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Heterogeneous effects of influencing factors on innovation performance: evidence from European Union countries

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ABSTRACT

This research evaluates and compares the status and trends of regional innovation efficiency (RIE) in 27 EU countries from 2004 to 2017. Regional analysis is further compared to investigate the performance differentials within the EU innovation system. In addition, the factors which influence the innovation efficiency in EU countries by performing the Tobit regression analysis are investigated. The results indicate that the innovation efficiency of EU changes slightly with high-efficiency values. Seven countries are the innovation leaders during the research period, whereas Northern and southern regions have relatively higher innovation efficiencies than other regions. Also, the regression results indicate that economic development, human capital investment and regional openness could enhance innovation efficiency in most EU regions, while industrial structure, urbanisation level and infrastructure level hinder the improvement of EU's innovation efficiency. Based on these results, recommendations are provided for policymakers aiming at stimulating innovation among the EU innovation system.

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Innovation efficiency; EU countries; influencing factors; Tobit regression analysis

Highlights

- This research evaluates and compares the status and trends of regional innovation efficiency in 27 EU countries from 2004 to 2017.
- This paper investigates the factors influencing the innovation efficiency in EU countries by applying the Tobit regression analysis.
- The evaluation results indicate that the innovation efficiency of EU changes slightly with high-efficiency values.
- Economic development, human capital investment and regional openness could enhance innovation efficiency in most EU regions.

1. Introduction

There is no doubt that technological innovation has become a key driver of a country's international competitiveness, economic growth and can contribute to evaluate a country's development level

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(Wang et al. 2015). Technological innovation is also the principal driving force to promote regional development and enterprise progress, which has profoundly altered the regional economy and industrial pattern. Countries all over the world, in the face of stiff competition, have taken advantage of innovation. Scientific and technological innovation activities are commonly accompanied by the inputs and usage of numerous innovative resources. Innovation efficiency is the conversion rate of innovation inputs to outputs, reflecting the quality and level of innovation (Barasa et al. 2019). Improving innovation efficiency is conducive to the full utilisation and rational allocation of innovation resources. Due to the complexity of the process of innovation activities, the demand for innovation cannot be met only by the investment of enterprises themselves. The innovation system is composed of universities, scientific research institutions, governments, financial institutions and intermediaries (Freeman 1987). It is crucial for the creation, dissemination and application of innovative knowledge (Cooke 1992; Cooke et al. 1996; Cooke, Gomez Uranga, and Etxebarria 1997). The formation of innovation system is instrumental in improving the level of innovation. The efficiency of the innovation system is reflected in innovation efficiency, and the development of the country's innovation capacity benefits from the improvement of innovation efficiency (Erdin and Çağlar 2022).

With the world economy demonstrating the clear trend of regional development, regional innovation activities ordinarily show visible signs of regional characteristics. As one of the world's famous innovation regions, the European Union (EU) attach great importance to innovation and take it as a long-term policy. Thus, major efforts have been made to increase investment in research and development (R&D). In the Lisbon Strategy, the EU set the target of 3% of gross domestic product (GDP) in R&D in Europe 2020, and the EU had reiterated it (Hervás-Oliver et al. 2021). All these efforts can contribute to the development of industries and enterprises (Blind and Niebel 2022). The EU's innovation system is composed of the innovation systems of various EU members, which rely on the geographical distribution of the countries, as well as the diversity of the participants. The innovation system of the EU is exceptionally complex and highly heterogeneous (Cirillo et al. 2019; Zabala-Iturriagagoitia et al. 2021). Also, different innovation modes, such as independent innovation, technology introduction innovation, cooperative R&D innovation, have distinct regional impacts on innovation outputs including scientific and technical journal articles, patient applications and intellectual property income (Parrilli, Balavac, and Radicic 2020). However, owing to the diverse geographical locations, cultures, institutional differences (Barbosa and Faria 2011), along with the unbalanced technology and economic development, innovation efficiency is perhaps incommensurate with each other among the EU countries (Aytekin et al. 2022). Economically developed and backward regions of the EU have different innovation mechanisms and unlike roles played by influencing factors (Filippopoulos and Fotopoulos 2022). In Europe, national authorities no longer exclusively control public research, technology and innovation policies, while increasingly national initiatives are complemented by regional innovation policies, especially for the EU's innovation activities (Kuhlmann 2001). The frequent international exchanges within the EU are in favour of the creation of new technologies (De Noni, Orsi, and Belussi 2018). In the meantime, the EU's innovation policy is constantly changing (Popiel and Jabłońska 2014). Therefore, it is important to assess the efficiency of innovation in the EU (Szopik-Depczyńska et al. 2020). How to evaluate the performance of the EU's innovation system thereby has become an important issue (Janger et al. 2017).

