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ANALYSIS OF REGIONAL ENDOGENOUS GROWTH

Roberto Basile
Stefano Usai

WORKING PAPERS

2012/11

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CRENoS – Cagliari
Via San Giorgio 12, I-09100 Cagliari, Italia
tel. +39-070-6756406; fax +39-070- 6756402

CRENoS - Sassari
Via Torre Tonda 34, I-07100 Sassari, Italia
tel. +39-079-2017301; fax +39-079-2017312

Title: ANALYSIS OF REGIONAL ENDOGENOUS GROWTH

ISBN: 978 88 84 67 739 6

First Edition: May 2012

Via Is Mirrionis, 1
09123 Cagliari
Tel./Fax 070 291201
www.cuec.it

Analysis of regional endogenous growth

Roberto Basile
Second University of Naples
Stefano Usai
University of Cagliari and CRENoS

Abstract

Endogenous growth theory has deeply influenced regional growth analyses and inspired regional development policies. Evidence of lack of convergence, club convergence and spatial polarization of per worker income levels has led scholars to question the explanatory power of neoclassical exogenous growth models and to look at endogenous growth theories as proper frameworks to interpret regional development. In particular, those models, which emphasize the role of knowledge spillovers as driving forces for economic growth and identify a large set of self-reinforcing mechanisms that can potentially cause low-productivity traps, have become central in the scientific debate. Only during the last ten years, however, there have been some analytical attempts to regionalize endogenous growth theory. This paper provides a critical survey of the growing literature on regional extensions of endogenous growth analysis. The focus is on those theoretical and empirical studies which have tried to explain lack of regional convergence, multiple equilibria and spatial polarization. The paper also suggests some directions for future research in this field.

Keywords: Endogenous growth, regional analysis.
JEL Classifications: O4, R11

* Correspondence Roberto Basile Second University of Naples, Corso Gran Priorato di Malta, 1, Capua (CE), Italy, e-mail: roberto.basile@unina2.it. Stefano Usai University of Cagliari, CRENoS, Via S. Ignazio 78, Cagliari, Italy, e-mail: stefanousai@unica.it.

1. Introduction

Neoclassic "exogenous" growth models predict that, under certain conditions (complete markets, free entry and exit, negligible transaction costs and convex technology relative to market size), economies navigate a sea of economic opportunities that reward productive efforts and savings (Solow, 1956; Swan, 1956; Borts, 1960; Borts and Stein, 1964; Barro and Sala i Martin, 1995). Thus, initially low-income economies typically do not entrap and tend to catch up; only those economies that do not make investments will not escape the low-income status quo.

However, the stylized facts observed for regions, especially for European regions, tell us a different story, that is a story of lack of global convergence, club convergence and strong spatial interdependence (Basile, 2009; Fiaschi and Lavezzi 2007; Fotopoulos 2008). These stylized facts have led scholars to question the explanatory power of neoclassical exogenous growth models and to look at endogenous growth theories as suitable frameworks to interpret the actual regional development, in Europe as well as in other contexts. Particularly appealing have been those models which identify a large set of self-reinforcing mechanisms that can potentially cause poverty traps (Azariadis and Stachurski, 2004) as well as those Schumpeterian models which emphasize the role of technology transfer as driving forces for economic growth and club convergence (Howitt, 2000; Howitt and Mayer-Foulkes, 2005; Acemoglu *et al.*, 2006)[1]. However, this group of studies lacks the necessary micro-foundations to model interregional

[1] Another potential cause of cumulative causation is proposed in the demand-oriented view of regional growth proposed by the Kaldorian growth theory. Here exogenous export demand is the key driver of regional output and may give rise to divergent paths across regions (Harris, 2011).

knowledge diffusion. Specifically, it does not properly take into account the issues related to spatial proximity.

First attempts to “regionalize” endogenous growth theory have been essentially non-analytical approaches, focusing on the issue of the boundaries of knowledge spillovers (Doring and Schnellenbach, 2006). These studies have questioned how geographically limited knowledge diffusion may help explain clusters of regions with persistently different levels of growth. The intrinsic limitations of these frameworks have raised the need for theoretical works focusing on the explicit incorporation of space into growth models.

Over the last years, there has been some work in this direction. Specifically, a group of authors have proposed extensions of multi-region neoclassical growth models (Lòpez-Bazo et al., 2004; Egger and Pfaffermayer, 2006; Pfaffermayer, 2009a, b; Ertur and Koch, 2007) as well as extensions of multi-region endogenous (Schumpeterian) growth models (Ertur and Koch, 2011) that include technological interdependence across regions to take account of neighborhood effects in growth and convergence processes. This group of studies has given rise to a large number of empirical analyses which have used spatial econometric tools to study the role of spatial interactions in regional growth behavior.

This Chapter provides a critical survey of the growing literature on regional growth analysis, focusing on those studies which have tried to explain the lack of regional convergence together with the presence of multiple equilibria and spatial polarization. Differently from previous reviews of the literature on regional growth and convergence (Magrini, 2004; Rey and Le Gallo, 2009; Ertur and Le Gallo, 2009), our work points out the link between the advances in endogenous growth theory and the evolution of regional growth analysis. Obviously, it is beyond the scope of the present study to provide a thorough review of the empirical literature on regional convergence (for which we refer the readers to the above mentioned surveys) as well as an exhaustive review of the theoretical literature on endogenous growth (for which we refer the reader to Aghion and Durlauf, 2005; Pozzolo 2004).

The rest of the Chapter is organized as follows. In Section 2, some stylized facts on the distribution dynamics of regional income per worker in Europe are reported to provide an indication of the existing scale of regional disparities. Section 3 examines the theoretical literature on endogenous growth while questioning its explanatory power for our understanding of regional growth. In Section 4 we review those studies that have extended multi-region growth models to take into account the neighborhood effects on growth and convergence processes. Section 5 discusses non-analytical attempts to include the role of industrial heterogeneity and agglomeration externalities in the explanation of diverse regional performances. Section 6 concludes and suggests new directions for future research in the field.

2. Long-run distribution of regional income in Europe

Regional income imbalances in Europe have been analyzed by different scholars. The most informative studies are those based on the continuous state-space approach developed by Quah (1997), based on the estimation of conditional density functions and on computation of the ergodic distribution to describe the long-run growth behaviour of the income per worker distribution (Fotopoulos, 2008; Fiaschi and Lavezzi, 2007; Basile, 2009). The main picture emerging from these studies, which mainly focus on the EU15, is a *polarization* of income levels: two clusters are identified, with a group of regions caught in a low-income trap. Such a clustering is also characterised by a *Core-Periphery* spatial pattern: high (low) income regions are in a proximate relationship with other high (low) income regions.

Using Cambridge Econometrics data and a sample of 257 NUTS2 regions for the 1990-2007 period, we extend this analysis to the enlarged Europe (EU-27), including both "Western" and "Eastern" regions. The shape of the ergodic distribution of regional income per worker[2] (computed using the transition matrix extracted from a conditional density estimation) suggests the existence of *convergence clubs*: three groups of regions tend to converge to three different long-run parallel growth paths (Figure 1).[3] A first mode of the stationary distribution is at about 0.25 times the EU average income; the second peak is at about 0.75 times the EU average, while the third one is at about the EU average.

Figure 1

In order to identify the proximate determinants of the shape of the long-run distribution of regional income, we analyze the contribution of capital accumulation and technology. While Azariadis and Stachurski (2004) ascribe the emergence of multiple equilibria to divergences in capital accumulation, the Schumpeterian approach (Howitt, 2000) attributes club convergence to differences in technology connected both to R&D investments and to capacity to absorb foreign knowledge (see Section 3). Thus, we analyze the transition dynamics of regional capital-labour ratio and total factor

[2] Regional income per worker is computed as the ratio between gross value added at constant prices 2000 and total employment. Income levels are normalized with respect to the EU27 average in order to remove co-movements due to the European wide business cycle and trends in the average values.
[3] To estimate the long run distribution, we followed Johnson (1995).

productivity (TFP) and compute the implied ergodic distributions (Figure 1).[4] The results imply that traps in both TFP growth and capital accumulation matter in explaining the multi-modality in regional income per worker, in line with cross-country evidence reported by Johnson (2005). Indeed, a bi-modality emerges in the long-run distribution of TFP and a tri-modality in the long-run distribution of capital-labour ratio. This result has important implications for theoretical modeling of regional development traps as it suggests that they are due to both productivity growth (as suggested by the Schumpeterian approach) and to traps in physical capital accumulation (Azariadis' argumentation).

