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The relationship between TFP and innovation performance: evidence from EU regions

JEL Classification: *R11; R12; O31; O33; O47*

Keywords: *TFP; innovation; knowledge spillovers; EU regions*

Abstract
Research background: Total factor productivity (TFP) determines how efficiently and intensely the available inputs are used and combined in production process. Improvement of TFP performance requires identification of its determinants, thus enabling policy actions to focus on them. Since the ability to create and absorb innovation is considered as a crucial factor of economic development, the investigation of the impact of the level of regional innovative performance on TFP distribution across EU regions is an important research problem.
Purpose of the article: The aim of the paper is twofold. Firstly, we attempt to develop a theoretical framework for the analysis of the impact of innovation on TFP. Secondly, we assess TFP levels for regions in the EU and investigate whether innovations account for the observed regional disparities in TFP.
Methods: The research sample consists of 202 European Union (EU) regions at NUTS 1 and NUTS 2 level from 22 countries. The regional data on GDP, employment and gross fixed capital formation come from the Eurostat. The source of data on the level of innovativeness of European regions is the Regional Innovation Scoreboard. To calculate TFP, we use the multiplicatively-complete Färe-Primont index. In turn, to examine the impact of innovation on TFP, we employ the spatially-lagged X model.
Findings & Value added: Our findings show a high degree of dispersion in TFP across EU regions. We find a positive impact of regional innovation performance on TFP. Although theoretical papers on economic development and regional economics suggest that improvements in TFP are key to regional economic performance, and that innovations are crucial to gain such produc-

tivity effects, there is a dearth of empirical studies on the link between innovation and TFP at the regional level. Therefore, our paper attempts to fill this gap by providing the evidence of positive effect of innovation externalities on TFP in European regions.

Introduction

Understanding the spatial distribution of total factor productivity (TFP) and its determinants is an inevitable step in modelling a long-run economic growth more precisely and design appropriate regional and innovation policies. The level of TFP determines how efficiently and intensely the available inputs are used in production. Empirical results indicate that differences in TFP growth account for about 90% of cross-country disparities in real per capita GDP (Benhabib & Spiegel, 1994; Easterly & Levine, 2001). Thus, it could be stated that differences in TFP, rather than in factor accumulation, should be taken into account when looking for the explanation of differences' disproportions in economic development.

The tendency of the factors of production to be accumulated in spatial proximity, which can be observed both at regional and national level, implies that economic activity is highly concentrated. Factors' accumulation results in positive externalities and, as a consequence, only certain places achieve higher levels of TFP. Such inequality in the levels of productivity is specific to the EU. Empirical analyses confirm the presence of a high and persistent level of TFP heterogeneity across EU regions and regional productivity polarisation between high and low TFP levels (Di Liberto & Usai, 2013).

Since the ability to create and absorb innovation is considered as a crucial factor of TFP growth, the investigation of the impact of the level of regional innovative performance on TFP distribution in the EU regional scope seems to be an interesting research problem. As innovation performance is significantly diversified across European regional space, we should expect its significant impact on differences in TFP levels.

Bearing in mind the aforementioned considerations, the aim of the paper is twofold. Firstly, we attempt to develop a theoretical framework for the analysis of the impact of innovation on TFP. Secondly, we measure TFP levels in each EU region and investigate whether innovations account for the observed regional differences in TFP.

The remainder of the paper is organised as follows. The next section presents a brief overview of the literature illustrating the relation between innovation and productivity in the spatial context. The third section describes the data and methods employed to assess innovation performance and TFP and the relationship between them in the EU regions. The fourth

section demonstrates the results of the analysis along with a brief discussion of the key findings. Finally, the last section recapitulates the main conclusions of the study and provides some suggestions for further research.

Literature review and hypotheses development

Basing on the "neo-Schumpeterian" approach to economic growth (Aghion & Howitt, 2006) the increase in TFP depends on the rate of innovation creation and on the rate of adoption or diffusion of new technologies in the regional economies. The effects of innovation processes are significantly determined by the innovation potential of a given area. Absorptive capacity, as discussed by Arrow (1969), captures the concept that economies may differ regarding their abilities to adopt new technologies. Economic geographers argue that regional innovation potential and knowledge infrastructure, perceived mainly as a complex of universities, research institutes, R&D expenditures and employees, and regional technology policy, is crucial for the innovative performance and growth of the regional economy (Beugelsdijk, 2007). However, as Crevoisier (2004) points out, innovation does not appear in space uniformly, but is predominantly spatially concentrated. Empirical contributions (eg. Audretsch & Feldman, 1996) indicate that regional concentrations of innovative activity can be observed in almost all countries of the world.

