TECHNOLOGICAL CHANGE, TECHNOLOGICAL CATCH-UP AND MARKET POTENTIAL: EVIDENCE FROM THE EU REGIONS

Dimitris KALLIORAS
Associate Professor, Department of Planning and Regional Development, University of Thessaly
ORCID ID: 0000-0003-3060-3745
dkallior@uth.gr

Nickolaos TZEREMES
Associate Professor, Department of Economics, University of Thessaly
ORCID ID: 0000-0002-6938-3404
bus9nt@uth.gr

Panayiotis TZEREMES
Assistant Professor, Department of Accounting and Finance, University of Thessaly
ORCID ID: 0000-0002-0746-3839
tzeremes@uth.gr

Maria ADAMAKOU
PhD Candidate, Department of Planning and Regional Development, University of Thessaly
madamakou@uth.gr

Abstract

The paper examines the way(s) market potential affects the EU regions' technological change and technological catch-up. The analysis refers to a sample of 263 NUTS II EU regions and covers the period 1995-2008 (i.e. prior to the outburst of the economic crisis). On the basis of the latest advances of nonparametric frontier analysis, and in the presence of dynamic effects, time-dependent conditional nonparametric frontiers are developed. The incorporation of the dynamic effects of the EU regions' market potential conditions, allows for modelling the corresponding effects on technological change and technological catch-up. The findings of the paper provide valuable insight to both theory and policy-making, revealing that, within the integrated EU space, market potential acts as a technology-initiating factor, creating asymmetric effects and leaving a distinct "spatial footprint" with respect to the processes of technological change and technological catch-up.

Keywords: technological change, technological catch-up, market potential, EU regions, nonparametric frontier analysis

JEL classification: C14, O3, R11

1. Introduction

Technological change may summarize into the overall process of invention, innovation, and diffusion of technology (Rothwell 1994, Godin 2006). Technology itself, capturing the array of ideas, skills, techniques, methods, and practices that are used in the production process, defined as "knowledge about how to produce goods and services" (Fagerberg et al. 2014, p.316), is a cornerstone of industrial and post-industrial economies (Ball 1957, Arthur 2009). The general understanding of technological change as a progressive, accelerating and cumulative process (Freeman 1994, Ziman 2000, Mokyr 2002, Ho and Lee 2015, Wei and Liu 2019) supports the idea of technological catch-up (Nelson and Phelps 1966, Abramovitz 1986, Choung et al. 2012, Ahn, 2017) in the sense that technology diffuses by linking economies ever more intensively (Patel and Pavitt 1994, Blomström and Kokko 1998, Keller 2004). In the field of economics, technological change and technological catch-up are reflected in the change in the set of the feasible production possibilities i.e., in the combinations of inputs and outputs that comprise a technologically feasible way to produce (Coelli et al. 2005). Particularly, technological change is reflected in the shift of the production possibilities frontier and technological catch-up is reflected in the decrease of the distance from the production possibilities frontier. It thus comes that factors that initiate technological change and technological catch-up may spur economic growth by allowing economic agents to produce more (and, presumptively, novel) output using fewer inputs (Solow 1957, Grossman and Helpman 1991, Aghion and Howitt 1992, Bresnahan and Trajtenberg 1995).

Technology creates externalities i.e., benefits and costs that are infeasible to charge to provide and not to provide, respectively (Pigou 1920/1932, Scitovsky 1954, Buchanan and Stubblebine 1962), so as the production function of a firm imposes positive and/or negative effects on the production functions of other firms. Despite the fact that geographical distance is thought to lose its significance, owing to the ongoing improvement of communication and transportation, technological externalities are imprinted in space, leaving a distinct "spatial footprint". As Ertur and Koch (2007) and Lu and Wang (2015) point out, spatial externalities are present in the processes of technological change and technological catch-up. Taking this into consideration, and given that, in the realm of the real world, firms – critical economic agents, especially within the knowledge economy (Teece 1996) – are not "isolated islands" (Waverman et al. 1997, p.322), it comes that the effect of technology-initiating factors may not, necessarily, bounded by administrative boundaries (Holl 2012). It comes, scrutinizing the literature, that it is the "non-delimited" concept / measure of market potential (Harris 1954) that may capture the spatial scope over which the effects of technology-initiating factors may take place. In this sense, market potential may become a technology-initiating factor itself. This is so as market potential may use as a proxy for market demand on the rationale that the volume of interactions among the economies considered (usually against the backdrop of their purchasing powers) is lower the further apart these economies are. As it relates to the "Law of Universal Gravitation" (Newton 1687/1846) (i.e., every point mass in the universe attracts every other point mass with a force that is directly proportional to the product of their masses and inversely proportional to the square distance between them), market potential is an intriguing concept and, as such, it has been used, extensively, in the empirical literature (Brülhart et al. 2004, Head and Mayer 2004 and 2006, Ottaviano and Pinelli 2006). This may, also, attribute to the fact that, within the new economic geography school, it has been provided with theoretical underpinnings (Fujita et al. 1999, Hanson 2005), thus receiving renewed interest.

The paper, following the latest advances of nonparametric frontier analysis, evaluates the patterns of the EU regions' technological change and technological catch-up subject to the corresponding market potential conditions, in the presence of dynamic effects. To this end, for the first time in the relative literature, at least to the best of knowledge, the paper applies the probabilistic approach of conditional nonparametric frontier analysis (Daraio and Simar 2005, 2007a and 2007b, Mastromarco and Simar 2015). The embodiment of time-dependent conditional nonparametric measures allows for such an evaluation to take place in the presence of dynamic effects. Studying a sample of 263 EU NUTS II regions, for the period 1995-2008 (i.e. prior to the outburst of the economic crisis), the paper provides clear-cut empirical evidence that market potential, actually, acts as a technology-initiating factor. Detecting a non-linear, and highly-influenced by its absolute level, effect of market potential on both technological change and technological catch-up, for specific groups of EU regions (i.e. Eastern, Western, Southern, Northern EU regions), the paper stresses out that, within the integrated EU space, market potential creates asymmetric effects and leaves a distinct "spatial footprint" with respect to the processes of technological change and technological catch-up.

The paper proceeds as follows: The next section provides a critical survey of the discussion in the literature concerning the spatial externalities that technology creates. The third section commends on the data and describes the methodological approach. The fourth section provides the findings of the empirical analysis. The last section offers the conclusions and some policy implications.

2. Technology and spatial externalities

Mankiw et al. (1992, p.410) by providing a human-capital-augmented empirical specification of the neoclassical Solow-Swan growth model (Solow 1956, Swan 1956), assert that technology "reflects primarily the advancement of knowledge, which is not country-specific". As Denison (1967, p.282) argues, "because knowledge is an international commodity, I should expect the contribution of advances of knowledge … to be of about the same size in all countries". On the other end of an imaginable theoretical spectrum, Arrow (1962), Romer (1986) and Lucas (1988) reject the treatment of technology as an exogenously-determined growth determinant (i.e. as a pure public good) postulating the exact opposite argument: technology is endogenously-determined as the outcome of cumulative experience (i.e. learning-by-doing) and, as such, is country-specific. Instead, learning (i.e. technological knowledge) is the pure public good: as the outcome of the country-wide experience it may apply at the firm-level. Nevertheless, even under such an assumption, technological catch-up is far from being an outright process (Griliches 1957, Basu and Weil 1998, Comin and Bart 2004) as technological knowledge is subject to distance-decay processes (Faggian and McCann 2006, Caragliu and Nijkamp 2016). This may consider as the aftereffect of the tacit (i.e. the non-codified) dimension of technological knowledge (Polanyi 1966, Nelson and Winter 1982, Nonaka and Takeuchi 1995). Tacit knowledge, which may condense into the informal exchange of ideas among firms does not travel easily since it is difficult to codify (Breschi and Lissoni 2001a). In this light, technological knowledge cannot be treated as a pure public good since the access of (tacit) knowledge is neither cost-free nor learning-free (Buchmann 2015). Thus, instead of easing technological catch-up, technological change may disclose the inability of the technologically less advanced economies to compete with their more advanced counterparts in the markets for knowledge-intensive activities (Camagni 1992, Cox and Wood 1997, Brülhart and Elliott 1998). This provides a clear-cut answer to questions such as "why do private firms perform basic research (with their own money)?" (Rosenberg 1990, p.165) and "why [an economy or a firm] should it not sit back and wait for technology diffusion that flows costlessly" (Benhabib and Spiegel 2005, p.937).

