

## The Spatial Diffusion of Innovations and the Evolution of Regional Disparities<sup>1</sup>

Ugo Fratesi<sup>2</sup>

**ABSTRACT:** This paper investigates the concurrent effects on regional disparities of the speeds of innovation and of the spatial diffusion of knowledge. The aim is to investigate whether an increase in the pace of innovation, identical in all regions, due to exogenous factors such as the «technological revolution» or policies targeting the «innovative effort» of territories, can give rise to increased disparities. In order to answer these questions, the paper focuses on the role of interregionally shared knowledge and shows that, due to the cumulativeness of knowledge, making the same innovative effort is not enough to maintain the same income *per capita*. Moreover, the speed of innovation is not the only determinant, because a role of equal importance is played by the ease of interregional knowledge diffusion. To support this argument, first a new simple static model is built to extend symmetrically existing north-south models of trade and to rigorously represent the actual producers of goods whose production technique is shared between regions. Then, building on the first model, two reduced forms for the dynamics of innovation and diffusion flows are introduced - one probabilistically, the other with multiple equilibria. These lead to the same conclusion: an increase in the pace of innovation, even with structurally identical regions, may generate regional income disparities if knowledge is cumulative and spillovers are essentially local. It is finally shown, however, that the divergence effect of increased innovation pace can be counterbalanced by an increase in the speed of spatial knowledge diffusion.

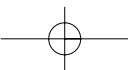
**JEL classification:** R13, R58, O3.

**Key words:** Spatial innovation diffusion, regional disparities, technological spillovers, ICTs.

<sup>1</sup> Comments by Roberta Capello, Giuliano Conti, Henri L. F. de Groot, Massimo Tamberi and two anonymous referees are gratefully acknowledged.

<sup>2</sup> Department of Management, Economics and Industrial Engineering, Politecnico di Milano, piazza Leonardo da Vinci, 32, 20133 Milano, Italy. Telephone: +39-(0)2-2399-3966. Fax: +39-(0)2-2399-2710. E-mail: ugo.fratesi@polimi.it.

*Recibido: 15 de noviembre de 2006 / Aceptado: 27 de septiembre de 2007.*



## La difusión espacial de la innovación y la evolución de las disparidades regionales

**RESUMEN:** Este trabajo investiga los efectos que concurren a la formación de las diferencias regionales en términos de velocidad de la innovación y de difusión territorial del conocimiento. El objetivo es investigar si un aumento en el ritmo de la innovación, idéntico en todas regiones y debido a factores exógenos tales como la «revolución tecnológica» o las políticas que fomentan el «esfuerzo innovador» a nivel regional, pueden ocasionar disparidades mayores. Para contestar a estas preguntas, la investigación se enfoca en el papel que juega el conocimiento compartido entre diferentes territorios y muestra que, debido al conocimiento acumulado y a paridad de esfuerzo innovador, no se mantienen los mismos ingresos *per capita*. Además, la velocidad de la innovación no es el único factor determinante, porque la facilidad de difusión del conocimiento a través del territorio, también juega un rol de igual importancia. Para apoyar esta idea, primero se construye un nuevo y simple modelo estático que amplía simétricamente los modelos conocidos de comercio Norte-Sur y que identifica a los verdaderos productores de bienes cuya técnica de producción es patrimonio de las dos regiones. Después a partir del primer modelo, se introducen dos formas reducidas que van a representar los flujos dinámicos de la innovación y de la difusión —una con un método probabilístico y la otra con un método multi-equilibrio—. Las dos formas reducidas llevan a la misma conclusión: el aumento en el ritmo de la innovación, aún en regiones idénticas estructuralmente, puede generar disparidades regionales en los ingresos *per capita*, si la acumulación del conocimiento y el spillover son esencialmente locales. Finalmente resulta que el efecto de divergencia del mayor ritmo en la innovación puede ser contrarrestado con un aumento en la velocidad de la difusión territorial del conocimiento.

**Clasificación JEL:** R13, R58, O3.

**Palabras clave:** Innovación, difusión, disparidades regionales, *spillovers* tecnológicos, TICs..

## 1. Introduction

According various authors, the pace of technology increased in the past century. In particular, Freeman and Soete (1997) and Freeman and Louça (2001) note that innovation itself has changed from being the outcome of initiatives by inventors or individual Schumpeterian entrepreneurs to being mostly the outcome of specifically designed R&D departments of companies and firms. In this context, comparative advantage in terms of material resources is no longer the main factor explaining the differentials of income among territories (Dollar, 1993). The main cause of competitive advantage, for both firms and regions, has become the ability to produce and reproduce technical knowledge (Porter, 1998; Boschma, 2004).

For this reason, the attention of scholars has increasingly focused on the contexts, sometimes termed «Systems of Innovation», in which innovative activities take place

(Lundvall, 1992, Edquist, 1997; Cooke *et al.*, 1998; Cooke *et al.*, 2004). Also, more orthodox economic theorists have successfully made innovation the specific growth engine of their models (Romer, 1990; Grossman and Helpman, 1991; Martin and Ottaviano, 2001), especially in order to move away from the old idea of decreasing returns (Pomini and Todini, 2006).

Innovation is a difficult process to export from one place to another, owing to its unique characteristics. For this reason, now that technology has become the most important factor in competition among countries and regions, interest has grown in development policies targeting R&D (Rodríguez-Pose, 2001).

Among the characteristics of technology (Dosi, 1988; Fagerberg *et al.*, 2005), those that appear to have played the principal role in inducing regional disparities are *tacitness*, since not everything can be blueprinted and hence easily transmitted elsewhere, and *cumulativeness*, since new technology can only be built upon previously existing technology, and not all regions are endowed with the same pre-existing stock of knowledge (Asheim and Gertler, 2004; Malerba, 2006; see also Simmie, 2006 for a discussion of the relationship between space and innovation).

The focus on knowledge creation, however, should not obscure the fact that — as opposed to an ordinary physical factor of production — knowledge itself can, in theory, be used in many different places and productions at the same time. For this reason, *innovation* (for my purposes here defined as the creation of new knowledge) is only a part — albeit a crucial one — of the mechanism of knowledge creation. *Imitation* (the acquisition of external knowledge through devoted efforts) and *diffusion* (the non-costly, spontaneous acquisition of external knowledge) also play essential roles (Coe and Helpman, 1995; Coe *et al.*, 1997). If, for example, the diffusion of technology were instantaneous (and not protected by some form of patenting or by any obstacle to learning), the physical place in which innovation occurs would be irrelevant. But since knowledge is «sticky», the location is relevant, but the extent of this relevance depends on the speed of spatial diffusion.

In the past fifteen years especially, this issue has been affected by the expansion of the information and communication technologies (ICTs), which have made the transfer of blueprinted knowledge from one place to the other easier, faster and much less expensive (Cairncross, 1997). This, however, is not the whole story, for in order to use this knowledge, it is always necessary to contextualize it: there is, in fact, the need for someone with the ability to interpret such knowledge and apply it to produce growth (Rodríguez-Pose, 1999; Bilbao Osorio and Rodríguez-Pose, 2004; Malmberg and Maskell, 2006).

Using a simple classification model, this paper investigates the interaction between the creation and diffusion of technology in order to detect their effects on regional disparities. It will show that an increase in the pace of innovation, such as the one that took place in the twentieth century, can engender regional income disparities. If, conversely, the speed of diffusion also increases to a sufficient extent, these disparities may disappear.

However, I shall not join the ongoing debate on advances in the ICTs and the «New Economy», and whether they will reduce disparities or lead to the «death of

distance», for, as Gillespie *et al.* (2001, p.110) noted, «*communication technologies should not be seen as simply pulling the balance of centrifugal and centripetal forces in one direction at the expense of the other, but rather as simultaneously strengthening both*».

Within this framework, the second question to address concerns policy for innovation and its effects on regional disparities. Assuming that a policy for competitiveness intends to increase expenditure on innovation or the number of researchers uniformly in all regions, the question arises as to whether this will bring about the same increase of welfare in all regions, or whether some regions will end up being richer than others.

To address these research questions, I use a two step procedure. I shall first build a base model that concentrates on location and technology as the causes of regional income disparities, without modelling growth and physical capital accumulation. The model is static, in the sense that all factors are fixed, included knowledge. For this reason the model is a useful simplification of models of growth with innovation (following Grossman and Helpman, 1991, amongst others) and, at the same time, a symmetric extension to North-South models of trade *à la* Krugman (1979) (Chui *et al.*, 2002, for a review). The model has some interesting features. For instance, it treats the knowledge shared by the two regions as a separate set. For this reason, it is a good base over which to able rigorously and separately to represent, rigorously and separately, bi-directional processes of spatial technological diffusion like those that exist between regions.

As a second stage in the argument, dynamics will be introduced through knowledge creation, obsolescence and interregional flows of knowledge. The static base model will be used in two ways to study innovation and diffusion mechanisms. There will be local spillovers in both cases, but the part of local knowledge upon which new knowledge is built will differ. Moreover, the extent of interregional spillovers will be allowed to vary.

With the use of both stages, I shall show that the most important factor determining the existence of income disparities is the ratio between the speed of spatial diffusion of knowledge and the speed of innovation. In particular, when the ratio is low, the model predicts an equilibrium with technology and income disparities. There will be technology disparities for intermediate values, but they will not be wide enough to generate income disparities. For higher values, technological disparities will disappear, and, consequently, income disparities will no longer exist.

The paper is organized as follows: Section 2 sets out the base static model, which extends north-south models by allowing symmetry and eliminating *a priori* differentiation between the regions in order to show the possible effects of technological differences on regional disparities. In section 3, dynamics is introduced in order to study the concurrent effects of innovation, obsolescence and imitation on the technological differences and, consequently, on regional income disparities. This is done in two complementary ways: first (Section 3.1) with probabilistic outcomes, and then (Section 3.2) with the representation of more complex and realistic dynamics that—now in terms of multiple equilibria— exhibit the effects of the parameters, and in

particular of the ratio between speed of innovation and speed of spatial diffusion, on regional income disparities. The last section draws some preliminary policy consequences from the exercise.

