal force, favouring regional polarisation. This force is a result of both feedback and feedforward mechanisms: consumers living in an area which is more crowded owing to the presence of skilled workers employed in research (in addition to the unskilled workers employed in manufacturing) must get a compensation, which can only derive from a lower price level, and can therefore be obtained only by reducing the share of goods on which transport costs must be paid: more than half of the consumption goods must then be produced in that region. Equilibrium is reached when the benefit of having one more good produced in the region is offset by the loss associated with the presence of the workers that produce it.

If the integration between two regions or countries is seen to determine a reduction in the transport costs as well as in the degree of vertical integration within firms, the overall effect on regional equilibrium is uncertain. In fact, the former effect determines an incentive for unskilled workers and manufacturing firms to migrate to the less populated region, where the congestion costs are lower. The latter determines the clustering of the research sector in one region, thus introducing a centripetal force that favours an asymmetric distribution of activities.

This clustering also implies the possibility of fully exploiting the positive spillovers in research, thus determining an increase in the rate of growth of the economy. However, it also has the effect of determining an uneven distribution of per capita income: if the nominal wages of skilled workers are higher, the region which hosts the R&D sector is richer than the other.

Appendix 1

Consider the case of a leading manufacturing firm producing in region *A*. If nominal wages are not equalised, this firm can sell its good in both regions only if it fixes a price that satisfies condition (8) and that is lower than that guaranteeing zero profits to a non-winning firm in region *B*, augmented for the transport costs: $P_t^A(i) < P_t^B(i)\tau$. Substituting equation (8) into the previous condition, it becomes clear that if nominal wages in *A* exceed those in *B* by too much, $W_t^{L,A}(i) > W_t^{L,B}(i)\tau$, the leading firm would prefer to move its production. The same reasoning applies for manufacturing firms locating in *B*. Therefore, the following relationships between nominal wages must be always satisfied in order to have manufacturing firms in both regions: $\frac{W_t^{L,B}}{\tau} < W_t^{L,A} < W_t^{L,B}\tau$. From profit maximisation this implies that there is also a relationship between the number of unskilled workers employed in production in each region. Substituting the two boundary conditions obtained from the previous expression into (12), it is possible to dereve respectively $\Delta L_t = \left(\frac{1+Z_t^B}{1+Z_t^A}\right)^{\frac{\vartheta}{n_t}} \tau^{2\lambda_t - 1 - \frac{\vartheta}{n_t}} - 1$ and $\Delta L_t = \left(\frac{1+Z_t^B}{1+Z_t^A}\right)^{\frac{\vartheta}{n_t}} \tau^{2\lambda_t - 1 + \frac{\vartheta}{n_t}} - 1$.