Focusing on knowledge spillovers, and, particularly, on tacit knowledge, Boschma (2005, pp. 62-68) stresses the argument that proximity besides geographical, is also cognitive (i.e. in the sense that "knowledge and innovations are often cumulative and localized outcomes of search processes within firms with a high degree of tacit knowledge"), organizational (i.e. in the sense that "knowledge creation […] depends on a capacity to coordinate the exchange of complementary pieces of knowledge owned by a variety of actors within and between organizations"), social (i.e. in the sense that "social ties or relations affect economic outcomes"), and institutional (i.e. in the sense that "the idea of economic actors sharing the same institutional rules of the game, as well as a set of cultural habits and values […] all provide a basis for economic coordination and interactive learning"). As Caragliu and Nijkamp (2016, p.754) indicate, "these forms of proximity complement the role of geographic distance as a factor which impedes the flow of knowledge". According to Rodriguez-Pose and Crescenzi (2008, p.377), "the reason behind the emergence of mountains in a flat world is, precisely, the interdependence of all the different types of proximity". In fact, reality is significantly far from clichés, such as the "end of geography" (O'Brien 1992) and the "death of distance" (Cairncross 1997), and the notions of "slipperiness" (Markusen 1996, Friedman 2005) or "flatness" (Friedman 2007), which are combined to suggest "tendencies towards an equalization of chances of economic development" (Cox 2008, 389) or the "transformation of the economic order into a liquefied space of flows" (Scott and Storper 2003, p.581), in general. As aptly put by Gertler (2003, p.79), "… it becomes apparent why geography now "matters" so much".

According to Winter (1988, p.171), a firm may describe as a "repository of productive knowledge". This stresses out the importance, for a firm, of having access to technological knowledge, and, especially, to tacit knowledge. Jaffe et al. (1993), Audretsch and Feldman (1996 and 2004), and Anselin et al. (1997) demonstrate that the spatial diffusion of tacit knowledge is not free, accentuating the importance of localized knowledge spillovers. On these grounds, Fujita and Thisse (2003) argue that agglomeration economies may lead to higher growth allowing for innovation to follow a fast(er) pace. Building on Marshall (1890) and Jacobs (1969), it comes that firms tend to cluster in order to enjoy the benefits of agglomeration economies (running, of course, the danger to encumber with negative effects, such as higher land rent and heavier congestion) in the sense of specialization (localization economies) and/or diversification (urbanization economies) (Glaeser et al. 1992, Henderson et al. 1995, Quigley 1998, Duranton and Puga 2001, Parr 2002). The so-called "third Italy" (Brusco 1982) as well as concepts such as the "innovative milieu" (Aydalot 1986, Camagni 1991) and the "business clusters" (Porter 1990) is a reminder that firms tend, indeed, to locate in close proximity to each other, forming clusters (Martin and Sunley 2003). Aside from labor market pooling and input sharing, agglomeration economies facilitate, with respect to technology, knowledge spillovers i.e., the transmission of (technological) knowledge among firms. As Audretsch et al. (2007) and Karagiannis (2007) point out, knowledge spillovers have been gaining paramount importance as efficiency-improving factor, especially as the markets for standardized products started to saturate.

Facilitating the creation of knowledge capital, through the diffusion of knowledge spillovers, the clustering of firms has, accordingly, been gaining paramount importance as well. This is so as, within clusters, technological knowledge becomes a local public good (Maskell and Malmberg 1999, Breschi and Lissoni 2001b, Crespo et al. 2014). Yet, not all clusters are equally successful as agglomeration economies exhibit an uneven impact. Asheim and Isaksen (2002) support that the extra-cluster knowledge exchange is the decisive factor for such an unevenness. As Cantwell and Iammarino (2003) point out, it is the formation of extra-cluster linkages that prevents a firm from being locked-in a cluster of firms that follow a mediocre technological path. As Essletzbichler and Rigby (2005 and 2006) demonstrated, trajectories of technological change suggest that heterogeneity in production techniques is a permanent feature of an economy, manifesting in the regional (i.e. intra-cluster) accumulation of technological knowledge. According to Rychen and Zimmermann (2008) and Crespo et al. (2014), the ability of regions to host networks of interacting firms is a key factor explaining regional performance differences. Hence, the formation of extra-cluster linkages may, essentially, translate as embeddedness in the global value chains, and as such it raises the variety of the knowledge ingredients of knowledge capital (Uzzi 1997). As Zhou et al. (2011) stress out, not only endogenous networks but also external agents, as well as the interaction between internal and external agents (Bathelt et al. 2004), are critical parameters as regards technological change and the production of technological trajectories. Thus, in line with Marques (2015), bringing mechanisms that encourage firms' inter-cluster interaction are necessary. Of course, access to a network of firms is not costless (Rosenberg 1990) and, apparently, differences in firm performance may, partly, explain with the heterogeneous levels of embeddedness within innovation networks (Granovetter 1985, Dosi and Nelson 2010, Buchmann and Pyka 2012). Hence, the discussion turns to the concept of market potential indicating that technology-intensive (and, in general, knowledge-intensive) firms tend (or aspire) to locate in territories that exhibit relatively high market potential so as to benefit from both the intra-cluster and the extra-cluster (technological) knowledge transfer. Yet, at this point, the question that comes forth is whether this is, also, the case within the integrated EU economic space - and especially at the regional level - at which technology barriers are, de facto, lean(er).

In the course of time, the EU has managed, in a series of enlargements, to expand, first southwards and then eastwards, integrating economies less and less (technologically) developed. The gradual "thinning" of (the artificial) border impediments is, precisely, the pure essence of the European (economic) integration process (Kallioras et al., 2009). The EU is, gradually, moving from "a space of States" to a "State of spaces" (Karanika and Kallioras, 2018), and, in this sense, within the integrated EU framework, the European territories have been experiencing a period of unprecedented change (Brülhart et al. 2004, Crescenzi et al. 2014). Particularly, the process of (economic) integration has, progressively, transformed spatial economies (i.e. regional economies, in particular) into integral parts of the emerging European (economic) space (Petrakos et al. 2005 and 2011). Yet, the latter, instead of getting "flat", is getting more "curved", as it appears to be, simultaneously, characterized - in analogy with the terminology used by McCann (2008) - both by European "flattening" and local "steepening", and thus more "sticky". Such "stickiness" may even reinforce spatial externalities (Kemeny 2011). This is so as although economic integration has greatly enhanced the mobility of people, products, and production factors – and money – this has "neither implied the ubiquity of economic activity nor undermined the need for urban concentration" (Scott et al. 2001, p.15). In contrast, technological change – a main force "behind perpetually rising standards of living" (Grossman and Helpman 1994, p.24) – becomes endogenous and changes "differently in different territories" (Rodríguez-Pose and Crescenzi 2008, p.378). The EU reality indicates, indeed, that the core EU regions generate advantages leading to differential growth performance operating as hubs for knowledge-intensive economic activities (Melachroinos 2002, Kallioras and Petrakos 2010, Petrakos et al. 2012).

3. Data and methodology

3.1. Data description

The paper utilizes employment, GVA, and capital stock data obtained from European Regional Database (Cambridge Econometrics). Employment is expressed in number of employees, whereas GVA and capital stock are expressed in € (in constant, year 2000, prices). The analysis refers to a sample of 263 NUTS II EU regions and covers the period 1995-2008; 1995 is the first year with available EU-wide regional data (note: Croatia is not included in the analysis) and 2008 is the year prior to the outburst of the world-wide economic crisis.

For the needs of the empirical analysis, the paper compiles a Harris-type (Harris 1954) market potential measure, which is expressed under the formula:

$$MP_i = \sum_{j=1}^{n} \frac{GVA_i GVA_j}{d_{ij}} \quad (1)$$

where i denotes the corresponding region, j denotes each of the other regions considered (i.e. $j = 1, 2, 3, \ldots, n = 262$), MP_i stands for the market potential of region i, GVA_i stands for the GVA of region i, GVA_j stands for the GVA of regions j, d_{ij} stands for the distance (i.e., Euclidean distance) between (i.e. between the centroids) of regions i and j. Essentially, market potential is a measure that may introduce as a proxy for both agglomeration and accessibility (Martín-Barroso et al. 2015). Thus, Equation (1) may use as a demand-for-technology index that allows for the detection of the (potential) effects of proximity in the sense of market potential (Duvivier 2013) under the central place theory perspective that larger regions (i.e. regions with larger market potential) serve many of the same functions as smaller regions (i.e. regions with smaller market potential) plus higher-order functions not found in smaller regions (Colwell 1982). Particularly, under conditions of imperfect competition, Equation (1) allows for the detection of the effects of market potential on the time-evolving processes of technological change and technological catch-up.