The innovation efficiency of the EU countries is compared. In addition, the RIE is analysed at the regional level, and the factors that influence the innovation efficiency of EU countries are quantitatively analysed as well. This research may provide meaningful decision support for innovation governance and policies. The theoretical contribution of this study is that it has been confirmed the strong correlation between innovation input and output. Furthermore, this study identified the factors influencing regional innovation efficiency (RIE) of the EU's innovation system, thus extending and complementing regional innovation theory.

The rest of this paper is arranged as follows. Section 2 presents literature on innovation efficiency and influencing factors. Section 3 introduces the research methodology and data. Section 4 displays

the results and comparative analysis of innovation efficiency of EU regions, as well as the influencing factors, are further analysed. Section 5 provides conclusions and policy implications.

2. Literature review

Innovation is widespread in processes, organisations, marketing and products. 'Innovation efficiency' is a critical factor for innovation system. And innovation system has a continuously developing structure with an increasingly pervasive and universal feature (Caird, Hallett, and Potter 2013; Cooke 1992) first introduced the concept of regional innovation system (RIS) and conducted a comprehensive and in-depth study of the theory and practice of RIS. RIS is a network structure consisting of geographically proximate and closely related firms, governments, financial institutions, etc. These components generate and support innovation at the regional level (Cooke et al. 1996; Cooke, Gomez Uranga, and Etxebarria 1997). When firms in the region are unable to complete complex systemic innovation among themselves, firms begin to cooperate with government, universities and other entities in a long-term and stable manner, forming a regional innovation network. Since it encourages innovative activities, the link between innovation inputs and outputs is a crucial requirement from the perspective of innovation system (Xu, Bossink, and Chen 2019). The generation of innovation outputs typically requires significant capital and personnel investments. Innovation systems not only provide the resources and elements for innovation activities but also facilitate the exchange and dissemination of information, as well as technology transfer. Companies come up with new technologies and products through independent R&D or by working with other members of the innovation system. This leads to publications and patents, as well as income through new product sales and the transfer of intellectual property rights. Innovative products and inventions are critical to the generation of a nation's innovation capacity, which offers long-term efficiency benefits that hasten technical rivalry and catch-up. Innovation efficiency helps to convert innovation resources into valuable innovation outputs.

The main focus of innovation efficiency is the output effectiveness of innovation inputs. A regional technical system with input–output functions undergoes input–output transformation through the regional innovation process (Chen, Delmas, and Lieberman 2015). The generation and diffusion of innovation depend on the regional economic, social and institutional environment. RIE is affected by the external environment and resources, such as regional economic and social development level, market openness, knowledge generation and flow. The moderating role of the innovation environment in the transformation of innovation resources directly determines the efficiency of RIS (Şipoş, Bîzoi, and Ionescu 2014). Good innovation environment results in the smooth progress of innovation activities and improves the efficiency of innovation activities (Liang and Xu 2022; Ferreira and Dionísio 2016).

Various studies on the influencing factors of innovation efficiency have been undertaken. The efficiency of innovation is affected by the external environment and internal driving forces, such as government technology expenditure, openness, environmental regulation, industrial structure, enterprise scale, R&D investment and government innovation policies (Liu et al. 2021). The industrial structure, the level of economic openness and the level of urban informatisation could impact the RIE (Guo, Xie, and Wu 2021). In different regions, the factors that influence the efficiency of innovation are distinguishable, and each factor has a differential impact on the efficiency of innovation (Liu et al. 2020; Dong et al. 2022). There are multiple influencing factors of RIE, whereas quantifying them still remains a challenge (Xu, Loh, and Chen 2020). Since R&D activities require significant capital investments, the level of regional economic development is closely linked to innovation activities. Public education expenditure provides the knowledge base for social development, promotes technological innovation and labour productivity and fosters the development of social production and economic growth. The close connection among the subjects of the regional innovation network is essential to promote the innovation resources flow and enhance the effectiveness of innovation initiatives (Pegkas, Staikouras, and Tsamadias 2019). The regional industrial structure

straightly influences the innovation capability of the RIS (Lin et al. 2018; Zhang et al. 2017). The innovation capacity of companies in different industries differs greatly, and industrial companies are regularly more active in innovation. The micro-environment is the necessary guarantee for regional innovation (Buesa, Heijs, and Baumert 2010). The level of network infrastructure, mobile phones network and transportation infrastructure are vital components in the innovation environment. Regional opening is critical in the spillover and diffusion of technological innovation, which in turn alters regional innovation capabilities. A significant external element affecting regional economic development and innovation activity is the degree of urbanisation. In general, higher levels of urbanisation are more conducive to promoting local economic growth.

