Spatial Evolutionary Pattern and Regional Innovation Efficiency of European Union

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Abstract. By method of standard deviation ellipse (SDE), this paper analyzes and visualizes the spatial evolutionary pattern of EU’s regional innovation activity from 1995 to 2013 compared with economic development. Then based on EU members’ panel data, using the logarithmic Cobb-Douglas production function model of stochastic frontier analysis (SFA) to estimate the regional innovation efficiency of EU members and its trend. The results show that (1) the spatial center of the EU’s innovation SDE is moving eastward. The role of agglomeration effect generated by Western and the Nordic Euro region is weakened while the impact of Eastern Euro is enhancing; (2) from 2002 to 2012, the whole average regional innovation efficiency of eu members decline. (3) the both R&D inputs plays positive role in regional innovation efficiency and the role R&D investment fund is dominant.

1. Introduction
In the era of global knowledge economy, innovation is an important driving force to promote national economy and regional competitiveness. Yet due to the global financial crisis of 2008, some European countries began to fall into recession with social unrest, a rise in unemployment, slow economic growth and rising national fiscal deficit, such as Iceland, Greece, Portugal. The center of European economic gravity starts to move from west to east on the whole, which also presents complicated and varied details of European economic spatial pattern. To get rid of the economic crisis in Europe, it is essential to take global situation as a whole region and big market for accelerating the European economy.

Although EU is generally regarded as the traditional leading region of worldwide innovation for centuries[1], it is also obvious in sub-regional disparities in innovation capacities among East and West, and also North and South, owing to diversified factors of regional innovation system (Camagni and Capello, 2013; Sleuwaegen and Boiardi, 2014; Varga and Sebestyen, 2017). Based on the innovation performances through European Innovation Scoreboard (EIS) from 2008 to 2015, we could find the regional differentiations among 21 Member States. As one part of the leading innovation group, Sweden has always been in top position, followed by Denmark, and the gap between them is narrowing. Since three years ago, innovation performance of these countries are declining, for instance Finland’s innovation index has been declining slightly since 2010, Denmark’s and Germany’s began to decline from 2012, Sweden from 2013. On the contrary, Over the analysed period of eight years, the innovation index of Netherland has grown as high as 2%, followed by Denmark1.7%, Germany and Sweden are only 0.2% and 0.1%. 2015 Netherlands has risen into the leading country from innovation follower. On the whole the innovation performance of the leading countries has decreased.

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As EU is now under dramatic transformation under Brexit inside and EU-world trade readjustments milieu outside, the innovation spatial trajectories across EU region are much more important for realising the possible trends in the future as resilience of worldwide uncertainties. By applying the method of standard deviation ellipse, the paper try to describe the evolutionary spatial pattern of innovative activities in European Union during the period from 1995 to 2013 from the perspective of quantity and spatial visualization, and to Figure out the EU innovative space-time evolution characteristics. Hopefully this research will provide some instructions for decision-makers within and outside EU.

1.1. Data and Methods
The research aims at the EU members of Belgium, Bulgaria, the Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Cyprus, Hungary, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Austria, Poland, Portugal, Romania, Slovakia, Slovenia, Finland, Sweden, United Kingdom. The panel data of the paper derives from 1995-2013 high-tech patent applications to the EPO and GDP of EU members measured as the innovative and economic index. The method of the paper is to apply standard deviation ellipse (SDE) analysis[2-3] firstly worked out by Lefever (1926)[4]. As one of spatial statistic methods, it is widely used to accurately reveal the overall spatial distribution characteristic of geographical elements[5]. SDE is spatial distribution ellipse that consists of basic parameters like center, long axis and short axis and rotation et al, to quantitatively describe wholly spatial characteristics of the object. Specifically, the spatial distribution ellipse takes the average of geographical factors as the spatial distribution center, and then calculate the standard deviation in the X and Y direction to decide the axis of the ellipse, checking whether the distribution of elements is elongated and what the direction of distribution trend is. According to the main area of the spatial ellipse of geographical elements, we could find the main region of economic activities. The center is the relative position of geographical elements in two-dimensional space and the rotation that is the clockwise angle to the long axis of the ellipse from the due north, reflects the main trend direction of the distribution. The long axis of. SDE means discrete degree of geographical elements in the main trend direction. After all, the center, scope, axis, direction and SDE reveals such as the overall distribution characteristics and time-space evolutionary process of the elements[6].