In order to avoid aggregated generalizations, which may provide misleading results, the empirical analysis of the paper is performed separately for specific groups of the EU regions. Particularly, the EU regions under consideration are classified as Eastern, Western, Southern, and Northern EU regions, according to the corresponding classification of the EU countries suggested by the UN (2012). Particularly, the group of the Eastern EU regions comprises of regions that belong to Bulgaria, Czech Rep., Hungary, Poland, Romania, and Slovakia; the group of the Western EU regions comprises of regions that belong to Austria, Belgium, France, Germany, Luxemburg, and the Netherlands; the group of the Southern EU regions comprises of regions that belong to Greece, Italy, Malta, Portugal, Slovenia, and Spain; and the group of the Northern EU regions comprises of regions that belong to Denmark, Estonia, Finland, Ireland, Latvia, Lithuania, Sweden, and the UK.

Tables 1a – 1d present the mean values for each of the variables considered, for each regional group, at a yearly basis, over the period 1995-2008. It comes that, by and large, the mean values of all variables considered are getting increased over time as regards the groups of the Western, the Southern, and the Northern EU regions. The same stands for market potential. The group of the Eastern EU regions provides a notable exception as regards the evolution of employment. Particularly, employment exhibits a decreasing trend over the period 1996-2002 as regards the Eastern EU regions, indicating the upsets of the period of transition (Kallioras and Petrakos 2010).

Table 1a. Mean values of the variables considered, period 1995-2008, Eastern EU regions

Eastern EU regions	Employment (employees)	Capital Stock (bn. €; constant, 2000, prices)	GVA (bn. €; constant, 2000, prices)	Market Potential (bn. bn. €; constant, 2000, prices)/km
1995	841,800	27,032	6,482	5,708
1996	849,433	27,794	6,759	6,079
1997	846,958	28,622	6,954	6,432
1998	827,103	29,519	7,139	6,789
1999	815,768	30,384	7,339	7,190
2000	813,539	31,239	7,660	7,789
2001	794,145	32,006	7,835	8,086
2002	764,225	32,716	8,051	8,390
2003	762,902	33,379	8,395	8,847
2004	764,539	34,091	8,847	9,544
2005	771,253	34,876	9,242	10,177
2006	787,380	35,801	9,826	11,180
2007	806,922	36,984	10,388	12,134
2008	822,270	38,244	10,837	12,766

Sources: European Regional Database (Cambridge Econometrics) / Authors' elaboration

Table1b: Mean values of the variables considered, period 1995-2008, Western EU regions

Western EU regions	Employment (employees)	Capital Stock (bn. €; constant, 2000, prices)	GVA (bn. €; constant, 2000, prices)	Market Potential (bn. bn. €; constant, 2000, prices)/km
1995	752,280	123,669	41,076	69,334
1996	784,281	129,048	41,617	71,416
1997	788,240	134,291	42,573	74,886
1998	799,411	139,673	43,747	78,978
1999	812,869	145,259	44,988	83,542
2000	829,911	150,897	46,602	89,617
2001	835,786	156,075	47,268	92,247
2002	834,852	160,476	47,506	93,381
2003	829,890	164,601	47,683	94,369
2004	832,463	168,506	48,587	98,126
2005	835,103	172,302	49,300	101,133
2006	843,213	176,297	50,690	106,980
2007	857,146	180,459	52,009	112,477
2008	867,314	184,456	52,584	114,886

Sources: European Regional Database (Cambridge Econometrics) / Authors' elaboration

Table 1c: Mean values of the variables considered, period 1995-2008, Southern EU regions

Southern EU regions	Employment (employees)	Capital Stock (bn. €; constant, 2000, prices)	GVA (bn. €; constant, 2000, prices)	Market Potential (bn. bn. €; constant, 2000, prices)/km
1995	734,946	89,021	29,691	27,418
1996	740,612	92,708	30,200	28,339
1997	749,730	96,402	31,017	29,760
1998	766,326	100,320	31,828	31,270
1999	780,147	104,432	32,701	32,926
2000	800,311	108,719	34,060	35,614
2001	817,567	112,978	34,929	37,143
2002	832,814	117,208	35,408	37,933
2003	848,547	121,286	35,866	38,707
2004	861,232	125,320	36,717	40,440
2005	876,569	129,267	37,382	41,774
2006	898,723	133,329	38,374	44,032
2007	915,007	137,360	38,435	45,031
2008	915,091	140,688	38,294	45,205

Sources: European Regional Database (Cambridge Econometrics) / Authors' elaboration

3.2. Methodology

The paper assumes that regions' production processes satisfy the properties of no free lunch, free disposability, and bounded, closed, and convex set, following the economic axioms specified by Shephard (1970). On this basis, the paper applies the probabilistic approach of conditional nonparametric frontier analysis, introduced, as extension of the work by Cazals et al. (2002), by Daraio and Simar (2005, 2007a and 2007b), which characterizes regions' production processes in the presence of the corresponding market potential levels. By using a dynamic framework, the paper allows for the insertion of the time dimension into the empirical analysis.

Let $X \in \Re_+^p$ and $Y \in R_+^q$ be the input and output vectors, respectively. Let, also, $Z \in R^d$ to denote the environmental (i.e. the exogenous to regions' production processes) variables (i.e., the regions' market potential levels). Then, the regions' unconditional attainable set (i.e. the set which is influenced by the regions' market potential levels) can be presented as the feasible combinations of regions' capital stock, employment and GVA like:

$$P = \left\{ (x, y) \in \Re_+^{p+q} \middle| x \text{ can produce } y \right. \tag{2}$$

and can be characterized as:

$$P = \left\{ (x, y) \middle| H_{X,Y}(x, y) > 0 \right\}, \tag{3}$$

where $H_{X,Y}(x,y) = \text{Prob}(X \le x, Y \ge y)$. Then, the output-oriented Farrell-Debreu technical efficiency (Debreu 1951, Farrell 1957) of regions' production process (x, y) may define as:

$$\lambda(x,y) = \sup\{\lambda | (x, \lambda y) \in P\} = \sup\left\{\lambda \middle| S_{Y|X}(\lambda y | x) > 0 \right. \tag{4}$$

Let time T is the extra-conditioning variable for every period t in the analysis, defining the attainable set $P_t^z \subset R_+^{p+q}$ as:

$$H_{X,Y|Z}^t(x, y|z) = \text{Prob}(X \le x, Y \ge y | Z = z, T = t \tag{5}$$

Accordingly, Equation (4) can be described as:

$$\lambda_t(x, y|z) = \sup\{\lambda | (x, \lambda y) \in P_t^z\} = \sup\left\{\lambda \middle| S_{Y|X,Z}^t(\lambda y | x, z) > 0 \right. \tag{6}$$

Equation (6) describes the output-oriented efficiency measure of regions' production processes at time t, facing the corresponding effect of market potential levels.

The unconditional and conditional efficiency measures, presented in Equations (4) and (6), respectively, enable the evaluation of the effect of time and market potential on regions' technological change (i.e. on the shift of the frontier) and, applying unconditional and conditional order-α quantile efficiency measures (Daouia and Simar 2007), on regions' technological catch-up levels (i.e., on the distribution of their efficiencies). This is so as, according to Kumbhakar and Lovell (2000) and Bădin et al. (2012), when the exogenous factors affect technological factors, the outcome is the shift of the frontier, and when they, correspondingly, affect the efficiency levels (i.e., the distribution of efficiency) the outcome is the movement towards to and away from the frontier. These partial (or robust) efficiency measures for any $\alpha \in (0,1)$ can be defined for the unconditional and conditional case as:

$$\lambda_\alpha(x, y) = \sup\left\{\lambda \middle| S_{Y|X}(\lambda y | x) > 1 - \alpha \right\} \tag{7}$$

and

$$\lambda_{t,\alpha}\left(x,y\middle|z\right)=\sup\left\{\lambda\middle|S^{t}_{Y|X}\left(\lambda y\middle|x,z\right)>1-\alpha\right. \tag{8}$$