## 2. A base model

It is generally argued that, in the present economy, regional growth and regional income disparities cannot be simply explained by traditional endowments and accumulation of capital and labour. A very important role is also played by different regional endowments of knowledge and differing abilities to use that knowledge and create it through innovation (Cheshire and Makecki, 2004).

This section accordingly introduces a simple static model to illustrate how different knowledge endowments can generate income disparities between regions when there is no or low mobility of workers. When the differences of technological capabilities are low, however, one would not expect them to be able to introduce significant differences in income *per capita*, because they can be off-set with adjustments in the use of the available production factors. But when the technological differences are sufficiently wide, it is difficult to remedy them with a different use of labour and capital, and income disparities are likely to appear. This is considered by the model, which shows that in order to generate disparities, the existence of technological differences is not enough; it is also necessary that those differences lie above a certain level.

Positive transport costs, in this model, have the effect of making the incomes of the regions more similar, even if the effect on aggregate welfare is negative, as will be shown at the end of this section.

The model is built upon intuitions present in Krugman (1979), Dollar (1986), and Grossman and Helpman (1991) amongst others, but it has an advantage over this literature in that it is able to rigorously separate, within a symmetric framework, both the common knowledge and the technology which is the exclusive property of one region or the other.

The model is based on the following assumptions, all of them designed to be compatible with the present European situation.

First it is assumed that workers are interregionally immobile. This hypothesis is strong and necessary for the results of the model, but it is justified by the evidence available. In fact, especially in the short and medium run, labour is very sticky, both between countries and within countries, and especially so in Europe where only small percentages of citizens are born in a country different from the one in which they live (Puga, 2002). Moreover, it has been shown that the effects of the mobility of workers on regional disparities is not necessarily one of convergence (Kanbur and Rapoport, 2005; Fratesi and Riggi, 2007). Hence changing this (realistic) hypothesis would require a much more complex framework in which labour is not homogeneous, without necessarily changing the outcomes of the model. The immobility of workers can be expressed analytically by the following:

**Hypothesis 1.** *The economy is composed of two regions A and B, with respective fixed endowments of workers  $L_a$  and  $L_b$ .*

The second hypothesis concerns the nature of technology: the production of certain goods requires specific abilities that are not easily transferable because, for example, they can be only acquired through learning by doing. The same holds if new varieties of goods are supposed to be the outcome of a patenting process which gives the firms exclusive rights on the production of those goods, and if individual firms are unable to shift their productions to other regions taking their abilities with them.

A model linking technology and regional income disparities will consequently have to account for the fact that not all the production techniques are common knowledge within both regions. Rather, some of them are «exclusive» to one region and others are «exclusive» to the other.

Indicating with  $N_a$  the number of varieties that can only be produced in A (hereafter those «exclusive» to A), with  $N_b$  the number of varieties that can only be produced in B (hereafter those «exclusive» to B) and with  $N_c$  the number of varieties that can be produced in both regions (hereafter «common»), this second hypothesis can be formalized as follows:

**Hypothesis 2.** *The technology is composed of a given number  $N$  of varieties of goods, with  $N = N_a + N_b + N_c$ .*

As in all models, a production function has to be defined. To keep the model simple, only one production factor (namely labour) is modelled, plus technology. Since innovation is not included in the model at this stage, but will be included in the second part of the paper, technology in the production function can be reduced to a binary option: whether or not the technology needed to produce a given good in the region is available. The returns to scale are assumed to be constant, in order to have neutral influence on the outcome of the model. All this can be summarized by the following:

**Hypothesis 3.** *The production technique for a variety ( $i = 1..N$ ) produced in region ( $j = a, b$ ), is:*

$$q_{ij} = l_{ij} I_{ij} \quad [1]$$

where  $q_{ij}$  is the quantity produced,  $l_{ij}$  is the labour employed and  $I_{ij}$  is an indicator which assumes value 1 when the production technique of variety  $i$  is known in region  $j$  and is equal to 0 when, on the contrary, the production technique of  $i$  is not known in region  $j$ .

An useful generalization is to assume that there is no correspondence between the number of workers and the population of the region. In fact, the regional income *per capita* depends on the productivity of workers as well as on the ratio of workers to total population. The activity rate and the employment rate are therefore important determinants of income *per capita*, and are consequently targeted by policies. For example, the Lisbon European Council of March 2000 set the objective of raising the overall employment rate in the European Union to 70% and the female employment rate to more than 60% by 2010. This assumption can be formalized by the following:

**Hypothesis 4.** *Only a quota of workers  $1 - r_j$  is involved in production in region  $j$ .*

Where  $r$  (which denotes «retired») represents all inactive members of the population, so that GDP is calculated *per capita*, not per employee.

Finally, there is no reason to assume different utility functions across regions, and some love of love for variety can plausibly characterize them. To simplify the model, it is assumed that all the varieties consumed enter the utility function symmetrically. This can be formalized by:

**Hypothesis 5.** *The utility function for all consumers/households in both regions is:*

$$U = \left[ \int_0^N q_i^\rho \right]^{\frac{1}{\rho}}, \text{ with } 0 < \rho < 1 \quad [2]$$

where  $q_i$  is the quantity consumed of each good. The love for variety hypothesis is necessary for the results of the model, but even a small degree suffices: i.e.  $\rho$  can be close to 1.

Moreover, price discrimination will not be allowed and, since no capital exists in the model, all revenue goes to workers through wages.

As a first step, we begin by assuming that there are no transport costs, so that all the consumers in both regions can buy the same products. This simplifying hypothesis will be relaxed later; and we will also be able to observe the changes in the model's results entailed by this relaxation.

When transport costs are null, each consumer/household, in either region, having the same utility function, will maximize its welfare by choosing the same varieties in the same proportion. Moreover, since there is love for variety and symmetry, consumers will demand the same quantity of all the varieties produced in the economy if the prices are equal. The prices, however, will not always be the same for varieties produced in different regions, owing to technological constraints on the production side.

In fact, on the supply side, the joint effect of concurrence and constant returns to scale would make it profitable to produce the same amount of each variety in each region, if all the production techniques were commonly known. However, regions may differ in their levels of technological advancement, so that the most advanced productions cannot be easily be delocalized. In formal terms (hypothesis 2), the varieties  $N_a$  can only be produced in  $A$ ; the varieties  $N_b$  can only be produced in  $B$ . The  $N_c$  common varieties can be produced in both regions, and a market mechanism hence allocates their production, as illustrated below.

When there is no large difference in technology level between one region and the other, the market will allocate the labour factor among the different products/varieties whose production is possible within the regions, so that each variety existing in the economy (belonging to either  $N_a$ ,  $N_b$  or  $N_c$ ) will be produced in the same amount and sold at the same price. If we indicate with  $N_{ca}$  and  $N_{cb}$  the common varieties respectively produced in  $A$  and  $B$  ( $N_{ca} + N_{cb} = N_c$ ), these values will be determined by the equation:

$$\frac{(1-r_a)L_a}{N_a + N_{ca}} = \frac{(1-r_b)L_b}{N_b + N_{cb}} \quad [3]$$

Equation [3] means that, if the two regions A and B were of equal size in terms of active population and the differences of technology endowments were small enough, they would produce the same amount of each of all their own varieties. Moreover, since the production function is linear, it is unimportant how the common varieties are allocated: it may be that some are only produced in one region and some in the other, or that they are partly produced in A and partly in B, or any combination of these two hypotheses which respects the aggregate ratio of quantity of common varieties produced in region A with respect to region B.

When one region (say B) is sufficiently more technologically advanced than the other, i.e., in formal terms, when the number of varieties which can be only produced in B ( $N_b$ ) is sufficiently high with respect to  $N_a$  and  $N_c$ , it will be profitable for B workers (or for B firms hiring B workers, which is equivalent in the model) to exit from the production of the common varieties. These latter will continue to be produced only in the less technologically advanced region (A), with the more technologically advanced one (B) focusing on the most advanced productions, i.e. producing only its  $N_b$  exclusive varieties. In formal terms, this happens when the following condition holds:

$$\frac{L_b(1-r_b)}{N_b} < \frac{L_a(1-r_a)}{N_a + N_c} \quad [4]$$

It is now possible to show that, in this model, as one would assume from common sense, the income *per capita* positively depends on the technological ability of the regions and negatively on the proportion of workers not involved in production.

When condition 4 is satisfied, in fact, indicating with  $q_a$  and  $q_b$  the amounts demanded of goods produced in A and B, owing to the rationing of quantities, the price will be determined by consumer maximization, which will be the same in both regions:

$$MaxU = \left[ \int_0^{N_a+N_c} q_a^p + \int_0^{N_b} q_b^p \right]^{\frac{1}{p}} \quad [5]$$

under the constraint:

$$q_a(N_a + N_c) + Pq_bN_b = M \quad [6]$$

Using the price normalisation  $P_a = 1$ ,  $P_b \equiv P \equiv \frac{P_b}{P_a}$  and indicating with  $M$  the amount of money possessed by the individuals.



By solving the utility maximization problem, we can obtain the unique equilibrium price:

$$P = \left( \frac{L_a}{L_b} \right)^{1-\rho} \left( \frac{1-r_a}{1-r_b} \right)^{1-\rho} \left( \frac{N_b}{N_a + N_c} \right)^{1-\rho} \quad [7]$$

Once the relative prices have been obtained, it is easy to calculate the aggregate nominal welfare of the two regions:

$$W_a = (N_a + N_c)q_a = (1-r_a)L_a \quad [8]$$

$$W_b = PN_bq_b = \left( \frac{L_a}{L_b} \right)^{1-\rho} \left( \frac{1-r_a}{1-r_b} \right)^{1-\rho} \left( \frac{N_b}{N_a + N_c} \right)^{1-\rho} (1-r_b)L_b \quad [9]$$

Which yields the following formula for the ratio between the GDPs:

$$\frac{W_b}{W_a} = \left( \frac{L_b}{L_a} \right)^\rho \left( \frac{1-r_b}{1-r_a} \right)^\rho \left( \frac{N_b}{N_a + N_c} \right)^{1-\rho} \quad [10]$$

The economic size of a region is hence relatively larger when it has a larger population (but this effect decreases as the love for variety effect increases). Its economic size is also relatively larger when it is more technologically advanced; contrary to the previous effect, this effect increases as the love for variety increases.

