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

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Abstract

I present an endogenous growth model that studies the effects of local inter-industry and intra-industry knowledge spillovers in R&D on the allocation of economic activities between two regions. The equilibrium is the result of a tension between a centripetal force, the cost of transporting goods from one region to the other, and a centrifugal force, the cost increase associated with life in a more crowded area. The presence of local knowledge spillovers, which determines the concentration of the R&D activities within one region, also introduces a further centripetal force that makes impossible a symmetric allocation of the economic activities. The concentration of R&D fosters the equilibrium rate of growth of the economy with respect to the case of no-integration, by increasing the positive effect of local knowledge spillovers. Contrary to the findings of the majority of models in the new economic geography literature, within this framework a reduction in the transport costs may be associated with a more even spatial location of economic activities.

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1 Introduction

In the last ten years there has been a revival of interest in the study of economic geography, fostered by the application of new theoretical results to the analysis of economies with static and dynamic increasing returns to scale (e.g., Dixit and Stiglitz, 1977, and Romer, 1986).[1] The main feature shared by the majority of models of the so-called "new economic geography" literature is the joint assumption of Dixit-Stiglitz monopolistic competition among firms offering differentiated products and transport costs for transferring goods from one location to another. As was first shown by Krugman (1991a, 1991b), this framework makes it possible to rationalise the interplay of the centripetal and centrifugal forces shaping the spatial location of economic activities.

A more recent strand of literature has extended models with the basic features of the "new economic geography" in order to study the equilibrium allocation of economic activities between endogenously growing economies, generally adopting the basic structure of the R&D model of growth with increasing product variety. Baldwin and Forslid (1997) have shown that the presence of localized knowledge spillovers, which are necessary in order to guarantee a positive equilibrium rate of growth, adds one more centripetal factor to Krugman's (1991a) model, thus reducing the parameter space for which a symmetric equilibrium is stable. Obviously, the equilibrium rate of growth of total output in the global economy is higher when research is concentrated in one region and the effects of all positive externalities are internalised. Using a similar framework, Martin and Ottaviano (1999) have shown that the rate of growth in a two regions endogenous growth model may differ only if knowledge spillovers are localised: with complete spillovers, the entire economy shares the same technology and the transport costs only affect the size of the manufacturing sector in each region.

The theoretical model proposed in this paper introduces some new assumptions with respect to the previous literature. First, it adopts the increasing product quality

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1 For recent surveys of the literature see Ottaviano and Puga (1998), Neary (2001) and the book by Fujita, Krugman and Venables (1999).

framework of R&D and endogenous growth of Aghion and Howitt (1992), in the version developed by Segerstrom, Anant and Dinopulos (1990).

Second, it assumes perfect labour mobility across regions and it introduces a congestion cost, implying that agents living in crowded areas experience a reduction in their utility. The rationale for this assumption is in the nature of the stylised facts that the model tries to account for: the allocation of economic activities in the case of two cities not too far away from each other. In this respect, the scenario proposed here can be considered complementary to the more standard models of the new economic geography literature, whose assumptions better fit the case of two large regions within a country.

Finally, it assumes that R&D activities benefit from intra-industry Marshall-Arrow-Romer externalities and inter-industry Jacobs (1961) externalities, coming from research firms and, to a lesser extent, from manufacturing firms located in the same region.[2]

These assumptions have a number of interesting implications. In the model, the centripetal force depends on both backward and forward linkages: workers prefer to live where the majority of firms are located, so that a smaller share of consumption goods is affected by transport costs. This exerts a downward pressure on wages in the largest region, which attracts new firms. Such pressure is opposed by the centrifugal force, which does not depend on the higher competition faced by firms located in the largest region (as in Krugman, 1991a), but on the congestion cost affecting workers living in more populated areas. The relationship between concentration and transport costs in this framework contrasts with that in Krugman (1991a) and in the majority of models of growth within the "new economic geography" framework. It is instead similar to the relationship in Helpman

[2] The existence of positive knowledge spillovers in R&D is a well-accepted result of empirical research (e.g. Jaffe, 1986 and 1989; Caballero and Lyon, 1990 and 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), Ellison and Glaeser (1997) and Feldman and Audretsch (1999). Glaeser, Kallal, Scheinkman and Shleifer (1992), Shea (1996 and 2002) and Henderson, Kuncoro and Turner (1995), while not attributing them explicitly to R&D activity, have found evidence of positive inter-industry and intra-industry geographically bounded spillovers in manufacturing.

(1998): for given congestion costs, higher transport costs produce an equilibrium in which all economic activities end up concentrated in one region.[3]

The reason for this result can be better understood if one considers the incentives for a firm to change location from one region to another. In Krugman's (1991a) framework, a reduction in transport costs has three effects: a) it augments the incentive for a firm to change location, through a lower increase in the competition faced by the firm when it moves to what becomes – with its arrival – a larger region (at the limit, with no transport costs, all firms would face the same level of competition, independently of their location); b) it reduces the incentive for a firm to change location, as the increase in the demand for its good that would result from moving to a larger region – induced by the fact that a larger share of output is sold to customers that do not pay the transport costs – is lower; c) it reduces the incentive for workers to change location, as the share of their total expenditure absorbed by transport costs is lower. The change in the equilibrium location of economic activities induced by a reduction in transport costs is driven by the first effect, which dominates when the elasticity of substitution between goods in consumers' utility function is sufficiently high relative to effect of the change in transport costs on workers' choices.