Following Bădin et al. (2012) the paper applies a median value α (i.e.$\alpha=0.5$) and calculates all the unconditional and conditional estimators by the Data Envelopment Analysis (DEA) mathematical programming approach (Daraio and Simar, 2005; 2007a; 2007b, Bădin et al. 2010; 2012). DEA is a non-parametric technique that has the advantage of avoiding misspecification problems regarding the characterization of regions' production processes. As a next step, the paper constructs ratios in order to investigate the effects of time and market potential on boundary (i.e., the shift of the frontier; technological change) and on distance (i.e., the distribution of efficiency; technological catch-up):

$$Q=\frac{\lambda_t(x,y|z)}{\lambda(x,y)} \tag{9}$$

and

$$Q_\alpha=\frac{\lambda_{\alpha,t}(x,y|z)}{\lambda_\alpha(x,y)} \tag{10}$$

For the purpose of the analysis, the paper uses nonparametric estimators of the efficiency scores in order to explore the effect of time and market potential, and it does so by perceiving the behavior of $\hat{Q}$ and $\hat{Q}_\alpha$ as a function of time and market potential. Particularly, the paper uses a local linear estimator (Jeong et al. 2010) and the Least Squares Cross Validation (LSCV) approach (Hall et al. 2004) for bandwidth selection. It comes that a tendency of the ratios to increase with time and market potential levels indicates a favorable effect on regions' technological change and catch-up. In the opposite case, it indicates an unfavorable effect. In the case where the effect is similar for both the full ($\hat{Q}$) and the robust ($\hat{Q}_\alpha$) frontiers, it may conclude that there is a shift on regions' frontier, while the distribution of regions' efficiencies remains the same, by accounting for the effect of time and regions' market potential levels. In any case, it has to be stressed out that the fully non-parametric methodological framework adopted allows for the drastic reduction of possible endogeneity problems (Frölich 2007 and 2008).

Table 1d: Mean values of the variables considered, period 1995-2008, Northern EU regions

Northern EU regions	Employment (employees)	Capital Stock (bn. €; constant, 2000, prices)	GVA (bn. €; constant, 2000, prices)	Market Potential (bn. bn. €; constant, 2000, prices)/km
1995	677,192	81,729	32,027	75,850
1996	681,946	84,957	32,972	81,149
1997	693,888	88,373	34,199	87,747
1998	701,135	92,291	35,511	95,986
1999	709,945	96,193	36,865	104,649
2000	719,806	100,084	38,438	113,391
2001	728,735	103,834	39,356	118,056
2002	733,932	107,471	40,239	123,409
2003	739,080	110,947	41,293	129,765
2004	744,433	114,512	42,541	137,483
2005	754,318	118,157	43,724	144,355
2006	765,060	122,046	45,161	153,216
2007	775,438	126,210	46,482	163,911
2008	780,453	129,657	46,797	166,565

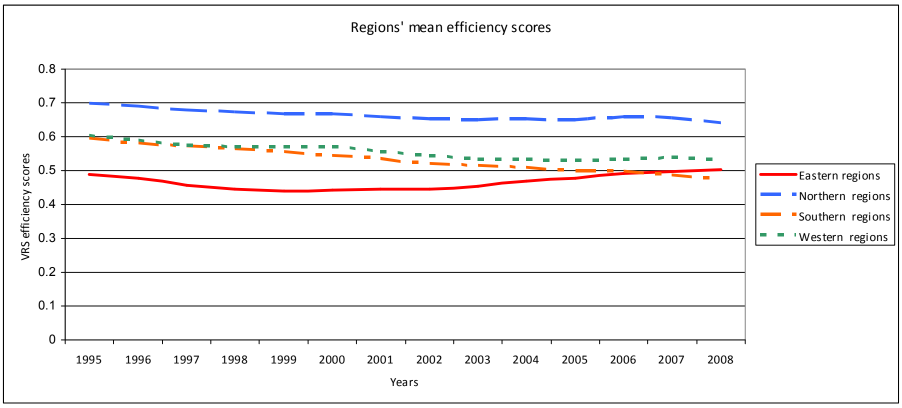
Sources: European Regional Database (Cambridge Econometrics) / Authors' elaboration

4. Empirical results

The efficiency estimates assume variable returns to scale (VRS) (Banker et al. 1984) in order to account for regions' different market potential. As has been indicated by Daraio and Simar (2007a), robust methods have two main advantages: firstly, they do not envelop all data points and, for that reason, are not influenced by extreme values; secondly, they do not suffer from the "curse of dimensionality" compared to the DEA efficiency estimators. The order-α frontiers are not bounded by 1.000 as the DEA frontiers. Therefore, the higher the order-α estimated efficiency scores the higher the regions' productive efficiency levels. In contrast, the VRS frontiers are bounded by 1.000, which indicates the productive efficient regions, whereas values less than 1.000 indicate productive inefficient regions. The productive efficiency score of a region indicates its ability to maximize its GVA levels relative to the other regions, given its employment and capital stock levels.

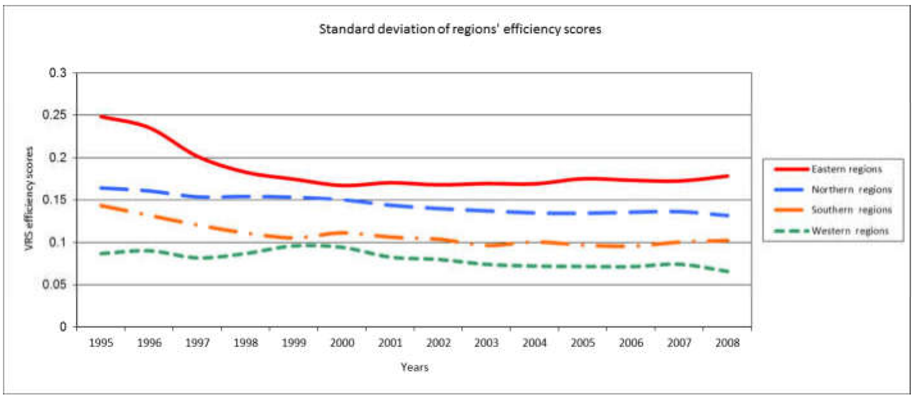
Figures 1A and 1B present the diachronic evolution of the EU regional groups mean productive efficiency estimates (i.e. scores) from the VRS frontiers. It comes that the EU regions with the highest productive efficiency levels are mainly regions from Northern Europe, whereas regions mainly from Eastern Europe are having the lowest productive efficiency levels. It, also, comes that, under the assumption of VRS, the Southern and the Western EU regions have similar productive efficiency levels, presenting constantly decreasing trends. The Eastern EU regions exhibit increasing trends in the second half of the period under consideration, even managing to outperform the Southern EU regions. The Northern EU regions exhibit the highest productive efficiency levels, despite the fact that they present a constantly decreasing trend. The standard deviation of the estimated efficiency levels is decreasing over the years for the majority of the EU regions except for the Eastern ones. It is evident that the efficiency standard deviation values are increasing as regards the Eastern EU regions (especially after 2000), suggesting an uneven pattern of production efficiency levels. Such a phenomenon can be attributed to the decisive role of structural and geographical conditions in identifying the relative winners of the market-driven economic integration process (Kallioras and Petrakos 2010).

Figure 1a. Diachronic representation of mean efficiency scores, VRS efficiency scores, period 1995-2008



Sources: European Regional Database (Cambridge Econometrics) / Authors' elaboration