According to the innovative milieus approach, a territory is understood as an organization that links companies, institutions, and local populations within a process of economic development. The territorial paradigm takes differences in innovation potential into account and shows that a territory as an organization can generate resources (e.g., know-how, competencies, and capital) and the actors (e.g. companies, innovators, and support institutions) that are necessary for innovation (Crevoisier, 2004). Moreover, growth and geographic agglomeration of economic activities are mutually self-reinforcing processes. Agglomeration in one region accelerates growth because it reduces the cost of innovation in that region through externalities due to lower transaction costs, thus implying that innovation processes take place in the core region (Martin & Ottaviano, 2001).

Regions with different innovation capabilities have unique TFP trajectories that result in the likely differences in TFP growth. The property that knowledge itself is an important input in creation of new knowledge leads to the situation when the regions that already possess an advantageous position in generating technological change for growth, are likely to maintain

this position, i.e. knowledge is cumulative, characterized by (dynamic) increasing returns (Dosi, 1988). Regions that are less prone to generate knowledge develop the culture of dependency on external sources of knowledge that consequently discourages regional entrepreneurship and innovativeness (Petrov, 2011). It is consistent with the concept of path dependence that is intended to capture the way in which regions set off the mechanisms of self-reinforcement that "lock in" particular structures and pathways of development (Martin & Sunley, 2006). A number of authors have argued that innovation is "path dependent", which means that the historical pattern of technological development plays a central role in determining technological progress in the future (Arthur, 1994; Redding, 2002).

A constant feature of productivity distribution along time is the spatial dependence as the changes in its distribution have a significant geographical component (Di Liberto & Usai, 2013). This approach is consistent with the New Economic Geography paradigm (Krugman, 1998), according to which geographical concentration and localised spillovers are beneficial to productivity and growth (Ottaviano & Thisse, 2004). As Marrocu *et al.* (2013) argue, the effects of agglomeration externalities according to the product life cycle and the maturity stage of a given area have an impact on productivity dynamics.

Besides the aforementioned characteristics, the differences in the level of productivity across economies results not only form the regional innovation performance, but also form the positive effects of foreign innovation activities. The literature on international technology diffusion has demonstrated the positive effect of foreign R&D on domestic productivity. Coe and Helpman (1995) report that the effect of foreign R&D on the level of domestic productivity is even larger than that of domestic R&D. Moreover, according to Kneller (2005), the impact of foreign technology on productivity varies according to the level of absorptive capacity and physical distance, however the former is quantitatively more important.

What is worth pointing out, the impact of innovation performance on TFP is shaped by a multitude of determinants. Undoubtedly, innovation performance depends on the level of each region's economic development. Among the other major determinants, the endogenous growth literature has included internationalization and human capital accumulation. FDI contributes to creation or adoption of new technologies and to an increase in more efficient activities, resulting in greater productivity (Holmes & Schmitz, 2001). Whereas improvements in human capital affect income inequality (Rodriguez-Pose & Tselios, 2009) and facilitate processes of innovation creation and absorption. Complementarities that occur between innovation

performance and other explanatory variables determining TFP (like human capital, openness or foreign investments) contribute to productivity enhancement. The greater the complementarity between variables the higher TFP growth (L'opez-Bazo *et al.*, 2006).

Given the availability of data, in the empirical literature regarding the impact of innovation on productivity two measures of innovative activity are mostly used: R&D spending (Hal *et al.*, 2010) and patent counts. Recently, economists have begun to look at innovation more broadly as a source of TFP growth (Hall, 2011). In our work, we employ the composite indicator Regional Innovation Index (Regional Innovation Scoreboard 2017), which captures a broad spectrum of innovation performance of the EU regions, showing framework conditions for innovation activities, investments, the effects of innovation activities and their impacts on the economy.

In the relevant literature, a wide range of different approaches is currently used to determine TFP as a crucial measure of productivity. As Schatzer *et al.* (2019) demonstrate, the model selection has an essential impact on estimation results for both TFP levels and TFP growth rates. Recently, to estimate TFP, a production frontier approach is frequently adopted as, according to O'Donnell (2012), it allows to avoid the possible bias resulting from the assumption, common in the classical literature on economic growth, that all economic units operate efficiently. In accordance with this argument, we use the multiplicatively-complete Färe-Primont index to calculate TFP.

As innovation performance is significantly diversified across European regional space, we expect its significant impact on the differences in TFP levels. This notion allows us to formulate the first hypothesis of the study:

H1: *Innovation performance has a significant positive impact on TFP*.