In the model proposed in this paper the effect of a reduction in transport costs on the allocation of economic activities is driven by the change in the price of imported goods relative to locally produced goods. The effect on firms' profits is less important: the assumption of unity elasticity of substitution between goods in the utility function implies that total revenues are independent of the level of transport costs, so that the change in profits depends solely on the effects coming through the change in wages. Firms are assumed to change location not in order to gain a larger market share (as their total output is invariant to this choice) but only to find lower wages. This implicitly focuses the analysis on the effects of workers' choices. A further interesting implication of the model is that when integration becomes possible, research firms always locate within the same region, making the realisation of a symmetric equilibrium impossible.

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[3] At the empirical level, cases where a reduction in transport costs is associated with a more even spreading of economic activities are described, for example, by Krugman (1991b, p. 81, table 3.4).

The model shares with the previous literature the circular causation effect of the location of workers in a given region. In fact, the relocation of a productive firm lowers the price level in the region of destination by reducing the share of goods on which the transport costs must be paid. This attracts new workers, and with them new firms providing an even larger share of goods in the same region. This cumulative mechanism is opposed by the congestion cost of living in an increasingly congested area.

Finally, as a result of local positive spillovers from manufacturing to research, the equilibrium rate of growth depends on the size of the region where R&D is located.

The rest of the paper is organised in four 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. The final section discusses the implications of the model and their policy content.

2 The model

The basic framework is similar to the quality-ladder models of Segerstrom, Anant and Dinopoulos (1990) and Grossman and Helpman (1991), adapted to the case where there are two regions and regional knowledge spillovers. The two regions are populated by a continuum of infinitely-lived agents who maximise their 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 in each industry which compete to become, in the next period, the technology leader and the only producer of that industry's consumption good.

Only two factors of production are assumed: unskilled and skilled labour. The former is employed in manufacturing, the latter in research. Each worker offers 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.[4] The solution of the model is a dynamic free-market equilibrium in which the

[4] This assumption could be relaxed to allow workers to move from manufacturing to research without affecting the main conclusions of the analysis. In this case the equilibrium allocation of

location of economic activities and the rate of growth in the volume of output are endogenously determined. As the two regions are identical, for any equilibrium location of activities there also exists a perfectly symmetric alternative. Unless stated differently, in the following I consider all choices from the point of view of agents and firms located in the region denominated as *A*.

2.1 Demand Side

Any worker, skilled or unskilled, uses the revenues from his activity to maximise the intertemporal utility function

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

subject to the budget constraint

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

where $u^{IA}(t)=\sum_{i=1}^{n^A}\ln\left[c_t^{IA}(i)\right]+\sum_{i=1}^{n^B}\ln\left[c_t^{IB}(i)\right]-\vartheta\ln\left(1+Z_t^A\right)$ is the instantaneous utility function for a worker of category *I* living in region *A* and *I=L,H* is an index taking value *L* to indicate unskilled workers and *H* to indicate skilled ones; n^S is the number of goods produced in region *S* (for *S=A,B*);[5] $Z_t^A = L_t^A + H_t^A$ is total population living in region *A*; $c_t^{IS}(i)$ is consumption by a generic worker of type *I* of good *i* produced in region *S*; σ is the subjective rate of time preference; $P_t^{AA}(i)$ is the price of the generic good produced and consumed in *A*; $P_t^{BA}(i)$ is the price in *A* of a good produced in *B* (including the transport cost, see section 2.2.1); W_t^{IA} is the nominal wage for labour of type *I* in region *A*; r_t is the

workers across different activities would depend solely on the relative efficiency of R&D and production, not on the geographical location of the two activities.

5 The number of goods is assumed to be large enough to avoid integer problems.

rate of interest on a safe asset and a_0^I is the initial level of nominal wealth of a worker of type *I*. The first term in the instantaneous utility function is a symmetric logarithmic Cobb-Douglas in the level of consumption of each type of good. The second term, $\vartheta \ln\left(1 + Z_t^A\right)$, represents the congestion cost associated with the size of the population living in the region.

The last term, similar to that introduced by Henderson (1974) and Gali (1994), is consistent with the early theory of residential rent, which suggests that the price of the land on which workers live decreases as the distance from the centre of each region increases.[6] Obviously, the presence of this centripetal force is crucial in the model, as in all geography models: in its absence the only possible equilibrium would be with all economic activities concentrated in only one point in space. In the standard two-region models of the new economic geography literature this centripetal force is obtained by assuming that a fixed share of demand for manufacturing goods comes from each region, due to the presence of one class of workers (farmers) who are assumed to be immobile (see, e.g., Krugman, 1991a). As it will be made clear later, the consequences of introducing the centripetal force have important implications for the results of the analysis. Which of the two assumptions is most plausible is, however, an empirical question that depends in particular on the stylised facts that the model intends to describe. This framework is probably more suited to describing the equilibrium location of productive activities between two competing cities; the other better captures the development of spatial agglomerations in a rural area.