Finally, we provide information on the *spatial* distribution of income per worker, capital-output ratio and TFP over the sample period. Using nonparametric methods, we regress each of the three variables on the smooth interaction between latitude and longitude, $y = f(lat, long) + \varepsilon$. Figures 2-4 plot the geographical components of this model, showing a *Core-Periphery* pattern in the spatial distribution of each variable. Specifically, higher incomes per worker are clustered in the Centre of the Continent, while lower incomes are concentrated in two peripheral areas: the first one includes Southern regions, while the lowest income levels are clustered in Eastern regions. These features are partially mirrored in the spatial distribution of capital-labour ratio and of TFP. This evidence suggests that the assumption of spatial randomness in regional growth behaviour is likely to be violated and that spatial autocorrelation must be taken into account when modelling regional development traps.

3. Endogenous growth theory and regional growth disparities

[4] To compute TFP we used the simple production function: $Y = AK^{\alpha}L^{1-\alpha}$, so as $y = Y/L = A(K/L)^{\alpha} = Ak^{\alpha}$ and $A = y/\left[k^{\alpha}\right]$.

3.1 Linear and nonlinear Solow model

Early contributions to regional growth analyses (Magrini, 2004) were based on the traditional neoclassical growth model (Solow, 1956) rooted in the assumptions of a convex (Cobb-Douglas) production function with constant returns to scale, diminishing returns to capital, access of all regions to the same pool of exogenous knowledge (instantaneous technology transfer) and absence of regional technological interactions.

The most suitable property of this model, which facilitates its econometric estimation, is that all regions have an identical long-run growth rate exclusively determined by the rate of exogenous technological progress. This implies that their steady-state balanced growth paths are parallel. During the transition to the steady state, the less capital endowed economies will have a lower income per worker and they will grow faster.[5]

In the steady state, income per worker (y) will be higher in the economies with higher rates of investment in physical capital (s_K) and with lower effective depreciation rates ($n + x + \delta$), with n the working-age population growth rate, g the common exogenous technology growth rate and δ the rate of depreciation of physical capital assumed identical in all economies. In a cross-region context, the econometric specification of the Solow growth model for region *i* (with *i* = 1,…,*N*) is

$$\ln y_i = \beta_0 + \beta_1 \ln \frac{s_{K,i}}{n_i + g + \delta} + \varepsilon_{Solow,i} \qquad (1)$$

[5] The open version of the neoclassical growth model also predicts that capital and labour move to obtain the highest returns and, with perfect flexibility of factor prices, mobility will automatically remove interregional factor price differences (Borts, 1960; Borts and Stein, 1964; Barro and Sala i Martin, 1995).

where β_0 and β_1 are unknown parameters to be estimated and $\varepsilon_{Solow,i}$ is an error term assumed to be identically and independently distributed.

Equation (1) entails strong homogeneity assumptions on the growth behavior. Imposing parameter homogeneity is equivalent to assume that the effect of a change in a particular variable (such as the savings rate) on economic growth is the same across regions. This assumption has been considered as particularly inappropriate for the analysis of complex heterogeneous regions. For example, it has been observed that regional growth behavior in the 'West' and in the 'East' of the European Union may greatly differ (Ertur and Koch, 2007) and, more generally, that the evidence of regional "club convergence" (parameter heterogeneity or multiple regimes) is the rule rather than the exception in regional growth analysis (Ertur and Le Gallo, 2009).

As it is well known, club convergence can be generated by the original Solow-Swan model by simply assuming that either the saving rate or the population growth rate is a function of income per worker. Masanjala and Papageorgiou (2004) have also shown how replacing the commonly used Cobb-Douglas aggregated production specification with the more general Constant-Elasticity-of-Substitution specification can generate parameter heterogeneity in the Solow growth equation. A nonlinear Solow model can therefore be derived:

$$\ln y_i = \beta_0 + f\left(\ln \frac{s_{K,i}}{n_i + g + \delta}\right) + \varepsilon_{Nonl.Solow,i} \qquad (2)$$

where $f(.)$ is a generic function to be estimated through, for example, nonparametric methods (see, e.g., Liu and Stengos, 1999; Durlauf et al., 2001; Fiaschi and Lavezzi, 2003; Kalaitzidakis et al, 2001; and, for applications to regional data, Arbia and Basile, 2005; Basile, 2008, 2009).

However, evidence of lack of convergence or of club convergence (especially in the case of European regions) has also stimulated interest among regional economists for alternative theoretical frameworks to the neoclassical model. In particular, a major stimulus to the comparative analysis of regional long-run behavior originated from the introduction of the endogenous growth framework during the mid 1980s (Roberts and Setterfield, 2007).

3.2 First and second generations of endogenous growth models

Early contributions to the endogenous growth literature (Romer, 1986; Lucas, 1988), classified as AK models (Rebelo, 1991), do not make an explicit distinction between capital accumulation and technological progress: the latter consists of the accumulation of knowledge, which is a kind of intellectual capital, as much as physical or human capital. Similarly to capital accumulation, technological knowledge also arises from decisions to save. If society saves a larger fraction of income, the pace of technological progress rises, permitting a higher rate of economic growth to be sustained indefinitely.

In these models, regional differences in income per worker should widen over time and random shocks to a region's income should have permanent effects. However, this prediction contradicts the empirical evidence that most regions tend to converge to roughly similar long-run growth rates or, better, that different groups of regions tend to converge to different long-run growth paths (club convergence).

Exceptions are those first-generation endogenous growth models which predict convergence clubs arising from threshold effects in the accumulation of important factors of production (Azariadis and Stachurski, 2006). Specifically, in these models non-convexities in the aggregate production function associated with threshold effects in the accumulation of capital lead to long-run dependence from initial conditions.[6] Not surprisingly, these studies are widely mentioned in regional growth analyses which underline the issue of club regional convergence (e.g., Funke and Niebuhr, 2005; Basile, 2008, 2009).

A second wave of endogenous growth models can be classified as "innovation-based" growth theory, since it recognizes that intellectual capital, the source of technological progress, is distinct from physical and human capital. The latter is accumulated through saving and schooling, while intellectual capital grows through innovation. One version of innovation-based theory was proposed by Romer (1990), who assumed that aggregate productivity is an increasing function of the degree of product variety: innovation causes productivity growth by creating new, but not necessarily improved, varieties of products. The other version is the one-country "Schumpeterian" model developed by Aghion and Howitt (1992, 1998). It focuses on quality-improving innovations that render old products obsolete, through the process that Schumpeter called "creative destruction". In both versions the long-run growth rate depends on the fraction of GDP spent on R&D, which in turn is a decision taken by profit-maximizing firms.

[6] Azariadis and Stachurski (2006) point out that numerous departures from the neoclassical benchmark (namely, increasing returns to scale and failure in credit and insurance markets) generate market failures and determine multiple equilibria and club convergence. Finally, they suggest that bad institutions (state, legal systems, social norms and conventions) may entrap entire economies in poverty or low-productivity equilibria.

A key issue of both first and second generation endogenous growth models is that technological inputs create spillovers due to their nature of non-rival and partially excludable goods. These externalities generate non-convexities in production, thus avoiding diminishing returns to capital prevalent in neoclassical exogenous models. In "innovation-based" growth theory, for example, spillovers are posited in research activities. While intellectual property rights deter the outright theft of ideas, nothing prevents a firm from building on ideas implicit in existing goods or the accumulated stock of public knowledge. Knowledge produced by a single firm becomes subsequently available to all agents as a starting point for their own research activity. This gives rise to either horizontal (Romer, 1990) or vertical (Aghion and Howitt, 1998) innovations.

The above mentioned contributions to endogenous growth theory treat, however, each economy as if it were an island, while regional economies typically display a greater deal of openness than is the case for national economies: they trade and communicate with one another and learn from one another, more than countries do. Therefore, regions cannot be treated as spatially independent units and endogenous growth models should explicitly take spatial interactions into account. In particular, there is no a priori reason to constrain knowledge spillovers within the barriers of the regional economy where the agent making the investment is located.

3.3 Open-economy endogenous growth models: the role of interregional knowledge spillovers

A class of endogenous growth models relaxed the closed-economy assumption allowing for international (or interregional) factor mobility, trade and knowledge diffusion.

These studies have important implications both for the effects of cross-country (and cross-region) integration on output convergence and for the overall growth performance of the integrated economy.[7] In particular, a strand of the literature recognizes that knowledge spillovers may have a cross-country dimension. For example, Rivera-Batiz and Romer (1991) and Grossman and Helpman (1991) propose a two-country extension of Romer's (1990) increasing variety model, while Segerstrom et al. (1990) and Grossman and Helpman (1991) propose a two-country versions of Aghion and Howitt's (1992) quality-ladder model.