Given the fact that innovation potential is not distributed uniformly, but is predominantly spatially concentrated, allows us to formulate the second hypothesis of the study:

H2: *TFP distribution across the European regions is shaped by the existence of innovation spillovers*.

Research methodology

Our sample consists of 202 European Union (EU) regions at NUTS 1 and NUTS 2 level from 22 countries. For the purpose of innovation performance measurement at the regional level, we employed data from the Regional Innovation Scoreboard (RIS) for 2015. The RIS database includes 220 regions at different NUTS levels from 22 EU countries, Norway, Serbia, and Switzerland. According to the RIS methodology, average regional innovation performance is measured using the Regional Innovation Index (RII), which is composed of the normalised scores of the 18 indicators. These indicators are classified into four groups. The first one relates to framework conditions which are formed by human resources and attractive research systems. The second group pertains to investments (i.e. finance and support, and firm investments). The third group consists of innovation activities. The last group includes employment and sales impacts. Relative RII values are calculated by dividing the RII of the region by the EU average. As regards TFP operationalization, we decided to use two inputs and one output. The input variables are gross fixed capital formation (GFCF), i.e. resident producers' investments, deducting disposals, in fixed assets during a given period, and employment (E) in thousand hours worked. In turn, the output variable is gross domestic product (GDP) at current market prices. The source of the regional data on gross fixed capital formation, employment, and GDP for 2015 is the Eurostat.

We employed the Färe-Primont index to calculate TFP. This index meets all economically-relevant axioms from index number theory. It includes the class of non-decreasing, non-negative, and linearly homogeneous output-input aggregator functions, which are as follows (O'Donnell, 2011):

$$Q(q) = D_O(x_0, q, t_0) \tag{1}$$

$$X(x) = D_I(x, q_0, t_0) \tag{2}$$

where x_0 and q_0 denote vectors of representative input and output quantities, t_0 is a representative time period, and $D_0(.)$ and $D_I(.)$ are output and input distance functions.

The Färe-Primont index, measuring TFP of region i in period t relative to TFP of region h in period s, has the form (O'Donnell, 2011):

$$TFP_{hs,it} = \frac{D_O(x_0,q_{it},t_0)}{D_O(x_0,q_{hs},t_0)} \times \frac{D_I(x_{hs},q_0,t_0)}{D_I(x_{it},q_0,t_0)} \tag{3}$$

To verify our research hypotheses, we applied the spatially-lagged X model (SLX). The model, which contains exogenous spatial dependence, takes the form (Elhorst, 2010):

$$\mathrm{TFP}_i = \alpha + \beta_1 RII_i + \beta_2 WRII_i + \varepsilon_i \quad (4)$$

where:
W – the spatial weight matrix,
$\beta_2 W$ – measures the spillover of RII.

The spatial weight matrix is calculated as the distance between the i's region centroid and the j's region centroid. To avoid overestimation problems, we use the row-standardization of the spatial weight matrix.

Results

Figure 1 shows the spatial distribution of RII across the EU regions. The most innovative region in 2015 was Hovedstaden (DK01) in Denmark, followed by Stockholm (SE11) in Sweden and Karlsruhe (DE12) in Germany. Seven out of the top 18 regions in 2015 were located in Germany, five in Sweden, two in Denmark and the UK, and one in the Netherlands and in Finland. It is worth noting that Germany as a country was the innovation leader. The Figure 1 also shows that the East of Germany was, on average, less innovative than the South and West. Moreover, the results reveal that the highly urbanised city regions, e.g. Hamburg (DE60) and Berlin (DE30) have higher innovation performance than their neighbouring regions. In turn, the least innovative regions were mainly located in Romania, Poland, Bulgaria, and Greece. Finally, the regional innovation performance appears to be spatially dependent, since the high innovation performance regions appear to be clustered together.

Figure 2 presents the TFP scores in 2015 for the sample regions. As can be noticed, the most productive EU regions were located along London, Düsseldorf, and Liguea corridor. It should be mentioned that there was a considerable interregional dispersion in regional TFP for large countries (e.g. Germany and Italy) where TFP is on average high. In general, a higher number of regions within the same country will result in larger TFP differences between regions. Going to the least productive EU regions, we find that the extremely low TFP scores were recorded in regions from Bulgaria, Poland, and Romania. The interregional dispersions of TFP in Poland was

relatively high, while the interregional variation of TFP in other countries, e.g. Bulgaria, was relatively low.