The solution of the maximisation problem in (1) gives the demand in each period and by each worker of type *I* of the generic good *i* produced in region *S*, $c_t^{IS}(i) = \dfrac{\hat{E}_t^{IA}}{(n^A + n^B)P_t^{SA}(i)}$, where $\hat{E}_t^{IA} = \left[\sum_{i=1}^{n^A} P_t^{AA}(i)c_t^{IA}(i) + \sum_{i=1}^{n^B} P_t^{BA}(i)c_t^{IB}(i)\right]$ is the nominal

[6] Instead of implicitly assuming the presence of a congestion cost by introducing it in the utility function, it could have been derived explicitly by assuming that productive activities are located in the centre of each region, workers must commute from their homes and land rents are evenly redistributed across all workers, an approach similar to that followed, for example, by Mills (1967), Elizondo and Krugman (1992) and Eaton and Eckstein (1997). However, this would have complicated the exposition of the basic features of the model without adding any insight to the analysis. Moreover, it is probably true that a number of factors not strictly related to the cost of the land make living in crowded areas less attractive.

expenditure of a representative worker *I*. From the assumption of Cobb-Douglas preferences, it follows that agents devote a fixed share of their total expenditures to each good. Total demand from region A for good i produced in region S is given by:

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

where $E_t^S = L_t^S E_t^{LS} + H_t^S E_t^{HS}$ is the total expenditure in region S, H_t and L_t are respectively the total number of skilled and unskilled workers and, as will be clear later, all the prices for goods produced in the same region are identical, by symmetry.

As in Grossman and Helpman (1991) there are no monetary variables in the model, so the numeraire can be freely chosen. Instead of following their approach of assuming that total nominal expenditure in each period is normalised to one (i.e., $E_t = E_t^A + E_t^B = 1$), I set $P_t^{AA}(i) = 1$. As it will be clear later, in equilibrium the price of goods produced in region B are also constant (and proportional to the nominal wage differential between the two regions). Defining $\overline{P}_t^A \equiv P_t^{AA^{\lambda_t}} P_t^{BA^{1-\lambda_t}} \equiv P_t^{BA^{1-\lambda_t}}$ as the price level in region A, $\lambda_t = \frac{n_t^A}{n}$ ($n \equiv n_t^A + n_t^B$) as the share of goods produced in region A and suppressing, by symmetry, the index i of prices, I finally obtain the following relation between the nominal interest rate, the subjective discount rate and the rate of growth of consumption, γ_C:

$$\frac{\Delta\hat{E}_t^{IA}}{\hat{E}_t^{IA}} = \frac{\Delta\overline{P}_t^A}{\overline{P}_t^A} + \frac{\Delta c_t^{IA}}{c_t^{IA}} = r_{t+1} - \sigma + \gamma_C = 0, \tag{3}$$

2.2 Supply Side

The supply side of the economy is an adaptation of the Segerstrom, Anant and Dinopoulos (1990) and Grossman and Helpman (1991) quality-ladder models. In each period there exists a fixed number of industries producing a different, non-storable good i (for $i=1,...,n$). Within each industry a number $m_t(i)$ of R&D firms conduct costly research aimed at improving the technology used in production. Similar to Segerstrom, Anant and Dinopoulos

(1990), in every period only one research firm finds a profitable way of increasing productivity in manufacturing. As a result it becomes the technology leader.[7] Having a technological advantage with respect to other potential manufacturers, the leading firm can set the price at such a level that it can be the only firm producing the industry's good with non-negative profits (i.e., Bertrand competition is assumed). Given free entry in research, for each industry i, the number $m_t(i)$ of firms doing R&D is endogenously determined. Every unit active in research chooses the amount of labour to employ in order to maximise expected profits (discounted 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 n manufacturing firms producing final consumption goods and $\sum_{i=1}^{n} m_t(i)$ ($=m_t n$, by symmetry) R&D firms doing research with the objective of becoming the next period's technology leader.

2.2.1 Productive Activities

All goods are produced using a technology that is linear in its only input, unskilled labour, and shows increasing returns to scale. This second assumption, common to the majority of models in geography economics, is essential in order to introduce the centripetal force needed to counterbalance the centrifugal effect associated with the presence of the congestion cost. In its absence, it would be optimal for any firm to set a production plant in each region.[8] Increasing returns to scale are introduced by assuming that 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

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7 With respect to the structure proposed by Grossman and Helpman (1991), in which the arrival of new discoveries is described by a Poisson distribution function, this assumption ensures that innovations in all industries, and in both regions, proceed at the same pace.

8 In the majority of models this assumption is generally introduced implicitly, assuming that each new plant produces a new variety of good.

industry i), and $l_t^A(i)$ is the amount of unskilled labour used in 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 transport costs must be paid. This cost takes the iceberg form first introduced by Samuelson (1954): for a quantity $X_t^{BA}(i)$ of good i to be imported from B and consumed in A, a quantity $X_t^{BA}(i)\tau$ must be produced (with $\tau \geq 1$).

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

2.2.2 Research Activities

R&D firms conduct 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:

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

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 victory with respect to the amount of skilled labour employed in research.

Technological progress takes the form of a continuous increase in the productivity of labour. Following the standard practice in endogenous models of R&D and growth, it is assumed that knowledge accumulation is characterised by an intertemporal externality: the technology used for production in previous periods is freely available, so that at time t research firms build on what is common knowledge from period t-1. Moreover, in order to avoid path dependency, it is imposed that knowledge spreads in both regions after one period. The rate of technological progress, $g_{\rho^A,t}$ (which coincides with that of the marginal productivity of labour in manufacturing), is assumed to be a positive function of the amount of labour employed in the previous period by the winning firm, $h_t^A(i,j)$. Research is characterised by three types of geographically bounded positive externalities: intra-industry knowledge spillovers from other R&D firms (proxied by the total number of R&D firms in the industry located in the same region, $m_t^A(i)$), inter-industry knowledge spillovers from other R&D firms (proxied by the total number of workers in the research sector that locate in the same region, H_t^A), and knowledge spillovers from productive firms (proxied by the total number of manufacturing workers located in the same region, L_t^A).[9] The function describing technological progress is therefore

$$\rho_{t+1}^A(i) = \rho_t^A(i) + \xi h_t^A(i,j)^{\alpha}(1+m_t^A(i))^{\beta}(1+H_t^A)^{\gamma}(1+L_t^A)^{\delta}\rho_t^A(i), \tag{6}$$

where $\alpha,\beta,\gamma,\delta > 0$ are parameters describing the elasticity of the technological improvement relative, respectively, to the number of skilled workers employed, to intra-industry and to inter-industry spillovers from other research firms, and to global spillovers from manufacturing firms; ξ is a positive constant.[10]