Within this framework we recognize the contribution of NEGG (New Economic Geography and Growth) models which combine endogenous growth models and New Economic Geography models to analyze the interactions between growth and agglomeration (Baldwin and Martin, 2004). To do so, they add a (knowledge) capital producing sector (i.e. an innovation sector), a typical feature of endogenous growth theory, to a two-region geography model (such as a core-periphery model or a footloose capital model). The innovation sector is characterized by the presence of intertemporal spillovers (like in Romer, 1990) and the localization of these externalities is a major concern. It is indeed recognized that the fact that technology spillovers are localized (in the sense that the cost of R&D in one region also depends on the location of firms, so that it is less costly to innovate in the region with the highest number of firms) should in theory lead to a positive link between (global) growth and spatial agglomeration of economic activities: when industrial agglomeration increases in the region where the innovation sector is located (the core), the cost of innovation decreases and the growth rate increases (that is being close to innovation clusters has a positive effect on

[7] See Pozzolo (2004) for a review of the literature on open-economy endogenous growth models.

productivity). Thus, the introduction of growth and localized spillovers in a NEG model is at the origin of a trade-off between growth and spatial cohesion which may have important policy implications. However, the welfare analysis suggests that the higher growth triggered by spatial concentration may lead to a Pareto-superior outcome: even those who live in the periphery are better off under agglomeration than under dispersion as long as the (global) growth effect spurred by the agglomeration is strong enough. Thus, a situation emerges in which everybody can have economic advantages because agglomeration generates faster growth in all regions. Nevertheless, Cerina and Pigliaru (2007), in their critical survey, show that this conclusion is far from robust and that it depends on restrictive assumptions on the values of the degree of love for variety and of the elasticity of substitution between traditional and manufacturing goods. Along this line, Cerina and Mureddu (2009) prove that the regional rate of growth might differ depending on the geographical allocation of industries when there is a non tradable sector, whose performance depends on its proximity to the industrial sector.

All in all, these models have been welcomed by regional economists since it appeared clear right away that knowledge spillovers could go a long way in explaining differences in growth performances across regions. However, the treatment of space in the endogenous open-economy growth models quoted above is very simple, whilst the geographical bounding of knowledge spillovers is assumed rather than explicitly modeled. Specifically, the consideration of only two countries (or two regions) does not allow discriminating between direct and indirect spatial technological interdependence (Behrens and Thisse, 2007). Thus, any satisfactory analysis of the reasons behind the existence of differences in the long-run equilibrium growth rates across regions needs to be conducted using multi-region models. In this sense the multi-country (or multi-region) version of the Schumpeterian growth model with technological transfer developed by Howitt (2000) appears as the most promising one.

3.4 Technology transfer and multi-country endogenous growth models

Howitt's (2000) model incorporates the force of technology transfer, whereby the productivity of R&D in one region is enhanced by innovations in other regions. This implies that all regions engaging in R&D grow at the same rate in the long run, that is they converge to parallel long-run growth paths. Thus, convergence in Howitt (2000) takes place not only thanks to diminishing returns to capital but also through technology transfer. The main rationale for this convergence is what Gerschenkron (1952) called "advantage of backwardness", that is, the further a region falls behind the (global) technology frontier, the larger is the average size of innovations. The increase in the size of innovations keeps raising the laggard region's growth rate until the gap separating it from the frontier finally stabilizes.

In a world where some regions have internal incentives for innovation and others do not, Howitt's model with technology transfer is also able to predict club convergence: the process of technology transfer will determine convergence among regions which perform R&D activity. Thus, as long as a region maintains enough incentives for innovation, it will join the convergence club and its growth rate will ultimately converge to that of all the other members. Instead, regions without incentives to innovate will stagnate, falling further behind the other regions.

The steady-state equation implied by Howitt's (2000) model is for region *i*:

$$\ln y_i = \beta_0 + \beta_1 \ln \frac{s_{K,i}}{n_i + g_w + \delta} + \beta_2 \ln s_{A,i} + \beta_3 \ln n_i + \varepsilon_{AH,i} \qquad (3)$$

where $\ln s_{A,i}$ is the R&D intensity of region *i*. Thus, in steady state, a region's relative income per worker y_i depends positively on its investment rate (s_K), on its effective depreciation rate $(n + g_w + \delta)$ - with g_w the world growth rate - and on its R&D intensity.

Although Howitt (2000) recognizes the relevance of technological interdependence, equation (3) is still characterized by interregional independence, since complex interactions between regions are overlooked or oversimplified. Thus, like model (1), it appears to be inadequate to analyze regional growth behaviour. In Section 4 we will review a recent extension of Howitt (2000) model which properly takes technological interdependence into account, thus generating an econometric reduced form characterized by interregional spatial contagion.

Howitt and Mayer-Foulkes (2005) take a variant of Howitt’s (2000) model demonstrating that a region’s education level can be important enough to spell the difference between convergence and divergence in growth rates. Technology transfer is indeed a difficult, skill-intensive process. It requires the implementation of “absorptive capacity”, such as investments in human and social capital (Nelson and Phelps, 1966; Abramovitz, 1986). Regions which have the opportunity to receive foreign technology, but do not have adequate absorption capacity or have eroded it, will find catching up more difficult. At this point, a “big push” is needed to reverse the erosion of absorptive capacity and to join the leading convergence club. Whether or not a poor region is capable of engineering this push on its own is a crucial open question.[8]

[8] Alexiadis (2010a, b) provides some contributions to model regional growth and (club) convergence within a technology transfer framework recognizing the role of absorptive capacities, which are considered as a function of regional infrastructural conditions. Benhabib and Spiegel (2006) generalize

A striking characteristic of this class of models is that, depending on the assumptions made on the pattern of knowledge diffusion, they can easily explain club convergence of the kind found in the empirical analysis (i.e. the twin peaks emerging in the ergodic distribution of national and regional per worker incomes). More generally, the literature surveyed in this Section has reached a broad consensus that the most promising channel to explain differences in growth performances across economies is knowledge diffusion. The way in which spillovers are modeled, however, still requires further work. The theoretical contributions reviewed in the next section take a step in this direction.

4. Regional growth and neighboring effects

During the second half of the 1990s a number of empirical studies have provided strong evidence of spatial contagion in regional growth behavior, thus challenging the cross-region independence assumption implicitly adopted by previous works (Armstrong, 1995; Bernat, 1996; Chatterji and Dewhurst, 1996; Ades and Chua, 1997; Fingleton and McCombie, 1998; Rey and Montouri, 1999; Attfield et al., 2000; Fingleton, 2001; Carrington, 2003; for a review, see Abreu et al. 2005; Rey and Janikas, 2005; and Fingleton and Lòpez-Bazo, 2006). Using spatial econometrics techniques, these studies have shown that regional growth rates depend crucially on the growth rates and initial (and structural) conditions of nearby economies, rather than just on any one region's own initial (and structural) conditions. When interpreting their results, these authors make reference to the notion of (geographically bounded) interregional knowledge

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the Nelson-Phelps model with exponential or logistic technological diffusion. In the latter case, a country with a small capital stock may exhibit slower total factor productivity growth than the leader nation and no catching up occurs.

spillovers (or spatial technological interdependence), without formally demonstrating the linkage between the two.

More recent studies (Lòpez-Bazo et al., 2004; Egger and Pfaffermayer, 2006; Pfaffermayr, 2009a, b; Ertur and Koch, 2007, 2011) have instead shown that spatial technological interdependence can be explicitly modeled in multi-country (or multi-region) exogenous and endogenous growth frameworks to account for neighborhood effects in growth and convergence processes. These studies have provided sound theoretical foundations for the specific form taken by spatial autocorrelation in econometric growth models. Thus, they have further stimulated the empirical assessment of the existence of neighboring effects in regional growth (Rey and Le Gallo, 2009).

4.1 A neoclassical perspective

Let us consider an economy composed by N regions. Each region *i* in every period *t* produces a homogenous output $\left(Y_{it}\right)$ through an aggregate Cobb-Douglas production function exhibiting constant returns to scale in labour $\left(L_{it}\right)$ and physical capital $\left(K_{it}\right)$:

$$Y_{it} = A_{it} K_{it}^{\alpha} L_{it}^{1-\alpha} \qquad 0 < \alpha < 1 \tag{4}$$

with parameter α denoting internal returns to physical capital. Technological interdependence is modelled by specifying the aggregate level of technology, A_{it}, as

$$A_{it} = \Omega_t k_{it}^{\phi} \prod_{j \neq i}^{N} A_{jt}^{\gamma w_{ij}} \tag{5}$$

Thus, technological knowledge is in part *exogenous and identical in all regions* (as in Solow), $\Omega_t = \Omega_0 e^{gt}$ (with g constant); in part it depends on the level of accumulated capital per worker, $k_{it} = K_{it} / L_{it}$, with the parameter ϕ reflecting the strength of physical capital externalities among firms *within the region*, in line with Romer (1986); in part, it depends positively on the technology accumulated in *neighbouring regions* proxied by the last term $\prod_{j \neq i}^{N} A_{jt}^{\gamma w_{ij}}$, which is a geometrically weighted average of the stock of knowledge of the j neighbours of region i (Ertur and Koch, 2007). The elements w_{ij} represent the connectivity between a region i and all regions belonging to its neighbourhood. The more a given region is connected to its neighbours, the higher w_{ij}. The intensity of spillover effects, captured by the parameter γ (identical for all regions), is assumed to be related to some concept of socio-economic or institutional proximity, which can be approximated by exogenous geographical proximity or other proximity measures (see Section 6 for a critical discussion of the notion of distance adopted in recent regional growth analyses). In other words, it is assumed that external effects of knowledge embodied in physical capital in one region extend across its borders but does so with diminished intensity because of frictions generated by socio-economic and institutional dissimilarities captured by exogenous geographical distance.