Appendix 2

Consider first the case when research and manufacturing firms are not vertically integrated. Defining for simplicity equation (15) as $\Delta L_t = \left[\frac{1+(1-\lambda)L_t}{1+\lambda L_t + H_t}\right]^{\frac{\vartheta}{n_t}} \tau^{2\lambda_t - 1} - 1 \equiv f(\lambda_t)$, $f(\lambda_t)$ and $f'(\lambda_t)$ are both continuous for $\lambda_t \in [0,1]$. Defining $\frac{3\vartheta L_t}{2n_t[2 + L_t(\lambda_t L_t + H_t)(1-\lambda_t)]} \equiv h(\lambda_t)$, it is easy to show that $f'(\lambda_t) > 0$ for $\log\tau > h(\lambda_t)$ and that $h(\lambda_t)$ has a minimum for $\lambda_t = \frac{L_t - H_t}{2L_t}$ (assuming $L_t > H_t$) and a maximum for $\lambda_t = 0$. Therefore, $f'(\lambda_t) < 0 \quad \forall\lambda_t$ if and only if $\log\tau < h\left(\frac{L_t - H_t}{2L_t}\right) = \frac{2\vartheta L_t}{3n_t}$; $f'(\lambda_t) > 0 \quad \forall\lambda_t$ if and only if $\log\tau > h(0) = \frac{3\vartheta L_t}{2n_t(2 + L_t H_t)}$; if $\log\tau \in \left[h\left(\frac{L_t - H_t}{2L_t}\right), h(0)\right]$, $f'(\lambda_t) < 0$ for $\lambda_t \in (0, \bar{\lambda})$, $f'(\lambda_t) > 0$ for $\lambda_t \in (\bar{\lambda}, \hat{\lambda})$ and $f'(\lambda_t)$ is either positive or negative for $\lambda_t \in (\hat{\lambda}, 1)$, where $0 < \bar{\lambda} < \hat{\lambda} < 1$. The possible equilibria are as follows: (i) for $\log\tau > \frac{\vartheta}{n_t}\log 2$, $f(0) < 0$, $f(1) > 0$ and therefore $\forall f'(\lambda_t)$ $f(\lambda_t)$ can only cross the x-axis once and from below; the only stable equilibrium is thus with complete concentration of economic activities in one region; any equilibrium with activities spread in both regions where $f(\lambda_t)$ crosses the x-axis from below is unstable because workers deciding to move would have a higher real wage adjusted for the congestion costs; (ii) for $\log(\tau) < \frac{\vartheta}{n_t}\log\left(\frac{1+L_t}{1+H_t}\right)$, $f(0) > 0$, $f(1) < 0$, $\log\left(\frac{1+L_t}{1+H_t}\right) < h\left(\frac{L_t - H_t}{2L_t}\right) = \frac{2\vartheta L_t}{3n_t} \quad \forall L_t, H_t \in [0,1]$, so that $f'(\lambda_t) < 0 \quad \forall\lambda_t$ and therefore $f(\lambda_t)$ can only cross the x-axis once and from above;

the only stable equilibrium is thus with activities spread in both regions; (iii) for $\log\tau \in \left[\frac{\vartheta}{n_t}\log\left(\frac{1+L_t}{1+H_t}\right), \frac{\vartheta}{n_t}\log 2\right]$ $f(0)<0$, $f(1)<0$ and $f'(\lambda_t)$can either be positive or negative depending on the values of λ_t, so that $f(\lambda_t)$ could never cross the x-axis or could cross it twice; there could thus be either one stable equilibrium with complete concentration or one stable equilibrium with activities spread in both regions.

Second, consider the case when research and manufacturing firms are vertically integrated. Defining for simplicity equation (17) as $\Delta L_t = \left[\frac{1+(1-\lambda_t)}{1+\lambda_t}\right]^{\frac{\vartheta}{n_t}} \tau^{2\lambda_t - 1} - 1 \equiv g(\lambda_t)$, $g(\lambda_t)$ and $g'(\lambda_t)$ are both continuos for $\lambda_t \in [0,1]$. Defining $\frac{3\vartheta}{2n_t(2+\lambda_t-\lambda_t^2)} \equiv i(\lambda_t)$, it is easy to show that $g'(\lambda_t)>0$ for $\log\tau > i(\lambda_t)$ and that $i(\lambda_t)$ has a minimum for $\lambda_t = \frac{1}{2}$ and a maximum for $\lambda_t = 0$ or $\lambda_t = 1$. Therefore, $g'(\lambda_t)<0$ $\forall\lambda_t$ if and only if $\log\tau < i\left(\frac{1}{2}\right) = \frac{2\vartheta}{3n_t}$; $g'(\lambda_t)>0$ $\forall\lambda_t$ if and only if $\log\tau < i(0) = \frac{3\vartheta}{4n_t}$; if $\log\tau \in \left[i\left(\frac{1}{2}\right), i(0)\right]$, $g'(\lambda_t)<0$ for $\lambda_t \in (0,\bar{\lambda})$, $g'(\lambda_t)>0$ for $\lambda_t \in (\bar{\lambda},\hat{\lambda})$ and $g'(\lambda_t)$ either positive or negative for $\lambda_t \in (\hat{\lambda},1)$, where $0<\bar{\lambda}<\hat{\lambda}<1$. The possible equilibria are therefore as follows: (i) for $\log\tau > \frac{\vartheta}{n_t}\log 2$, $g(0)<0$, $g(1)>0$ and therefore $\forall g'(\lambda_t)$ $g(\lambda_t)$ can only cross the x-axis once and from below; the only stable equilibrium is thus with complete concentration of economic activities in one region; (ii) for $\log(\tau) < \frac{2\vartheta}{3n_t}$, $g(0)>0$, $g(1)<0$ and $i\left(\frac{1}{2}\right) < \frac{\vartheta}{n_t}\log 2$ so that $g'(\lambda_t)<0$ $\forall\lambda_t$ and therefore $g(\lambda_t)$