Research on innovation efficiency, covering efficiency assessment, influencing factor analysis, convergence analysis and the relationship between efficiency and economic growth, has received increasing attentions (Fritsch and Slavtchev 2011; Chen and Guan 2012; Broekel 2012). Some scholars have studied the efficiency of innovation in regions with rapid innovation development, especially in China (Sun and Loh 2019). However, fewer studies have quantitatively assessed the efficiency and its influencing factors at the regional level in the EU countries. Due to the distinct innovation levels in the EU countries, there perhaps be significant differences in innovation efficiency between the EU regions. Moreover, innovation efficiency is influenced by various factors. The innovation efficiency in lagging regions can be improved through the play of influencing factors. Therefore, it is requisite to analyse the factors impacting innovation efficiency in the EU regions. The major contributions of this paper are the complements to the area with a data envelopment analysis (DEA) model and a Tobit regression model. By evaluating the innovation efficiency and analysing its influencing factors of 27 EU countries and its five regions, this study is concerned at the following research questions: 'What are the differences between innovation efficiencies of EU regions?' and 'which factors can affect the innovation efficiency of EU regions?'

3. Methodology and data

Non-parametric DEA method, which can handle multi-output analysis, is widely utilised in efficiency study on energy, environment, ecology and technological innovation(Sueyoshi, Yuan, and Goto 2017; Emrouznejad and Yang 2018; Mardani et al. 2017). The best efficient frontier is one in which additional output cannot be produced by increasing input, as determined by the DEA, within a set of comparable decision-making units (DMUs). DEA method was first proposed by Charnes, Cooper and Rhodes (1978) to calculate the relative efficiency and productivity of DMUs. Under the condition of constant return to scale, Banker, Charnes and Cooper (1984) broadened the model assumption and developed the BCC (Banker, Charnes and Cooper) model. BCC model assumes that there are n DMUs. Each DMU has m inputs and S outputs. θ is the efficiency of the DMU. When $\theta = 1$, the DMU is called DEA efficient. The efficiency value of DEA models is between 0 and 1. The BCC model is expressed as follows.

$$\begin{aligned} &\min \theta \\ &s.t. \sum_{j=1}^{n} \lambda_j x_j \leq \theta x_0 \\ &\sum_{j=1}^{n} \lambda_j y_j \geq y_0 \\ &\sum \lambda_j = 1;\ \lambda_j \geq 0, j = 1, 2, \ldots, n \end{aligned} \tag{1}$$

R&D activities are the core of RIS and serve as the primary source of new discoveries, innovations and technological advancement. R&D employees facilitate knowledge development and spillover (Fritsch and Slavtchev 2011). R&D expenditure, R&D researchers and imports of high-tech products

are selected as the input indicators in this research (Chen and Guan 2011; Evangelista et al. 2001). Scientific and technical journal articles, patent applications and intellectual property income are chosen as the output indicators. The time lag is set as one year (Chen, Liu, and Zhu 2018). Given the availability of indicator data, we picked input indicators from 2004 to 2017 and output indicators data from 2005 to 2018. Since the United Kingdom has formally voted to leave the EU in 2016, there are 27 existing members in the EU, which are divided into five regions, namely northern, western, central, southern and eastern regions. Additionally, in view of that the United Kingdom is a traditional technological innovation power and that it is located outside the European continent with a relatively independent technological innovation policy system, this paper focuses on these 27 countries other than the United Kingdom. Data are collected from the World Bank database and World Trade Organization database.

On account of the efficiency value calculated by the DEA method is between 0 and 1, the dependent variable belongs to censored data. If ordinary least squares model is performed for regression analysis, the estimated parameter value tends to be biased towards 0, resulting in the deviation of the estimated result. Tobin (1958) initially proposed an interception regression model, namely the Tobit model, to deal with regression analysis problems with limited dependent variables. Tobit regression model is typically employed in studies on the influences on innovation efficiency (McDonald 2009), as shown in Equation (2). $\varepsilon_{it} \sim N(0, \sigma^2)$. β represents the parameter vector. x_{it} is the independent variable.y_{it}^* is the latent variable. y_{it} is the dependent variable.

$$\begin{cases} y_{it}^* = \beta x_{it} + \varepsilon_{it} & \\ y_{it} = y_{it}^* & (\text{if } y_{it}^* > 0\ ) \\ y_{it} = 0 & (\text{if } y_{it}^* \le 0) \end{cases} \tag{2}$$

In our research, the left and right cutoff values of innovation efficiency (*EFF*) in the Tobit model are set to 0 and 1, respectively, and the regression equation is shown in Equation (3). EFF_{it} is the innovation efficiency value. β_0 is a constant term. γ is the coefficient of each variable. ε_{it} is the error term.

$$EFF_{it} = \beta_0 + \gamma X_{it} + \varepsilon_{it} \tag{3}$$

In light of the available research and data, this paper examined the effects of economic development (ECON), human capital investment (HC), industrial structure (IND), infrastructure level (INF), regional openness (OPEN), urbanisation level (URBAN) on RIE. Also, statistics data, such as GDP, the ratio of education expenditure to GDP, the ratio of industrial added value to GDP, Internet users per 100 people, foreign direct investment and the ratio of urban population to total population, are adopted to indicate the above variables. Data for this research came from the World Bank database.