As in Solow, the working-age population growth rate (n), the growth rate of Ω_t (g), the depreciation rate (δ) and the rate of accumulation of physical capital (s_K) are exogenous. Moreover, the evolution of capital per worker in region *i* is governed by the fundamental Solowian dynamic equation:

$$\dot{k}_{it} = s_i \, y_{it} - (n_i + \delta) k_{it} \qquad (6)$$

Under the assumption of decreasing returns to capital within each economy, equation (6) implies that k_{it} and, thus, y_{it} converge to a balanced growth rate, $g_b = g / [(1-\alpha)(1-\gamma)-\phi]$ and the (empirical counterpart of the) equation for the steady-state level of real income per worker is in vector form:

$$\ln y_i = \beta_0 + \beta_1 \ln \frac{s_i}{n_i + g_b + \delta} + \theta \sum_{j \neq i}^{N} w_{ij} \ln \frac{s_j}{n_j + g_b + \delta} + \rho \sum_{j \neq i}^{N} w_{ij} \ln y_j + \varepsilon_i \qquad \text{(7a)}$$

In matrix form we have:

$$\mathbf{y} = \mathbf{X}\beta + \mathbf{WX}\theta + \rho\mathbf{Wy} + \varepsilon \qquad \text{(7b)}$$

where $\mathbf{y}$ is a $(N \times 1)$ vector of the logarithms of real income per worker, $\mathbf{X}$ a $(N \times 2)$ matrix including the constant term and the vector of logarithms of the investment rate in physical capital divided by the effective depreciation rate. $\mathbf{W} = \{w_{ij}\}$ is a $N \times N$ standardized spatial weights matrix. $\mathbf{WX}$ is the spatial lag of $\mathbf{X}$ and $\mathbf{Wy}$ is an endogenous spatial lag term. β and θ are vectors of parameters associated to $\mathbf{X}$ and $\mathbf{WX}$, respectively, while $\rho \equiv \frac{\gamma(1-\alpha)}{1-\alpha-\phi}$ is the spatial autoregressive parameter. Finally, ε is the $(N \times 1)$ vector of *iid* errors.

The reduced form of equation (7b) can be easily derived:

$$\mathbf{y} = (\mathbf{I} - \rho\mathbf{W})^{-1}\mathbf{X}\beta + (\mathbf{I} - \rho\mathbf{W})^{-1}\mathbf{WX}\theta + (\mathbf{I} - \rho\mathbf{W})^{-1}\varepsilon \qquad \text{(8)}$$

The steady-state level of income per worker in a location i is therefore influenced not only by the exogenous characteristics (saving rate and working-age population growth rate) of i (as in Solow), but also by those in all other locations through the inverse spatial transformation $(\mathbf{I}-\boldsymbol{\rho}\mathbf{W})^{-1}$, the so-called "spatial multiplier effect" (Anselin, 2004). Equation (8) also suggests that there are spatial externalities in un-modelled effects: a random shock (or disturbance) in a specific location i does not only affect the outcome in that region, but it has also an impact on the outcome in all other locations through $(\mathbf{I}-\boldsymbol{\rho}\mathbf{W})^{-1}$ ('spatial diffusion process of random shocks').

It is worthwhile observing that, even if the estimated parameters in the structural equation (7b) are fixed and homogenous across spatial units, the expected marginal effect of each explanatory variables *k* (computed from the reduced form in equation 8) takes the form of a $N \times N$ matrix: $\frac{\partial E[\mathbf{y}]}{\partial x_k} = (\mathbf{I}-\boldsymbol{\rho}\mathbf{W})^{-1}(\mathbf{I}\boldsymbol{\beta}+\mathbf{W}\boldsymbol{\theta}) = S_k(\mathbf{W})$. In other words, the impact of each exogenous variable is specific to each region. This kind of heterogeneity, called "*interactive heterogeneity*", is different from the one mentioned in section 3, generated from threshold effects in the accumulation of capital or from nonlinearities in the production function. *Interactive heterogeneity* is a direct consequence of the assumption of technological interdependence.

The diagonal elements of matrix $S_k(\mathbf{W})$ measure the "*direct effect*", $\frac{\partial E[y_i]}{\partial x_{k,i}}$, that is the impact *on region i* of changes of variable *k* in the same region. The extent of this effect is quantitatively different from the value of the corresponding estimated parameter β_k, since it includes *feedback effects.* For example, if a region raises its rate of investment in physical capital, the direct effect accounts for the localized effect and feedback effects, where region *i* affects region *j* and region *j* also affects observation *i*. The row-sums of the matrix elements of $S_k(\mathbf{W})$, instead, measure "*indirect effects*", which correspond to cross-partial derivatives, $\frac{\partial E[y_i]}{\partial x_{k,j}}$. These are *interregional spillover effects*. Finally, the "*total effect*" is the sum of the direct and indirect impacts.

Ertur and Koch (2007) test this new growth framework using country level data. Applications of similar frameworks to regional data (especially European regional data) are in Fischer (2009), Egger and Pfaffermayer (2006), Pfaffermayr (2009a) and Pfaffermayr (2009b). All these studies find evidence of significant neighboring effects in regional growth in Europe.

Finally, a nonlinear extension of model (7a) has been proposed by Basile (2008, 2009):

$$\ln y_i = \beta_0 + f\left(\ln\frac{s_i}{n_i + g_b + \delta}, \sum_{j \neq i}^{N} w_{ij} \ln\frac{s_j}{n_j + g_b + \delta}\right) + \rho\sum_{j \neq i}^{N} w_{ij} \ln y_j + \varepsilon_i \qquad (7c)$$

where $f(.)$, to be estimated through nonparametric methods, captures the smooth interaction between the effective saving rate in region *i* and in its neighborhood. He applied this framework to regional data in Europe and found significant evidence of both nonlinearities and spatial dependence. In particular, a trade-off emerged between nonlinearities and spatial auto-correlation; the value of the parameter ρ is lower when possible nonlinearities are taken into account.

4.2 A Schumpeterian perspective

Ertur and Koch (2011) have also provided an extension of the multi-country Schumpeterian growth model with technology transfer elaborated by Howitt (2000). Here, each region *i* in every period *t* produces under perfect competition a homogenous output $\left(Y_{it}\right)$ through an aggregate production function using labour $\left(L_{it} = L_{i0}e^{n_i t}\right)$ and a continuum of horizontally differentiated intermediate goods, $x_{it}\left(s\right)$:

$$Y_{it} = \int_0^{Q_{it}} A_{it}\left(q\right) x_{it}\left(q\right)^{\alpha} l_{it}^{1-\alpha} ds \qquad 0 < \alpha < 1 \qquad (9)$$

where Q_{it} is the number of different intermediate goods produced and used in region *i* at date *t*, $l_{it} \equiv \left(\frac{L}{Q}\right)_{it}$, $x_{it}\left(q\right)$ is the flow output of the intermediate product $q \in \left[0, Q_{it}\right]$ used at time *t* and $A_{it}\left(q\right)$ is a productivity parameter attached to the latest version of intermediate product q.