can only cross the x-axis once and from above; the only stable equilibrium is thus with activities spread in both regions; (iii) for $\log\tau \in \left[\frac{2\vartheta}{3n_t}, \frac{\vartheta}{n_t}\log 2\right]$ $g(0) > 0$, $g(1) < 0$ and $g'(\lambda_t)$can be either positive or negative depending on the values of λ_t so that $g(\lambda_t)$ could cross the x-axis either once or three times; therefore there could be either one stable symmetric equilibrium or two stable asymmetric equilibria and in both cases activities would be spread in both regions.

In the case in which nominal wages are not equalised, the conditions for determining the signs of $f(0)$, $f(1)$, $g(0)$ and $g(1)$ are different from the previous ones, while those for determining the signs of $f'(\lambda_t)$ and $g'(\lambda_t)$ are unchanged.

When research and manufacturing are not vertically integrated and $W_t^{LA} = \frac{W_t^{LB}}{\tau}$, it is possible to identify the following cases: (i) for $\log\tau > \frac{\vartheta}{n_t - \vartheta}\log 2$ there can be only one stable equilibrium, with activities concentrated; (ii) for $\log\tau < \min\left[\frac{\vartheta}{n_t + \vartheta}\log\left(\frac{1+L_t}{1+H_t}\right), \frac{3\vartheta L_t}{5n_t}\right]$ there can be only one stable equilibrium with activities spread; (iii) for $\frac{3\vartheta L_t}{n_t} < \log\tau < \frac{\vartheta}{n_t + \vartheta}\log\left(\frac{1+L_t}{1+H_t}\right)$ there can be either one stable equilibrium or two stable equilibria, with activities spread; (iv) for $\frac{\vartheta}{n_t + \vartheta}\log\left(\frac{1+L_t}{1+H_t}\right) < \log\tau < \frac{3\vartheta L_t}{n_t}$ there can be only one stable equilibrium, with activities concentrated; (v) for $\log\tau \in \left[\max\left(\frac{\vartheta}{n_t + \vartheta}\log\left(\frac{1+L_t}{1+H_t}\right), \frac{3\vartheta L_t}{5n_t}\right), \frac{\vartheta}{n_t - \vartheta}\log 2\right]$ there can be either one stable equilibrium, with activities concentrated, or one stable equilibrium, with activities spread.