In order to solve for the number of R&D firms in equilibrium, it is assumed that undertaking R&D activities requires the payment of a fixed cost, μ, expressed in labour

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9 At the theoretical level, this hypotheses are necessary in order to determine the location of research firms; at the empirical level, it is consistent with the majority of the results in the literature (see footnote 2). Assuming positive, but limited, spillovers between the two regions would have made the analysis more cumbersome, without modifying the basic results.

10 This function guarantees a constant rate of growth because of its linearity in the level of knowledge.

units.[11] The profit function for the generic firm j of industry i, located in region S and deciding to produce in A is therefore:

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

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 that at which non-winning firms could profitably start production; given that prices of the goods produced in region A are the numeraire,

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

Profit-maximising firms will always set a price satisfying this condition as an equality. The marginal productivity of labour (which reflects the level of technology reached in industry i), $\rho_t^A(i)$, grows through time at a rate described by equation (6). As the number of workers employed in the production of each good, $l_{t+1}^A(i)$, is bounded by the size of the total labour force, condition (8) can be satisfied in the steady state only if nominal wages grow at the same rate as the level of technology.

Substituting previous expressions into the profit function (7), together with the expressions for the probability of victory in the R&D race (5) and the research technology (6), we obtain

$$\Pi_t^A(i,j) = \frac{W_{t+1}^{LA} l_{t+1}^A(i) h_t^S(i,j)^{\alpha+\varepsilon} \xi (1 + m_t^S(i))^{\beta} (1 + H_t^S)^{\gamma} (1 + L_t^S)^{\delta}}{\left(1 + r_{t+1}\right) \hat{H}_t^{\varepsilon}} - W_t^{HS} \left[h_t^S(i,j) + \mu \right]. \tag{9}$$

Research firms are aware of the positive effect of knowledge spillovers coming from research firms operating in the same region. However, it is assumed that they do not

11 For a similar assumption see Blackburn, Hung and Pozzolo (2000).

consider the positive spillovers coming from contiguous manufacturing firms.[12] From the point of view of firms, the profit function is therefore:

$$\Pi_t^A(i,j) = \frac{W_{t+1}^{LA} l_{t+1}^A(i) h_t^S(i,j)^{\alpha+\varepsilon} \xi (1+m_t^S(i))^\beta (1+H_t^S)^\gamma}{(1+r_{t+1})\hat{H}_t^\varepsilon} - W_t^{HS}\left[h_t^S(i,j)+\mu\right]. \tag{10}$$

Maximising (10) with respect to the number of workers involved in research and assuming, from equation (9), free entry in the R&D sector within each industry, it is possible to solve for the amount of labour employed in each R&D firm, which is a decreasing function of the number of manufacturing workers in the same region:

$$h_t^S(i,j) = \frac{\mu(\varepsilon+\alpha)}{(1+L_t^S)^\delta - \varepsilon - \alpha} \equiv \Theta(L^S). \tag{11}$$

Substituting this expression into (5), it is evident that the probability of winning the technology race is the same for all firms within the same industry and locating in the same region, 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 number of skilled workers in the economy: $m_t = \dfrac{H_t}{\Theta(L_t^S)n}$.

3 Geographical Equilibrium

3.1 Workers' Location

In this two-region model, 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 density of population suffer a loss of utility owing to the congestion cost. Given free labour mobility, in equilibrium the utility of agents living in the

[12] The extreme assumption that firms completely disregard the presence of spillovers from manufacturing firms is made for analytical convenience. The alternative assumption that firms

two regions must be equalised. Moreover, such an equilibrium is stable only if agents cannot increase their utility by moving to a different location.

Thanks to the hypothesis of increasing congestion costs, in the model presented here it is possible to have equilibria where activities are unevenly spread in both regions, as in Walz (1996). In order to describe the equilibrium allocation of resources across the two regions I use a different approach from the one usually adopted in the core-periphery models of economic geography, where an equilibrium is assumed and conditions for its stability are tested. I first solve explicitly for the number of workers (and therefore firms) that must locate in each region in order to obtain utility equalisation, and then check for stability by verifying the effect on a worker's utility if he moves to a different region. Assuming that skilled workers choose first where to locate, in order to avoid potential complementary slackness problems, this can also be interpreted as the equilibrium that obtains when skilled and unskilled workers can move across regions at no cost.