4. Results and discussions

4.1. Innovation efficiency evaluation

The innovation efficiency of 27 EU countries from 2004 to 2017 is calculated by conducting the BCC model, as shown in Table 1. Big values indicate high efficiencies. '1' displays the efficient frontier. As it can be inferred from Table 1, efficiency values for 27 countries differ significantly across years. Some countries have been on the efficiency frontier, but others have relatively lower efficiency values. The average efficiency values in the 27 countries from 2004 to 2017 are demonstrated in Figure 1.

It is apparently that only seven countries have efficient values, which constitutes the frontier of innovation efficiency, namely, Netherlands, Germany, Croatia, Italy, Malta, Romania and Cyprus. As innovation hubs in the EU, Netherlands, Germany and Italy typically have an innovation efficiency of 1 between 2004 and 2017. This is closely related to their leading role in technological innovation. The southern countries-Croatia, Malta, Romania and Cyprus-also also have efficient innovation

Table 1. Innovation efficiency evaluation results.

Region	Country	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean
Northern	Denmark	0.8095	0.8007	0.8261	0.9027	0.9184	0.7759	0.8944	0.8672	0.7987	0.8559	0.8609	0.8691	0.9636	0.9708	0.8653
	Finland	1	0.9830	0.9969	0.9981	0.9974	1	1	1	1	1	1	1	1	1	0.9982
	Sweden	1	1	1	1	1	1	1	1	1	1	1	1	1	0.9432	0.9953
Western	Belgium	0.3513	0.3760	0.3320	0.3310	0.3525	0.3206	0.3198	0.3109	0.3206	0.3133	0.2964	0.3474	0.3164	0.3291	0.3298
	France	1	1	1	1	1	1	1	1	0.9900	0.9173	0.9390	1	0.9603	0.9233	0.9807
	Ireland	0.4645	0.4639	0.5050	0.5235	0.6547	0.8297	1	1	1	1	1	1	1	1	0.8172
	Luxembourg	0.2832	0.3102	0.3113	0.3218	0.3079	0.2897	0.3823	0.4556	0.5447	0.6391	0.6526	0.7333	0.8386	0.9340	0.5003
	Netherlands	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Central	Austria	0.4552	0.4905	0.5620	0.5457	0.5373	0.5181	0.5150	0.4880	0.4428	0.4206	0.4523	0.4451	0.4380	0.4356	0.4819
	Czech Republic	0.6418	0.5454	0.5594	0.5460	0.5339	0.5823	0.5320	0.4957	0.4596	0.4870	0.4944	0.4859	0.5078	0.4674	0.5242
	Germany	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Hungary	0.6953	0.6770	0.5784	0.6143	0.6130	0.5622	0.5781	0.5585	0.5429	0.4903	0.4581	0.5233	0.5174	0.5012	0.5650
	Poland	1	1	1	1	1	1	0.9768	1	0.9304	0.8895	0.9003	0.8750	0.9064	0.8889	0.9548
	Slovak Republic	0.7164	0.7629	0.8285	0.9164	0.8427	0.9391	0.7263	0.6900	0.5539	0.5320	0.5149	0.4507	0.5793	0.5738	0.6876
Southern	Bulgaria	1	0.9556	0.9559	0.9448	0.9559	0.9254	0.9509	0.9121	0.8629	0.8250	0.7329	0.6577	0.6967	0.7847	0.8686
	Cyprus	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Croatia	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Greece	0.8973	1	1	1	1	0.9686	1	1	1	1	1	1	1	1	0.9904
	Italy	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Malta	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Portugal	0.6376	0.6726	0.6361	0.6974	0.7425	0.8619	0.7808	0.7888	0.9309	0.9284	0.9766	0.8684	0.8542	0.8376	0.8010
	Romania	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Slovenia	0.7827	0.7728	0.7599	0.6663	0.7107	0.7199	0.6911	0.6454	0.6237	0.5187	0.5984	0.5397	0.5595	0.4762	0.6475
	Spain	0.8487	0.8568	0.8789	0.8828	0.9563	1	1	1	1	1	0.9645	0.9508	0.9698	0.9550	0.9474
Eastern	Estonia	0.7744	0.7004	0.6383	0.6971	0.7894	1	0.7883	0.4837	0.3311	0.4128	0.5057	0.5560	0.6275	0.5443	0.6321
	Latvia	1	0.9542	0.8483	0.9106	0.9143	1	1	0.9209	0.9083	0.9362	0.8889	0.9425	1	1	0.9446
	Lithuania	0.8782	0.8541	0.6808	0.7481	0.7261	0.9221	0.6882	0.5887	0.5729	0.5706	0.5377	0.5500	0.5855	0.5891	0.6780

