

# Regional Efficiency, Innovation and Productivity

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## Abstract

A blossoming stream of the regional innovation systems (RIS) literature is being devoted to investigate the relationship between RIS efficiency and productivity growth. Our study aims at evaluating: first, the ex-post relative technical efficiency in innovation in a sample of OECD regions by means of a DEA (data envelopment analysis) methodology. We will also match these results with regression analysis of a “knowledge production function”. Secondly, it aims at assessing if there is a positive linkage between increased efficiency in innovation and productivity at regional level. We find some consistency between the DEA and knowledge production function analysis, with, for example, EU regions overtaking US regions when performance in Tertiary Education is concerned. We also find that innovation inputs and outputs are positively related to productivity although patents are a very imperfect measure for innovation. The policy implications from the empirical results are of uttermost relevance for local governments and administrations, especially when evaluating the leverage given by the inputs in the knowledge production function, and since, increasingly, RIS are seen as a target for economic policy while pursuing the more general objective of competing in the global innovation economy.

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## 1. Motivation

The economic debate about innovation and growth has increasingly focused on the importance of competitiveness, knowledge creation and productivity gains. In a ever-changing environment where new players emerge in the global panorama, finding the right formula to boost knowledge creation has become the key to long term development and sustainability for both developed and developing countries.

In particular, the issue of regional innovation systems has become increasingly interesting as long as the economic structure of businesses, by means of international alliances and multinational corporations, has crossed over the boundaries of national states to give birth to dynamic emerging locations. Such areas have regional features rather than national, in that the importance of linkages and learning by interacting provides these locations (e.g. clusters, districts, special economic zones) with an intangible asset that can be considered shared tacit knowledge and/or spillovers. In a regional context, innovation can also refer to ‘soft’ use of knowledge in business activities, resulting in higher productivity and performance. And while emerging economies increasingly become the favored location for R&D by MNE (multinational enterprises) , once performed in home countries, we are witnessing the shift from global production networks to global innovation networks.

Several studies in the literature tried to measure the technical efficiency of regional innovation systems, where often the regional administrative governments act as catalyzers between private firms and research centres and universities.

A common approach in the literature sees the ideal output of the underlying knowledge production function or innovation activity as patents. Patents protect the original idea of the inventor and builds the base for future research and innovation by reaping the profits from the original idea on a competitive market. Besides, as noted extensively, they allow their users to develop further innovation and research, so that they can also be seen as inputs in the global innovation activity.

The idea herself of knowledge – a non rival public good rich in externalities – can be seen in turn as the output and as the input in a dynamic perspective of addictive knowledge, since new discoveries and information constitute the basis for future efforts and developments.

Therefore, some hypotheses need to be made while evaluating technical efficiency of regions, about the role of patents, that, again represent only a limited, measurable aspect of knowledge creation. Other important aspects of knowledge creation in a regional framework, as socioeconomic linkages, personal interactions and traditions, are hardly measurable.

The importance of efficiency in the innovation systems lies in the contribution that can be given to productivity. Economic growth can become endogenous only if some internal factors can be shaped and exploited in such a way that we don't need to borrow external interventions to justify growth. In a Romer-fashioned perspective, technological progress increases the productivity of inputs and therefore their contribution to GDP growth.

The following step should therefore try and connect the relative technical efficiency of regional innovation systems to productivity growth. If knowledge creation and technological progress take place, there must be a positive correlation with productivity gains. At aggregate level, notwithstanding, it must be considered that the two events are correlated and, probably, productivity gains also help technological progress.

Our study aims at evaluating: first, the ex-post relative technical efficiency in innovation in a sample of OECD regions by means of a DEA (data envelopment analysis) methodology and by a knowledge production function. We find some consistencies between the two different approaches. Thirdly, it aims at assessing if there is a positive causation from increased efficiency in innovation and productivity gains at regional level. Our scope is to provide some indicators for the policy makers, constantly in the search of evaluation instruments for their actions and their effects. Indicators that rank several regions can illustrate which are the comparative advantages in specific fields and suggest more or less investment in certain areas. We follow strictly the approaches in the literature on regional RIS efficiency; our original contribution is to link the efficiency analysis to the more general productivity performance of regions.

The study is organized as follows. In the next paragraph we discuss the relevant literature on measuring regional innovation systems efficiency and links with productivity gains with various methodological approaches. In the third paragraph, we introduce the data (OECD and Eurostat) with some descriptive statistics, where the best performing regions for each state will be highlighted. In the fourth paragraph we adopt the DEA methodology to evaluate and rank regions according to their innovation performance, and we will compare these results

with a basic approach - a knowledge production function. In the fifth paragraph we will correlate productivity with the innovative activity of regions. The sixth paragraph discusses the findings and concludes.

## **2. Efficiency of regional innovation systems and productivity in the literature**

In recent years, the system of innovation approach has been increasingly applied to the analysis of innovation activities in both a national and a regional context (Cooke 1998; Lundvall 1992; Edquist 1997). Regional systems of innovation may constitute an adequate approach for the analysis of innovation activities if spatial proximity matters, and the effect of certain influences is limited to a particular region.

The idea of technical efficiency was originally introduced by Farrell (1957). Farrell regards an economic unit as being inefficient if it fails to generate the maximum feasible output from a given set of inputs. Reasons for technical inefficiency can be manifold and comprise all sorts of mismanagement such as inappropriate work organization and improper use of technology, scarcity of inputs as well as X-inefficiency as exposed by Leibenstein's (1966) seminal work.

Applying this definition to the concept of a regional innovation system means that a region is technically efficient if it is able to produce the possible maximum of innovative output from a given amount of innovative input. Accordingly, a RIS is regarded as technically inefficient if its output falls below the maximum possible value (Fritsch and Slavtchev, 2007). Moreover, Regional innovation systems (RIS) have increasingly been recognized as a fruitful alternative analytical framework and tool for generating economic policies (De Bruijn and Lagendijk, 2005; Asheim and Jan, 2006). Of course, the RIS that reaches the theoretical optimum can be considered a benchmark for future policies.

The idea of a knowledge production function and ideas-driven growth is empirically tested in Furman, Porter and Stern (2002), where they find that a great deal of variation of innovation activity across countries is due to differences in the level of inputs devoted to innovation (R&D manpower and spending). Fritsch (2002) and Fritsch and Slavtchev (2007) adopt the knowledge production function approach, where the R&D expenditure is the main input while the number of patents granted to a given geographical area is the output.