Although not more productive in terms of quantities produced, labour in the more advanced region will be better paid in nominal and real terms by means of the price mechanism. This is because the labour of A and B workers is only substitutable for the common varieties, and it is not possible to move the production of exclusive varieties elsewhere. The ratio between *per capita* incomes will in fact be:

$$\frac{y_b}{y_a} = \frac{W_b}{L_b} \frac{L_a}{W_a} = \left( \frac{1-r_b}{1-r_a} \right)^\rho \left( \frac{N_b/L_b}{(N_a + N_c)/L_a} \right)^{1-\rho} \quad [11]$$

If we take joint account of the dispersed case of equation [3], the agglomerate/specialised case of equation [4] and its symmetric, the relative wage of the two regions will be:

$$\frac{y_b}{y_a} = \begin{cases} \left( \frac{1-r_b}{1-r_a} \right)^\rho \left( \frac{N_b/L_b}{(N_a + N_c)/L_a} \right)^{1-\rho} & \text{if } \frac{L_b(1-r_b)}{N_b} < \frac{L_a(1-r_a)}{N_a + N_c} \\ \left( \frac{1-r_b}{1-r_a} \right)^\rho \left( \frac{(N_b + N_c)/L_b}{N_a/L_a} \right)^{1-\rho} & \text{if } \frac{L_a(1-r_a)}{N_a} < \frac{L_b(1-r_b)}{N_b + N_c} \\ 1 & \text{otherwise} \end{cases} \quad [12]$$

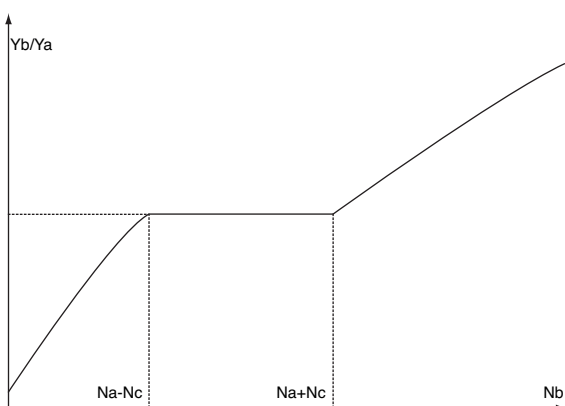
As conjectured, the relative income of the two regions positively depends on their endowment of varieties *per capita* and negatively depends on the proportion of workers not involved in production.

The effect of the relative technological advancement of one region on its income *per capita*, represented by  $N_b$  and  $y_b/y_a$ , is depicted by figure 1. The relation between regional technological disparities and *per capita* income disparities, although not discontinuous, will not be increasing, but just non-decreasing. for there will be a certain range of technological disparities which do not entail income disparities because of the existence of shared knowledge. This is due to the adjustments in the prices and use of production factors which enable the less technologically endowed region to compensate with a relatively higher availability of labour.

Outside this interval, the relation is increasing, and the more different the number of varieties *per capita*, the larger the wage difference.

The outcome of the model is therefore consistent with that obtained by Krugman (1979) but, since it takes into two structurally identical regions account, this model can be used to study inter-regional disparities within countries. In fact this model is symmetric and avoids the north-south dichotomy by allowing each region to have its own exclusive varieties. Moreover, the market equilibrium is made to depend on a number of parameters. For example, it is possible to represent regions of different sizes or activity rates.

**Figure 1.** Relation between the number of varieties possessed in B and the relative incomes for given  $N_a$  and  $N_c$



In economic terms, if consumers have a greater love for variety, i.e. are reluctant to substitute one product with another more abundant, they will be keen to pay more for the scarcer goods, in particular for the most technologically advanced ones that can only be produced in particular locations. When high level productions cannot be delocalized to poorer regions, and consumers' demand for these products is high, it is

likely that the productions of these goods will have wider margins, and also that the wages paid to workers will be high.

To verify whether the model complies with this intuition, the effect of love for variety ( $\rho$ ) in equation 12 can be investigated: it has no effect on the width of the flat trait of the curve of figure 1; outside this, it changes curvature and we can prove that the greater the love for variety (the smaller the  $\rho$ ), the wider the income disparities. In fact, assuming  $r_a = r_b$  for simplicity, we find that the derivative of the disparity with respect to  $\rho$  is always negative:

$$\frac{\partial(y_b/y_a)}{\partial\rho} = -\left(\frac{N_b/L_b}{(N_a + N_c)/L_a}\right)^{1-\rho} \ln\left(\frac{N_b/L_b}{(N_a + N_c)/L_a}\right) < 0 \quad [13]$$

This means that the greater the love for variety, the wider the income disparities for any level of technology gap, as assumed.

Now to be studied is the effect of a transport cost parameter. This is a little more cumbersome. Readers not directly interested in the proofs can skip to section 3, bearing in mind that the introduction of transport costs into this model yields results which are quite widely reported in the recent economic geography literature, since positive transport costs have negative aggregate welfare effects but reduce the disparities between the regions.

When the hypothesis of null transport costs is removed, the utility functions of households in the two regions become different, and it is no longer the case that all the varieties are demanded and consumed in equal proportions in both regions. The easiest way to introduce transport costs — and which is the method most commonly used in the literature — is to assume iceberg transport costs, i.e. to represent with a  $t < 1$  the amount of goods shipped from one region to another that reach their destination.

With competitive markets, there will again exist a relative price for the goods produced in region *B* with respect to those produced in *A*. Since, however, the goods involved in the utility maximization will have different proportions depending on the region, I shall use the notation  $q_{ij}$  to indicate the amount of goods produced in region *i* (*A*, *B*) and consumed in region *j* (*A*, *B*).

Under the competitive markets hypothesis, there will be complete specialization, with region *A* producing all the common (*C*) varieties only when the consumers of both regions find it more convenient to buy these goods from *A*, i.e. when the two following conditions apply simultaneously (note the similarity with equation 4):

$$t \frac{L_b(1-r_b)}{N_b} < \frac{L_a(1-r_a)}{N_a + N_c} \quad \text{for A, and} \quad \frac{L_b(1-r_b)}{N_b} < t \frac{L_a(1-r_a)}{N_a + N_c}, \quad \text{for B}$$

Because  $t < 1$ , the conditions above are simultaneously satisfied when:

$$\frac{L_b(1-r_b)}{N_b} < t \frac{L_a(1-r_a)}{N_a + N_c} \quad [13]$$

142 Fratesi, U.

This equation shows that the case of complete specialisation (i.e. all common varieties are produced in the less advanced region) becomes less probable when transport costs increase (and indeed, when  $t = 0$ , each region will produce all common varieties without regard to any other parameter). In fact, the least advanced products can normally be more cheaply produced in the least technologically advanced region owing to the relative abundance of labour. However, consumers in the more advanced regions would also need to pay the transport costs, which, if sufficiently high, may make it inconvenient for them to buy products from lagging regions, even if the production price of the former is lower.

In case of complete specialization, with region B more technologically advanced (the opposite case is symmetric), consumers of region A will maximize their utility as follows:

$$\text{Max}U_A = \left[ \int_0^{N_a+N_c} q_{aa}^\rho + \int_0^{N_b} q_{ba}^\rho t^\rho \right]^{\frac{1}{\rho}} \quad [15]$$

under the constraint:

$$q_{aa}(N_a + N_c) + Pq_{ba}N_b = q_{aa}(N_a + N_c) + q_{ab}(N_a + N_c) = (1 - r_a)L_a \quad [16]$$

The utility maximization allows one to obtain the price needed for equilibrium in A:

$$P = \left( \frac{q_{ba}}{q_{aa}} \right)^{\rho-1} t^\rho \quad [17]$$

In B a similar utility maximization will take place:

$$\text{Max}U_B = \left[ \int_0^{N_a+N_c} q_{ab}^\rho t^\rho + \int_0^{N_b} q_{bb}^\rho \right]^{\frac{1}{\rho}} \quad [18]$$

under the constraint:

$$q_{ab}(N_a + N_c) + Pq_{bb}N_b = q_{ba}(N_b) + q_{bb}(N_b) = (1 - r_b)L_b \quad [19]$$

By solving the maximization in the same way as for A, we obtain the price needed for market equilibrium in B:

$$P = \left( \frac{q_{bb}}{q_{ab}} \right)^{\rho-1} t^{-\rho} \quad [20]$$

The global equilibrium is the solution of a system of 6 equations (of which only 5 are independent) in 5 unknowns (the 4 quantities plus the equilibrium price). This system can be made simpler by adopting the following change of notation:

$$\begin{aligned}
 q_{aa} &\equiv \alpha q_a = \alpha \frac{(1-r_a)L_a}{N_a + N_c} \\
 q_{ab} &\equiv (1-\alpha)q_a = (1-\alpha) \frac{(1-r_a)L_a}{N_a + N_c} \\
 q_{ba} &\equiv \beta q_b = \beta \frac{(1-r_b)L_b}{N_b} \\
 q_{bb} &\equiv (1-\beta)q_b = (1-\beta) \frac{(1-r_b)L_b}{N_b}
 \end{aligned}$$

With this new notation, equation 17 becomes:

$$P = \left( \frac{\beta}{\alpha} \frac{N_a + N_c}{N_b} \frac{(1-r_b)L_b}{(1-r_a)L_a} \right)^{\rho-1} t^\rho \quad [21]$$

And equation 20 becomes:

$$P = \left( \frac{1-\beta}{1-\alpha} \frac{N_a + N_c}{N_b} \frac{(1-r_b)L_b}{(1-r_a)L_a} \right)^{\rho-1} t^{-\rho} \quad [22]$$

The two constraints 16 and 19 become identical and equal to:

$$(1-\alpha)(1-r_a)L_a - \beta(1-r_b)L_b P = 0 \quad [23]$$

Equations 21, 22 and 23 now form a system of three equations in three unknowns:  $\alpha$ ,  $\beta$  and  $P$ . Unfortunately, the analytical solution to this non-linear system does not exist; nevertheless, something can be said about the effects of transport costs on consumption within the two regions.