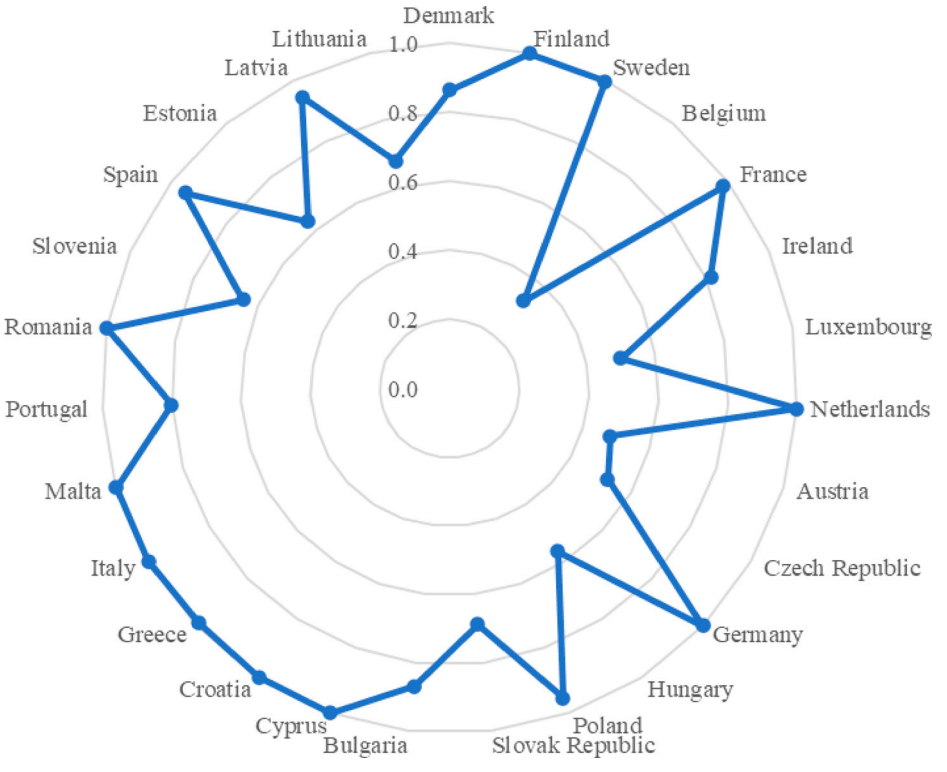

Figure 1. Average efficiency in 27 countries.

efficiency. It derives from that they attach great importance to the EU's innovation programs in recent years.

Eleven countries have values above 0.8, including Finland, Sweden, Greece, France, Poland, Spain, Latvia, Bulgaria, Denmark, Ireland and Portugal. Most of these countries are located in northern and southern Europe with sophisticated economic institutions, established social systems and access to more cutting-edge technologies.

There are seven countries with an average value between 0.5 and 0.8, covering Slovak Republic, Lithuania, Slovenia, Estonia, Hungary, Czech Republic and Luxembourg. The majority of these countries locate in central and eastern Europe and have undergone a process of increasing urbanisation and industrialisation. Furthermore, these countries have somewhat underdeveloped economies, education systems and levels of technological innovation.

It is noteworthy that Austria and Belgium have the lowest efficiency, below 0.5 and rank at the bottom. Austria and Belgium have relatively higher R&D investments but perform poorly in terms of innovation outputs.

To assess RIE on a larger scale, we analysed the northern, western, central, southern, eastern regions of the EU. The innovation efficiency of these regions is shown in Table 2. The average efficiency for the whole EU is 0.8226. The average efficiency is in the order of northern, southern, eastern, western and central. The northern region has the highest average value of 0.9529, while the central region has the lowest average value of 0.7022.

To further reflect the differences between these regions, RIE is depicted in Figure 2. What we have seen that the RIE of these five regions is higher than 0.6 during this research period. The innovation efficiency of the EU as a whole changed narrowly over the entire study period, remaining merely above 0.8, which demonstrates the EU's continued efforts in innovation strategy. The RIE is relatively higher in northern and southern regions than the other, with average efficiency values exceeding

Table 2 . Innovation efficiency of the regions, 2004–2017.

Region	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean
Northern	0.9365	0.9279	0.9410	0.9669	0.9719	0.9253	0.9619	0.9557	0.9329	0.9520	0.9536	0.9564	0.9879	0.9713	0.9529
Western	0.6198	0.6300	0.6297	0.6353	0.6630	0.6880	0.7404	0.7533	0.7711	0.7740	0.7776	0.8161	0.8231	0.8373	0.7256
Central	0.7515	0.7460	0.7547	0.7704	0.7545	0.7670	0.7214	0.7054	0.6549	0.6366	0.6367	0.6300	0.6581	0.6445	0.7022
Southern	0.9166	0.9258	0.9231	0.9191	0.9365	0.9476	0.9423	0.9346	0.9418	0.9272	0.9272	0.9017	0.9080	0.9054	0.9255
Eastern	0.8842	0.8362	0.7224	0.7853	0.8099	0.9740	0.8255	0.6644	0.6041	0.6399	0.6441	0.6828	0.7377	0.7111	0.7516
EU	0.8236	0.8213	0.8110	0.8239	0.8353	0.8598	0.8450	0.8224	0.8079	0.8051	0.8064	0.8072	0.8267	0.8205	0.8226