Each intermediate product is generated under monopolistic competition using sector specific capital:

$$x_{it}\left(q\right) = K_{it}\left(q\right) / A_{it}\left(q\right) \qquad (10)$$

Division by $A_{it}\left(q\right)$ indicates that successive vintages of the intermediate product are obtained by increasingly capital-intensive techniques. Since all firms are symmetric, they supply the same quantity of intermediate goods, $x_{it} = x_{it}\left(q\right) \ \forall q$. Putting this common quantity into (10) and assuming that the total demand of capital equals the given supply K_{it} yields:

$$x_{it} = x_{it}\left(q\right) = \hat{k}_{it} l_{it} \qquad (11)$$

where $\hat{k}_{it} \equiv K_{it} / \left(A_{it} L_{it} \right)$ is the capital stock per effective worker and A_{it} is the average productivity parameter across all sectors. Substituting (11) into (9) shows that the output per effective worker, $\hat{y}_{it} \equiv Y_{it} / \left(A_{it} L_{it} \right)$, is given by

$$\hat{y}_{it} = \hat{k}_{it}^{\alpha} \qquad (12)$$

Innovations in Schumpeterian theory create improved versions of old intermediate products and occur in each sector at the Poisson rate $\lambda_i \kappa_{it}^{\phi}$, with λ_i the productivity parameter of vertical R&D, $\kappa_{it} = \dfrac{S_{A,it}}{Q_{it} A_{it}^{\max}}$ the productivity-adjusted R&D intensity in each sector and $0 \leq \phi \leq 1$ the parameter measuring the impact of R&D expenditure on arrival rate. R&D intensity in each sector $\dfrac{S_{A,it}}{Q_{it}}$ is deflated by $A_{it}^{\max}$, the leading-edge productivity parameter, in order to take the force of increasing complexity into account: as technology advances, the resource cost of further advances increases proportionally.

In order to introduce spatial technological interdependence, the research productivity parameter λ_i is defined as follows:

$$\lambda_i = \lambda \prod_{j=1}^{N} \left(\frac{A_{jt}}{A_{it}} \right)^{\gamma_i v_{ij}} \qquad (13)$$

R&D productivity is therefore a positive function of the technological gap of region *i* with respect to *its own (or local) technological frontier* defined as a geometric average of knowledge levels in all regions denoted by A_{jt} for $j = 1, ..., N$.

The technological frontier is *local* (i.e. it is specific to each region) because of the v_{ij} parameters, which define the specific access of region *i* to the accumulated knowledge of all other regions (i.e. the proximity relationship of region *i* with all other regions *j*). In Howitt (2000), instead, all regions share the same *global* technological frontier since each region diffuses the same quantity of knowledge, that is $v_{ij} = v_j$. The assumption of a local technological frontier can be more intuitively justified if v_{ij} parameters capture the technological or specialisation proximity among regions. In other words, if we assume that each region produces and uses a certain number of intermediate goods, its local technological frontier is represented by the knowledge created in other regions which produce and use similar intermediate products.

Thus, the further away a region is from its own technological frontier, the higher its productivity in the research sector, because it can benefit from the accumulated knowledge in other regions ("advantage of backwardness" conferred to technological laggards). The parameter $\gamma_i > 1$ measures the "*absorption capacity*" of region *i*, which in line with Nelson and Phelps (1966), is assumed to be a function of its human capital stock, as: $\gamma_i = \gamma H_i$.

Given these assumptions, the growth rate of the average accumulated knowledge is given by:

$$g_{it} \equiv \frac{\dot{A}_{it}}{A_{it}} = \lambda\sigma\kappa_{it}^{\phi} \prod_{j=1}^{N} \left(\frac{A_{jt}}{A_{it}} \right)^{\gamma_i v_{ij}} \qquad (14)$$

Because of the direct relationship between R&D productivity and the region specific technological gap, all regions undertaking R&D activity converge to the same steady-state (world) growth rate $g_i^* = \frac{\dot{A}_i^{\max}}{A_i^{\max}} = g_w$ and, thus, to parallel growth paths, like in Howitt (2000) and in Solow (1956).

The evolution of each economy *i* is governed by a system of two differential equations, one describing the law of motion of aggregate physical capital and the other describing the accumulation of R&D:

$$\dot{\hat{k}}_{it} = s_{K,i}\hat{k}_{it}^{\alpha} - \left(n_i + g_{it} + \delta\right)\hat{k}_{it} \qquad (15)$$

$$\dot{\kappa}_{it} = \frac{\kappa_{it}}{1-\phi}\left[r_{it} + \lambda_i\kappa_{it}^{\phi} - \lambda_i\kappa_{it}^{\phi-1}l_{it}\alpha\left(\alpha-1\right)\hat{k}_{it}^{\alpha}\right] \qquad (16)$$

with $s_{K,i}$ the investment rate, δ the rate of depreciation of physical capital, assumed identical for each region, and r_{it} the interest rate.

Given the assumption of spatial technological interdependence, the steady-state log-level of technological knowledge accumulated in region *i* is a function of the knowledge accumulated in other regions:

$$\ln A_i^* = \text{constant} + \frac{\phi}{1-\phi}\left(\ln s_{A,i} + \ln n_i + \ln y_i\right) + \frac{\gamma H_i}{1-\phi}\sum_{j\neq i}^{N} v_{ij}\ln A_j^* \qquad (17)$$

Moreover, at steady state

$$\ln\hat{k}_i^* = \frac{1}{1-\alpha}\ln\frac{s_{K,i}}{n_i + g_i^* + \delta} \qquad (18)$$

Finally, replacing equations (17) and (18) in the production function (12), we obtain the steady-state log-level of real income per worker, whose empirical counterpart is:

$$\ln y_i = \beta_0 + \beta_1 \ln \frac{s_{K,i}}{n_i + g_w + \delta} + \beta_2 \ln s_{A,i} + \beta_3 \ln n_i$$
$$+ \theta H_i \sum_{j \neq i}^{N} v_{ij} \ln \frac{s_{K,j}}{n_j + g_w + \delta} + \gamma H_i \sum_{j \neq i}^{N} v_{ij} \ln y_j + \varepsilon_i \qquad (19a)$$

In matrix form we have

$$\mathbf{y} = \mathbf{X}\beta + \theta \mathbf{W}\mathbf{Z} + \gamma \mathbf{W}\mathbf{y} + \boldsymbol{\varepsilon} \qquad (19b)$$

where $\mathbf{y}$ is a $(N \times 1)$ vector of the logarithms of real income per worker, $\mathbf{X}$ the $(N \times 4)$ matrix of the explanatory variables, including the constant term, the logarithms of the investment rates in physical capital divided by the effective depreciation rate, the logarithms of the working-age population growth rates and the logarithms of expenditures in the research sector. $\mathbf{W} = diag[H_i]\mathbf{V}$ is a $N \times N$ spatial weights matrix (with $diag[H_i]$ the diagonal matrix of human capital stock and $\mathbf{V}$ the matrix collecting the interaction terms v_{ij}), $\mathbf{WZ}$ is the $(N \times 1)$ vector of the spatial lag of the logarithms of the investment rates in physical capital divided by the effective depreciation rate and $\mathbf{Wy}$ is the endogenous spatial lag term. β and θ are vectors of parameters associated to $\mathbf{X}$ and $\mathbf{WZ}$, respectively. γ is the spatial autoregressive parameter measuring the degree of technological interdependence and $\boldsymbol{\varepsilon}$ is the $(N \times 1)$ vector of *iid* errors.

The reduced form of equation (19b) can be easily derived:

$$\mathbf{y} = (\mathbf{I} - \gamma\mathbf{W})^{-1}\mathbf{X}\boldsymbol{\beta} + (\mathbf{I} - \gamma\mathbf{W})^{-1}\mathbf{WZ}\boldsymbol{\theta} + (\mathbf{I} - \gamma\mathbf{W})^{-1}\boldsymbol{\varepsilon} \qquad (20)$$

Like in equation (8), the presence of the inverse spatial transformation $(\mathbf{I} - \gamma\mathbf{W})^{-1}$ in equation (20) implies the existence of spatial externalities in modelled as well as in un-modelled effects. It is also important to note that equation (19a) encompasses the multi-region Solow growth model with imperfect technological interdependence (equation 7a). Indeed, in addition to factor accumulation, equation (19a) shows that innovation caused by R&D investment plays a major role in explaining the growth process. Moreover, one can also observe that the Solow growth model (equation 1) constitutes a particular case of the multi-region Schumpeterian growth model when R&D expenditures have no effect on growth (φ = 0) and there is no technological interdependence between regions (γ = 0). Finally, equation (19a) encompasses also the econometric specification elaborated by Howitt (2000) (equation 3). As already observed, Howitt (2000) assumes that $v_{ij} = v_j$ (each region diffuses the same amount of knowledge to other regions), so that the last term of equation (19a) is identical to each region and can be incorporated in the constant term. In this way, Howitt (2000) excludes the possibility of specific technological interdependence across regions.

Ertur and Koch (2011) test the theoretical predictions of their model using cross-country data.[9] Some authors provide evidence of a positive effect of R&D intensity on regional growth in Europe (e.g. Sterlacchini and Venturini, 2009). However, comparisons between the neoclassical growth model with technological interdependence and the Schumpeterian growth model with technological interdependence based on regional data are still missing. More flexible specifications of equation (19a) are also needed to assess the hypothesis of parameter heterogeneity and, more specifically, to identify possible threshold effect in the relationship between R&D intensity and growth.