The first step is to find the conditions for the equalization of the level of utility of the workers living in the two regions, for given nominal wages (and thus for both types of workers). Substituting the level of consumption which maximises each worker's utility, $c_t^{IS}(i) = \frac{E_t^{IS}}{P_t^{SS}(i)}$, into the instantaneous utility function, it is possible to obtain each worker's instantaneous level of utility:

$$u^A(t) = n\ln\left(\frac{E_t^{IA}}{n\overline{P}_t^A}\right) - \vartheta\ln\left(1+Z_t^A\right) = n\ln\left[\frac{E_t^{IA}}{n\overline{P}_t^A\left(1+Z_t^A\right)^{\frac{\vartheta}{n}}}\right]. \qquad (12)$$

The willingness of workers to move from one region to the other depends on the difference between the levels of utility that they can achieve in the two places: it is

perceive lower than actual spillovers would lead to similar conclusions.

therefore a function of the congestion cost, of the differences in price levels and of the level of nominal wages in the two regions.[13]

From equation (12), agents' utilities in the two regions are equalised as long as

$$u^A(t) = u^B(t) \qquad \Leftrightarrow \qquad \frac{\overline{P}_t^B\left(1+Z_t^B\right)^{\frac{\vartheta}{n}}}{W_t^{IB} l_t^B} = \frac{\overline{P}_t^A\left(1+Z_t^A\right)^{\frac{\vartheta}{n}}}{W_t^{IA} l_t^A}. \tag{13}$$

In equilibrium the utility of workers in the two regions must be equalised at each point in time. In fact, any equilibrium in which overall utility is equalised but differences in the level reached at each point in time are still present would not be time-consistent: due to the absence of migration costs, workers would in fact find it optimal to move to the region where they obtain the highest possible level of utility, even for just one period. Substituting the equilibrium price of goods (8) into (13), the condition under which workers do not have an incentive to move can be rewritten as

$$\left(\frac{1+Z_t^B}{1+Z_t^A}\right)^{\frac{\vartheta}{n}} \tau^{2\lambda_t - 1} = \frac{W_t^{IB}}{W_t^{IA}}, \tag{14}$$

which makes it possible to solve endogenously for the share of workers who choose to stay in each region. Having reached this step, solving the model is simply a matter of finding a relationship between the number of manufacturing and research firms in each region and that of workers.

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13 Appendix 1 shows that the ratio between nominal wages in manufacturing in the two regions must lie within a range defined by the level of the transport costs and its reciprocal: $\frac{W_t^{LA}}{W_t^{LB}} \in \left(\frac{1}{\tau}, \tau\right)$. In fact, if $W_t^{LA}(i) > W_t^{LB}(i)\tau$ a firm producing in region *B* could sell its products in region *A* at a price lower than that of a firm producing the same good in region *A*. No equilibrium with firms producing in *A* would in this case be sustainable. The opposite is true if $W_t^{LB}(i) > W_t^{LA}(i)\tau$.

3.2 R&D Location

I assume that firms can choose where to locate production independently of where they have conducted research.[14] In order to solve the model it is easier to first determine the optimal location of research firms. Substituting the equilibrium number of workers in each research firm (11) into the profit function as perceived by research firms (10), it is possible to obtain:[15]

$$\Pi_t^A(i) = \frac{W_{t+1}^{LA} l_{t+1}^A(i)\Theta^{\alpha+\varepsilon}\xi(1+m_t^S(i))^\beta (1+H_t^S)^\gamma}{(1+r_{t+1})\hat{H}_t^\varepsilon} - W_t^{HS}[\Theta+\mu]. \tag{15}$$

From the point of view of the single research firm, profits increase in the number of research firms within the same industry locating in the same region, $m_t^S(i)$, and in the number of research workers, H_t^S. Assuming that manufacturing can take place either in *A* or *B*, independently of where research that led to the victory in the R&D race in previous period was located, the only stable equilibrium such that all firms have the same expected profits occurs with all research activities located in the same region. Indeed, research firms have an incentive to locate where they benefit from larger spillovers, i.e., where the number of R&D workers is larger.[16]

Result 1. *All research firms locate in the same region.*

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[14] The companion case where firms can only start production in the same region where R&D took place is studied in Pozzolo (2000).

[15] Consistent with the assumption that research firms do not consider the positive spillovers that come from contigous manufacturing firms, it is assumed that they take the number of workers in each research firm as independent from L_t^S.

[16] Another possible set of equilibria is with $(1+m_t^A(i))^\beta(1+H_t^A)^\gamma = (1+m_t^B(i))^\beta(1+H_t^B)^\gamma$, so that the size of spillovers is identical for research firms in both regions. This equilibria can be locally stable, because a single research firm wishing to change location would benefit from a larger size of the overall number of workers in research, but it would lose the spillovers coming from research firms working in the same industry, $m_t^S(i)$. However, this set of equilibria is inefficient and it is only possible in the case of coordination failures among research firms of the same industry.

3.3 Production Location

Having shown that all R&D workers locate in a single region, it is now possible to solve for the equilibrium allocation of manufacturing activities. 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 (15) it must follow that

$$W_{t+1}^{A} l_{t+1}^{A} = W_{t+1}^{B} l_{t+1}^{B} . \tag{16}$$

This expression, together with the fact that the share of the labour force employed in the production of each good is bounded, implies that in the long-run equilibrium the nominal wages in the two regions must grow at the same rate, given by the rate of technological progress. Thus, the homologous of the marginal pricing condition (8) in region B implies that in the long-run equilibrium nominal prices in the two regions are constant.

From equation (16) it is also possible to obtain an expression for the total number of workers employed in manufacturing in each region, given respectively by $L_t^A = \dfrac{\lambda L_t}{\lambda + \omega_t (1-\lambda)}$ and $L_t^B = \dfrac{(1-\lambda)\omega_t L_t}{\lambda + \omega_t (1-\lambda)}$, where $\omega_t \equiv \dfrac{W_t^{LA}}{W_t^{LB}}$ is the ratio of the nominal wages in manufacturing in the two regions.