As a first step, recall that when transport costs are null ( $t = 1$ ), the consumers in the two regions will consume the goods in the same proportion, that is,  $\alpha = \beta$ . By joining equations 21 and 22 it is also possible to obtain the function that links  $\alpha$  and  $\beta$ :

$$\frac{1-\alpha}{\alpha} t^{\frac{2\rho}{\rho-1}} = \frac{1-\beta}{\beta} \quad [24]$$

Equation 24 verifies that the composition of consumption is identical in all regions with null transport costs (i.e.  $\alpha = \beta$  when  $t = 1$ ), and it also states that (as is intuitively evident), as the transport costs increase ( $t$  decreases) the consumers in each region will shift their consumption towards domestic products because imported goods become less convenient. Finally, an increase in love for variety (a decrease in  $\rho$ ) reduces the effect of an increase in transport costs on the consumption shift, because

the willingness of consumers to pay for a differentiated consumption basket, including imported goods, is higher.

As a second step, using a linear approximation around  $t = 1$ , one can also study the effect of the introduction of transport cost on prices. When, in fact,  $t$  shifts from 1 to  $1 - \varepsilon$ , the variation of price will be:

$$\delta P = \varepsilon P_0 \rho [-1 + 2\rho (1 - \alpha_0)(2\alpha_0 - 1)] \quad [25]$$

When, for example, B is the richest region without transport costs,  $P_0 > 1$  and  $\alpha_0 < 1/2$ . In this case  $\delta P$  is negative, implying that, with the introduction of positive transport costs, regional disparities decrease. In fact, however, the difference in price is due to the effect of love for variety. In this framework, positive transport costs actually have the effect of introducing a bias in favour of home products. This makes the demand functions of the two regions different, so that it is less convenient for the less advanced region to demand and consume the products of the more advanced region. Additionally, this causes a decrease in the (relative) price of the products of the most advanced region.

The boundary case of no love for variety ( $\rho = 1$ ) is also interesting, since, in this case, for  $t = 1$  in each region any amount whatever of varieties produced in either region is consumed. However, when even very small transport costs exist, each region will immediately shift all its consumption to its own domestic goods (which will be consumed in undefined proportions) and no trade at all will take place.

### 3. Innovation dynamics

As shown in the previous sections, regional income disparities may depend on technology alone, as represented in the model by the number of varieties that it is possible to produce in each region. For this reason, the dynamics of *innovation* (i.e. the creation of new varieties) and *spatial diffusion* (i.e. the flows of knowledge on some varieties from one region to the other), which determines the existence of technological disparities, will also determine the long run equilibrium of a multi-regional system in terms of relative income.

This section hence introduces the second step of the exercise, the one in which dynamics is introduced through the creation of new knowledge, the obsolescence of old one and, very important for regional disparities, the flows of existing knowledge from one region to the other. Two main aspects will hence be dealt in this section of the modelling exercise: the first one is the pace of technological processes, i.e. the speed of innovation and of the obsolescence of old technology; the second one is the dynamics of knowledge spillovers.

As in the previous section, knowledge is assumed to be non-rival and non-excludable inside the regions (Foray, 2004), i.e. local knowledge spillovers are assumed to be fast enough that an entire region is characterized by its total endowment of technology. Interregional knowledge spillovers, on the contrary, are, consistently with the literature, assumed to be slower and their speed allowed to vary in the model. The mo-

del hence draws from the very ample and debated literature on local innovation and knowledge spillovers (e.g. Acs *et al.*, 1994; Feldman and Florida, 1994; Audretsch, and Feldman, 1996; Varga, 2000; Breschi and Lissoni, 2001; Fisher, 2001; Asheim and Gertler, 2004; Asleben, 2004; Boschma, 2005; Simmie, 2005). However, the treatment of spillovers in the model is obviously simplified and cannot take into account all complex evidence on how local they are, how fast and how far do they spill, and what are the characteristics needed to get them.

Cumulativeness (Foray, 2004) will also play an important role in the model for knowledge creation. For this reason, this part of the paper studies the dynamics of local innovation and the dynamics of interregional spillovers, in order to determine, from their interaction, the outcome in terms of regional disparities.

The dynamics of interregional spillovers will be analyzed in two ways in the next two sub-sections. For what concerns innovation, on the contrary, a parsimonious approach has been chosen and I have decided not to model innovation as the product of the effort of a separate sector<sup>3</sup> for the following reasons:

- First, this restriction simplifies the modelling process and allows us to concentrate on the reduced form. In fact, we may assume for example that, in Hypothesis 4, an additional quota of the population (call it  $d$ , for developers) is not used for the production of goods but for the production of knowledge, with a knowledge production function of the type  $N_a = dL_a N$ . This assumption, besides exposing the model to problems of scale effect (Young, 1998; Dinopoulos and Thompson, 1999), would not add new insights to the results.
- Second and more importantly, we are interested in what happens to identical regions when the innovative effort changes as the consequence of structural change or policies but remains identical in both regions. In this case, whatever the mechanism used to generate innovation in the model, the innovation parameter will end up by being the same for both regions, and the results of the model will be economically the same as those obtainable from a reduced form, only more complicated to write.

When innovation is not modelled as the product of a separate sector, there are basically two relevant approaches in the literature, both initially deriving from north-south models (Chui *et al.*, 2002)<sup>4</sup>. In both, innovation is assumed to be a process cumulative on previously possessed knowledge, with no decreasing returns to scale. The two approaches differ in what new knowledge is built upon.

<sup>3</sup> Coe and Helpman (1995) identify two basic mechanisms to do this: through horizontally or vertically differentiated intermediate goods.

<sup>4</sup> In these models the two regions/countries are assumed to be different: one region (the «South») does not generally innovate but only imitates, (i.e. acquires from the north the technology used to produce older varieties), the other (the «North») usually knows all the production techniques but does not produce everything, focusing instead on the most advanced goods, which it finds convenient to produce. This difference is plausible at a World scale since almost all R&D activities are in advanced countries and lagging countries only benefit of the diffusion of external R&D (Coe *et al.*, 1997). The asymmetry of these models is not a significant drawback when they are applied to international trade and growth at the global level.

The first approach has been used, for example, by Dollar (1986) who assumes that northern innovations are built on previous knowledge of only those varieties ( $N_n$ ) which are currently produced by the North, not on all the varieties known to the North ( $N$ , which coincides with all the varieties of the economy in a N-S context):

$$\dot{N}_n = \dot{N} = \alpha N_n \quad [26]$$

The second approach has been used, for example, by Krugman (1979) and Grossman and Helpman (1990). It assumes that the amount of new varieties invented in the North in any period is proportional to the varieties known in the North (i.e. in a north-south context, to all the varieties existing in the economy), not just to those actually produced by the North:

$$\dot{N}_n = \dot{N} = \alpha N \quad [27]$$

Both models assume forms of local spillovers. The option of completely global spillovers, where a region is able to innovate by also building on knowledge techniques that it does not know, would be highly unrealistic and also in contrast with the model of Section 2. Some extent of interregional spillovers, however, will be introduced in Sections 3.1 and 3.2.

Apart from speculative interest, the use of both mechanisms is interesting because they lead to approximately the same conclusions, but in different ways: one in terms of probability, and the other with the presence of deterministic multiple equilibria. Moreover, the use of two mechanisms allows us to see the effects of the interregionally shared knowledge.

Since the focus here is regional, the asymmetry of North-South models would be a limitation. For this reason, consistently with what was done in section 2, symmetric extensions of the two mechanisms will be used. Two different assumptions can therefore be made at regional level:

1. A region can innovate by building upon the varieties that it actually produces, in particular those in which it has exclusive ability because of patents or learning mechanisms, more similarly to equation 26;
2. A region is able to innovate by building on all the knowledge that it possesses, regardless of the fact that it does not find it profitable to produce all the varieties that it could, similarly to equation 27.

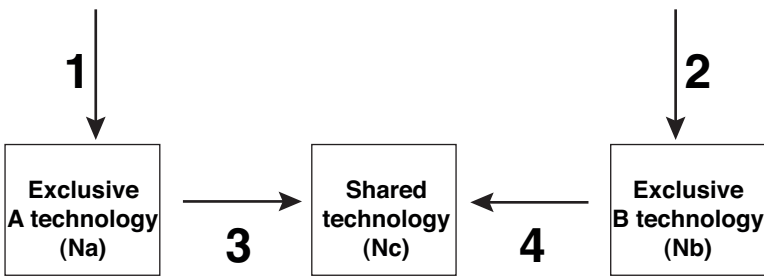
In the following section I shall investigate the dynamics and the extent of innovation and diffusion and analyse the results with respect to the static model developed in the previous sections. Without any assumption on exogenous differences among the regions, I shall examine the evolution of regional disparities in relation to the magnitude of innovation and diffusion. To do so, the focus will be on the amount of interregionally shared knowledge, which will be treated as a separate set.



### 3.1. A simple model of innovation dynamics and the probability of experiencing regional income disparities

The first type of dynamics (and the easiest to treat analytically) to be implemented assumes the existence of local spillovers and some degree of interregional spillovers. It also assumes that the technology shared between the two regions (i.e. the common varieties) is sufficiently old that no new product can be invented by building upon it.