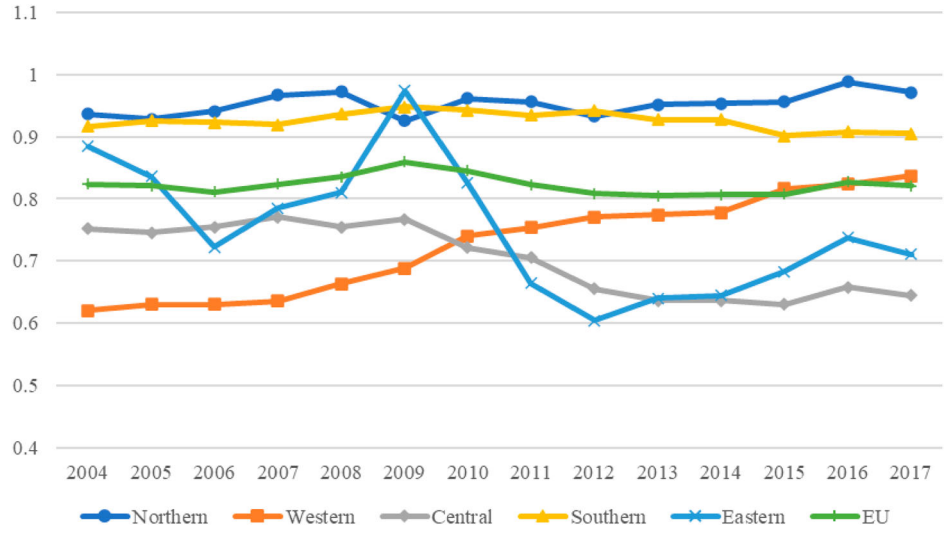

Figure 2. Regional innovation efficiency, 2004–2017.

0.9. The western region is essentially rising from 0.6198 to 0.8373, indicating innovation efforts. However, the RIE in the central region shows a slow downward trend, from 0.7515 to 0.6445, but the RIE value in the eastern region fluctuates greatly. Compared with the EU, northern and southern scores higher than the average value. The central area displays considerably lower scores compared to the intermediate level. It is evident that the northern and southern regions are the key force to foster technological innovation in the EU. Central area lags behind in technological innovation. Thus, the economically developed and coastal regions have higher innovation efficiencies. Nevertheless, the less developed and landlocked central regions have lower innovation efficiencies.

4.2. Analysis of influencing factors

Based on the results of RIE assessment, we analyse the influencing factors in EU countries. The variance inflation factor (VIF) of the variables is calculated, as shown in Table 3. All the VIF values are all less than 5, indicating no significant collinearity, and then regression analysis can be carried out.

The impacts of influential factors are calculated, as shown in Table 4. The results of the analysis of the influencing factors differ greatly from region to region. For the EU as a whole, our results indicate that economic development has a positive impact with a significance level of 1%. Regional economic development provides the necessary capital investments, which is essential for R&D activities. Regions with high levels of economic development typically have higher RIE. Industrial structure has a negative impact on RIE with a significance level of 1%. It shows that an unoptimised industrial structure may reduce RIE. Regional openness has a positive impact on RIE with a significance level of 1%, which means that regional openness is an important factor for RIE. The higher the amount of FDI

Table 3. VIF results.

Variable	VIF	1/VIF
urban	1.77	0.57
ind	1.41	0.71
inf	1.40	0.71
hc	1.36	0.74
open	1.16	0.87
econ	1.09	0.92
Mean VIF	1.36	

Table 4. Regression results.

	EU	Northern	Western	Central	Southern	Eastern
econ	0.000*** (0.000)	0.000** (0.000)	0.000*** (0.000)	0.001*** (0.000)	0.000*** (0.000)	0.005 (0.005)
ind	−0.013*** (0.004)	−0.029* (0.016)	0.026* (0.015)	0.001 (0.007)	−0.018*** (0.005)	−0.049*** (0.006)
open	0.003*** (0.001)	0.007 (0.004)	0.003** (0.002)	0.000 (0.002)	0.008*** (0.003)	0.002 (0.005)
urban	−0.005** (0.002)	−0.108*** (0.032)	−0.013*** (0.005)	−0.010*** (0.002)	−0.002 (0.003)	0.017 (0.063)
inf	−0.005*** (0.001)	0.011** (0.004)	0.015*** (0.003)	−0.009*** (0.001)	−0.003** (0.001)	−0.009*** (0.002)
hc	0.042** (0.018)	−0.054 (0.040)	−0.048 (0.065)	−0.124*** (0.041)	−0.102*** (0.027)	0.087** (0.036)
_cons	1.539*** (0.188)	10.200*** (2.822)	0.175 (0.547)	2.225*** (0.393)	2.087*** (0.317)	0.834 (4.401)
Pseudo R^2	0.2709	11.9743	0.6068	1.9444	0.5278	15.0266