A DEA methodology is adopted in Zabala-Iturriagoitia, Voigt, Gutiérrez-Gracia and Jiménez-Sáez (2007), that use the European Innovation Scoreboard data to assess the technical efficiency of EU regions. The DEA approach is also used by Fu (2008), that assess performance of regional innovations systems in China in relation to absorptive capability and foreign direct investment. The discussion on the importance of MNE in the European RIS has been investigated by Cantwell and Iammarino (2003). Xibao (2006) adopts a stochastic frontier specification to analyze the effect of region-specific factors on the efficiency of innovation systems.

The step that specifically links the performance of regional innovation systems to productivity growth has been relatively neglected in the literature. The obvious difficulty lies in the simultaneity of productivity and innovation performance at regional level together with the usual lack of comprehensive data. Usually, studies concentrate on firm level analyses (Griffith, Huergo, Mairesse and Peters, 2006), where data is available on the different types of innovation (product and process) that firms introduce.

### **3. Data description**

The OECD Statistical Database, covering 29 OECD countries with overall 323 regions, provides Regional Innovation Indicators, together with economic accounts, demographic and labor markets indicators. This allows us to have a potential set for innovation inputs and outputs: R&D expenditure performed by the business sector, R&D expenditures performed by the government sector, Tertiary education (as % of labor force), High and medium high-technology manufacturing (as % of total employment), Knowledge intensive services (as % of total employment), Patent applications to the national patent office (EPO for EU countries), GDP PPP, Per capita GDP, Labor Force, for the time span 1995 – 2008. Where EU countries data were missing or inconsistencies were found because of the different geographical criteria by which patent data were collected, we used Eurostat regional data. The OECD database is under construction and for many countries, complete data are not available. We also included the datum on the number of researchers at national level from UNESCO survey data<sup>1</sup>.

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<sup>1</sup> [http://www.uis.unesco.org/ev.php?URL\\_ID=5746&URL\\_DO=DO\\_TOPIC&URL\\_SECTION=201](http://www.uis.unesco.org/ev.php?URL_ID=5746&URL_DO=DO_TOPIC&URL_SECTION=201)

**Table 1.**

<b>Average regional R&amp;D expenditure, 1995 -2007, (PPP), top 10 and a sample of lower rank regions</b>			
Region		Region	
California (USA)	48353.59	Lazio (ITA)	2755.375
Michigan (USA)	16017.13	London (GBR)	2643.354
Ile De France (FRA)	13914.16	New South Wales (AUS)	2525.143
Massachusetts (USA)	13637.08	Piemonte (ITA)	1972.034
New York (USA)	13203.36	Emilia Romagna (ITA)	1229.215
Texas (USA)	12489.6	Kosep-Magyarország (HUN)	920.6931
New Jersey (USA)	12000.12	Eszak-Alföld/Northern Great Plain (HUN)	108.0411
Baden-Wuerttemberg (DEU)	11965.53	Del-Alföld/Southern Great Plain (HUN)	101.6819
Bayern (DEU)	10481.08	Kosep-Dunantul/Central Transdanubia (HUN)	74.2525
Maryland (USA)	9992.613	Nyugat-Dunantul/Western Transdanubia (HUN)	58.03336
Ontario (CAN)	7467.534	Del-Dunantul/Southern Transdanubia (HUN)	43.37487
Lombardia (ITA)	3349.218	Eszak-Magyarország/Northern Hungary (HUN)	37.05556

Source, OECD and Eurostat. Note: data is not available for all regions for all years.

**Table 2.**

<b>Average regional patent application, 1995 – 2007, top 10 and a sample of lower rank regions</b>			
Region		Region	
California (USA)	16908.86	Ontario (CAN)	811.2217
New York (USA)	5585.214	Emilia-Romagna (ITA)	609.2593
Texas (USA)	5537	Piemonte (ITA)	476.4238
Baden-Wuerttemberg (DEU)	4882.011	London (GBR)	461.0511
Bayern (DEU)	4533.099	New South Wales (AUS)	332.1749
Nordrhein-Westfalen (DEU)	3995.366	Cataluna (ESP)	325.619
Kinki (JAP)	3492.117	Lazio (ITA)	185.807
Michigan (USA)	3449.428	Kosep-Magyarország (HUN)	73.54684
Massachusetts (USA)	3327.643	Eszak-Alföld/Northern Great Plain (HUN)	8.777467
New Jersey (USA)	3280.5	Del-Alföld/Southern Great Plain (HUN)	7.612167
Illinois (USA)	3254.714	Kosep-Dunantul /Central Transdanubia (HUN)	3.042883
Pennsylvania (USA)	3001.357	Eszak-Magyarország/Northern Hungary (HUN)	2.845075
Ile De France (FRA)	2734.571	Del-Dunantul/Southern Tran (HUN)	2.7643
Lombardia (ITA)	1235.011	Nyugat-Dunantul/Western Transdanubia (HUN)	2.220533

Source, OECD and Eurostat. Note: data is not available for all regions for all years.

**Table 3.**

Average Tertiary Education, 1995 – 2007, top 10 and a sample of lower rank regions			
Region		Region	
California	6261358	Cataluna	925910
Florida	2754636	Lombardia	537075.7
Ile De France	1945913	Lazio	368265.6
Illinois	2283470	Kosep-Magyarország	325961.9
New Jersey	1854916	Emilia-Romagna	246182.7
New York	3769525	Piemonte	213548.8
Ontario	2569958	Eszak-Alfold/Northern Great Plain	84740
Pennsylvania	2005638	Del-Alfold/Southern Great Plain	74500
Texas	3247320	Kosep-Dunantul	67780
Bayern	1426161	Eszak-Magyarország/Northern Hungary	66150
London	1393556	Nyugat-Dunantul/Western Transdanubia	62170
Baden-Wuerttemberg	1314647	Del-Dunantul/Southern Transdanubia	54210
New South Wales	1123560		

*Source, OECD and Eurostat. Note: data is not available for all regions for all years.*

For R&D expenditure, patent application and tertiary education California ranks first, and on average most top 10 regions (states) belong to the USA, with some German regions presence. The only European Region comparable to the US top standards is Ile de France. Italian regions rank far below and so do most other EU regions.

#### **4. DEA analysis of the best performing regions.**

The DEA (Data Envelopment Analysis) has become popular especially when the aim is to evaluate the relative performance in terms of profits for a sample of firms, as it consists of a non-parametrical mathematical programming approach to frontier estimation. The key paper introducing the term DEA dates back to 1978 (Charnes, Cooper and Rhodes, 1978), where they coined the DEA term and set up an input – oriented (as opposed to the dual problem, output oriented) model with constant returns to scale.