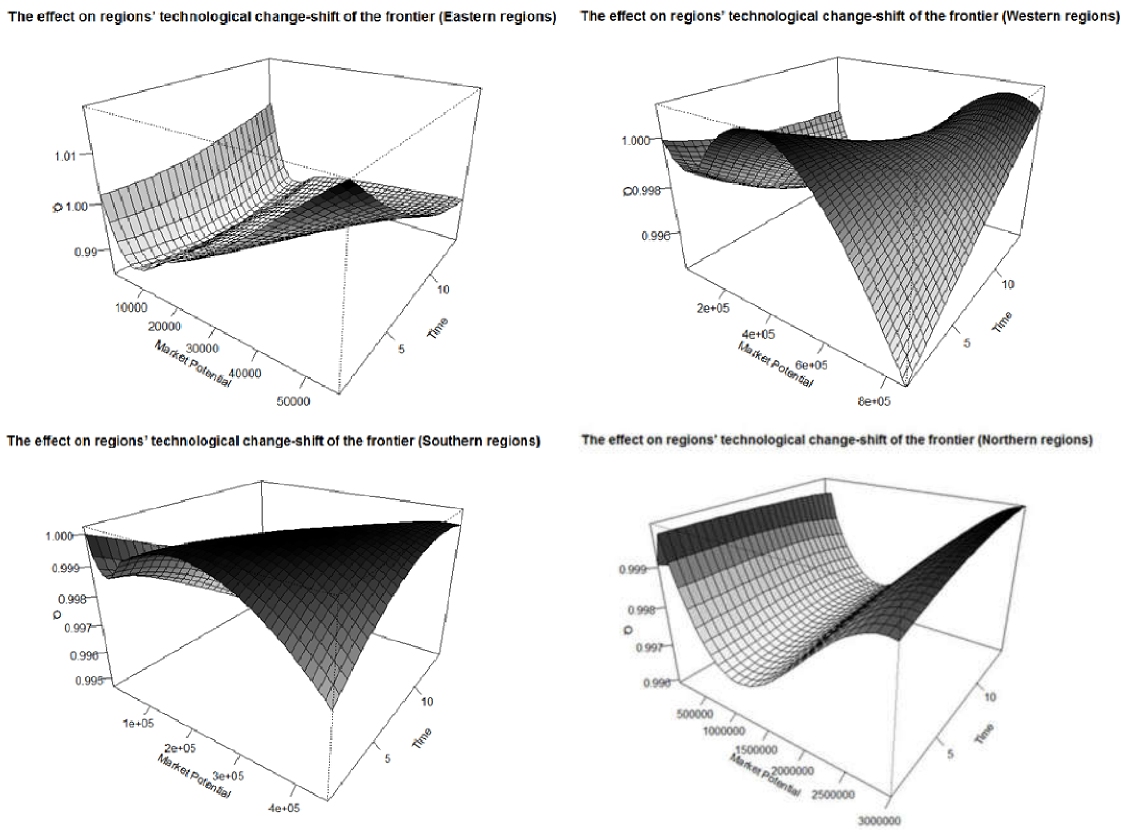
Figure 1b. Diachronic representation of standard deviation of the VRS efficiency scores, period 1995-2008



Sources: European Regional Database (Cambridge Econometrics) / Authors' elaboration

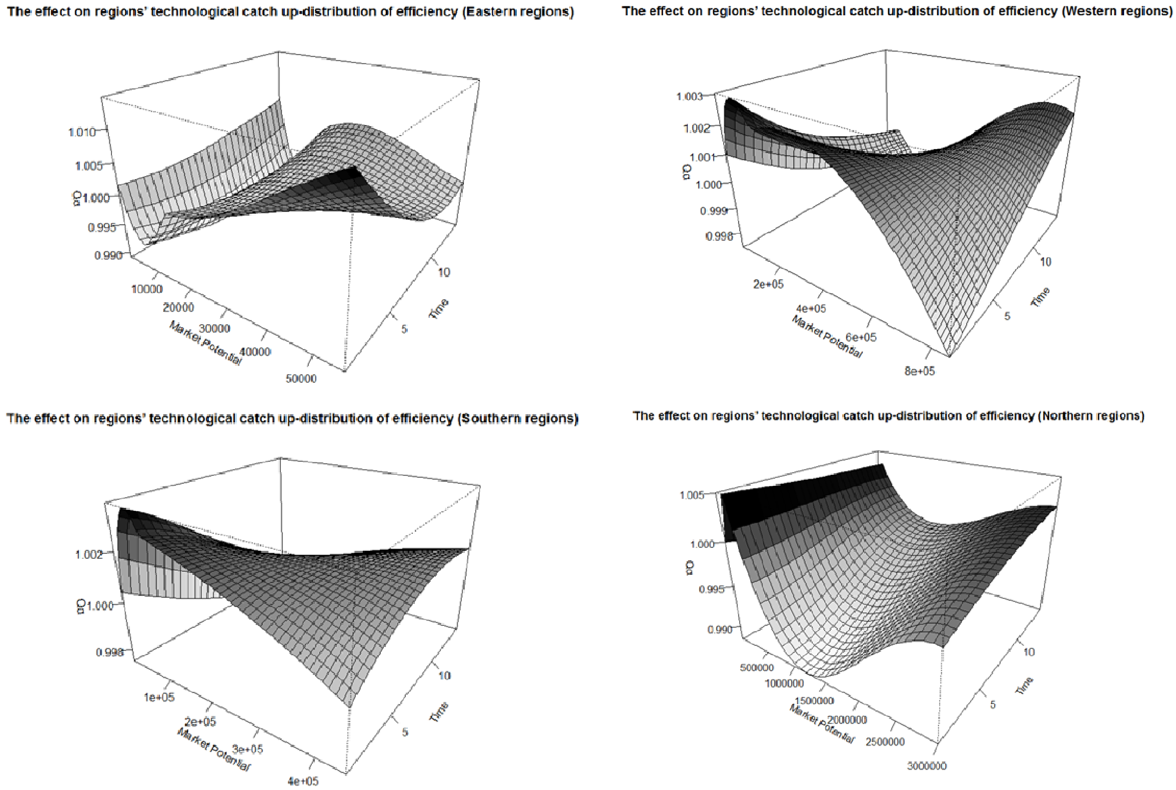
Figures 2a – 2d and Figures 3a – 3d present, providing a combined 3-dimensional view, the effect of time and market potential on EU regional groups' technological change and technological catch-up, respectively. The effect of time on both technological change and technological catch-up is getting increased, either in a linear or in a non-linear fashion, as regards the Western, the Southern and the Northern EU regions. In contrast, as regards the Eastern EU regions the effect of time on both technological change and technological catch-up is initially getting decreased and then becomes neutral and is getting increased, respectively. The effect of market potential on both technological change and technological catch-up is non-linear. Particularly, as regards the Eastern EU regions the effect of market potential on both technological change and technological catch-up is initially getting decreased and then is getting increased. As regards the Western EU regions, the effect of market potential on technological change is initially getting decreased, then is getting increased and then is getting decreased. The corresponding effect on technological catch-up is initially getting increased, then is getting decreased, then is getting increased again, and finally is getting decreased again. Concerning the Southern EU regions, the effect of market potential on technological change is initially getting decreased, then is getting increased and then is getting decreased. The corresponding effect on technological catch-up is initially getting increased and then is getting decreased. As regards the Northern EU regions, the effect of market potential on both technological change and technological catch-up is initially getting increased, then is getting decreased and then is getting increased.

Figures 2a-2d . The effect of market potential and time on regions' technological change, period 1995-2008



Sources: European Regional Database (Cambridge Econometrics) / Authors' elaboration

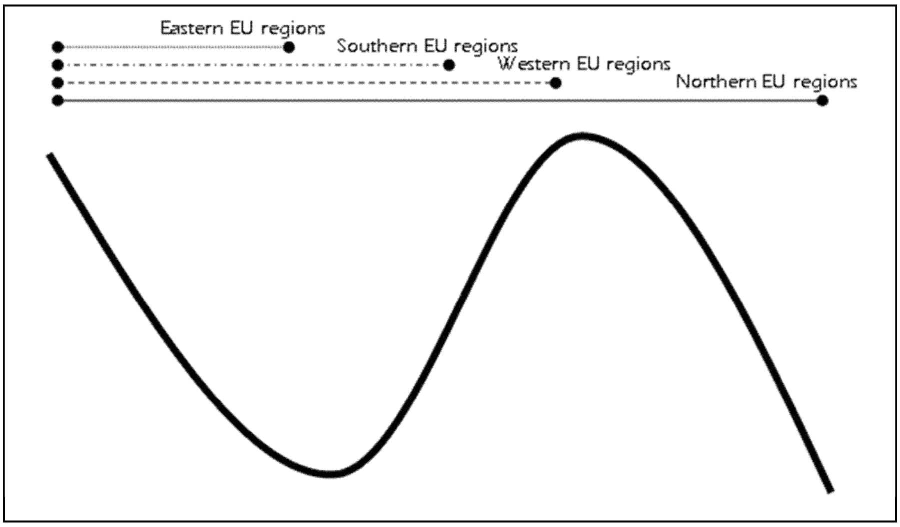
Figures 3a-3d. The effect of market potential and time on regions' technological catch-up, period 1995-2008



Sources: European Regional Database (Cambridge Econometrics) / Authors' elaboration

In absolute levels, it comes that the Northern EU regions exhibit the highest levels of market potential (i.e., ranging between 0 and 3,000,000 units approx.), followed by the Western EU regions (i.e., with market potential ranging between 0 and 800,000 units approx.), the Southern EU regions (i.e., with market potential ranging between 0 and 400,000 units approx.), and the Eastern EU regions (i.e., with market potential ranging between 0 and 50,000 units approx.). This is an absolutely justifiable result, given that "North-South" and the "West-East" dichotomies that characterize regional inequality in the EU in terms of GVA (Barrios and Strobl 2005, Petrakos et al. 2011). Under a macroscopic perspective, it comes that the effect of market potential on technological change and technological catch-up is highly influenced by its level. The juxtaposition of the results, for each particular regional group, reveals that the effect of market potential on technological change and technological catch-up follows a "mirror-image inclined N-shaped pattern". Figure 4 provides a conceptual visualization of the "mirror-image inclined N-shaped pattern" that governs the relationships between market potential and technological change as well as between market potential and technological catch-up. Apparently, the tendency that characterizes the relationships for the Eastern, the Southern and the Western EU regions matches, in an imaginary superposition, with the first, the second, and the third part, respectively, of the tendency that characterizes the relationships for the Northern EU regions. Thus, it comes that the effect of market potential on technological change and technological catch-up may increase either in very low levels of market potential or, most prominently, in very high levels of market potential.