Standard errors are in parenthesis.
***$p < 0.01$.
**$p < 0.05$.
* $p < 0.1$.

is, the better it is for improving innovation capability. Urbanisation level has a negative impact on RIE at a significance level of 5%, indicating that urbanisation does not improve RIE of the EU countries. The reason could be that the urbanisation level of the EU countries has been high over the last decades, which has had little impact on the improvement of its RIE. Infrastructure level has a negative impact on RIE with a significance level of 1%. It shows that the infrastructure level do not improve the RIE of EU countries. More internet which has little effect on the improvement of RIE access could account for it. Human capital investment has a positive impact on RIE with a significance level of 5%, which implies that human capital investment is a consequential factor. Public education expenditure provides a guarantee for the cultivation of innovative talents, which has an immediate effect on promoting technological innovation and labour productivity. The higher the regional public education expenditure, the higher the RIE.

Initially, for the northern region, the level of economic development, industrial structure, urbanisation level and infrastructure level has a significant impact on RIE, while others have no significant impact. More specifically, the level of economic development and infrastructure has a significant positive impact on RIE with a significance level of 5%. Economic development has brought about an increase in RIE in the northern region. Network infrastructure could help enhance RIE in the northern region. The industrial structure is negatively correlated with RIE at the 10% significance level. A parallel result indicates that the urbanisation level is negatively correlated with RIE at the 1% significance level, which shows that industrial structure and urbanisation level have failed to improve RIE.

Secondly, for the western, economic development, industrial structure, regional openness, urbanisation level and infrastructure level have significant impacts on RIE, while human capital investment has no significant impact. To be more specific, the level of economic development and infrastructure is positively correlated with RIE at 1% significance, which demonstrates that the RIE in the western region can be effectively improved by promoting economic development and upgrading infrastructure standard. Economic structure is positively correlated with RIE at 10% significance. And regional openness is positively correlated with RIE at 5% significance, whereas urbanisation level is negatively correlated with RIE at the 1% significance level. This suggests that urbanisation has decreased the RIE of the western region.

Next, for the central region, economic development is positively correlated with RIE at 1% significance, while urbanisation level, infrastructure level and human capital investment are negatively correlated with RIE at 1% significance, and the rest has no significant effect. It indicates that the RIE in the central region can be effectively enhanced by stimulating economic development. Moreover, urbanisation level, infrastructure level and human capital investment reduce the RIE in the central region.

What's more, for the southern region, economic development and regional opening are positively related to RIE with 1% significance. Nevertheless, industrial structure and human capital investment are negatively related to innovation efficiency with 1% significance, and infrastructure is also negatively related to innovation efficiency with 5% significance. Besides that, urbanisation level has no significant influence on RIE, which means that the RIE in the southern region can be effectively by promoting economic development and regional openness. Still, industrial structure, human capital investment and infrastructure level reduce the RIE in the southern region.

Finally, for the eastern region, human capital investment is positively correlated with RIE at 5% significance, while industrial structure and infrastructure level are negatively correlated with RIE at 1% significance, and the rest has no significant effect. This indicates that the RIE in the eastern region can be effectively fostered by the increasing investments, yet the industrial structure and infrastructure level reduce the RIE in the eastern region.

In general, the level of economic development in the EU countries is significantly positively correlated with RIE, demonstrating that the RIE of the EU countries can be efficiently improved by economic development. Regional openness is significantly positively correlated with RIE, revealing that regional openness can promote RIE. The impact of human capital investment varies considerably across regions, which may be due to the difference in the level of higher education across

Table 5. Robustness test results.