When research and manufacturing are not vertically integrated and $W_t^{LA} = W_t^{LB}\tau$ it is possible to identify the following cases: (i) for $\log\tau > \max\left[\frac{\vartheta}{n_t - \vartheta}\log\left(\frac{1+L_t}{1+H_t}\right), \frac{\vartheta}{n_t + \vartheta}\log 2\right]$ there can be only one stable equilibrium with activities concentrated; (ii) for $\log\tau < \min\left[\frac{\vartheta}{n_t - \vartheta}\log\left(\frac{1+L_t}{1+H_t}\right), \frac{\vartheta}{n_t + \vartheta}\log 2\right]$ and $\log\tau < \frac{3\vartheta L_t}{5n_t}$ there can be only one stable equilibrium, with activities spread; (iii) for $\log\tau < \min\left[\frac{\vartheta}{n_t - \vartheta}\log\left(\frac{1+L_t}{1+H_t}\right), \frac{\vartheta}{n_t + \vartheta}\log 2\right]$ and $\log\tau \in \left[\frac{3\vartheta L_t}{5n_t}, \frac{3\vartheta L_t}{2n_t(2+L_t H_t)}\right]$ there can be either one stable equilibrium or two stable equilibria, with activities spread; (iv) for $\log\tau \in \left[\min\left[\frac{\vartheta}{n_t + \vartheta}\log 2, \frac{\vartheta}{n_t - \vartheta}\log\left(\frac{1+L_t}{1+H_t}\right)\right], \max\left[\frac{\vartheta}{n_t + \vartheta}\log 2, \frac{\vartheta}{n_t - \vartheta}\log\left(\frac{1+L_t}{1+H_t}\right)\right]\right]$ and $\log\tau > \frac{3\vartheta L_t}{2n_t(2+L_t H_t)}$ or $\log\tau < \frac{3\vartheta L_t}{5n_t}$ there can be only one stable equilibrium, with activities concentrated; (v) for $\log\tau \in \left[\min\left[\frac{\vartheta}{n_t + \vartheta}\log 2, \frac{\vartheta}{n_t - \vartheta}\log\left(\frac{1+L_t}{1+H_t}\right)\right], \max\left[\frac{\vartheta}{n_t + \vartheta}\log 2, \frac{\vartheta}{n_t - \vartheta}\log\left(\frac{1+L_t}{1+H_t}\right)\right]\right]$ and $\log\tau \in \left[\frac{3\vartheta L_t}{5n_t}, \frac{3\vartheta L_t}{2n_t(2+L_t H_t)}\right]$ there can be either one stable equilibrium, with activities concentrated, or one stable equilibrium, with activities spread.

When research and manufacturing are vertically integrated and $W_t^{LA} = \frac{W_t^{LB}}{\tau}$ or $W_t^{LA} = W_t^{LB}\tau$ it is possible to identify the following cases: (i) for $\log\tau > \frac{\vartheta}{n_t - \vartheta}\log 2$ and there can be only one stable equilibrium, with activities concentrated; (ii) for $\log\tau < \min\left[\frac{2\vartheta}{3n_t}, \frac{\vartheta}{n_t + \vartheta}\log 2\right]$ there can be only one stable equilibrium, with activities spread; (iii) for $\log\tau \in \left[\frac{\vartheta}{n_t + \vartheta}\log 2, \frac{\vartheta}{n_t - \vartheta}\log 2\right]$ and $\log\tau < \frac{2\vartheta}{3n_t}$ or $\log\tau > \frac{3\vartheta}{4n_t}$ there can be only one stable equilibrium, with activities concentrated; (iv) for $\log\tau \in \left[\max\left[\frac{\vartheta}{n_t + \vartheta}\log 2, \frac{2\vartheta}{3n_t}\right], \min\left[\frac{\vartheta}{n_t n\vartheta}\log 2, \frac{3\vartheta}{4n_t}\right]\right]$ there can be either one stable equilibrium, with activities concentrated, or one stable equilibrium, with activities spread.