Figure 4. The "mirror-image inclined N-shaped pattern" between market potential and technological change and technological catch-up



Sources: Authors' elaboration

5. Conclusions and policy implications

The paper applies the probabilistic approach of time-dependent conditional nonparametric frontier analysis and evaluates the patterns of the EU regions' technological change and technological catch-up subject to the corresponding market potential conditions, in the presence of dynamic effects. As time proves to have an increasing effect on both technological change and technological catch-up, for the entire sample of the EU regions under consideration (with the exception of the Eastern EU regions, for the early period of the analysis), the results of the empirical analysis indicate that market potential acts as a technology-initiating factor. This is so as the effect of market potential on both technological change and technological catch-up is non-linear, for the entire sample of the EU regions under consideration, and highly influenced by its level. In fact, it comes that, within the integrated EU space, market potential creates asymmetric effects and leaves a distinct "spatial footprint". Particularly, the relationship between market potential and technological change as well as the relationship between market potential and technological catch-up follow, in an imaginary superposition, a "mirror-image inclined N-shaped pattern".

Such a finding provides important policy implications. It comes that the most prominent effect of market potential on technological change and technological catch-up may find on the Northern and the Western EU regions (i.e. the core EU regions). Exhibiting, on average, the highest levels of market potential, the Northern and the Western EU regions may operate as hubs for technology-intensive (and knowledge-intensive, in general) economic activities as they manage to enjoy the benefits of both intra-cluster and extra-cluster technological knowledge. The effect of market potential on technological change and technological catch-up is, in contrast, less prominent in the Southern and the Eastern EU regions (i.e. the peripheral EU regions). It comes that in order to reap the benefits of market potential, so as to spur their levels of technological change and technological catch-up, the Southern and the Eastern EU regions need to increase their level of embeddedness in the European value chains so as to increase the intensity of interactions with their technologically more advanced counterparts. To do so, they need to increase their learning ability so as to increase the variety of the products they produce. Otherwise, they run the danger to be locked-in a mediocre technological path.

References

Abramovitz, Moses. 1986. 'Catching up, forging ahead, and falling behind'. Journal of Economic History 46: 385-406.

Aghion, Phillipe, and Peter Howitt. 1992. 'A model of growth through creative destruction'. Econometrica 60: 323-351.

Ahn, Sang-Jin. 2017. 'Institutional basis for research boom: From catch-up development to advanced economy'. Technological Forecasting and Social Change 119: 237-245.
Anselin, Luc, Attila, Varga, and Zoltan, Acs. 1997. 'Local geographic spillovers between university research and high technology innovations'' Journal of Urban Economics 42: 422-448.
Arrow, Kenneth. 1962. 'The economic implications of learning by doing'. Review of Economic Studies. 29: 155-173.
Arthur, Brian. 2009. 'The nature of technology'. New York: Free Press.
Asheim, Bjørn, and Arne, Isaksen. 2002. 'Regional innovation systems: The integration of local 'sticky' and global 'ubiquitous' knowledge'. Journal of Technology Transfer 27: 77-86.
Audretsch, David, Oliver, Falck, and Stephan, Heblich. 2007. 'It's all in Marshall: The impact of external economies on regional dynamics'. CESifo Working Paper 2094.
Audretsch, David, and Maryann, Feldman. 1996. 'R&D spillovers and the geography of innovation and production'. American Economic Review 86: 630-640.
Audretsch, David, and Maryann, Feldman. 2004. 'Knowledge spillovers and the geography of innovation'. In Henderson, Vernon, and Jacques-Francois Thisse (Eds.). 'Handbook of regional and urban economics (vol. 4)'. Amsterdam: North Holland, 2713-2739.
Aydalot, Phillipe. 1986. 'Innovative environments in Europe'. Paris: GREMI (in French).
Bădin, Luiza, Cinzia, Daraio, and Léopold, Simar. 2010. 'Optimal bandwidth selection for conditional efficiency measures: A data-driven approach'. European Journal of Operational Research 201: 633-640.
Bădin, Luiza, Cinzia, Daraio, and Léopold, Simar. 2012. 'How to measure the impact of environmental factors in a nonparametric production model?'. European Journal of Operational Research 223: 818-833.
Ball, Richard. 1957. 'The impact of technology on economic growth'. American Journal of Economics and Sociology 16: 281-290.
Banker, Rajiv, Abraham, Charnes, and William, Cooper. 1984. 'Some models for estimating technical and scale inefficiencies in DEA'. Management Science 32: 1613-1627.
Barrios, Salvador, and Eric, Strobl. 2005. 'The dynamics of regional inequalities'. European Commission Economic Papers 229.
Basu, Susanto, and David, Weil. 1998. 'Appropriate technology and growth'. Quarterly Journal of Economics 113: 1025-1054.
Bathelt, Harold, Anders, Malmberg, and Peter, Maskell. 2004. 'Clusters and knowledge: Local buzz, global pipelines and the process of knowledge creation'. Progress in Human Geography 28: 31-56.
Benhabib, Jess, and Mark, Spiegel. 2005. 'Human capital and technology diffusion'. In Aghion, Phillipe, and Steven, Durlauf (Eds.). 'Handbook of economic growth (vol. 1)'. Amsterdam: Elsevier, 935-966.
Blömstrom, Magnus, and Ari, Kokko. 1998. 'Multinational corporations and spillovers'. Journal of Economic Surveys 12: 247–277.
Boschma, Ron. 2005. 'Proximity and innovation: A critical assessment'. Regional Studies 39: 61-74.
Breschi, Stefano, and Franceso, Lissoni. 2001a. 'Localized knowledge spillovers vs innovative milieux: Knowledge "tacitness" reconsidered'. Papers in Regional Science 80: 255-273.
Breschi, Stefano, Francesco, Lissoni. 2001b. 'Knowledge spillovers and local innovation systems: A critical survey'. Industrial and Corporate Change 10: 975-1005.
Bresnahan, Timothy, and Manuel, Trajtenberg. 1995. 'General purpose technologies: Engines of growth?'. Journal of Econometrics 65: 83-108.
Brülhart, Marius, Matthieu, Crozet, and Pamina, Koenig. 2004. 'Enlargement and EU periphery: The impact of changing market potential'. World Economy 27: 853-875.
Brülhart, Marius, and Robert, Elliott. 1998. 'Adjustment to the European Single Market: Inferences from intra-industry trade patterns'. Journal of Economic Studies. 25: 225-247.
Brusco, Sebastiano. 1982. 'The Emilian model: Productive decentralization and social integration'. Cambridge Journal of Economics 6: 167-184.
Buchanan, James, and Craig, Stubblebine. 1962. 'Externality'. Economica 29: 371-384.
Buchmann, Tobias. 2015. 'The evolution of innovation networks: An automotive case study'. Wiesbaden: Springer Gabler.
Buchmann, Tobias, and Andreas, Pyka. 2012. 'Innovation networks. In Dietrich, Mickael, and Jackie, Krafft (Eds.), Handbook on the economics and theory of the firm'. Cheltenham: Edward Elgar, 466-484.
Cairncross, Frances. 1997. 'The death of distance: How communications revolution will change our lives'. London: Orion Business Books.
Camagni, Roberto. 1991. 'Innovation networks, spatial perspectives'. London: Belhaven Press.
Camagni, Roberto. 1992. 'Development scenarios and policy guidelines for the lagging regions in the 90s'. Regional Studies 26: 361-374.