Region	EU		Northern		Western		Central		Southern		Eastern	
Model	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
econ	0.000***	0.000***	0.000**	0.000***	0.000***	0.000***	0.001***	0.001***	0.000***	0.000***	0.005 (0.005)	
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
ind	−0.013***	−0.013***	−0.029*	−0.011	0.026* (0.015)	0.018**	0.001 (0.007)		−0.018***	−0.016***	−0.049***	−0.047***
	(0.004)	(0.004)	(0.016)	(0.012)		(0.009)			(0.005)	(0.004)	(0.006)	(0.006)
open	0.003***	0.003***	0.007 (0.004)		0.003**	0.004**	0.000 (0.002)		0.008***	0.007***	0.002 (0.005)	
	(0.001)	(0.001)			(0.002)	(0.002)			(0.003)	(0.003)		
urban	−0.005**	−0.005**	−0.108***	−0.113***	−0.013***	−0.015***	−0.010***	−0.010***	−0.002		0.017 (0.063)	
	(0.002)	(0.002)	(0.032)	(0.033)	(0.005)	(0.003)	(0.002)	(0.002)	(0.003)			
inf	−0.005***	−0.005***	0.011**	0.014***	0.015***	0.014***	−0.009***	−0.009***	−0.003**	−0.003**	−0.009***	−0.009***
	(0.001)	(0.001)	(0.004)	(0.004)	(0.003)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
Hc	0.042**	0.042**	−0.054		−0.048		−0.124***	−0.128***	−0.102***	−0.099***	0.087**	0.064**
	(0.018)	(0.018)	(0.040)		(0.065)		(0.041)	(0.032)	(0.027)	(0.026)	(0.036)	(0.030)
_cons	1.539***	1.539***	10.200***	9.553***	0.175 (0.547)	0.339 (0.484)	2.225***	2.287***	2.087***	1.921***	0.834 (4.401)	2.196***
	(0.188)	(0.188)	(2.822)	(2.884)			(0.393)	(0.236)	(0.317)	(0.193)		(0.275)
Pseudo R^2	0.2709	0.2709	11.9743	10.7381	0.6068	0.6012	1.9444	1.9429	0.5278	0.5237	15.0266	14.4776

Standard errors are in parenthesis.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

regions, resulting in greater variation in the quality of the workforce. However, industrial structure, urbanisation level– and infrastructure level are significantly negatively correlated with RIE, suggesting that the current industrial structure, urbanisation level and infrastructure level in the EU countries reduce RIE. The marked disparities in urbanisation levels across regions, especially in southern and eastern Europe, lead to different impacts of urbanisation levels on innovation efficiency. It is worth noting in terms of adjusting innovation strategies.

4.3. Robust test

To test the robustness of the regression results, based on the results of the factors influencing the EU and the five regions (Model 1), this study removes insignificant factors and conducts regression analysis again. The results are shown in Model 2 in Table 5. There is no significant change in the coefficient and significance of each impact factor by comparing the two regression results. In the Tobit regression results after removing the insignificant factors from each region, the significant influences are still significant and even increased in significance for some factors. This demonstrates that the good robustness of the results of the Tobit regression analysis in the research.

5. Conclusions

While the literature has looked into the effectiveness of innovation across the EU countries using a number of innovation measures, lesser attention has been given to regional innovation performance in the EU. Research on the factors influencing innovation efficiency in the EU countries is insufficient. Due to the heterogeneity among the EU countries, it is essential to analyse the influencing factors at the regional level.

In conclusion, the RIE in 27 EU countries from 2004 to 2017 is evaluated, and regional analysis is further compared. Furthermore, this research attempts to investigate explicitly the factors influencing the RIE in the EU countries. To this end, the relevant influencing factor indicators are analysed and the Tobit regression analysis is examined to obtain the estimation results.

Our findings suggest that the efficiency values of the 27 countries differ significantly from one year to another. Seven EU countries, namely, Netherlands, Germany, Croatia, Italy, Malta, Romania and Cyprus acted as innovation leaders during the research period. The RIE of the EU changes slightly with high-efficiency values above 0.8, demonstrating the EU's continuous efforts in innovation strategies. More importantly, we reassess the RIE based on the location of these EU countries. There are noticeable differences in the performance of RIE between regions. Innovation efficiency is relatively higher in the north and south than in other regions. The results indicate that the economically developed regions and coastal areas have higher innovation efficiency, which is consistent with previous studies in other regions (Li, Li, and He 2018; Bai 2013). The difference of innovation efficiency also indicates the mutual independence of technological innovation policies in these countries.

The regression results highlight the role of economic development, investment in human capital, and regional openness in increasing RIE in the EU countries, which indicate that higher levels of economic development, investment in human capital and regional openness are associated with higher RIE. On the contrary, industrial structure, infrastructure level and urbanisation level are negatively correlated with RIE. The results of the analysis of influencing factors are particularly distinguishable in different regions. This is similar to the results of previous findings (Li, Li, and He 2018).

These results would be of considerable assistance in developing policies that encourage innovation in the EU innovation system, especially in the regions that are lagging behind in innovation. On the one hand, more attention is needed to innovation performance rather than focusing only on innovation inputs. Good governance of innovation techniques and measures is a necessary condition for increasing RIE. Investments in innovation resources should not be increased blindly. On the other hand, efforts should be made, ensuring efficient and effective influencing factors utilisation with a view to promote innovation. Furthermore, it is necessary to optimise the allocation of

innovation resources on a larger scale to improve efficiency. Since the RIE varies greatly from region to region, the EU must address these issues in the long run. Moreover, regional differences must be taken into account to strengthen regional innovation cooperation and reduce regional disparities.

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