Figures

Figure 1

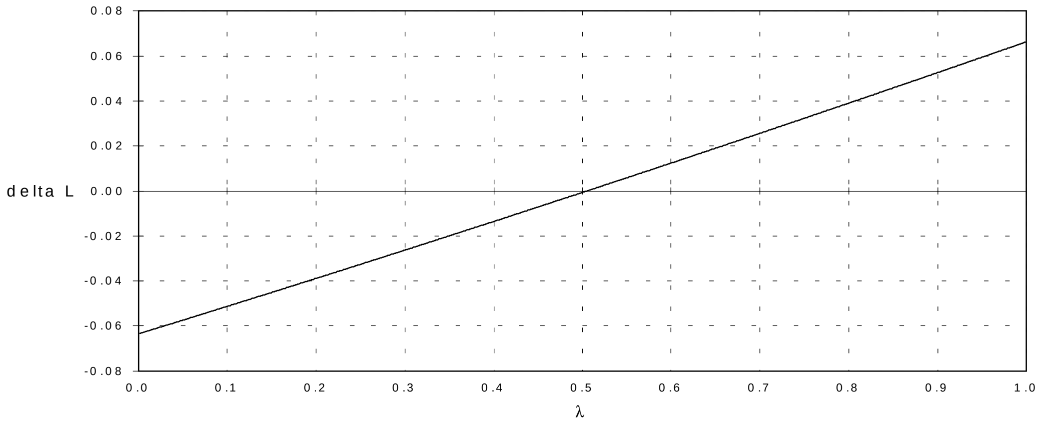


Figure 2

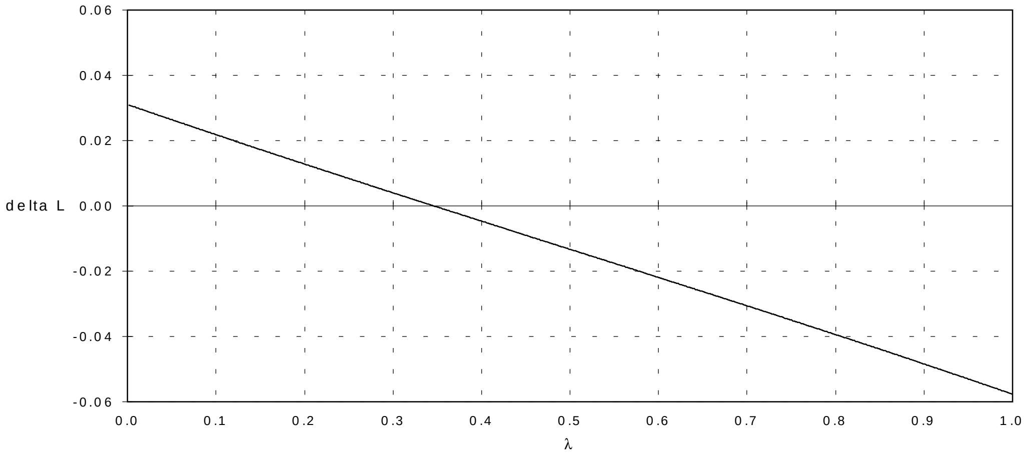
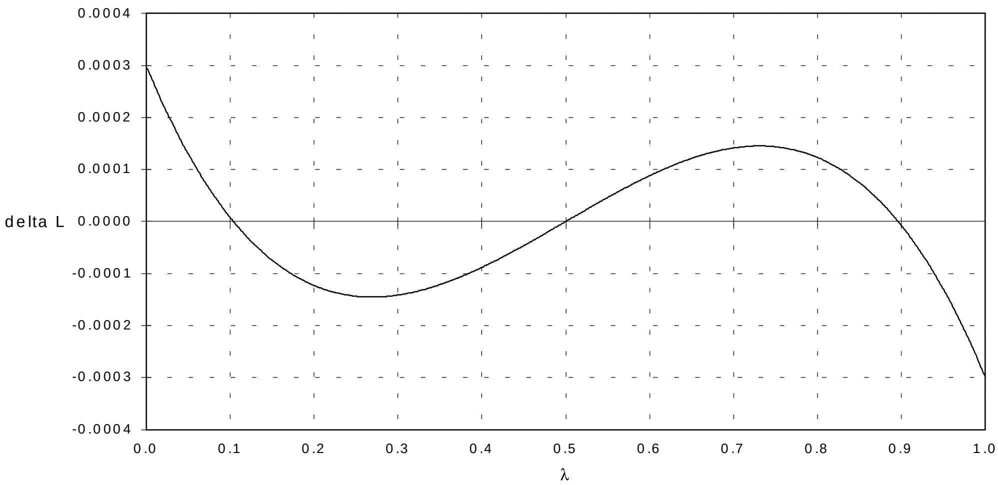


Figure 3



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