Table 1 provides the results of the spatially-lagged X model estimation. Our model accounts for 38% of the total variance of TFP. Looking at the direct effect of RII on TFP, we find that the increase of own-region innovation performance leads to higher regional TFP. This finding is in line with our expectations, since innovation performance, being significantly diversified across European regional space, has positive impact on TFP levels, which supports the first hypothesis of the study.

The value of the indirect effect implies existence of innovation spillovers, which are proportional to the inverse of the distance between regions. This finding, in turn, supports the second hypothesis stating that TFP distribution across the European regions is shaped by innovation spillovers.

Discussion

The results of our research indicate that innovation performance has a significant positive impact on TFP in EU regions. These findings are in line with the "neo-Schumpeterian" approach to economic growth (Aghion & Howitt, 2006)), which assumes that the increase in productivity depends on the rate of innovation creation.

It is worth pointing out that although region is increasingly regarded as an important level of innovation policy and development strategies implementation, there have been very few attempts so far to investigate the impact of innovation performance and innovation spillovers on regional TFP distribution.

Previous empirical studies in the literature regarding the impact of innovation on productivity usually employ two measures of innovative activity: R&D spending and patent counts (see e.g. Coe & Helpman, 1995; Hall *et al*., 2010; Bengoa *et al*., 2017). However, according to Atella and Quintieri (2001), the impact of R&D on TFP is not straightforward and strongly depends on the way in which TFP is measured. Therefore, following the evidence provided by Lopez-Rodriguez and Martinez-Lopez (2017), suggesting that the investigation of the impact of innovation performance on TFP should take into account the distinction between R&D and non-R&D endowments, we attempted to employ a more complex approach to measuring the innovation performance. Therefore, in our work, we have measured innovation performance of regions by the composite indicator RII, which captures the framework conditions for innovation activities, investments, the effects of innovation activities and their impacts on the economy. This,

in turn, has enabled us to demonstrate the impact of a broad spectrum of innovation performance on TFP in the EU regions.

The RII indicator is composed of diverse indicators. One group of these indicators relates to human resources and attractive research systems. According to the geography of innovation and systems of innovation theory, human capital and investment in public and private research infrastructure are important sources of regional growth (Frenz & Oughton, 2005). Although there are fewer empirical studies on TFP determinants at the regional level than the national one, the regional TFP studies confirm the importance of human capital as a driver of regional productivity growth. The study by Di Liberto *et al.* (2005) is of particular interest in that they provide evidence on the significant role of human capital in explaining regional variation in TFP.

Although our research concentrates directly on the impact of innovation performance on TFP, it is worth mentioning that regional differences in TFP might also be influenced by the differences in economic geography, historical development paths and social capital (see Beugelsdijk *et al*., 2018).

In line with the findings reported by Dettori *et al.* (2012) or Puškárová and Piribauer (2016) our paper reveals that in the EU regional space both innovation potential and TFP are not distributed uniformly, but they are predominantly spatially concentrated.

Furthermore, we hypothesize and demonstrate that TFP distribution across the European regions is shaped by the existence of innovation spillovers. In this aspect our results also adhere to the findings of previous studies. For example, Keller (2002) who argues that knowledge spillovers impact TFP and that the benefits from foreign spillovers are declining with distance. Moreover, our paper contributes to extension of the limited evidence on the impact of innovation spillovers on TFP in the regional scope in the relevant literature. To our knowledge, to date only a few studies attempted to investigate this problem and arrived at similar conclusions. In particular, Fischer *et al.* (2009) who show that productivity effects of knowledge spillovers increase with geographic proximity. Similarly, Bengoa *et al.* (2017) reveal that spatial spillovers are crucial in explaining long-run productivity and that overall TFP increases when neighbouring territories engage in R&D activities. More recently, Puškárová (2018) shows that a region's patent stock affects positively the TFP of other regions. What is symptomatic, indirect (spillover) effects dominate the productivity changes decomposition. Our results also confirm previous evidence delivered by Dettori *et al.* (2012) that spatial spillovers are bounded in space and knowledge diffusion is more effective among closer regions.

Conclusions

In the present study, we hypothesize and demonstrate that innovation performance has a significant positive impact on TFP. We find that the increase of regional innovation performance (measured by RII) leads to higher regional TFP. Moreover, the value of the indirect effect implies the existence of innovation spillovers, which are proportional to the inverse of the distance between regions. This finding supports the second hypothesis of the study stating that TFP distribution across the European regions is shaped by innovation spillovers.