Using the result that all R&D firms locate in the same region, and assuming that it is region A (as mentioned earlier, a perfectly symmetric equilibrium is possible with R&D firms located in region B), equation (14) can be rewritten as

$$f(\lambda) = \left[\frac{\lambda + \omega(1-\lambda)(1+L_t)}{\lambda(1+H_t+L_t) + \omega(1-\lambda)(1+H_t)} \right]^{\frac{\vartheta}{n}} \tau^{2\lambda_t - 1} - 1 = 0 , \tag{17}$$

Appendix 2 studies analytically the shape of equation (17) for the case where nominal wages are equalised across regions.[17] It shows that three different equilibrium allocations of economic activities are possible, depending on the values of the parameters.

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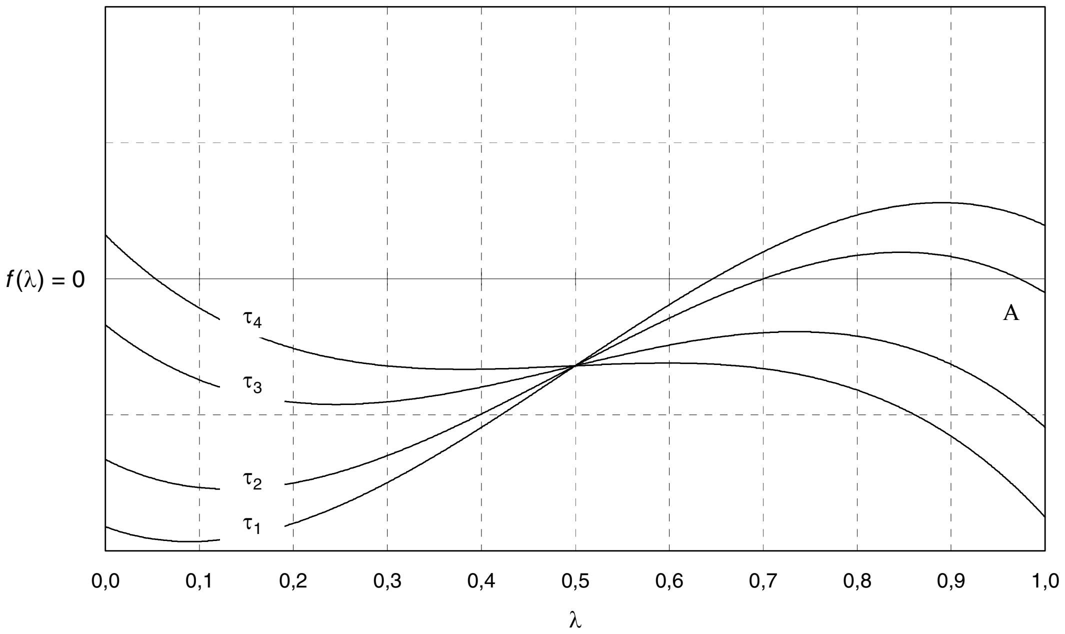
[17] This assumption can be justified on a number of grounds. For example, it could be the result of collective wage fixation at the national level or the outcome of a bargaining over the surplus that workers in each region can obtain by increasing their nominal wages above the level of the other

The first equilibrium realizes for sufficiently high transport costs. In this case it is never beneficial to live in a less-crowded region, and all economic activities end up concentrated in region *A*. In fact, although there exists an equilibrium with productive activities located in both regions that satisfies equation (17), it is unstable: as it is clear from curve τ_1 in figure 1, workers have an incentive to move from region *B* to region *A*, because in this way they increase their level of utility.

Figure 1



The curves are obtained from equation (17), by setting: $\omega = 1$, $\vartheta = 2.88$, $n = 200$, $L_t = 0.98$, $H_t = 0.02$ and $\tau_1 = 1.01015$, $\tau_2 = 1.010$, $\tau_3 = 1.0097$, $\tau_4 = 1.0095$. $f(\lambda)>0$ implies that workers have an incentive to move from region *B* to region *A* (i.e., equation 17 is greater than zero).

Result 2a. *When* $\ln(\tau) > \frac{\vartheta}{n}\ln(2)$, *i.e., the transport costs and the total number of goods produced in the economy are high relative to the congestion cost, the only stable equilibrium occurs when all economic activities are concentrated in one region (curve* τ_1 *in figure 1).*

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region, while keeping it within the boundaries described in footnote 13. Moreover, in all other cases where nominal wages are not equalised but their ratio lies within the boundaries described in footnote 13 it is possible to demonstrate that the qualitative properties of the equilibrium are similar.

With lower transport costs two equilibria with productive activities in both regions become possible, one of which is stable (point A in curve τ_2). Further lowering transport costs, the only possible equilibrium is with research in region *A* and production in region *B*; in this case the real wages adjusted for the congestion costs are always higher in region *B* (see curve τ_3 and remember that it has been assumed that R&D is concentrated in region *A*). Appendix 2 proves the following proposition.

Result 2b. *For* $\ln(\tau) \in \left(\frac{\vartheta}{n} \ln\left(\frac{1+L_t}{1+H_t} \right), \frac{\vartheta}{n} \ln(2) \right)$*, i.e., when the transport costs and the total number of goods produced in the economy are in a medium range relative to the congestion cost and the relative number of workers employed in R&D, two different equilibria are possible: with production in one region and research in the other (curve* τ_2*) or with manufacturing activities unevenly spread in both regions (curve* τ_3*)*

For even lower values of the transport costs only an equilibrium with activities spread across both regions is possible. As it has been argued before, such an equilibrium must necessarily be asymmetric.