**Figure 2.** Representation of the flows of knowledge in a simplified model of innovation dynamics



We can graphically depict the process as in figure 2. The technology available to region A is represented by the first two squares, whereas the technology available to region B is represented by the second and the third square. Arrows 1 and 2 represent innovation (the creation of new varieties) as flows into the specific knowledge sets of the two regions (i.e. their exclusive varieties  $N_a$  and  $N_b$ ). Arrow 3 is the first spatial diffusion flow of knowledge, which becomes available to B after it has been exclusively available to A. Arrow 4 is the diffusion of knowledge that becomes available to A after being exclusively available to B.

This definition is consistent with equation 26: each region will be able to innovate cumulatively by creating new varieties on the basis of varieties that it has exclusive ability to produce.

We will use two parameters to represent the strength of innovation in the two regions ( $\alpha$  and  $\beta$  for arrows 1 and 2 respectively), which is exogenous because it depends on factors such as the indigenous research effort or policies like those of the Lisbon Agenda. Leaving these parameters exogenous allows us to concentrate on the innovative efforts of the two regions and to evidence what changes if those efforts change.

Since the context is bi-regional, the spatial diffusion of knowledge is assumed to be symmetric, i.e. the ease of acquiring external technology is similar and the flow of arrows 3 and 4 is regulated by the same diffusion parameter  $\gamma$ .

The dynamics of innovation and diffusion will be analytically defined by a set of three differential equations. The first one depicts the dynamics of knowledge posses-

sed exclusively by region *A* as the outcome of an innovation process, cumulative on previously available exclusive knowledge and regulated by the parameter  $\alpha$ , and a diffusion process, regulated by the parameter  $\gamma$ , which makes a part of this exclusive knowledge spill to the other region:

$$\dot{N}_a = \alpha N_a - \gamma N_a \quad [28]$$

The second equation depicts the dynamics of knowledge possessed exclusively by region *B* and is similar to the previous one:

$$\dot{N}_b = \beta N_b - \gamma N_b \quad [29]$$

The third equation depicts the dynamics of the amount of knowledge which is shared among the regions as the sum of the two diffusion processes coming from formerly proprietary technology of *A* or *B*:

$$\dot{N}_c = \gamma N_a + \gamma N_b \quad [30]$$

As a consequence, the dynamics of total knowledge (which is equal to the sum of the three sets  $N = N_a + N_b + N_c$ ) depends only on how many innovations are introduced in the two regions and is defined by the following equation:

$$\dot{N} = \alpha N_a + \beta N_b \quad [31]$$

The dynamics of this system can be easily transformed into a set of two differential equations by analyzing the system in terms of the relative (to the total) technological endowment of the regions, defining the quota of knowledge which is exclusively available to region *A* ( $x \equiv \frac{N_a}{N}$ ) and the one which is exclusively available to region *B* ( $y \equiv \frac{N_b}{N}$ ).

After simple calculations, the dynamics will be entirely defined, in terms of regional shares of knowledge by the following two equations:

$$\dot{x} = x (\alpha - \gamma - \alpha x - \beta y) \quad [32]$$

$$\dot{y} = y (\beta - \gamma - \alpha x - \beta y) \quad [33]$$

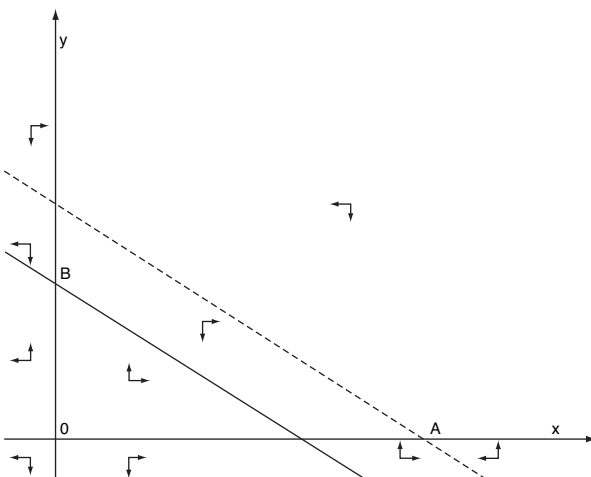
from which it is possible to study the equilibria of the model by analyzing the cases in which the quota of knowledge exclusively possessed by region *A* is constant ( $\dot{x} = 0$  when:  $x = 0$  or  $y = \frac{\alpha - \gamma}{\beta} - \frac{\alpha}{\beta} x$ ) and the cases in which the quota of knowledge exclusively possessed by *B* is constant ( $\dot{y} = 0$  when  $y = 0$  or  $y = \frac{\beta - \gamma}{\beta} - \frac{\alpha}{\beta} x$ ).

First, to study the case in which the regions have different innovative efforts, it is possible to use the phase diagram derived from the conditions above (figure 3) in which one region (A for instance) is more innovative than the other ( $\alpha > \beta$ ).

Figure 3 shows that there are three possible equilibria:

- A first one (point  $O$ , unstable) in which all the technology is common knowledge of both regions;
- A second one (point  $A$ , stable) in which the more innovative region (A) is the more advanced and possesses some technology not available in the other region (a quota  $\frac{\alpha - \gamma}{\alpha}$  of the total varieties), and the rest of knowledge is common;
- A third one (point  $B$ , saddle) in which it is the less innovative region (B) to be more advanced and possessing a quota  $\frac{\beta - \gamma}{\beta}$  of exclusive varieties, and the rest are common.

**Figure 3.** Phase diagram of the first model of innovation dynamics when the two regions have different innovative efforts ( $\alpha > \beta$ )



According to the model of section 2, if the regions are of equal size in terms of active workers, there will exist disparities of income *per capita* if either region exclusively owns more than half of the total knowledge ( $x$  or  $y$  is larger than 0.5). This means that if interregional spillovers are low ( $\alpha > \beta > 2\gamma$ ), both points  $A$  and  $B$  will feature equilibria with regional disparities; when region  $B$  is weakly innovative ( $\alpha > 2\gamma > \beta$ ) there will exist regional disparities only in point  $A$ , which is however the only stable equilibrium. For strong interregional spillovers ( $2\gamma > \alpha > \beta$ ), finally, in both equilibria there will be technological differences, but such differences would not be sufficient to generate income disparities between the regions. For this reason:

**Statement 1:** the speed of the diffusion of knowledge, i.e. the magnitude of inter-regional spillovers, is essential for the determination of the existence of regional income disparities.

The aim of the paper is to analyze the evolution of regional disparities between structurally identical regions, and therefore in the case where the innovative effort is the same in both regions ( $\alpha = \beta$  in the model). One can in fact quite straightforwardly conclude that the more innovative region is more advanced in economic terms if technology is the main determinant of economic success.

It is less obvious what one can expect in terms of regional income disparities if competing regions devote the same effort to innovation. The result ought to depend on the amount of this effort and on the ease with which innovations diffuse inter-regionally.

This case, in the model, produces the phase diagram of figure 4, where any point in the segment  $AB$  is a feasible stable equilibrium outcome for the economy, but only the part included in the square  $OPQR$  is composed of equilibria without income disparities.

The phase diagram shows that, when the pace of innovation increases in an economy, equilibria with differences of income become more likely. In fact, an increase in  $\alpha (= \beta)$  shifts the segment  $AB$  upwards, and a smaller part of the segment  $AB$  will be inside  $OPQR$ .

If, instead (or in a successive period), something makes the diffusion of knowledge from one place to the other easier, income disparities will become *ceteris paribus* less probable, since in the model an increase in  $\gamma$  shifts the segment  $AB$  downwards.

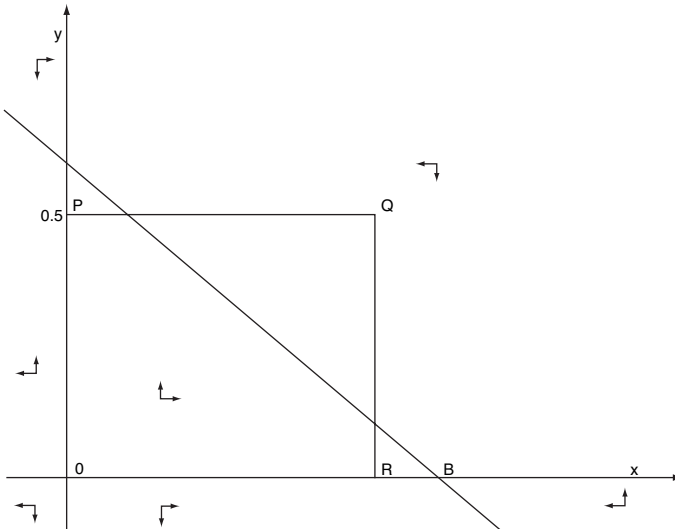
The aggregate effect on regional disparities of innovation competition between identical regions hence depends on the interaction between the parameters regulating the speed of innovation and the speed of diffusion. As limit cases, if the speed of diffusion is very high ( $\alpha = \beta < 2\gamma$ ), there will be equal income in all the possible equilibria. If knowledge diffusion is nil ( $\gamma = 0$ ), differences of income will exist in all equilibria except the point  $(x, y) = (0,5, 0,5)$ . Hence,

**Statement 2:** fiercer regional competition on innovation (higher innovative efforts by both contenders) makes it more likely the existence of regional income disparities. At the same time, the ease of the interregional diffusion flows of knowledge reduces this likelihood.

### 3.2. A full model of innovation, spatial diffusion of knowledge and the existence of regional income disparities

Section 3.1 presented a first dynamic model whose outcome was that regional disparities become more probable if innovation proceeds more rapidly, and less probable if spatial technological diffusion becomes easier. However, we cannot know which equilibrium will be the outcome of the model and, as a consequence, if regional disparities will indeed exist.

If, unlike in the previous section, a more comprehensive model is built, now based on equation 27, it is possible to obtain definite equilibria. In this case, the spillo-

**Figure 4.** Phase diagram of the first model of innovation dynamics with  $\alpha = \beta$ 

vers are still local, but new knowledge can be built upon all knowledge possessed, not just on exclusive knowledge; this is more likely in cases where obsolescence processes are faster and old products –those built with old technologies from which very few innovations can be created– are rapidly running out of the market. Obsolescence will hence be included in this dynamic representation.