Cambridge Econometrics. European Regional Database. http://www.camecon.com/SubNational/SubNationalEurope/RegionalDatabase.aspx, (last accessed: May 2020).
Cantwell, John, and Simona, Iammarino. 2003. ‘Multinational corporations and European regional systems of innovation’. London: Routledge.
Caragliu, Andrea, and Peter, Nijkamp. 2016. ‘Space and knowledge spillovers in European regions: The impact of different forms of proximity on spatial knowledge diffusion’. Journal of Economic Geography 16: 749-774.
Cazals, Catherine, Jean-Pierre, Florens, and Léopold, Simar. 2002. ‘Nonparametric frontier estimation: A robust approach’. Journal of Econometrics 106: 1-25.
Choung, Jae-Yong, Tahir, Hameed, and Illyong, Ji. 2012. ‘Catch-up in ICT standards: Policy, implementation and standards-setting in South Korea’. Technological Forecasting and Social Change 79: 771-788.
Coelli, Tim, Prasada, Rao, Christopher, O’Donnell, and George, Battese. 2005. ‘An introduction to efficiency and productivity analysis’. Boston: Kluwer.
Colwell, Peter. 1982. ‘Central place theory and the simple economic foundations of the gravity model’. Journal of Regional Science 22: 541-546.
Comin, Diego, and Hobijn, Bart. 2004. ‘Cross-country technology adoption: Making the theories face the facts’. Journal of Monetary Economics 51: 39-83.
Cox, Kevin, and Andrew, Wood. 1997. ‘Competition and cooperation in mediating the global: The case of local economic development’. Competition and Change 2: 65-94.
Cox, Kevin. 2008. ‘Globalization, uneven development and capital: Reflections on reading Thomas Friedman’s The World Is Flat’. Cambridge Journal of Regions, Economy and Society 1: 389-410.
Crescenzi, Riccardo, Carlo, Pietrobelli, and Roberta, Rabellotti. 2014. ‘Innovation drivers, value chains and the geography of multinational corporations in Europe’. Journal of Economic Geography 14: 1053-1086.
Crespo, Joan, Raphaël, Suire, and Jerome, Vicente. 2014. ‘Lock-in or lock-out? How structural properties of knowledge networks affect regional resilience’. Journal of Economic Geography 14: 199-219.
Daouia, Cinzia, and Léopold, Simar. 2007. ‘Nonparametric efficiency analysis: A multivariate conditional quantile approach’. Journal of Econometrics 140: 375-400.
Daraio, Cinzia, and Léopold, Simar. 2005. ‘Introducing environmental variables in nonparametric frontier models: A probabilistic approach’. Journal of Productivity Analysis 24: 93-121.
Daraio, Cinzia, and Léopold, Simar. 2007a. ‘Advanced robust and nonparametric methods in efficiency analysis: Methodology and applications’. New York: Springer.
Daraio, Cinzia, and Léopold, Simar. 2007b. ‘Conditional nonparametric frontier models for convex and non-convex technologies: A unifying approach’. Journal of Productivity Analysis 28: 13-32.
Debreu, Gerard. 1951. ‘The coefficient of resource utilization’. Econometrica 19: 273-292.
Denison, Edward. 1967. ‘Why growth rates differ’. Washington DC: Brookings Institution.
Dosi, Giovanni, Richard, Nelson. 2010. ‘Technical change and industrial dynamics as evolutionary processes’. In Hall, Bronwyn, and Nathan, Rosenberg (Eds.). ‘Handbook of the economics of innovation (vol. 1)’. Burlington: Academic Press, 51-128.
Duranton, Gilles, and Diego, Puga. 2010. ‘Nursery cities: Urban diversity, process innovation and the life cycle of products’. American Economic Review 91: 1454-1477.
Duvivier, Chloé. 2013. ‘Does urban proximity enhance technical efficiency? Evidence from Chinese agriculture’. Journal of Regional Science 53: 923-943.
Ertur, Cem, and Wilfried, Koch. 2007. ‘Growth, technological interdependence and spatial externalities: Theory and evidence’. Journal of Applied Econometrics 22: 1033-1062.
Essletzbichler, Jürgen, and David, Rigby. 2005. ‘Competition, variety and the geography of technological evolution’. Tijdschrift voor Economische en Sociale Geografie 96: 48-62.
Essletzbichler, Jürgen, and David, Rigby. 2006. ‘Technological variety, technological change and the geography of production techniques’. Journal of Economic Geography 6: 45-70.
Fagerberg Jan, Maryann, Feldman, and Martin, Srholec. 2014. ‘Technological dynamics and social capability: US states and European nations’. Journal of Economic Geography 14: 313-337.
Faggian, Alessandra, and Phillip, McCann. 2006. ‘Human capital flows and regional knowledge assets: A simultaneous equation approach’. Oxford Economic Papers 58: 475-500.
Farrell, Michael. 1957. ‘The measurement of the productive efficiency’. Journal of the Royal Statistical Society. Series A 120: 253-290.
Freeman, Chris. 1994. ‘The economics of technical change’. Cambridge Journal of Economics 18: 463-514.
Friedman, Thomas. 2005, ‘The world is flat: A brief history of the twenty-first century’. New York: Farrar, Strauss and Giroux.
Friedman, Thomas. 2007. ‘The world is flat’. New York: Picador.

Frölich, Markus. 2007. 'Nonparametric IV estimation of local average treatment effects with covariates'. Journal of Econometrics 139: 35–75.

Frölich, Markus. 2008. 'Parametric and nonparametric regression in the presence of endogenous control variables'. International Statistical Review 76: 214-227.

Fujita Masahisa, Paul Krugman, and Antony Venables. 1999. 'The spatial economy: Cities, regions and international trade'. Cambridge Mass.: MIT Press.

Fujita, Masahisa, and Jacques-Francois, Thisse. 2003. 'Does geographical agglomeration foster economic growth? And who gains and losses from it?'. Japanese Economic Review 54: 336-351.

Glaeser, Edward, Hedi, Kallal, José, Sheinkman, and Andrei, Schleifer. 1992. 'Growth in cities'. Journal of Political Economy 100: 1126-1152.

Godin, Benoît. 2006. 'The linear model of innovation: The historical construction of an analytical framework'. Science, Technology, and Human Values 31: 639-667.

Granovetter, Mark. 1985. 'Economic action and social structure: The problem of embeddedness'. American Journal of Sociology 91: 481-510.

Griliches, Zvi. 1957. 'Hybrid corn: An exploration in the economics of technological change'. Econometrica 25: 501-522.

Grossman, Gene, and Elhanan, Helpman. 1991. 'Innovation and growth in the global economy'. Cambridge Mass.: MIT Press.

Grossman, Gene, and Elhanan, Helpman.1994. 'Endogenous innovation in the theory of growth'. Journal of Economic Perspectives 8: 23-44.

Hall, Peter, Jeff, Racine, and Qi, Li. 2004. 'Cross-validation and the estimation of conditional probability densities'. Journal of the American Statistical Association 99: 1015-1026.

Hanson, Gordon. 2005. 'Market potential, increasing returns and geographic concentration'. Journal of International Economics 67: 1-24.

Harris, Chauncy. 1954. 'The market as a factor in the localization of industry in the United States'. Annals of the Association of the American Geographers 44: 315–348.

Head, Keith, and Thierry, Mayer. 2004. 'Market potential and the location of Japanese investment in the European Union'. Review of Economics and Statistics 86: 959-972.

Head, Keith, and Thierry, Mayer. 2006. 'Regional wages and employment responses to market potential in the EU'. Regional Science and Urban Economics 36: 573-594.

Henderson, Vernon, Ari, Kuncoro, and Matt, Turner. 1995. 'Industrial development in cities'. Journal of Political Economy 103: 1067-1090.

Ho, Jonathan, and Chung-Shing, Lee. 2015. 'A typology of technological change: Technological paradigm theory with validation and generalization from case studies'. Technological Forecasting and Social Change, 97: 128-139.

Holl, Adelheid. 2012. 'Market potential and firm-level productivity in Spain'. Journal of Economic Geography 12: 1191-1215.

Jacobs Jane. 1969. 'The economy of cities'. London: Jonathan Cape.

Jaffe, Adam, Manuel, Trajtenberg, and Rebecca, Henderson. 1993. 'Geographic localization of knowledge spillovers as evidenced by patent citations'. Quarterly Journal of Economics 108: 577-598.