Result 2c. *For* $\ln(\tau) < \frac{\vartheta}{n} \ln\left(\frac{1+L_t}{1+H_t} \right)$*, i.e., when the congestion cost is high relative to the transport cost, the total number of goods produced in the economy and the relative number of workers employed in R&D, the only possible equilibrium occurs with activities unevenly spread in both regions (curve* τ_4 *).*

The intuition for these results is the following. Manufacturing workers face a trade-off between the total burdens of transport costs (proportional to the number of goods produced in the region where they live) and the level of the congestion cost. In absence of R&D workers it would always be possible to have an equilibrium where half of the population lives in each region and produces half of the goods for consumption: in this case congestion costs and the burden of transport costs would be exactly equalised. Whether such an equilibrium is stable depends on the usual interaction between the centripetal force (the transport costs) and the centrifugal one (the congestion cost).[18]

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[18] In the standard Krugman-type models such force is instead the demand coming from immobile workers in agriculture.

In presence of R&D firms, which in equilibrium locate all in the same region in order to exploit intra- and inter-industry externalities (result 1), a perfectly symmetric equilibrium is instead impossible. In this case, one of the regions hosts workers that do not produce for final consumption (leaving unchanged the burden of transport costs for those living by them) but at the same time increase the congestion cost. The only possibility is therefore to have an asymmetric equilibrium, with more (less) goods produced where R&D takes place in exchange for a higher (lower) congestion cost. The presence of the R&D activities introduces therefore a further centripetal force that interacts with that due to transport costs. The share of workers employed in research is in this way another key variable determining the geographical allocation of economic activities: a share of workers employed in research favours regional concentration.

When transport costs – relative to the congestion cost – are above a certain level, an allocation with activities spread in both regions is unstable: the benefit from reducing the burden of the transport costs always exceeds the loss of utility caused by the increase in the congestion cost. At the opposite, for sufficient low levels of the transport costs the asymmetric equilibrium with activities spread across both regions is always stable: the benefit from reducing the burden of the transport costs is always lower than the loss of utility caused by the increase in the congestion cost. In the middle range there exists an equilibrium such that research is located in one region and production in the other.

The relationship between geographical allocation of economic activities and the equilibrium rate of growth of total output depends on the interaction of three effects. First, from equation (6) it is clear that when research firms are located in a larger region they benefit from more intense spillovers from the manufacturing sector. Second, from equation (11), R&D firms located in larger regions have a smaller size, and therefore the increase in the marginal productivity of labour brought forward by their discoveries is smaller. Third, given the size of the labour force employed in R&D, a smaller size of each research firm implies a larger number of firms, and therefore higher spillovers.

When the first and the third effects prevail – i.e., the spillovers coming from research firms of the same industry and from manufacturing activities located in the same region are sufficiently large, and the effect of the number of workers employed in research size of research firms on the improvement in labour productivity and on each firm's probability of victory in the R&D race are sufficiently low –, the equilibrium rate of growth of the economy is an increasing function of the size of the region where research is located.

Result 3. *For* $\alpha < \frac{\left(1+L_t^S\right)^{\delta}(1+\beta)-\varepsilon}{\left(1+L_t^S\right)^{\delta}+1}$, *the equilibrium rate of growth of the economy is an increasing function of the size of the region where research is located.*

When the previous condition for a positive relationship between geographical concentration and growth is satisfied, results 2a-2c imply that a reduction in transport relative to congestion costs, favouring the spreading of productive activities across regions, determines a reduction in the equilibrium rate of growth of the overall economy. However, once the low transport costs equilibrium described in result 2c is reached, further reductions in transport costs determine an enlargement of the region where research is located, and therefore an increase in the rate of growth of the economy.

4 Discussion and Conclusions

The model presented above has a number of implications that might be of some interest also from a normative point of view. A first set of issues relates to the option for policy interventions. Within the framework of the model, policies that increase welfare are only possible to the extent that they favour the location of research activities in the larger regions, where they can benefit from more intense spillovers from the manufacturing sector. The clustering of research in a single region, an obvious outcome of the assumption that firms consider the effect of the presence of local knowledge spillovers, has the straightforward implication that the geographical equilibrium has no other effects on the equilibrium rate of growth of the economy than those coming from neglected spillovers from the manufacturing sector.[19] Finally, it is easily seen that the concentration of research activities has the further effect of causing an uneven distribution of per-capita income

[19] I am not considering dynamic efficiency, related to the optimal level of research. On this issue the model presented here share the conclusions of Aghion and Howitt (1992) and Grossman and Helpman (1991).

whenever the nominal wages of skilled workers are higher than those of unskilled workers (as it happens if human capital accumulation is costly and agents decide optimally whether to undertake it or not) the region which hosts the R&D activities will be richer than the other.

A second set of issues relates to the effects of changes in the parameters determining the geographical equilibrium. As it has been shown above, the clustering of R&D firms in one region introduces a new centripetal force in addition to the transport cost, making a symmetric allocation of economic activities impossible. Moreover, starting from an asymmetric equilibrium with activities located in both regions, a reduction in the congestion cost may determine a clustering of economic activities in a single place. Although this would be optimal from the agents' point of view, if policy makers have a preference for a more even spatial distribution of the population they could prefer not to adopt policies aiming at reducing the cost of living in more populated regions, unless this is accompanied with a reduction of the transport cost.

A third aspect relates to the relationship between the geographical equilibrium and the equilibrium rate of economic growth. When the localized knowledge spillovers within the research sector and those coming from manufacturing are sufficiently large, the equilibrium rate of growth of the economy is an increasing function of the size of the region where research is located, and of the transport costs relative to the congestion cost.