Owing to the greater complexity of this case, it will be useful to normalize the total existing technology (by imposing that the total number of varieties is 1) and, through appropriate processes of obsolescence, maintain this normalization as time passes. On the one hand, this is allowed by the fact that, for purposes of this paper and according to the model of Section 2, it is the ratio of varieties possessed by the regions that matters. Focusing on regional disparities and not on growth, only important are the ratios of regional technologies on the total ( $N_a/N$  and  $N_b/N$ ), and the dynamics of these are not affected by the normalization that we impose on the total number of varieties being produced ( $N$ ). On the other hand, it is not realistic to allow people to consume any large number of goods in small proportions, so that a limit on  $N$  is also justified by the fact that old products are continuously replaced by new ones in people's consumption baskets.

There is another assumption to make, this one in favour of realism: a region is allowed to «invent» products that the other region is already able to produce, and not only to imitate them. A clarifying historical example is the «space race» between the Americans and the Russians: some of the technology independently developed by both countries was the same even without espionage by the other.

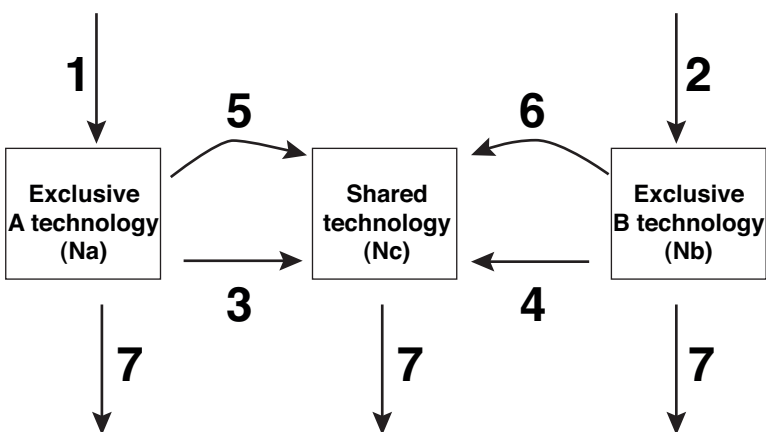
How large would be the part of new region A technology already possessed by region B? The best assumption is to make it proportional to the size of region B techno-

logy compared to all the existing technology. In fact, this assumption verifies that (i) all  $A$  innovations are known to  $B$  if  $B$  knows everything known in the economy and (ii) all  $A$  innovations are new to  $B$  if  $B$  has no exclusive knowledge.

For the above reason, the innovation of region  $A$  is now represented by two flows of knowledge (figure 5): one is completely new innovation (arrow 1), and the other consists of innovations that make some varieties previously exclusive to  $B$  become also available to  $A$  (arrow 6 in figure 6). The two flows add to spontaneous diffusion, i.e. interregional knowledge spillovers, still represented by arrow 4 as in section 3.1.

Obsolescence, justified by normalization but also by the fact that new products often replace the old ones in the utility function, is represented by the three flows of arrows 7. At this stage, it is useful to add to the model the possibility to represent speedier obsolescence for the older varieties, that is, those which are common knowledge to both regions (since they were first invented and then imitated). For this reason, a parameter  $m$ , representing the ratio between the speed of obsolescence of old varieties and the speed of obsolescence of new varieties will be introduced.

**Figure 5.** Full representation of the flows of knowledge



Three dynamic equations fully describe the model.

Equation 34 depicts the dynamics of the exclusive technology of region  $A$ . The first term is the net innovation flow, corresponding to arrow 1. This is cumulative on all knowledge possessed by the region ( $N_a + N_c$ ) and net of the part of innovation which was already known to region  $B$ , i.e. (arrow 6) proportional to the quota of  $A$  knowledge on the total. The second term is the normal diffusion process from region  $A$  to region  $B$ , proportional to the amount of proprietary knowledge owned by  $A$ , regulated by the parameter  $\gamma$  (arrow 3). The third term is the technology «invented» in region  $B$  which was already known in region  $A$ , cumulative to region  $B$  total knowledge and proportional to  $A$  proprietary knowledge (arrow 5). The fourth term is the obsolescence of the  $A$  exclusive technology, regulated by the parameter  $\pi$  (arrow 7):

$$\dot{N}_a = \alpha \frac{N_a + N_c}{N} (N_a + N_c) - \gamma N_a - \beta \frac{N_a}{N} (N_b + N_c) - \pi N_a \quad [34]$$

The dynamics of the exclusive technology of region B is symmetric to the previous:

$$\dot{N}_b = \beta \frac{N_b + N_c}{N} (N_b + N_c) - \gamma N_b - \alpha \frac{N_b}{N} (N_a + N_c) - \pi N_b \quad [35]$$

The dynamics of shared technology is the sum of the two diffusion flows (arrows 3 and 4) and of the innovations of the two regions which were previously available to the other region (arrows 5 and 6), minus the obsolescence, regulated by  $\pi$  and an additional parameter  $m$ :

$$\dot{N}_c = \gamma N_a + \gamma N_b + \beta \frac{N_a}{N} (N_b + N_c) + \alpha \frac{N_b}{N} (N_a + N_c) - m\pi N_c \quad [36]$$

In order to maintain constant the amount of technology existing in the economy ( $\dot{N} = 0$ , an assumption neutral to the conclusions which instead depend on regional knowledge shares), the obsolescence parameter can be set to:

$$\pi = [\alpha (N_a + N_c)^2 + \beta (N_b + N_c)^2] / [N(N_a + N_b + mN_c)] \quad [37]$$

Without loss of generality, it is now possible to normalize to 1 the constant value of total knowledge ( $N = 1$ ).

All the system can finally be dealt with in terms of shares of proprietary regional technologies on the total, defining  $x \equiv \frac{N_a}{N} = N_a$ ,  $y \equiv \frac{N_b}{N} = N_b$ .

Since  $\frac{N_c}{N} = 1 - x - y$  by definition, after simple computations it is possible to obtain two dynamic differential equations describing all the dynamics of the system:

$$\dot{x} = \alpha(1-y)^2 \frac{m+(1-m)(x+y)-x}{m+(1-m)(x+y)} - \gamma x - \beta x(1-x) \frac{m+(1-m)(x+y)+(1-x)}{m+(1-m)(x+y)} \quad [36]$$

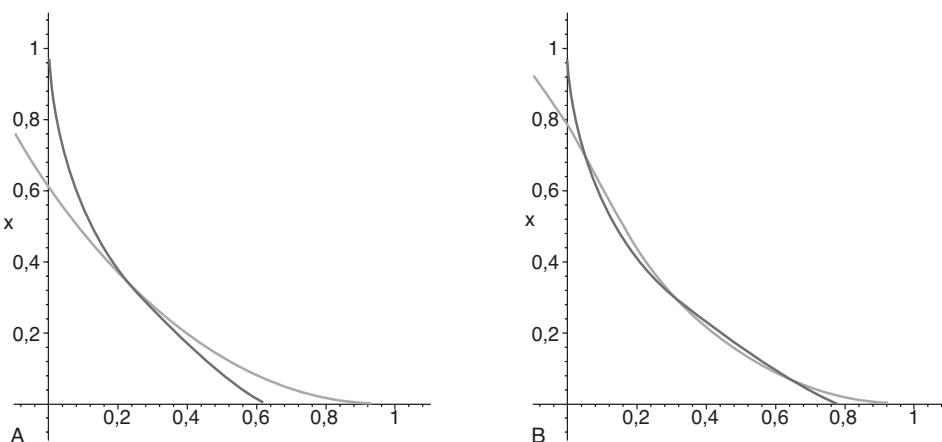
$$\dot{y} = \beta(1-x)^2 \frac{m+(1-m)(x+y)-y}{m+(1-m)(x+y)} - \gamma y - \alpha y(1-y) \frac{m+(1-m)(x+y)+(1-y)}{m+(1-m)(x+y)} \quad [37]$$

### 3.2.1. Dynamic behaviour

It is now possible to study the long run equilibria of the model, depending on the parameters. Regions will always be assumed to devote the same effort to innovation

( $\alpha = \beta$ ), since the investigation of emerging regional disparities between identical regions is the focus of the paper.

**Figure 6.** Phase diagram of the full model of innovation dynamics with  $m = 1$  (left) and  $m = 2$  (right),  $\alpha = 0.5$  and  $\gamma = 0.1$



In the limit and unrealistic case in which obsolescence affects older varieties as rapidly as it does new ones, the system has only one stable equilibrium, which is shown in the phase diagram in figure 6A. Modification of the parameters affects the equilibrium only quantitatively, since the curves still cross the axes at (1,0) and (0,1) and are only slightly rotated. When the innovative effort of regions ( $\alpha = \beta$ ) increases, the equilibrium shifts upwards; when the speed and ease of spatial knowledge diffusion ( $\gamma$ ) increases, the equilibrium shifts downwards. These shifts do not change the fact that, in equilibrium, the two regions are identically technologically advanced ( $x = y$ ), with no regional income disparities as a consequence.

The only thing that changes is the quota of common varieties existing in the economy. This quota increases, the faster the spatial diffusion of knowledge, consistently with the conjecture that if knowledge has little stickiness, it will be easily shared inter-regionally.

If instead, while maintaining the regions identical ( $\alpha = \beta$ ), it is allowed, realistically, to have obsolescence more rapidly affecting older varieties ( $m > 1$ ), the phase diagram yields more complex and more economically interesting results.

For relatively low values of the innovative effort of regions (low  $\alpha$  and  $\beta$ ) and relatively high values of the speed of innovation diffusion (relatively easy interregional knowledge spillovers - high  $\gamma$ ), the phase diagram remains similar to that in figure 6A, with only one (stable) symmetrical equilibrium in which the regions do not differ in terms of technology possessed and income *per capita*.