The advantage of the DEA approach is that it's based on pure empirical evidence, with no need of formulating alternative hypotheses, as it is instead necessary with linear regression. While DEA analysis is based on extreme points (with respect to an efficient frontier), linear

regression is based on averages values of variables. Of course, the shortcoming of DEA is that error terms are not allowed while with linear regression, they are. We report here the preliminary results of DEA analysis run with the Zhu software<sup>2</sup>.

Typically, inputs are linearly related to outputs and the most efficient firm, resulting from a linear combination of inputs with given outputs, ranks first with a coefficient equal to 1 (= maximum efficiency), while the others rank below with coefficients smaller than 1.

Without entering into the detail of the analysis from the mathematical point of view, an important choice to be made concerns the criterion by which comparing regions with each other. We selected a sample with three different criteria alternatively:

- a. For every country in the database, picked up the region in which the share of R&D over GDP was highest (input based criterion);
- b. For every country in the database, picked up the region in which the share of workers with Tertiary Education over total Labor force was highest (input based criterion);
- c. For every country in the database, picked up the region in which the number of patent application was highest (output based criterion).

The first, general specification of regional efficiency we want to analyze here is simply:

$$Pat_{it} = f\left(\frac{R \& D_{it}}{GDP_{it}}; \frac{Tert_{it}}{Labor_{it}}\right)$$

Where Pat is the number of patent application to the respective national or regional patent office for region  $i$  at time  $t$ ,  $R\&D_{it}/GDP_{it}$  is the share of total Research and Development Expenditure over regional GDP for region  $i$  at time  $t$ ,  $Tert_{it}$  over  $Labor_{it}$  is the percentage of educated workforce over total workforce for region  $i$  at time  $t$ .

The three alternative efficiency analyses produced the results in Table 3.

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<sup>2</sup> The popular Zhu software (<http://www.deafrontier.com/>) with his free evaluation version has some limitation, as for the maximum number of units (called DMU), in our case regions, that can be jointly analyzed, which is 20.

**Table 3a. DEA analysis. Criterion a. Efficiency ranking for 19 OECD regions, 2005\***

Country	Region	Efficiency rank
Belgium	Vlaams Gewest05	1.00000
United States	Maryland05	1.00000
United Kingdom	Estearn05	0.91092
Germany	Berlin05	0.57648
Italy	Lazio05	0.39296
Canada	Quebec05	0.37577
Austria	Wien04	0.33542
France	Midi-Pyrenees04	0.33269
Finland	Pohjois-Suomi05	0.28182
Greece	Attiki05	0.15367
Hungary	Kosep-Magyarország05	0.14463
Ireland	Border - Midlands And Western05	0.11883
Spain	Navarra04	0.07492
Portugal	Lisboa05	0.07456
Norway	Trøndelag05	0.05724
Sweden	Övre Norrland05	0.04545
Poland	Mazowieckie05	0.03763
Czech Republic	Stredni Cechy04	0.02308
Australia	Australian Capital Territory (Act)05	0.01372

\*where 2005 was not available, 2004 was used.

**Table 3b. DEA analysis. Criterion b. Efficiency ranking for 19 OECD regions, 2005\***

Country	Region	Efficiency
France	Ile De France04	1.00000
Canada	Ontario05	0.53045
United Kingdom	London05	0.45143
Germany	Berlin05	0.20407
Sweden	Stockholm05	0.19743
Italy	Lazio05	0.13477
Austria	Wien04	0.12522
Ireland	Southern And Eastern05	0.12131
Belgium	Reg -Bruxelles-Cap -/Brussels Hfdst -Gew -05	0.06966
Norway	Oslo Og Akershus05	0.06713
Spain	Pais Vasco04	0.06631
Greece	Attiki05	0.06622
Hungary	Kosep-Magyarország05	0.06233
Portugal	Lisboa05	0.03213
Poland	Mazowieckie05	0.01622
Czech Republic	Praha04	0.01506
United States	District Of Columbia05	0.01451
Finland	Etela-Suomi05	0.01150
Australia	Australian Capital Territory (Act)05	0.00469

\*where 2005 was not available, 2004 was used.

**Table 3c. Criterion c. Efficiency ranking for 19 OECD regions, 2005\***

Country	Region	Efficiency
United States	California05	1.00000
Germany	Baden-Wuerttemberg05	0.31578
Italy	Lombardia05	0.26089
France	Ile De France04	0.21858
Finland	Ita-Suomi05	0.15407
Canada	Ontario05	0.11594
United Kingdom	South East05	0.10388
Belgium	Vlaams Gewest05	0.09420
Spain	Cataluna04	0.07288
Australia	New South Wales05	0.05204
Sweden	Stockholm05	0.03209
Ireland	Southern And Eastern05	0.02652
Austria	Wien04	0.01841
Norway	Oslo Og Akershus05	0.01467
Greece	Attiki05	0.01447
Hungary	Kosep-Magyarorszag05	0.01362
Portugal	Lisboa05	0.00702
Poland	Mazowieckie05	0.00354
Czech Republic	Praha04	0.00329

\*where 2005 was not available, 2004 was used.

The most interesting feature of the DEA analysis is the correlation between inputs and the patent output. We performed the analysis according three different selection criteria and found that in about half cases there is no coincidence between the region with the highest R&D share and highest number of patent application with the region, for the same country; and with the highest Tertiary education share and highest number of application. As an example, the case of Spain is particularly clear: in 2004, Navarra was the region selected according to the highest share of R&D/GDP; País Vasco was the region selected according to the highest share of Tertiary Education/Labor force; and Cataluña was the region selected according to the highest number of patent application. The underlying initial hypotheses were such that we expected the region with the highest R&D to be the most innovative, and/or the region with the highest share of tertiary education to be the most innovative, and/or the one with the highest number of patent application to be the most innovative.

In an ideal theoretical framework, we would expect the region with the highest number of patent applications to be the one with also the highest R&D and Tertiary education. Evidence instead goes against this relationship.

The interpretation of this evidence, is of uttermost importance. For those countries as Portugal and Hungary, where the same region ranks first whatsoever the criterion used, there is consistency or homogeneity between the relative technical effort employed into the theoretical knowledge production function at territorial level, or, also, there is a concentration of economic activity into poles that remain homogeneous according to several parameters. For those countries where a lot of economic differentiation among regions emerge, the situation is more likely similar to that of Spain, where not necessarily the region with the most educated workforce also performs best into patent application, or, even most surprisingly, not necessarily the region with the highest share of R&D over GDP is also the leader in patent application.