[9] Following the recent developments by Howitt and Mayer-Foulkes (2005) and Acemoglu et al. (2006), Ertur and Koch model might be generalized by taking into account non-parallel long-run growth paths which allow richer club structures.

5 Industrial heterogeneity, agglomeration externalities and regional endogenous growth

Up to now we have reviewed the growing literature on spatial extensions of growth analysis which emphasizes the role of spatial technological interdependence (or spatial spillovers) and of neighboring effects in regional growth and convergence. Now, it is important to recognize the parallel development of another strand of literature which has got underway following the contributions of Lucas (1988) and Glaeser (2000), who argue that cities and local districts should be elected as the most natural environment for the ordinary working of knowledge spillovers which are at the base of endogenous growth models . In a nutshell, spillovers are more likely to occur at the local level since they are favored by direct human interactions (Von Hippel, 1994). This phenomenon is due to the fact that new knowledge is often extremely complicated and contains complex (and sometimes tacit) elements which imply that often new knowledge is only accessible via interactions within inter-firm innovation networks or general innovation systems that tend to be bounded by geographical proximity (Karlsson and Manduchi, 2001; Andersson and Karlsson, 2004; Audretsch and Feldman, 2003). This intuition has given rise to a broad theoretical, mostly conceptual, literature, surveyed in Doring and Schnellenbach (2006), while more analytical NEG models have until now failed to provide a deep enough theoretical understanding of learning mechanisms at the local level (Puga, 2010).

The importance of such understanding is emphasized by Breschi and Lissoni (2001), who recommend some caution in the use of the notion of local knowledge spillovers and suggest opening the black box of local externalities to disentangle different potential causes. Krugman (1991), for instance, distinguishes between pecuniary and technological spillovers, the former being market mediated and the latter due to unintended actions. Marshall's (1890) partition of local agglomeration forces into three categories (labor market pooling, transport cost savings and knowledge sharing) provides examples of both categories. The former two operate through market interactions whilst the latter has the true nature of a pure technological externality. Actually, Marshall definitions are mostly used to indicate those local forces which come from the concentration of an industry in a region which encourages other firms in the same industry to locate in the same place. This vision is usually contrasted to the one by Jacobs (1969), according to whom the main source of local spillovers is external to the industry where the firm operates, as the presence of a variety of sectors facilitates imitation and recombination of ideas and cross-fertilization across industries. Finally, a third alternative vision is given by Porter (1990) who argues that local competition rather than monopoly favors local economic growth by channeling knowledge within specialized geographically concentrated industries.

The question as to which one of the three agglomeration forces (Marshall, Jacobs or Porter) is the most beneficial to regional growth, directly or through innovation, is rather complex and it has been at the centre of a heated debate in the empirical literature. Beaudry and Shiffeurova (2009) show that twenty years of research have produced results which are, to say the least, contradictory[10] and argue that much of this controversy depend on the way externalities and economic growth are measured. Moreover, there is clear evidence of the presence of sectoral, temporal, geographical

[10] In their literature review, De Groot et al (2009) compute 393 estimates of externalities, which yield quite a mixed evidence in terms of sign and statistical significance.

and institutional heterogeneity which influences the role of specialization, competition and diversity on regional growth (De Groot et al., 2008). Despite that, we may conclude that there is substantial, but not unanimous, academic support for the positive impact of Marshallian externalities based on specialization. Results for diversification are less mixed and point mainly to a positive role of Jacobian spillovers. As for Porter externalities, results are often inconclusive but when the impact is significantly different from zero, the positive effect prevails.

Nonetheless, the question of which agglomeration externalities are at work and with what effect is not just an empirical issue but, most importantly, a theoretical one. Along this line of research, Duranton and Puga (2001) propose a model which, combining static and dynamic advantages of specialization and diversity, predicts that firms create new products in diversified regions but, when production becomes standardized, they switch to mass-production and relocate to specialized regions. They endow with solid micro-foundations the well-known Jacobs' claim that diversified urban environment are essential to promote search and experimentation of new prototypes and therefore innovation. Once products and processes are stabilised and routinised, the consequent mass-production entails the aversion of congestion and high costs of urban areas by moving to a specialized area, where Marshall's externalities prevail.[11] At the end of the life cycle, according to Boschma (2005), specialisation

[11] Henderson et al. (1995) show that specialisation (or Marshallian) externalities are stronger in low-tech industries while diversity (or Jacobs') externalities are positive among high-tech sectors and services. Further empirical support is provided by Marrocu et al. (2011), who distinguish among Marshallian and Jacobian externalities operating in Eastern and Western European regions, and Neffke et al. (2011), who investigates agglomeration externalities along the industry life cycle in Sweden. Both studies find that intra-industry externalities increase with the maturity of industries and are relatively more important in backward regions, while the effects of local diversity are positive for young and dynamic industries, especially in urban regions and can be negative in other industries and local areas.

might even prove harmful to economic growth since lock-in effects prevent economies from exploiting new promising technological trajectories.

However, according to Duranton and Puga (2004), the search of a theoretical framework to include different types of agglomeration externalities needs to go beyond the so called Marshallian "trinity" and the distinction among Marshall, Jacobs and Porter spillovers. They suggest, as an alternative, three main causes for the existence of local increasing returns which are based on the mechanisms at work rather than on the markets in which they take place (as in Marshall, where externalities arise in the labour market, in the market for intermediates and in an incomplete market for ideas). The first mechanism is due to the possibility to have a more efficient sharing of local infrastructure, facilities, risks and intermediate inputs in larger local markets. The second one is due to the fact that a larger market also allows for a better matching between employers and employees, buyers and suppliers, or among business partners. Finally, a larger market can facilitate learning about new technologies and promote the development of new ideas thanks to more frequent direct interactions between economic agents. Hence, the presence of different mechanisms which can generate local increasing returns and the need for appropriate modellisation in order to identify the actual nature of the market failure at stake and possibly an effective and non distorting policy intervention. According to Puga (2010), despite some progress, the theoretical literature has been relatively unsuccessful in identifying and distinguishing these different sources of agglomeration externalities. There are a few models which include sharing and matching mechanisms (see the review in Duranton and Puga, 2004 and Glaeser, 2010), but more work is needed to model knowledge externalities which occur through learning (Duranton and Puga, 2001 being an important but rare exception).

6. Conclusions and future research

In this Chapter we have provided a critical survey of the growing literature on regional growth analysis. In particular, we have pointed out the existence of an unsuspected strong interaction between regional growth analysis and the development of endogenous growth theory. On the one hand, endogenous growth models (both of the first and second generation), which identify a large set of self-reinforcing mechanisms that can potentially cause poverty traps, have strongly stimulated regional growth analysis and justified regional development policies over the last decade. In particular, a large number of empirical regional growth analyses have provided evidence that in large contexts such as the European Union as well as within many countries (such as Italy, Spain and Greece) a group of regions tend to converge towards a high equilibrium level, while other regions languish behind or tend to converge towards a low equilibrium level. As widely discussed in this Chapter, this evidence is consistent with the existence of non-convexities in the aggregate production function associated with threshold effects in the accumulation of capital which lead to long-run dependence from initial conditions (Azariadis and Stachurski, 2004). It is also consistent with Schumpeterian growth models which predict club convergence in relation to the capacity of regions to perform R&D and to absorb foreign technological knowledge (Howitt, 2000; Howitt and Mayer-Foulkes, 2005). On the other hand, empirical regional growth analysis has uncovered important weaknesses, which theorists have remedied by introducing elements of reality that were missing from the original theory. In particular, considerable effort has been devoted to incorporating more realistic assumptions on technological spatial interdependence into (endogenous) growth models. This group of studies has given rise to a large number of empirical analyses aimed at capturing the role of neighboring effects in regional growth and convergence. Nonetheless, there are several open issues which are still relatively neglected by the literature and are therefore left for future research in this field.

First of all, while the role of spatial frictions in the interregional diffusion of knowledge is now recognised within the growth theory, there is still much scope for further theoretical work on endogenous growth in a spatial-economic context. Specifically, while the economic theory has gone a long way in modeling interregional feedbacks and interregional spillovers (see Section 4 in this Chapter), intra-regional spillovers occurring from Marshallian (within industry) and diversification (cross-industry) economies are not explicitly included (MAR externalities are only implicitly taken into account in Ertur and Koch, 2007). As discussed in Section 5, firms may co-locate to obtain knowledge spillovers that occur when similar firms engage in R&D to solve similar or related problems. Physical proximity (and density) speeds the flow of ideas, especially when a significant part of intangible knowledge is often tacit and social networks tend to be strong. Thus, regions characterized by a denser clustering of industries exhibit agglomeration economies that lead to higher R&D productivity and, thus, to higher levels of innovation output. These argumentations should be explicitly taken into account in a multi-region endogenous growth theory which combines both vertical and horizontal innovation.