The analysis of spatial distribution of TFP and its determinants is a necessary step in modelling long-run economic growth more accurately and designing effective regional and innovation policies. The revealed positive correlation between innovation performance and TFP confirms the crucial role of innovation in shaping long-term economic development and the need for fostering innovation within regional policy actions. Our conclusions are in line with the current vision of EU regional policy demonstrated in Europe 2020 strategy, recognizing that innovations are critical to improving productivity and that improvements in productivity are the key to accelerate the regional economic development. Our results indicating that the existence of innovation spillovers shapes the distribution of TFP, have yet another important policy implication. Namely, that there is a role for regional policies and institutions to help less developed regions catch up with the more developed by building up their absorptive capacity.

The main limitation of our study is related to the employment of a composite indicator in measurement of innovation performance. In this way we were unable to determine the relative impact of its particular components on TFP levels.

Since the impact of innovation performance on TFP is shaped by a multitude of determinants, while simultaneously the complementarities between innovation performance and other variables explaining TFP contribute to productivity growth, future research might try to explore the synergic impact of complementary determinants on TFP.

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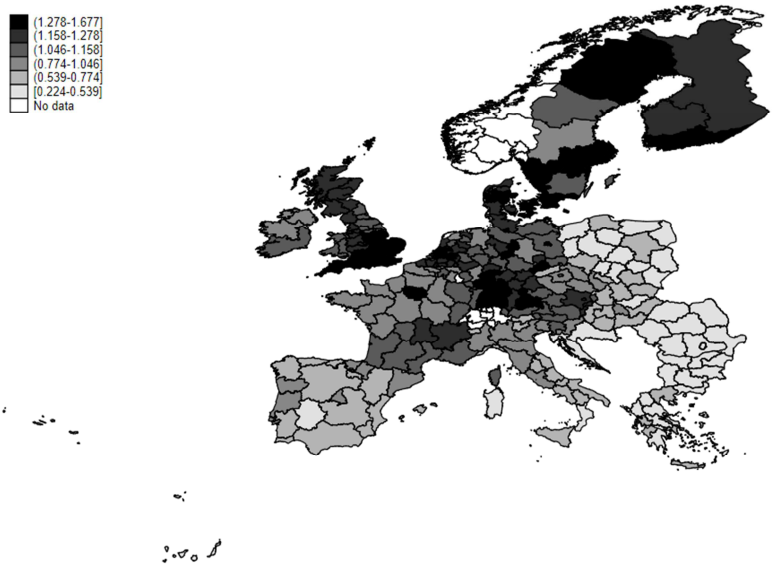
Annex

Table 1. Estimates of model parameters

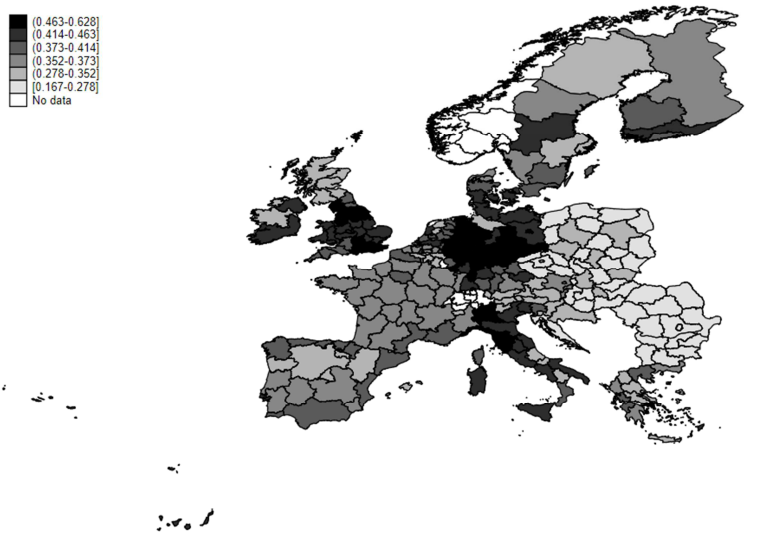
TFP	Coef.	Std. Err.	z	P>|z|
TFP				
RII	0.069	0.027	2.56	0.010
Cons.	0.011	0.057	0.20	0.841
W				
RII	0.326	0.081	4.01	0.000
Direct effect				
RII	0.069	0.027	2.56	0.010
Indirect effect				
RII	0.326	0.081	4.01	0.000
Total effect				
RII	0.395	0.061	6.46	0.000
Wald test of spatial terms:		chi2(2) = 16.05	Prob > chi2 = 0.000	
Pseudo R2=0.3822				

Figure 1. Innovation performance of the EU regions



*For NUTS 1 regions the combined areas of NUTS 2 regions have been presented.

Figure 2. TFP of the EU regions



*For NUTS 1 regions the combined areas of NUTS 2 regions have been presented.