From the technical efficiency point of view, these results are extremely important for the policy maker. For example, for relatively inefficient regions on the international panorama, the same result in terms of patents could be reached by reducing inputs, that is R&D or Education. Of course these options make sense for firms, but are not desirable from the long run economic growth perspective and from the social point of view. Actually, the real strong implication stemming from this analysis is probably the fact, already acknowledged in RIS

and innovation economics, that is, immeasurable linkages, quality of infrastructures, social interaction and shared knowledge at regional-local level account more in explaining the innovation performance than the mere R&D or Education figures. In other words, these variables alone are necessary but insufficient conditions to guarantee some extra innovation output, here - partially – measured by patent application. An interesting simulation would entail increasing the input value for a region so to see if the relative ranking in inefficiency changes.

## 5. Knowledge production function: regression analysis

We can now compare the results above from the DEA analysis with the linear regression analysis of the knowledge production function, as presented in Fritsch (2002):

$$\text{R\&D output} = f(\text{R\&D expenditure, Tertiary education})$$

We consider as inputs, in turn, the total R&D expenditure over GDP by region and the Tertiary Education over total Labor Force, as output the number of patent application by region: since various years are available, we can use a panel data approach after checking for consistency among regions, at least for a pooled estimation. Taking the Cobb-Douglas production function as a framework, the basic relationship is:

$$\text{R\&D output} = a \text{ R\&D input}^b$$

with the term  $a$  representing a constant factor and  $b$  giving the elasticity by which R&D output varies in relation to the R&D input. For estimation with standard regression methods, we take the natural logarithms of both sides:

$$\ln \text{ R\&D output} = \ln a + b \ln \text{ R\&D input} + e$$

where the  $b$  parameter represents the marginal contribution of R&D inputs – expenditure and education – to the innovation output, measured by patents, and  $e$  is an error term. The aspect under which our analysis differs from Fritsch (2002) is that we rely on the OECD regional

data on innovation, while his sample was made of firm-level survey data, and therefore probably the difference is that we should find less variance with a smaller number of cases.

In order to make results comparable with the previous DEA analysis, we limited the analysis to the set of regions previously selected to apply the criterion c., that is, those regions for every country with the largest number of patent application.

The dependent variable, Patents, has the features of a count variable and therefore a negative binomial regression can be used (Fritsch, 2002). In this case, log variables cannot be used since the low average number of patents for some regions and year produces a negative outcome. The nature of our observations does not allow us to run region-by-region regressions, since the number of observations for each region is limited and ranges from 4 to 10, that corresponds to the years for which the datum is available. We will therefore run a panel data analysis with pooled negative binomial regression and regional dummies to assess for regional differences in the R&D inputs productivity, using R&D expenditure and Tertiary education in turn as regressors. Estimation results are reported in Table 4.

**Table 4. Regression results, R&D expenditure ad knowledge input**

Dependent Variable: Patent Applications						
<i>Region/Indipendent variables</i>	<i>Coef.</i>	<i>Std. Err.</i>	<i>z</i>	<i>P&gt; z </i>	<i>[95% Conf.</i>	<i>Interval]</i>
R&D expenditure	0.0000	0.0000	4.7500	0.0000	0.0000	0.0000
Vlaams Gewest	3.2554	0.9239	3.5200	0.0000	1.4447	5.0662
Ile De France	2.6718	0.7982	3.3500	0.0010	1.1075	4.2362
Lombardy	1.9871	0.8123	2.4500	0.0140	0.3951	3.5791
Stockholm	2.3275	1.0261	2.2700	0.0230	0.3164	4.3387
South East (UK)	2.0400	0.9231	2.2100	0.0270	0.2308	3.8493
Southern And Eastern (IR)	1.7003	0.9306	1.8300	0.0680	-0.1236	3.5241
Kosep-Magyarorszag	1.5325	0.8426	1.8200	0.0690	-0.1190	3.1840
Ita-Suomi	1.4156	0.7957	1.7800	0.0750	-0.1440	2.9752
Baden-Wuerttemberg	1.5380	0.9152	1.6800	0.0930	-0.2557	3.3316
Oslo Og Akershus	1.0828	0.8390	1.2900	0.1970	-0.5615	2.7272
New South Wales	0.9059	0.8610	1.0500	0.2930	-0.7816	2.5933
California	1.0586	1.0418	1.0200	0.3100	-0.9833	3.1006
Ontario	0.8038	0.7944	1.0100	0.3120	-0.7532	2.3607
Wien	0.9055	0.9156	0.9900	0.3230	-0.8890	2.7000
Cataluna	0.5298	0.7810	0.6800	0.4970	-1.0008	2.0605
Praha	0.2633	0.8838	0.3000	0.7660	-1.4689	1.9956
Mazowieckie	-0.4541	0.8103	-0.5600	0.5750	-2.0423	1.1342
Lisboa	-0.5188	0.8272	-0.6300	0.5310	-2.1402	1.1025
constant term	1.6451	0.6665	2.4700	0.0140	0.3389	2.9514
Number of observations			130	Wald chi <sup>2</sup> (19)		121.65
Number of groups			19	Prob > chi <sup>2</sup>		0

**Table 5. Tertiary Education as knowledge input.**

Dependent Variable: Patent Applications						
<i>Region/Independent variables</i>	<i>Coef.</i>	<i>Std. Err.</i>	<i>z</i>	<i>P&gt; z </i>	<i>[95% Conf.</i>	<i>Interval]</i>
Tertiary Education	0.0000	0.0000	7.6000	0.0000	0.0000	0.0000
Lombardia	3.2748	0.7329	4.4700	0.0000	1.8383	4.7112
Vlaams Gewest	2.1565	0.7242	2.9800	0.0030	0.7370	3.5759
Baden-Wuerttemberg	1.9485	0.7315	2.6600	0.0080	0.5148	3.3823
New South Wales	2.0927	0.8234	2.5400	0.0110	0.4788	3.7065
Stockholm	1.6683	0.6956	2.4000	0.0160	0.3050	3.0315
South East (UK)	1.3907	0.7307	1.9000	0.0570	-0.0415	2.8228
Oslo Og Akershus	1.3327	0.7454	1.7900	0.0740	-0.1282	2.7936
Cataluna	1.2438	0.7244	1.7200	0.0860	-0.1760	2.6637
Wien	1.0305	0.7242	1.4200	0.1550	-0.3889	2.4499
Kosep-Magyarország	1.0354	0.7540	1.3700	0.1700	-0.4425	2.5132
Ile De France	0.9819	0.7402	1.3300	0.1850	-0.4688	2.4326
Ita-Suomi	0.9539	0.7294	1.3100	0.1910	-0.4757	2.3835
California	0.8221	0.8297	0.9900	0.3220	-0.8041	2.4483
Southern And Eastern (IR)	0.3853	0.7283	0.5300	0.5970	-1.0421	1.8127
Ontario	0.0110	0.6753	0.0200	0.9870	-1.3126	1.3345
Praha	-0.5762	0.7361	-0.7800	0.4340	-2.0189	0.8665
Lisboa	-0.8844	0.7210	-1.2300	0.2200	-2.2976	0.5288
Mazowieckie	-1.3133	0.7181	-1.8300	0.0670	-2.7207	0.0941
constant term	2.4614	0.5315	4.6300	0.0000	1.4196	3.5032
Number of observations	159		Wald chi <sup>2</sup> (19)		192.75	
Number of groups	19		Prob > chi <sup>2</sup>		0	