A better integration of micro and macro level approaches is also desirable. We are still unable to get a comprehensive picture of the underlying mechanisms that create spatial variations in efficiency and its dynamics across sectors, firms and regions. In particular, the future research agenda should focus on the causes of agglomeration externalities in an attempt to better formalise the microeconomic sources of local spillovers. We need to distinguish, on the one hand, the mechanisms at work: sharing, matching and learning according to the trilogy proposed by Duranton and Puga (2004); and, on the other hand, the market in which they apply: labour, intermediates or ideas as in the Marshallian "trinity". Finally, we need to understand how and when such forces operate across sectors (as in Jacobs) and when within sectors (as in Marshall). As argued by Ottaviano (2011) in his research agenda for the "New" New Economic Geography, we need to shift from 'macro-heterogeneity' across regions with identical economic agents to 'micro-heterogeneity' across firms and families in order to understand how the juxtaposition of the decision levels of these agents, which operate in differentiated contexts and sectors, affect the local economic system, its industrial structure and its evolution. These theoretical efforts should go hand in hand with the empirical attempts to provide a rationale for the co-existence of heterogeneous firms and sectors within and across regions and explain how firm productivity distribution and economic growth are affected by geographical factors and vice versa.

Among geographical factors, we need to investigate the spatial extent of agglomeration forces while trying to go beyond physical proximity, no longer believed to be sufficient to transmit knowledge and other spillovers across local units (Capello, 2007, 2009). Boschma (2005) and Mattes (2011), among others, have convincingly suggested that other dimensions may prove crucial in channelling spillovers across economic agents, such as institutional, cognitive, social and organizational proximity. We certainly need to investigate more on the characteristics of spillovers flowing along these different dimensions both from a theoretical (Cowan and Jonard, 2004) and an empirical point of view (Basile et al., 2011; Marrocu et al., 2011). This dual path entails an effort to understand which local agglomeration forces are mediated by the market and which are not (Breschi and Lissoni, 2001), which spillovers are intended and which are involuntary (Maggioni et al., 2007), which flows involve public institutions and private firms (D'Este and Iammarino, 2010) and, finally, hierarchical and a-hierarchical relationships (Maggioni et al., 2011). Moreover, we need to distinguish real agglomeration forces from other mechanisms, such as selection and sorting of workers and firms, as suggested in Behrens et al. (2010).

Another important challenge for the future of empirical analysis on regional economic growth refers to possible extensions and enhancements of spatial econometric techniques. On this issue, it is important to note that, thanks to the "introductory" textbook by Le Sage and Pace (2009), the state of the art of applied spatial econometrics has taken a step change (Elhorst, 2011). The authors enrich and widen the usual toolkit of applied econometrics with several new routines which allow to use diverse alternatives to spatial lag and error models. Moreover, they introduce the use of indirect effects as a more valid basis for testing whether spatial spillovers are significant and, most importantly, the use of Bayesian posterior model probabilities to determine which spatial weights matrix best describes the data (see also Harris et al, 2011). Finally, Le Sage and Pace (2009) make the case for extending the usual cross section setting of spatial economic analysis to include the temporal dimension. This challenge has been so far accepted both with the development of exploratory spatial data analysis thanks to the integration of dynamic local indicators of spatial association (LISA) together with directional statistics, as it is done in Rey et al. (2011) and in Ye and Rey (2012) and with development of explicit spatial temporal econometric models, again, by Le Sage and Pace (2009). They propose two interesting candidates for this task: the time-space dynamic model and the time-space recursive model which, just as the spatial Durbin for cross-sectional data, can be used to estimate both global and local spatial spillover effects without imposing prior restrictions on the magnitude of these effects.

Finally, if the aim of a researcher is to provide evidence to discriminate between different theoretical approaches which predict club convergence (widely observed in empirical analysis), linear regression analyses are of limited use. As already observed by Magrini (2004), the regression approach tends to concentrate on the behavior of the representative economy. In other words, with few exceptions, convergence analyses based on such an approach can only shed light on the transition of this economy towards its own steady state whilst giving no information on the dynamics of the entire cross-sectional distribution of income. Scholars should conform to the analysis of intra-distribution dynamics proposed for the first time by Quah and to its integration with nonlinear regression models (see, e.g., Basile, 2009; Fiaschi et al. 2009).

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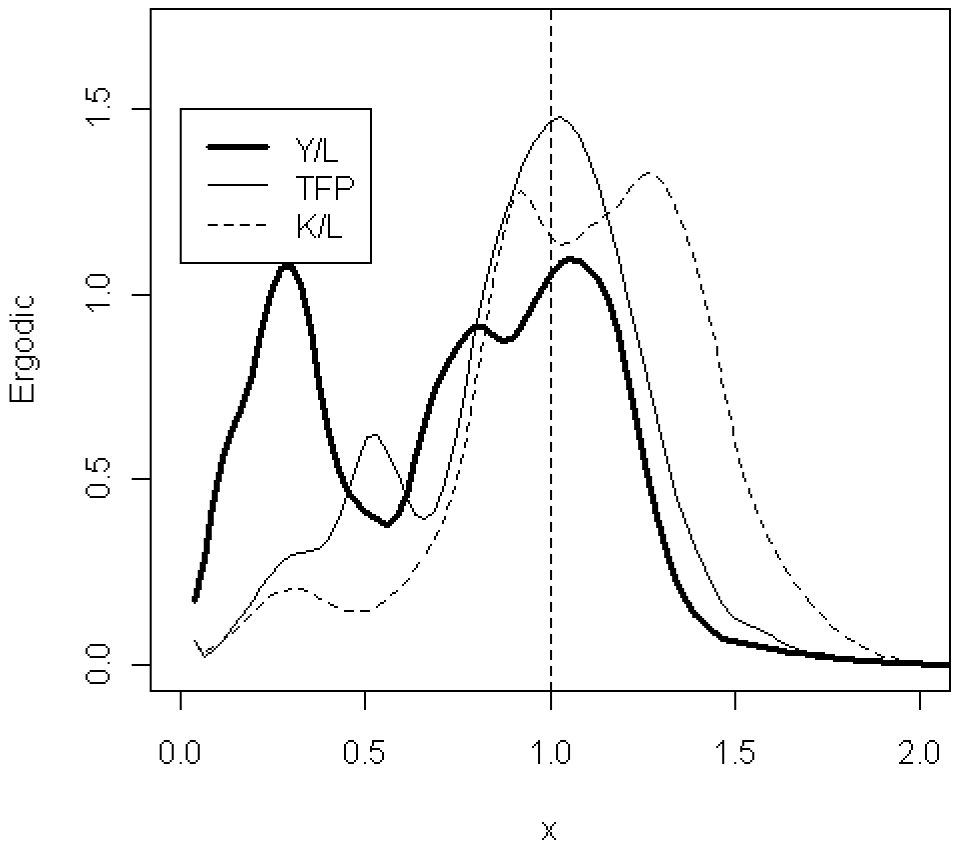
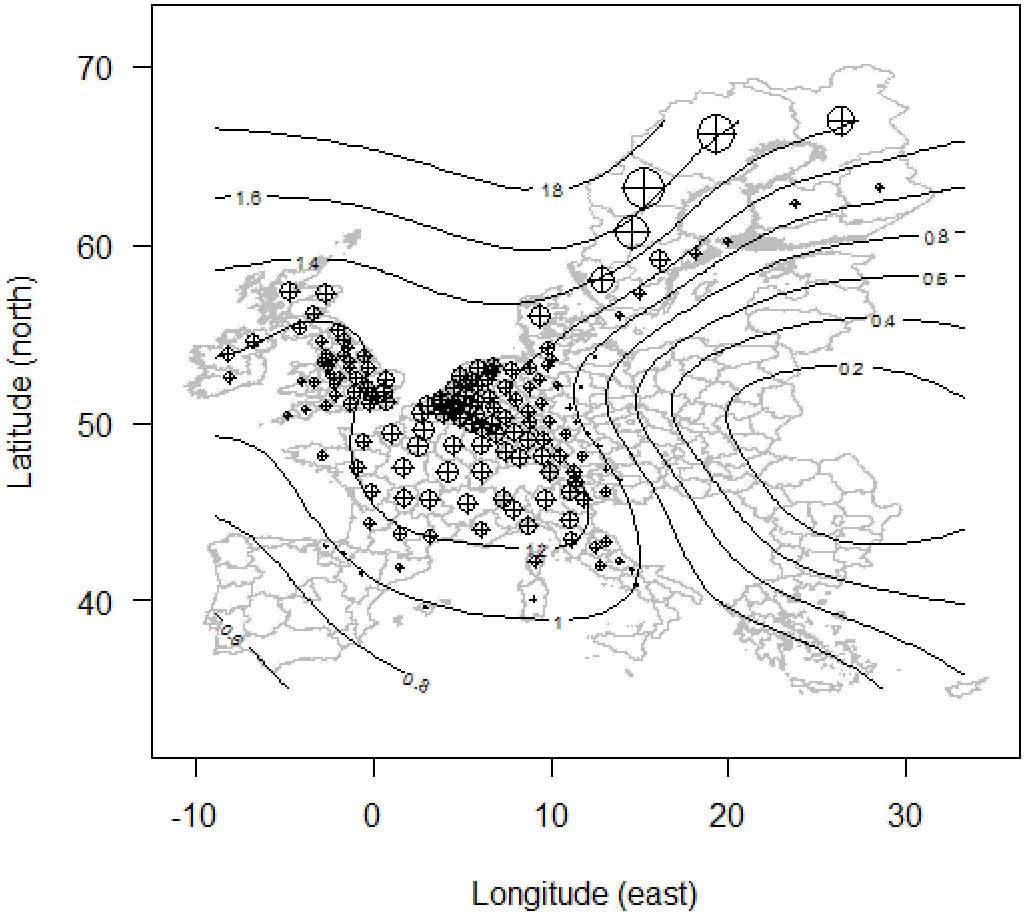
Figure 1: Estimated ergodic densities