Finally, in the model proposed above also the share of population employed in research affects the equilibrium allocation of economic activities. With the increase in the share of educated workers that has taken place in advanced countries in the last decades, this might introduce a further reason for geographical concentration. This can be reasonably counterbalanced only by a reduction in transport costs.

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 the conditions imposed by Bertrand competition by a non-winning firm producing in the same region (equation (8) in the text), or in the foreign market, are both satisfied: $P_{t+1}^{A}(i) \le \frac{W_{t+1}^{LA} l_{t+1}^{A}(i)}{\rho_t(i)\left[l_{t+1}^{A}(i) - \kappa\right]}$ and $P_t^A(i) \le P_t^B(i)\tau$. Substituting the first expression into the second, it becomes clear that if $W_t^{LA}(i) > W_t^{LB}(i)\tau$, the leading firm would prefer to move production to *B*. A symmetric argument applies for manufacturing firms locating in *B*. The following relationships between nominal wages must hold in order to have manufacturing firms in both regions: $\frac{W_t^{LB}}{\tau} < W_t^{LA} < W_t^{LB}\tau$.

Appendix 2

Setting ω = 1 in equation (17) in the text and remembering that we have assumed $L_t + H_t = 1$, one obtains: $g(\lambda_t) \equiv \left[\frac{1 + (1-\lambda)L_t}{1 + \lambda L_t + H_t}\right]^{\frac{\vartheta}{n_t}} \tau^{2\lambda_t - 1} = f(\lambda_t) + 1$. Define, for the ease of notation, $h(\lambda_t) \equiv \frac{3\vartheta L_t}{n_t\left[2 + L_t(\lambda_t L_t + H_t)(1-\lambda_t)\right]}$, where $g'(\lambda_t) = g(\lambda_t)[2\ln\tau - h(\lambda_t)]$ and $g(\lambda_t) > 0 \ \forall \lambda_t$.

Note that $g(\lambda_t)$, $g'(\lambda_t)$ and $h(\lambda_t)$ are all continuous for $\lambda_t \in [0,1]$; $h(\lambda_t)$ has a minimum for $\lambda_t = \frac{L_t - H_t}{2L_t}$ and a maximum for $\lambda_t = 1$. It is then possible to establish the first set of conditions:

c.1 $g'(\lambda_t) > 0 \ \forall \lambda_t$ if and only if $2\ln(\tau) > h(1) = \frac{3\vartheta L_t}{2n_t}$;

c.2 $g'(\lambda_t) < 0 \ \forall \lambda_t$ if and only if $2\ln(\tau) < h\left(\frac{L_t - H_t}{2L_t}\right) = \frac{4\vartheta L_t}{3n_t}$;

c.3 for $2\ln(\tau)\in\left[h\left(\dfrac{L_t-H_t}{2L_t}\right),h(1)\right]$ and $0<\hat{\lambda}<\overline{\lambda}<1$, $g'(\lambda_t)$ is either positive or negative for $\lambda_t\in\left(0,\hat{\lambda}\right)$, $g'(\lambda_t)>0$ for $\lambda_t\in\left(\overline{\lambda},\hat{\lambda}\right)$, because $\log(\tau)<h\left(\dfrac{L_t-H_t}{2L_t}\right)$ as otherwise we would be in case (c.2), and $g'(\lambda_t)<0$ for $\lambda_t\in\left(\overline{\lambda},1\right)$, because $h(1) < \log(\tau)$ as otherwise we would be in case (c.1).

The next step is to consider the signs of $g(0)$ and $g(1)$ for different levels of the parameters. After some algebra, a second set of conditions can be established:

c.4 for $\ln(\tau)>\dfrac{\vartheta}{n_t}\ln(2)$, $g(0)<1$, $g(1)>1$;

c.5 for $\ln(\tau)<\dfrac{\vartheta}{n_t}\ln\left(\dfrac{1+L_t}{1+H_t}\right)$, $g(0)>1$, $g(1)<1$;

c.6 for $\log(\tau)\in\left[\dfrac{\vartheta}{n_t}\ln\left(\dfrac{1+L_t}{1+H_t}\right),\dfrac{\vartheta}{n_t}\ln(2)\right]$ $g(0)<1$, $g(1)<1$.

Results 2*a* to 2*c* in the text follow from previous conditions:

– condition (c.4) implies that $g(\lambda_t)$ must be increasing in some range in order to go from a negative to a positive value. From previous analysis we know that in order to have $g'(\lambda_t) > 0$ for $\lambda_t \in [0,1]$ it must either be the case that $g'(\lambda_t) > 0$ $\forall\lambda_t$ – condition (c.1) – or that $g'(\lambda_t)$ can change sign at most twice, ending negative – condition (c.3). Therefore, in order to have a positive $g(\lambda_t)$ can only cross the *x*-axis once and from below, which proves result 2*a*.
– condition (c.6) and the fact that $g'(\lambda_t)$ can change sign at most twice for $\lambda_t \in [0,1]$, ending negative – condition (c.3) –, imply that $g(\lambda_t)$ can either never cross the *x*-axis or it can cross it twice, which proves result *2b*.

– when condition (c.5) is satisfied $g(\lambda_t)$ can only cross the x-axis once and from above, because condition (c.5) implies condition (c.2), as $\log\left(\frac{1+L_t}{1+H_t}\right) < h\left(\frac{L_t - H_t}{2 - L_t}\right)$ $\forall L_t, H_t \in [0,1]$; this proves result *2c*.

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