Table 4 reports the estimates when R&D expenditure is used as an independent variable, while Table 5 reports the estimates when Tertiary Education is used. We notice first that both coefficients are positive and significant, although the coefficient for R&D is not far from zero. The estimates for the slopes of the knowledge production function as resulting from the negative binomial regression represent a raw estimate for the R&D inputs productivity, that, their marginal contribution to innovation when expressed through patenting activity.

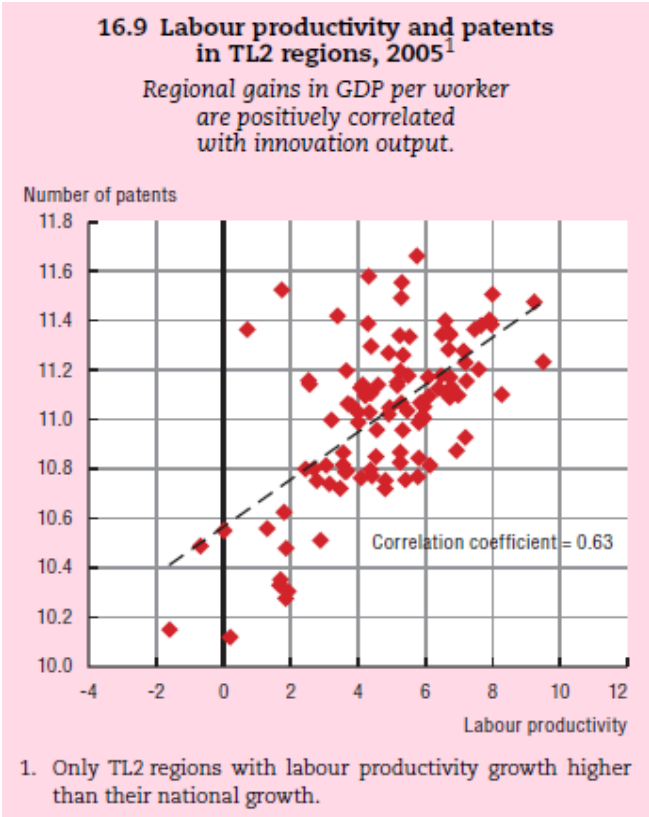
We obtain some quite interesting results. When maximum likelihood estimation is adopted, the relative importance of regions in their marginal contribution to patenting changes significantly with respect to the DEA analysis. It is important that we used the same sample of regions adopted for the DEA analysis, those are the regions with the highest number of patents in their country. So while California was at the top of the ranking, we see that the marginal contribution of California in patenting when R&D and Education are separately considered is relatively weaker. Instead, we observe that Vlaams Gewest and Lombardy give the higher contribution to patenting thanks to R&D and Education, respectively. We could think of some relative comparative advantages here, with respect to the absolute advantages expressed by the DEA analysis. The first half of regions, that were ordered according to their

z-statistics, all have positive and significant coefficients with respect to the patents variable. Those in the lower part of the ranking have non-significant coefficients and therefore could not really be evaluated in the perspective of their marginal contribution to the knowledge production function.

### 6. Linking regional innovation and productivity

Our next step is to try and link these findings with the productivity variable, trying to overcome the well known limit – and already discussed above – of evaluating the innovation output simply by using patent application. In particular, we rely on the empirical findings in OECD (2009, page 101) according to which labor productivity change is positively correlated to patents, in those regions whose labor productivity is growing faster than the national average. The results from OECD are reported in Figure 1.

**Figure 1. OECD study over patents and gains in labor productivity at TL2 level.**

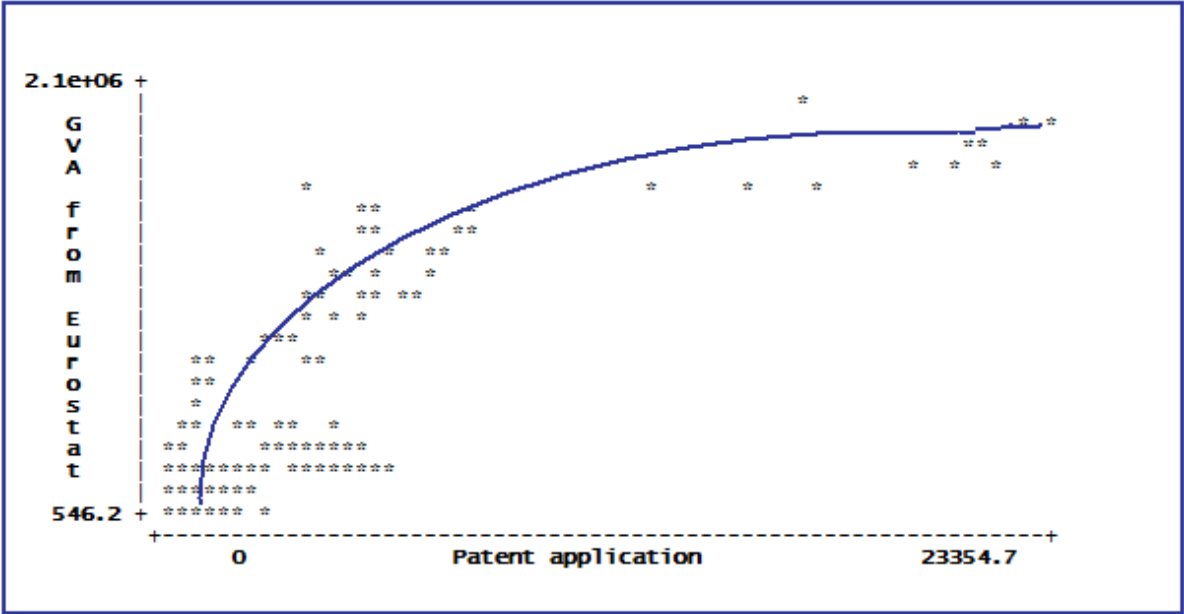


Source, OECD, 2009

This correlation supports our idea that a large part of innovation contribute to labor productivity growth, therefore, those regions that register more patent application, should also register a higher labor productivity growth. In other words, we could estimate a different version of the knowledge production function above, by replacing the R&D output “patents”, with the expected result from increased innovation, that is “productivity growth”. In that sense, by means of regression analysis we should be able to evaluate the marginal contribution of R&D expenditure and tertiary education to innovation captured by productivity growth.