If, however, the technological competition becomes fiercer and the regions devote greater effort to innovation ( $\alpha$  and  $\beta$  increase while remaining identical), while



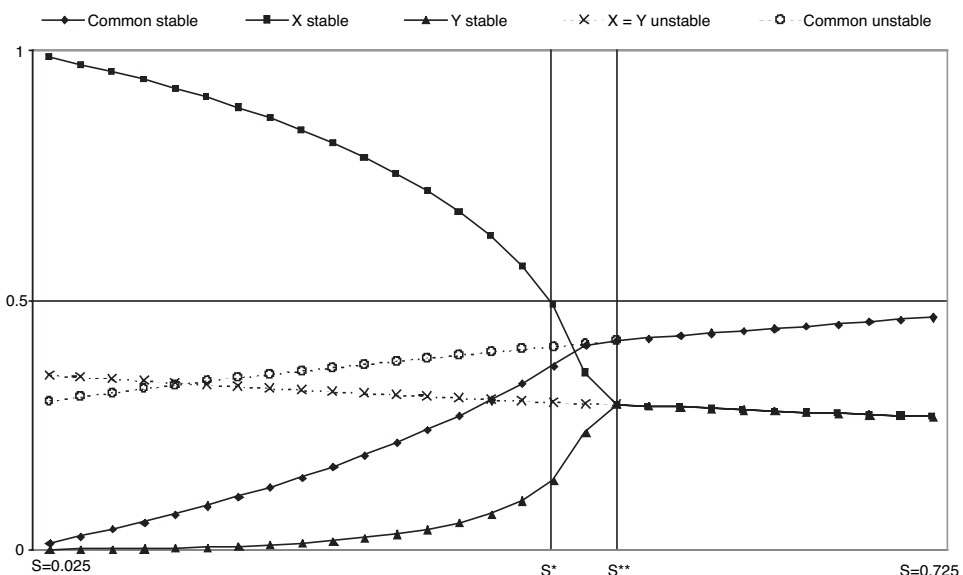
the speed of interregional technological diffusion ( $\gamma$ ) remains relatively slow (Figure 6B), the symmetric equilibrium of the phase diagram becomes a saddle point, and two asymmetric equilibria arise, one with region A possessing a large part of the technology, and one with region B in the same situation.

Once it is assumed that the regions are identical ( $\alpha = \beta$ ), the equilibria of the model only depend on  $m$  (the obsolescence parameter) and on the ratio of the speeds of innovation and of spatial diffusion:

$$S = \frac{\gamma}{\alpha} \quad [38]$$

It is possible to solve the system numerically for any  $m$  and  $S$  and obtain, as in figure 7, a diagram that, for given  $m$ , plots the equilibrium values as a function of  $S$ .

**Figure 7.** Representation of the equilibria of the model, depending on the size of the ratio between the speed of diffusion and the speed of innovation ( $S = \gamma/\alpha$ ), case of  $m = 3$



For innovative forces that are relatively high with respect to the spatial diffusion (i.e. for low values of  $S$  in figure 7) there exists one equilibrium in which the regions are identically endowed in technology ( $N_a = N_b$ ) and hence have the same income per capita. However, this equilibrium is unstable, and two symmetric stable equilibria (of which figure 7 plots only the one with  $x > y$ ) exist. In these latter equilibria, one of the two regions exclusively possesses a large part of the technology/varieties existing, and only a few varieties are possessed by the other region or common. This means that the equilibrium with no income disparities is unstable, and that two multiple equilibria with regional disparities exist and are stable.

In so far as the speed of innovation diffusion grows with respect to the innovative effort of the regions (the ratio  $S$  increases), in each of the stable equilibria the more advanced region becomes relatively less endowed with exclusive technology, and the number of common and the other region's varieties grow, i.e. it becomes increasingly difficult for the forerunner region to maintain for long the exclusive ability to produce the most advanced products, and this is reflected in an increasingly shorter regional life-cycle of products.

As the ratio  $S$  increases, it reaches a value  $S^*$  where the proportion of varieties possessed by the most advanced region amounts to half of the total<sup>5</sup>. For higher values of  $S$  ( $S \geq S^*$ ), even if one region is more technologically endowed, the difference is not, according to the model of section 2, large enough to generate income disparities.

If  $S$  increases further, i.e. if the speed of spatial innovation diffusion is high with respect to the innovative effort of the regions, it reaches a point  $S^{**}$  where the stable and the two unstable equilibria begin to coincide. For  $S = S^{**}$ , the technological endowments of the regions are the same ( $N_a = N_b$ ) and there are neither income disparities nor technological disparities. When  $S$  rises further above  $S^{**}$ , the outcome of the model does not change qualitatively: only the quota of common varieties becomes larger with respect to those exclusive to one of the two regions, as one would expect in cases where knowledge spills very rapidly from one place to the other.

The essence of the result can be expressed by the following:

**Statement 3:** when innovation is rapid compared to interregional technological diffusion (low values of  $S$ ), the economy will have regional technological disparities generating income disparities. For intermediate values, the equilibrium of the economy will exhibit regional technological disparities, but these will be less wide than for low values, so that there will be no income disparities. For little innovative efforts and/or relatively fast spatial diffusion processes, the model predicts one stable symmetric equilibrium, with all the regions being equally endowed technologically and, therefore, with no income disparities.

The model's answer to the research question is therefore as follows: from a situation of similar regional incomes, the acceleration of the technological pace will generally conclude in an equilibrium with regional disparities. Even if a decrease in innovative effort is not desirable for general growth and aggregate welfare reasons (considerations omitted from this article), there still is a way to make the disparities decrease: by increasing the speed of the processes of spatial diffusion of knowledge, i.e. by making it easier for regions lagging in innovation to acquire knowledge from the forerunner regions.

Finally, the results of the model also depend on the parameter representing the ratio between the speed of obsolescence of old varieties with respect to new ones ( $m$ ).

<sup>5</sup> 0.5 is the critical value in this easier case in which  $L_a = L_b$  and  $r_a = r_b$ , and the number of total varieties is standardized to 1. Otherwise, according to the model of section 2, we would have to write the condition

$$\frac{x}{L_a(1-r_a)} = \frac{1-x}{L_b(1-r_b)}$$

Its effect should also be investigated. In the most plausible case in which old varieties become obsolescent faster ( $m > 1$ ), a change of  $m$  affects the model's predictions only quantitatively, by moving the thresholds  $S^*$  and  $S^{**}$ . In particular, an increase in  $m$  increases both  $S^*$  and  $S^{**}$ , i.e. it facilitates the emergence of regional technological and income disparities. This means that:

**Statement 4:** because faster obsolescence processes (i.e. shorter product life-cycle) make doing less important than inventing, they are further drivers of regional income disparities.

#### 4. Conclusions and policy consequences

This article has investigated the effects on regional disparities of changes in the pace of innovation, such as the «technological revolution» that took place in the twentieth century. In particular, it has investigated the effects on regional disparities when identical regions devote the same effort to innovation but this effort changes for both of them because, for example, a supra-regional policy uniformly increases expenditure on innovation or the number of researchers in all regions.

It has been shown that, owing to the cumulateness of knowledge, the same amount of innovative effort is not enough to maintain the same income *per capita*. Moreover, it has been shown that the speed of innovation is not the only determinant, since an equally important role is played by the ease of interregional knowledge diffusion, i.e. of non-local knowledge spillovers.

To support its thesis, the paper has focused on the role of interregionally shared knowledge and has used a framework in which innovation, imitation, diffusion and obsolescence flows are treated separately. This has also allowed for the possibility that something invented in one region is already known in the other.

As a first step, the base model of Section 2 straightforwardly showed that regional disparities can be caused by differences in technological endowment, when these differences are sufficiently wide. The model is symmetric and able to represent bi-regional systems in which one region is similar to another. It consequently makes it possible to identify which region produces the varieties whose knowledge is common. The model is built upon traditional north-south models, with respect to which it has the advantage of being both symmetric and able rigorously to separate the stock of shared knowledge from that possessed by only one region. It is hence useful for the representation of flows of knowledge from one region to the other, and vice versa. The model has shown that if differences in technology are to induce income disparities, they must lie above a certain level.

As a second step, the concurrent effects of innovation and interregional knowledge diffusion have been studied in a context of cumulative knowledge and local spillovers. Used for this purpose have been two representations of the dynamics of interregional knowledge flows between identical regions.

The first and simpler framework has been used to evidence that, for higher values of the speed of innovation, income disparities become more probable whilst, with faster spatial diffusion, income disparities become less probable.

The second, more complex and realistic framework introduced the possibility that something may be invented, in one region, which is not completely new because it is already known in the other region. Within this second framework it has been shown, in terms of multiple equilibria, that the key variable is the *ratio* between the speeds of diffusion and of innovation. When this ratio is low, the economy exhibits two stable and opposite equilibria in which there are both regional technological and income disparities, with either region being the most advanced. For intermediate values of the ratio, the two equilibria persist but, owing to the spatial diffusion mechanism, the two differently technologically endowed regions have the same welfare. For higher values of the ratio –i.e. when the speed of diffusion is rapid compared to the speed of innovation– the stable and unique equilibrium is the one in which the two regions are equally endowed with technology and, as an obvious consequence, have the same income.

Within this second framework, it has also been shown that shorter product life-cycles (modelled with faster obsolescence) are further drivers of regional income disparities, because they make inventing new products more important than producing them cheaply.

The economic consequence of the exercise is that an acceleration in the pace of innovation can contribute to the generation of regional disparities. At the same time, a reduction in the innovative effort of regions is not recommended for growth considerations (Crescenzi, 2005). Nevertheless, the paper has shown that a way out exists: if the interregional diffusion of technology becomes sufficiently rapid and spillovers less local, regional disparities may eventually decrease.