Jeong, Seok-Oh, Byeong, Park, and Léopold, Simar. 2010. 'Nonparametric conditional efficiency measures: Asymptotic properties'. Annals of Operations Research 173: 105-122.

Kallioras, Dimitris, and George, Petrakos. 2010. 'Industrial growth, economic integration and structural change: Evidence from the EU new member-states regions'. Annals of Regional Science 45: 667-680.

Kallioras, Dimitris, Lefteris, Topaloglou, and Stephanos, Venieris. 2009. 'Tracing the determinants of economic cross-border interaction in the European Union'. Spatium 21: 1-10.

Karagiannis, Stelios. 2007. 'The knowledge-based economy, convergence and economic growth: Evidence from the European Union'. Journal of Economic Asymmetries 4: 65-85.

Karanika, Maria, and Dimitris, Kallioras. 2018. 'EU spatiality under question – Territorial cohesion in danger'. Territories 1: 59-72.

Keller, Wolfgang. 2004. 'International technology diffusion. Journal of Economic Literature'. 42: 752–782.

Kemeny, Thomas. 2011. 'Are international technology gaps growing or shrinking in the age of globalization?'. Journal of Economic Geography 11: 1-35.

Kumbhakar, Subal, and Knox, Lovell. 2000. 'Stochastic frontier analysis'. Cambridge: Cambridge University Press.

Lu, Shengrong, and Yanwu Wang. 2015. 'Convergence, technological interdependence and spatial externalities: A spatial dynamic panel data analysis'. Applied Economics 47: 1833-1846.

Lucas, Robert. 1988. 'On the mechanics of economic development'. Journal of Monetary Economics 22: 3-42.

Mankiw, Gregory, David, Romer, and David, Weil. 1992. 'A contribution to the empirics of economic growth'. Quarterly Journal of Economics 107: 407-437.
Markusen, Ann. 1996. 'Sticky places in slippery places: A typology of industrial districts'. Economic Geography 72: 293-313.
Marques, Pedro. 2015. 'Why did the Portuguese economy stop converging with the OECD? Institutions, politics and innovation'. Journal of Economic Geography 15: 1009-1031.
Marshall, Alfred. 1890. 'Principles of economics'. London: Macmillan.
Martin, Ron, and Peter, Sunley. 2003. 'Deconstructing clusters: Chaotic concept or policy panacea?'. Journal of Economic Geography 3(1): 5–35.
Martín-Barroso, David, Juan, Núñez-Serrano, and Francisco, Velázquez. 2015. 'The effect of accessibility on productivity in Spanish manufacturing firms'. Journal of Regional Science 55: 708-735.
Maskell, Peter, and Anders, Malmberg. 1999. 'Localized learning and industrial competitiveness'. Cambridge Journal of Economics 23: 167-185.
Mastromarco, Camilla, and Léopold, Simar. 2015. 'Effect of FDI and time on catching up: New insights from a conditional nonparametric frontier analysis'. Journal of Applied Econometrics 30: 826-847.
Melachroinos, Konstantinos. 2002. 'European integration and the spatial dynamics of manufacturing employment change'. Environment and Planning A, 34: 2017-2036.
McCann, Phillip. 2008. 'Globalization and economic geography: The world is curved, not flat'. Cambridge Journal of Regions, Economy and Society 1: 351-370.
Mokyr, Joel. 2002. 'The gifts of Athena: Historical origins of the knowledge economy'. Princeton: Princeton University Press.
Nelson, Richard, and Edmund, Phelps. 1966. 'Investment in humans, technological diffusion and economic growth'. American Economic Review 56: 69-75.
Nelson, Richard, and Sidney, Winter. 1982. 'An evolutionary theory of economic change'. Cambridge Mass.: Harvard University Press.
Newton, Isaak. 1687/1846. 'Mathematical principles of natural philosophy'. New York: Daniel Adee (translated by Motte Adrew).
Nonaka, Ikujiro, and Hirotaka, Takeuchi. 1995. 'The knowledge-creating company: How Japanese companies create the dynamics of innovation'. Oxford: Oxford University Press.
O'Brien, Richard. 1992. 'Global financial integration: The end of geography'. New York: Council on Foreign Relations Press.
Ottaviano, Gianmarco, and Dino, Pinelli. 2006. 'Market potential and productivity: Evidence from Finnish regions'. Regional Science and Urban Economics 36: 636-657.
Parr, John. 2002. 'Missing elements in the analysis of agglomeration economies'. International Regional Science Review 5: 151-168.
Patel, Parimal, and Keith, Pavitt. 1994. 'Uneven (and divergent) technological accumulation among advanced countries: Evidence and a framework of explanation'. Industrial and Corporate Change 3: 759-787.
Petrakos, George, Georgios, Fotopoulos, and Dimitris, Kallioras. 2012. 'Peripherality and integration: Industrial growth and decline in the Greek regions'. Environment and Planning C 30: 347-361.
Petrakos, George, Andres, Rodriguez-Pose, and Antonis, Rovolis. 2005. 'Growth, integration and regional inequalities in Europe''. Environment and Planning A, 37: 1837-1855.
Petrakos George, Dimitris, Kallioras, and Ageliki, Anagnostou. 2011. 'Regional convergence and growth in Europe: Understanding patterns and determinants'. European Urban and Regional Studies 18: 375-391.
Pigou, Arthur Cecil. 1920/1932. 'The economics of welfare (4th edition)'. London: Macmillan.
Polanyi, Michael. 1966. 'The tacit dimension'. New York: Doubleday.
Porter, Michael. 1990. 'The competitive advantage of nations'. New York: The Free Press.
Quigley, John. 1998. 'Urban diversity and economic growth'. Journal of Economic Perspectives 12: 127-138.
Romer, Paul. 1986. 'Increasing returns and long-run growth'. Journal of Political Economy 94: 1002–1037.
Rosenberg, Nathan. 1990. 'Why do private firms perform basic research (with their own money)?' Research Policy 19: 165-174.
Rothwell, Roy. 1994. 'Towards the fifth generation innovation process'. International Marketing Review 11: 7-31.
Rychen, Frédéric, and Jean-Benoît, Zimmermann. 2008. 'Clusters in the global knowledge based economy: Knowledge gatekeepers and temporary proximity'. Regional Studies 42: 767-776.
Scitovsky, Tibor. 1954. 'Two concepts of external economies'. Journal of Political Economy 62: 143-151.

Scott, Allen, John, Agnew, Edward, Soja, and Michael, Storper. 2001. 'Global city-regions. In Scott, Allen (Ed.), Global city-regions: Trends, theory, policy'. Oxford: Oxford University Press, 11-32.
Scott, Allen, and Michael, Storper. 2003. 'Regions, globalization, development'. Regional Studies 37(6-7): 579-593.
Shephard, Ronald. 1970. 'Theory of cost and production function'. Princeton: Princeton University Press.
Solow, Robert. 1956. 'A contribution to the theory of economic growth'. Quarterly Journal of Economics 70: 65–94.
Solow, Robert. 1957. 'Technical change and the aggregate production function'. Review of Economics and Statistics 39: 312-320.
Swan, Trevor. 1956. 'Economic growth and capital accumulation'. Economic Record 32: 334–361.
Teece, David. 1996. 'Firm organization, industrial structure and technological innovation'. Journal of Economic Behavior and Organization 31: 193-224.
UN. 2012. 'World population prospects: The 2012 Revision: Classification of countries by major area and region of the world'. Washington DC: UN Population Division, Department of Economics and Social Affairs.
Uzzi, Brian. 1997. 'Social structure and competition in interfirm networks: The paradox of embeddedness'. Administrative Science Quarterly 42: 35-67.
Waverman, Leonard, William, Comanor, and Akira, Goto. 1997. 'Competition policy in the global economy: Modalities for cooperation'. London: Routledge.
Wei, Taoyuan, and Yang, Liu. 2019. 'Estimation of resource-specific technological change'. Technological Forecasting and Social Change 138: 29-33.
Winter, Sidney. 1988. 'On Coase, competence and corporation'. Journal of Law, Economics and Organization 4: 163-180.
Ziman, John. 2000. 'Technological innovation as an evolutionary process'. Cambridge: Cambridge University Press.
Zhou, Yu, Yifei, Sun, Yehua Denis, Wei, and George, Lin. 2011. 'De-centering 'spatial fix' – patterns of territorialization and regional technological dynamism of ICT hubs in China'. Journal of Economic Geography 11: 119-150.