Considering the whole of our dataset (2201 observations), we find that the correlation between patent application and regional gross value added (GVA) is about 86%. This strong correlation also holds when considering 1-year lagged patent applications. When plotting the relationship between regional GVA (for EU countries for which data is available) and patents, we find an interesting non-linearity:

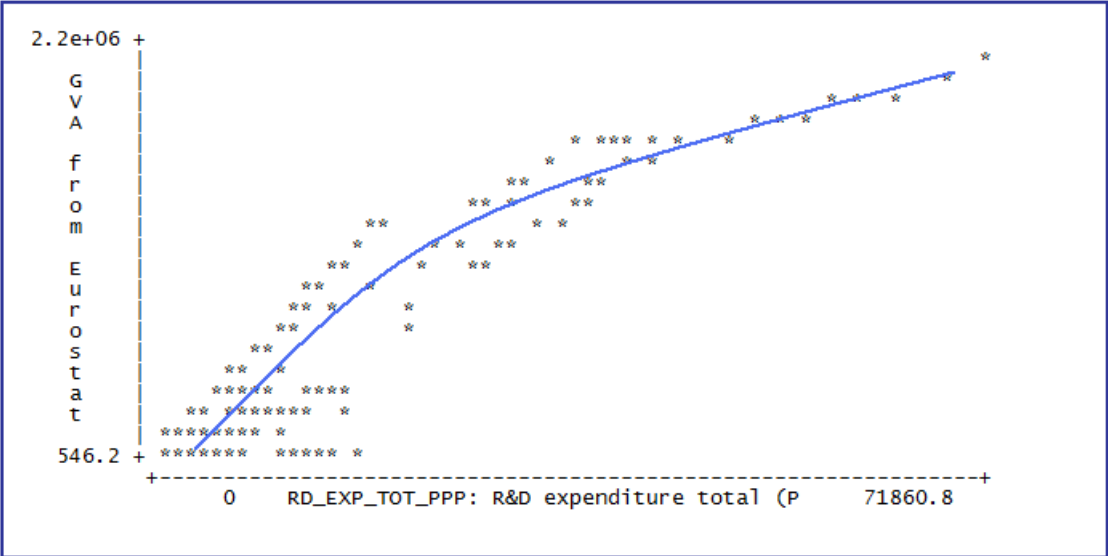
**Figure 2. Regional GVA and Patent applications, EU, 1995 – 2007.**



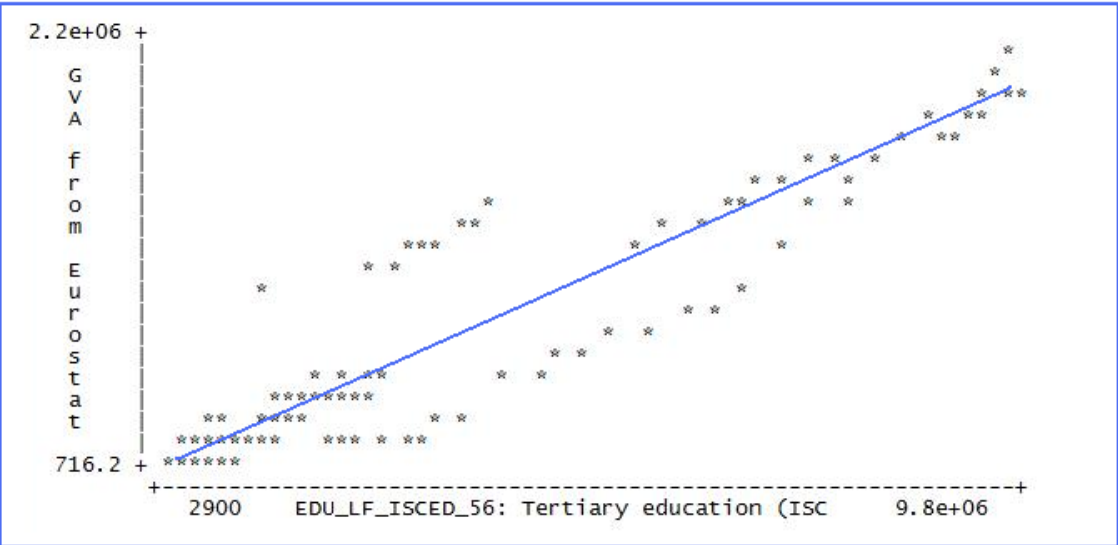
This relationship suggests the existence of a non-linear relationship between the measurable output of the innovation function and gross valued added. Therefore, a first interpretation would imply some decreasing returns to scale when innovation is taken into account in the

explanation of regional gross value added. In other words, the contribution of the innovative activity based on patents is positive but decreasing. A similar positive and strong relationship is found when plotting GVA against the total regional R&D expenditure and Tertiary-educated labor force. In Figure 3, we notice that R&D expenditure also has non-linear relationship with GVA, but less evident than in Figure 2.

**Figure 3. Regional GVA and R&D expenditure, EU, 1995 – 2007.**



**Figure 4. Regional GVA and Tertiary Education, EU, 1995 – 2007.**



Several factors contribute to GDP growth and GVA growth. If we consider GVA growth as good proxy for global regional productivity, we may try and use innovation related variables (inputs and outputs) to assess the contribution of the innovative performance of regions to the regional global productivity. Following the growth model proposed by Fu (2008), we estimate the impact of innovation on regional economic growth by the following equations, in turn:

$$y_{it} = \alpha + \varphi P_{it} + \theta P_{it}^2 + \gamma L_{it} + \delta K_{it} + \varepsilon_{it} \quad [1]$$

$$y_{it} = \alpha + \varphi R \& D_{it} + \theta R \& D_{it}^2 + \gamma L_{it} + \delta K_{it} + \varepsilon_{it} \quad [2]$$

$$y_{it} = \alpha + \varphi TE_{it} + \gamma L_{it} + \delta K_{it} + \varepsilon_{it} \quad [3]$$

Where  $y_{it}$  is the log of gross value added at time  $t$  for region  $i$ ,  $P_{it}$  is the log number of patent applications at time  $t$  for region  $i$ ,  $P_{it}^2$  is the square of the previous variable,  $L_{it}$  is log employment at time  $t$  for region  $i$ ,  $K_{it}$  is the log gross fixed capital formation as a proxy for capital endowment. We use adopt two estimation techniques: an OLS estimate with regional dummies and random effect panel data estimation to take into account the longitudinal dimension that could provide some additional information. The results of estimation are reported in Table 6.