All the literature on innovation points out that the transfer of blueprinted knowledge is not in itself enough to render others able to use that information. However, the current ICT revolution, as well as new conditions for global trade, new governmental policies, and now corporate strategies are creating a smoother path for the diffusion of at least some knowledge from one place to the other (Malmberg and Maskell, 2006). At the same time, also as a result of the development of the ICT and semiconductor industries, the speed of innovation may increase further (Oliner and Sichel, 2000; Gillespie *et al.*, 2001; Jorgenson, 2001). For this reason, we are unable at this stage to identify the final outcome of these global processes.

Two policy implications can be drawn in light of the model's results, both of them stemming from the crucial role played by the spatial diffusion of knowledge after invention has taken place. Owing to the importance of technology for competitiveness, policy makers everywhere are often «obsessed» by the desire to create the next Silicon Valley (Audretsch, 1998). But this strategy, besides being overwhelmingly difficult, may actually be the wrong one for the development of less-advanced regions (Rodríguez-Pose, 2001). Since innovation is a cumulative process, in fact, there must be a technological base wide enough to build upon; if a region is lagging behind because it does not possess front-line technology or because it lacks social capability (Abramovitz, 1986), even the implementation of strong innovative efforts will not create a large quantity of new knowledge. Furthermore, a large part of the «new» discoveries may even be already «old» for the most advanced regions.

Therefore, in seeking to encourage an under-developed region to catch up with richer and more developed ones, an easier and more effective strategy would be to target, at least in an initial phase, the spatial diffusion of knowledge, thereby enabling

the lagging region to enter rapidly into competition with the foremost regions in the production of goods still invented in the most advanced regions.

The second policy implication is that when countries composed of different regions implement policies aimed at increasing the innovative pace (such as the EU is doing with the Lisbon strategy), and when these policies are targeted indifferently on all regions, they carry the risk of increasing regional disparities. Since the innovation policy is too important for competitiveness to be abandoned, the solution is to make knowledge spillovers less local, and to complement competitiveness policies with policies that ease the interregional transfer of knowledge.

## References

- Abramovitz, M. (1986): Catching Up, Forging Ahead, and Falling Behind. *The Journal of Economic History*, vol. 46, No.2, 385-406.
- Acs, Z., Audretsch, D. and Feldman, M. (1994): R&D Spillovers and Recipient Firm Size. *Review of Economics and Statistics*, vol. 76, 336-340
- Asheim, B. and Gertler, M. S. (2004): The Geography of Innovation: Regional Innovation Systems, in: Fagerberg, J., Mowery, D. C. and Nelson, R. R. *The oxford Handbook of Innovation*, Oxford University Press, Oxford, pp. 291-317.
- Asleben, C. (2004): The Downside of Knowledge Spillovers: An Explanation for the Dispersion of High-tech Industries. *Journal of Economics*, vol. 84, No. 3, 217-248.
- Audretsch, D. B. (1998): Agglomeration and the Location of Innovative Activity. *Oxford Review of Economic Policy*, vol. 14, No. 2, 18-29.
- Audretsch, D. B. and Feldman, M. P. (1996): R&D spillovers and the geography of innovation and production. *American Economic Review*, vol. 86, No. 3, 630-640.
- Bilbao-Osorio and Rodriguez-Pose, A. (2004): From R&D to Innovation and Economic Growth in the EU. *Growth and Change*, vol. 35, no. 4, 434-455.
- Boschma, R. A. (2004): Competitiveness of Regions from an Evolutionary Perspective. *Regional Studies*, vol. 38, No. 9, pp. 1001-1014.
- Boschma, R. A. (2005): Proximity and Innovation: a Critical Assessment. *Regional Studies*, 39.1:61-74.
- Breschi, S. and Lissoni, F. (2001): Knowledge Spillovers and Local Innovation Systems: a Critical Survey. *Industrial and Corporate Change*, 10-4:975-1005.
- Cairncross, F. (1997): *The Death of Distance*, Harvard Business School press, Cambridge, MA.
- Coe, D. T. and Helpman, E. (1995): International R&D Spillovers. *European Economic Review*, vol. 39, 859-887.
- Coe, D. T., Helpman, E. and Hoffmaister, A. W. (1997): North-South R&D Spillovers. *The Economic Journal*, vol. 107, No. 440, 134-149.
- Cheshire, P. C. and Malecki, E. J. (2004): Growth, development, and innovation: A look backward and forward. *Papers in Regional Science*, vol. 83, 249-267.
- Chui, M., Levine, P., Mansoob Murshed, S. and Pearlman, J. (2002): North-South Models of Growth and Trade. *Journal of Economic Surveys*, vol. 16, No 2, 123-165.
- Cooke, P., Uranga, M. G. and Extbarria, G. (1998): Regional Systems of Innovation: an Evolutionary Perspective. *Environment and Planning A.*, vol. 30, No. 9, 1563-1584.
- Cooke, P., Heidenreich, M. and Braczyk, H.-J. (2004): *Regional Innovation Systems, the Role of Governance in a Globalized World*, 2nd Edition, Routledge, London.
- Crescenzi, R. (2005): Innovation and Growth in the Enlarged Europe: the Role of Local Innovative Capabilities Peripherality and Education. *Growth and Change*, vol. 36, No. 4, 471-507.
- Dinopoulos, E. and Thompson, P. (1999): Scale Effects in Schumpeterian Models of Economic Growth. *Journal of Evolutionary Economics*, vol. 9, 157-185.
- Dollar, D. (1986): Technological Innovation, Capital Mobility and the Product Cycle in North South Trade. *American Economic Review*, vol. 76, 177-90.

- Dollar, D. (1993): Technological Differences as Source of Comparative Advantage. *American Economic Review*, vol. 83, No. 2, pp. 431-435.
- Dosi, G. (1988): Sources, Procedures and Microeconomic Effects of Innovation. *Journal of Economic Literature*, Vol. XXVI (September, 1988), pp. 1120-1171.
- Edquist, C. (ed.) (1997): «Systems of Innovation», Pinter, London.
- Fagerberg, J., Mowery, D. C. and Nelson, R. R. (2005): *The oxford Handbook of Innovation*. Oxford University Press, Oxford
- Feldman, M. P. and Florida, R. (1994): The geographic sources of innovation: technological infrastructure and product innovation in the United States. *Annals of the Association of American Geographers*, 84(2):210-229.
- Fisher, M. (2001): Innovation, Knowledge Creation and Systems of Innovation. *The Annals of Regional Science*, 35-2:199-216.
- Foray, D. (2004): *The Economics of Knowledge*. MIT Press, Cambridge and London.
- Fratesi, U. and Riggi, M. (2007): Does Migration Reduce Regional Disparities? The Role of Skill-Selective Flows. *Review of Urban and Regional Development Studies*, vol. 19, No. 1, 78-102.
- Freeman, C. and Louça, F. (2001): *As Time Goes by: From the Industrial Revolution to the Technological Revolution*. Oxford University Press, Oxford.
- Freeman, C. and Soete, L. (1997): *The Economics of Industrial Innovation*. MIT Press, Cambridge, MA.
- Gillespie, A., Richardson, R. and Conford, J. (2001): Regional Development and the New Economy. *EIB Papers*, Vol. 6, No.1, 109-131.
- Grossman, G. and Helpman, E. (1990): Comparative Advantage and Long Run Growth, *American Economic Review*, Vol. 80, No. 4, 796-815.
- Grossman, G. and Helpman, E. (1991): *Innovation and Growth in the Global Economy*. MIT Press, Cambridge, MA.
- Kanbur, R. and Rapoport, H. (2005): Migration Selectivity and the evolution of spatial inequality. *Journal of Economic Geography*, vol. 5, No. 1, 43-57.
- Krugman, P. (1979): A model of Innovation, Technology Transfer and the World Distribution of Income. *Journal of Political Economy*, vol. 87, No. 2, 253-66.
- Jorgenson, D. W. (2001): Information Technology and the U.S. Economy. *The American Economic Review*, vol. 91, No.1, 1-32.
- Lundvall B.-A. (ed.), (1992): *National Systems of Innovation*. Pinter, London.
- Malerba, F. (2006): Innovation and the Evolution of Industries. *Journal of Evolutionary Economics*, vol. 16, 3-23.
- Malmberg, A. and Maskell, P. (2006): Localized Learning Revisited. *Growth and Change*, vol. 37, No.1, 1-18.
- Martin, P. and Ottaviano, G. I. P. (2001): Growth and Agglomeration. *International Economic Review*, vol. 42, No. 4, 947-68.
- Oliner, S. D. and Sichel, D. E. (2000): The Resurgence of Growth in the 1990s: is Information Technology the Story? *Journal of economic perspectives*, vol. 14, No.4, 3-22.
- Pomini, M. and Tondini, G. (2006): The Idea of Increasing Returns in Neoclassical Growth Models. *The European Journal of the History of Economic Thought*, vol. 13, No. 3, 365-386.
- Porter, M. (1998): *On Competition*. Harvard Business School Press, Harvard, MA.
- Puga, D. (2002): European Regional Policy in Light of Recent Location Theories. *Journal of Economic Geography*, vol. 2, No. 4, 372-406.
- Rodríguez-Pose, A. (1999): Innovation Prone and Innovation Averse Societies: Economic Performance in Europe. *Growth and Change*, vol. 30, 75-105.
- Rodríguez-Pose, A. (2001): Is R D Investment in Lagging Areas of Europe Worthwhile? Theory and Empirical Evidence. *Papers in Regional Science*, vol. 80, pp. 275-295.
- Romer, P. (1990): Endogenous Technological Change. *Journal of Political Economy*, vol. 98, No. 5, S71-S102.
- Simmie, J. (2005): Innovation and Space: A Critical Review of the Literature. *Regional Studies*, vol. 39, No. 6, 789-804.
- Varga, A. (2000): Local Academic Knowledge Transfers and the Concentration of Economic Activity. *Journal of Regional Science*, 40.2:289-309.
- Young, A. (1998): Growth without Scale Effects. *Journal of Political Economy*, vol. 106, No. 1, 41-63.