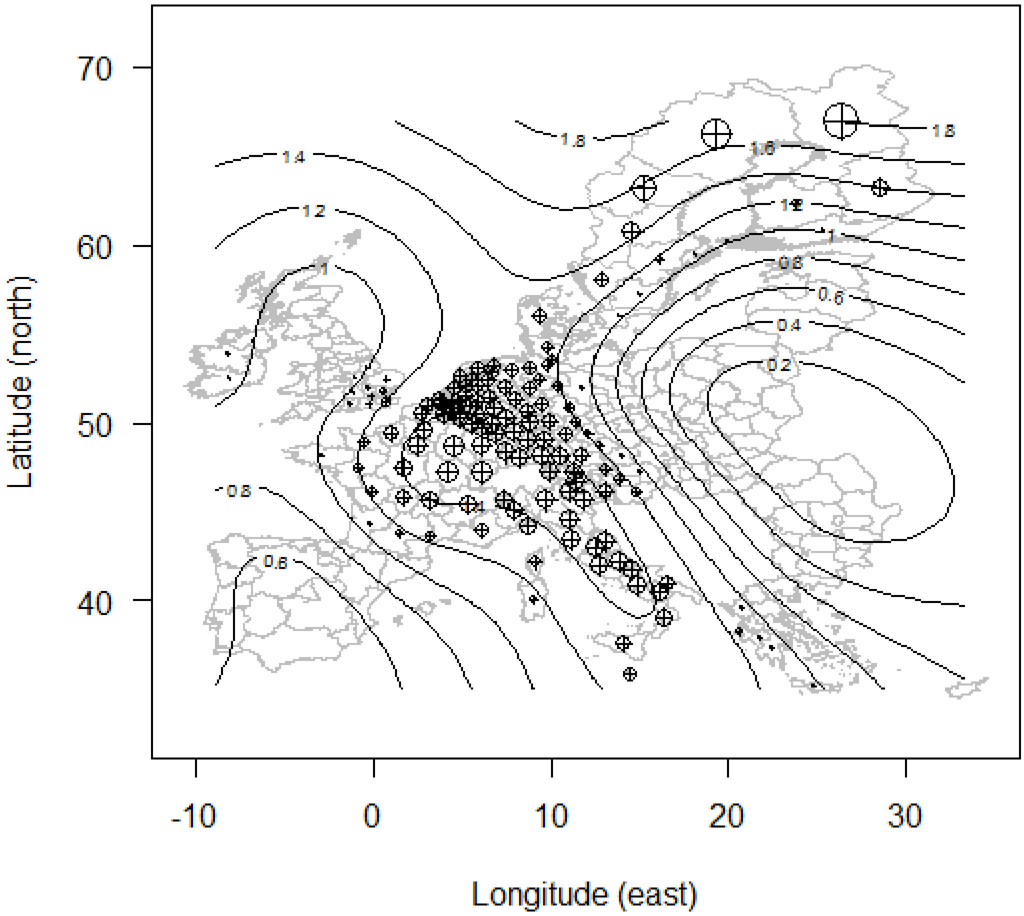
Note: Y/L denotes "income per worker", TFP denotes Total Factor Productivity and K/L indicates capital/labour ratio.

Figure 2: Income per worker



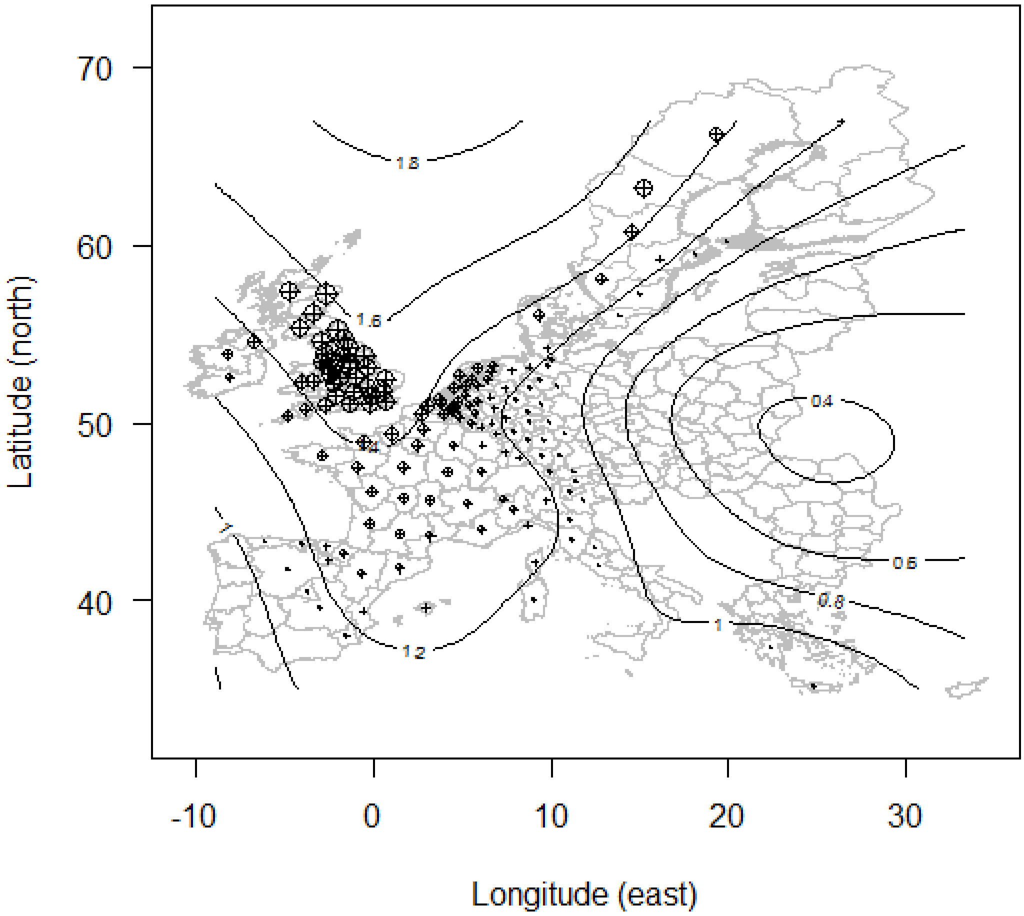
Note: Contour lines are drawn for different values of the predicted value of regional income per worker. Each circle in the plot, centred at the regional centroid, is proportional to the same predicted value. X and Y axis measure degrees of longitude and latitude, respectively.

Figure 3: Capital/Labour ratio



Note: Contour lines are drawn for different values of the predicted value of regional capital/labour ratio. Each circle in the plot, centred at the regional centroid, is proportional to the same predicted value. X and Y axis measure degrees of longitude and latitude, respectively.

Figure 4: Total Factor Productivity



Note: Contour lines are drawn for different values of the predicted value of regional TFP. Each circle in the plot, centred at the regional centroid, is proportional to the same predicted value. X and Y axis measure degrees of longitude and latitude, respectively.

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Finito di stampare nel mese di Luglio 2012
Presso **Copy…Right! studio grafico & stampa digitale**
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ISBN 978-88-84-67-739-6

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