**Table 6a. Equation [1], OLS with regional dummies**

Dependent Variable	Log Gross Value Added					
<i>Region/ Independent Variable</i>	<i>Coef.</i>	<i>Std. Err.</i>	<i>t</i>	<i>P&gt; t </i>	<i>[95% Conf. Interval]</i>	
Log Patents	0.44	0.07	6.24	0.00	0.30	0.58
Log Patents^2	-0.02	0.01	-2.27	0.03	-0.04	0.00
Log Employment	0.00	0.02	0.10	0.92	-0.04	0.04
Log Capital	0.39	0.04	9.89	0.00	0.31	0.47
Baden-Wuerttemberg	0.07	0.25	0.26	0.79	-0.43	0.57
Cataluna	-0.15	0.08	-1.81	0.07	-0.31	0.01
Ile De France	0.29	0.20	1.41	0.16	-0.11	0.69
Ita-Suomi	-1.72	0.21	-8.25	0.00	-2.14	-1.31
Kosep-Magyarorszag	-0.82	0.07	-11.45	0.00	-0.97	-0.68
Lisboa	0.01	0.06	0.09	0.93	-0.12	0.13
Lombardia	0.14	0.15	0.90	0.37	-0.16	0.44
Mazowieckie	-0.18	0.06	-2.92	0.00	-0.30	-0.06
Praha	-0.72	0.06	-11.34	0.00	-0.85	-0.60
South East	0.21	0.16	1.28	0.20	-0.11	0.53
Stockholm	-0.50	0.14	-3.59	0.00	-0.77	-0.22
Vlaams Gewest	-0.20	0.13	-1.59	0.11	-0.46	0.05
Wien	-0.44	0.08	-5.29	0.00	-0.61	-0.28
Constant	5.89	0.39	15.09	0.00	5.12	6.66
Number of observations	133		R-squared	0.9914		
F( 17, 115)	783.22		Adj R-squared	0.9902		
Prob > F	0.00000		Root MSE	0.10988		

**Table 6b. Equation [1], Random Effects**

Dependent Variable		Log Gross Value Added				
<i>Independent Variable</i>	<i>Coef.</i>	<i>Std. Err.</i>	<i>t</i>	<i>P&gt; t </i>	<i>[95% Conf. Interval]</i>	
Log Patents	0.40	0.07	5.38	0.00	0.25	0.55
Log Patents^2	-0.02	0.01	-2.11	0.04	-0.03	0.00
Log Employment	0.01	0.02	0.26	0.80	-0.04	0.05
Log Capital	0.46	0.04	11.89	0.00	0.39	0.54
Constant	5.02	0.39	13.03	0.00	4.26	5.77
Number of observations	133		R-sq: within	0.7584		
Number of groups	14		between	0.8645		
Wald chi2(4)	438.33		overall	0.8561		
Prob > chi2	0					

**Table 6c. Equation [2], OLS with regional dummies**

Dependent Variable		Log Gross Value Added				
<i>Region/ Independent Variable</i>	<i>Coef.</i>	<i>Std. Err.</i>	<i>t</i>	<i>P&gt; t </i>	<i>[95% Conf. Interval]</i>	
Log R&D	(dropped)					
Log R&D Squared	0.22	0.03	7.61	0.00	0.16	0.28
Log Employment	0.31	0.08	3.76	0.00	0.15	0.48
Log Capital	0.16	0.03	4.82	0.00	0.09	0.23
Baden-Wuerttemberg	-0.13	0.14	-0.93	0.36	-0.41	0.15
Cataluna	0.00	0.06	-0.06	0.95	-0.13	0.12
Ile De France	0.01	0.15	0.08	0.94	-0.28	0.31
Ita-Suomi	-0.86	0.10	-8.24	0.00	-1.07	-0.65
Kosep-Magyarorszag	-0.49	0.08	-5.91	0.00	-0.66	-0.33
Lisboa	-0.12	0.06	-1.89	0.06	-0.25	0.01
Lombardy	0.72	0.14	5.18	0.00	0.44	1.00
Mazowieckie	-0.62	0.06	-10.71	0.00	-0.74	-0.51
Praha	-1.42	0.10	-13.70	0.00	-1.63	-1.21
South East	-0.15	0.12	-1.24	0.22	-0.40	0.09
Stockholm	0.18	0.24	0.77	0.45	-0.29	0.65
Vlaams Gewest	-0.03	0.10	-0.33	0.74	-0.24	0.17
Wien	-0.86	0.11	-8.06	0.00	-1.07	-0.64
Constant	5.24	0.31	16.94	0.00	4.62	5.86
Number of observations	74		R-squared	0.9974		
F( 16, 57)	1390.14		Adj R-squared	0.9967		
Prob > F	0.00000		Root MSE	0.06605		

**Table 6d. Equation [2], Random Effects**

Dependent Variable		Log Gross Value Added				
<i>Independent Variable</i>	<i>Coef.</i>	<i>Std. Err.</i>	<i>t</i>	<i>P&gt; t </i>	<i>[95% Conf. Interval]</i>	
Log R&D	0.54	0.05	10.38	0.00	0.44	0.65
Log Employment	0.11	0.07	1.58	0.11	-0.03	0.24
Log Capital	0.19	0.04	5.09	0.00	0.12	0.26
Constant	4.78	0.35	13.48	0.00	4.09	5.48
Number of observations	74		R-sq: within	0.8319		
Number of groups	14		between	0.8805		
Wald chi2(3)	368.7		overall	0.9049		
Prob > chi2	0.0000					

**Table 6.e, Equation [3], OLS with regional dummies**

Dependent Variable Log Gross Value Added						
<i>Region/ Independent Variable</i>	<i>Coef.</i>	<i>Std. Err.</i>	<i>t</i>	<i>P&gt; t </i>	<i>[95% Conf. Interval]</i>	
Log Tertiary Education	0.35	0.09	3.86	0.00	0.17	0.53
Log Employment	0.04	0.03	1.31	0.20	-0.02	0.09
Log Capital	0.60	0.06	9.55	0.00	0.47	0.72
Baden-Wuerttemberg	0.26	0.13	1.94	0.06	-0.01	0.53
Cataluna	-0.09	0.10	-0.90	0.37	-0.28	0.10
Ile De France	0.23	0.16	1.39	0.17	-0.10	0.55
Ita-Suomi	-0.08	0.15	-0.55	0.59	-0.37	0.21
Kosep-Magyarország	-0.21	0.07	-3.08	0.00	-0.34	-0.07
Lisboa	-0.03	0.08	-0.37	0.71	-0.18	0.13
<i>Lombardy</i>	<i>0.63</i>	<i>0.11</i>	<i>5.70</i>	<i>0.00</i>	<i>0.41</i>	<i>0.85</i>
Mazowieckie	-0.35	0.05	-6.93	0.00	-0.45	-0.25
Praha	-0.47	0.10	-4.76	0.00	-0.66	-0.27
South East	0.15	0.13	1.16	0.25	-0.11	0.41
<i>Stockholm</i>	<i>0.35</i>	<i>0.07</i>	<i>4.98</i>	<i>0.00</i>	<i>0.21</i>	<i>0.49</i>
Vlaams Gewest	0.07	0.09	0.73	0.47	-0.12	0.25
<i>Wien</i>	<i>0.26</i>	<i>0.10</i>	<i>2.57</i>	<i>0.01</i>	<i>0.06</i>	<i>0.47</i>
Constant	0.66	1.10	0.60	0.55	-1.53	2.85
Number of observations	84		R-squared	0.9929		
F( 16, 57)	589.68		Adj R-squared	0.9913		
Prob > F	0		Root MSE	0.09683		

**Table 6.f, Equation [3], Random effects**

Dependent Variable Log Gross Value Added						
<i>Independent Variable</i>	<i>Coef.</i>	<i>Std. Err.</i>	<i>t</i>	<i>P&gt; t </i>	<i>[95% Conf. Interval]</i>	
Log Tertiary Education	0.33	0.07	4.56	0.00	0.19	0.47
Log Employment	0.02	0.03	0.77	0.44	-0.03	0.07
Log Capital	0.71	0.06	12.58	0.00	0.60	0.82
constant	-0.02	0.67	-0.04	0.97	-1.33	1.28
Number of observations	84		R-sq: within	0.6955		
Number of groups	14		between	0.9575		
Wald chi2(3)	527.4		overall	0.9457		
Prob > chi2	0.0000					

From Table 6.a and 6.b we find that the contribution of patenting to Gross Value added is positive and significant, while the diminishing return is captured by the squared term that has a negative and significant sign. While employment is almost never significant in all estimation, the capital variable is always positive and significant. The interpretation for the employment variable to be so weak in our framework is puzzling. Since value added should be mainly related to the performance of the production function, where labor should play a major role with respect to capital, we would expect the two aggregate inputs to have almost the same weight in determining GVA. Instead, employment has a positive (slightly) and

significant coefficient only once among our estimations. There could be inefficiencies in the labor market that hinder the reallocation of labor forces towards the more productive sectors, or there could be some undetected competition effects. These observations about employment capital hold through all the estimations. Using two different approaches allowed us to capture the single region's effect on gross value added and the longitudinal dimension with a panel data approach. Interestingly, when the patenting activity is considered, no single region has a positive and significant effect on gross value added, while many have a significant negative effect, in virtually all the newly EU entered regions (Kosep-Magyarország, Praha, Mazowieckie) but also Ita Suomi, Stockholm and Wien. As a general consideration, the goodness of fit is high in all estimations, no matter the technique being adopted. When analyzing Table 6.c and 6.d, we look at the first input-related aspect of innovation, that is R&D expenditure. In Table 6.c we find for the first time a region, Lombardy with a positive and significant coefficient on gross value added. This is a first indication of the already observed discrepancy between input and output related measures for innovation, under the DEA analysis: there is in general no connection between the performance in terms of the output –patents – and the input measures in the knowledge production function. Again, the same considerations for employment and capital hold (but for R&D squared dropped because of collinearity). When coming to Table 6.e and 6.f, we find a further indication for the signal preliminarily captured in Table 6.c. We have three regions (Lombardy, Stockholm and Wien) for which the dummies are positive and significant. This adds to the previous DEA findings and tells further that Education –in our case, deliberately chosen at the highest level – has an impact in the knowledge production function, in the sense that quality matters in basically quantitative evaluation of the knowledge production function.

## **7. Conclusions**

The aim of our paper has been to move a step towards a relatively neglected field, that is the relationship between regional innovation systems efficiency and productivity. In particular, we turned to different approaches in the effort of finding comparable measures for regional innovation performance (DEA and knowledge production function approach) and then trying to link regional innovation indicators (input and output based) with gross regional value

added. Let us first discuss the limits of our analysis. First, patents are such an imperfect measure for innovation results that any analysis can lead to questionable results. From this point of view, firm based and survey based studies can shed some more light on issues like product and process innovation. Secondly, OECD data do not appear completely reliable because of different geographical criteria adopted – maybe no other option was available - in collecting data at NUTS2 and NUTS3 level. For this reason for our final analysis we turned to Eurostat data. Thirdly but not lastly, the specification of the final relationship between GVA, input factors and innovation indicators could be more deeply investigated. As an example, FU (2008) also enters exports and FDI as productivity determinants for China regions. This research area surely deserves investigation. Moreover, no one can conclusively tell if input or output measures for innovation should be correctly considered in GVA determination, since in a global perspective the innovation function does not look like a linear process, but rather a circular one as what is output for one agent becomes input for the other. When coming instead to the main promising findings of our research, they are the following: 1) the extreme points DEA analysis and the average value econometric approach partially provide consistent results, mainly when outstanding regions as California, Ile de France or Baden – Wuerttemberg are considered. But things get more complicated when lower ranking regions are considered. We chose to focus on some Eastern European regions and Italian regions, noticing anyway their poor performance with respect to leaders as California. 2) Results of DEA and econometric analysis vary a lot depending on the criterion adopted. Looking at efficiency in terms of patents, R&D expenditure and Tertiary Education provide different rankings under the DEA analysis, meaning that patent application is a very imperfect measure of innovation output. When Tertiary Education is the input of the knowledge production function, European regions overtake USA, Canada and Australia regions, with Lombardy ranking first in terms of dummy effects. 3) When trying to connect innovation output and inputs with gross value added –as a way to measure the partial contribution of these factors of productivity - we find that, controlling for the labor and capital inputs, patents give a positive but decreasing contribution to GVA, while the single region dummy effect is disappointing, and employment is never significant, that would suggest some major issue in the EU labor market. Data for non-EU regions were not available. Some different results appear when considering GVA and R&D expenditure and Tertiary Education. Again, the role of Lombardy in this framework emerges.

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## **Data Sources**

<http://stats.oecd.org/Index.aspx>

<http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/>