2. Spatial Dynamics of EU Regional Innovation
In the period of 9 years(1995-2013), the overall spatial distribution of regional innovation in EU is “west by south- east by north” pattern. Distribution in the spatial center of SDE is located in Germany, internal areas mainly in Western and the Nordic Europe. Generally speaking, the regional innovation EU shows obvious spatial changing evolutionary trend: as time goes, the ellipse is moving southeast, and the space range is expanding (Figure.1(a)). While from 1995 to 2013, the European Union region innovation space movement (Figure.1(b)). Innovation focus points of 26.41 km, total displacement of moving east 20.89 km, mobile 16.159 km to the south, southeast direction of the general trend. In the direction of east - west, as a whole, the EU’s innovation center has roughly trend that moves from west to the east. Since 1995, the EU’s innovation center of SDE has been moving to the east. the longest distance move to east is in from 1995 to 1996, reaching 11.98 km meanwhile total moves of the innovation center is the biggest, 13.66 km. Yet, the period of 1997-1999, 2007-2009 and 2010-2011, the EU innovation center moves backward west, the distance returned were 5.989 km, 8.755 km and 14.651 km, respectively.
Figure. 1. EU regional innovation space pattern of (a) and footprints of innovation focus (b) from 1995 to 2013

In the direction of north-south, Overall, the innovation center has trend that moves from north to the south. There are roughly three stages (shown in Figure 2). Firstly, from 1995 to 1999, the EU’s innovation center is obviously moving north, the total distance is 11.969 km; The second phase of 1999-2005, the innovation center moves southward with the 43.158 km; The third phase is from 2005 to 2013, the innovation center moves to north, reaching 15.03 km.

Figure. 2 1995-2013 the trace distance centers of EU’s innovation SDE

2.1. The distribution range
For 1995-2013 EU’s innovation distribution range of SDE is expanding between 180.89km² and 192.5 km² (shown in Figure 3). 1999-2003, the spatial area is shrinking significantly, then after 2003,
turn in expanding with a little fluctuation in 2008-2009, but then continue to sustain increasing, the biggest one is in 2013, 192.5 km$^2$.

![Figure 3 EU innovation space distribution range in 1995-2013](image)

2.2. **The long and short axis of SDE**
The long axis of SDE represents the direction of distribution and short axis is the range of distribution. The smaller gap between long axis and short axis, the less obvious direction is. The shorter short axis of SDE, the stranger centripetal force is, the longer the more discrete.

From 1995 to 2013, the long axis of EU’s innovation SDE overall grows slightly and short axis basically remains stable, the overall length of half shaft (a) the greater the flat rate. The greater gap between both axis, the more obvious innovation distribution direction in EU. The EU’s regional innovation space distribution in the vertical direction is expanding for upward in the horizontal direction keeps sustaining state. At the same time, the long/short axis ratio of EU’s innovation distribution SDE generally has a decreasing trend (shown in Figure 4). Specifically, 1995-1999 and 1999-1995, the ratio of goes down significantly; 1999-2002 showed a significant increase with volatility.

![Figure 4 1995-2013 The short/ long axis ratio of EU’s innovation SDE](image)

2.3. **The distribution direction of SDE**
From 1995 to 2013, generally, the rotation of EU’s innovation SDE is reducing with little waves (shown in Figure 5). There are mainly following three stages. For 1995-1997 phase is increasing; 1999-1999 and 2004-2013 are decreasing, which means that compared with western and southern countries in EU, the innovation activities in northern and eastern countries stress more growing influences.
3. Model Specification

Based on the basic principles of Stochastic Frontier Analysis (SFA) model by Battese and Colli (1992) [7], this paper builds the logarithmic Cobb-Douglas model to estimate the regional innovation efficiency of EU members from 2002 to 2012. The model formula is as follows.

\[
\ln Y_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \nu_{it} - u_{it}
\]

(1)

\[
TE_{it} = \exp(-u_{it})
\]

(2)

\[
u_{it} = \exp[-\eta(t-T)]u_{i}
\]

(3)

\[
\gamma = \frac{\sigma^2_u}{\sigma^2_u + \sigma^2_v}
\]

(4)

In the Equation (1), \(Y\) represents output; \(L\) and \(K\) indicate the input; the subscripts \(i\) and \(t\) mean country and year, respectively. \(\beta_0\) is intercept; \(\beta_1, \beta_2, \eta, \gamma\) are the parameters to be estimated, and the error term \(\nu_{it}\) is composed of two parts. \(\nu_{it}\) (expressing random error) and \(u_{it}\) (expressing inefficiencies), both are independent of each other. The Equations (2), \(TE_{it} = \exp(-u_{it})\) represents regional innovation efficiency level of country \(i\) in year \(t\); Equations (3) describes the influence of time factor on \(u_{i}\). In the statistical test, if the Equations (4) \(\gamma = 0\) (\(\gamma = 0\)), the null hypothesis is accepted, SFA model estimation is no more required, rather than use the OLS (ordinary least squares) to estimate directly.

3.1. Variable Selection and Data Source

According to the researches by Griliches (1991) [8], the R&D personnel (unit: person) and R&D investment funds each country (unit: euro/person) are selected as the indicators of \(L\) and \(K\), respectively. The market value of national patent applications (unit: millions of euros/person) is selected as the output \(Y\). All the data come from EU official database (http://ec.europa.eu/eurostat/).

By Frontier4.1 process, we used the maximum likelihood method to estimate the regional innovation efficiency of EU member states. The regression results estimated by OLS and SFA models are shown in Table 1, and the regional innovation efficiency of EU member states are shown in Table 1.

### Table 1. The results estimated by OLS model and SFA model

| Parameters | OLS     | SFA     |
|------------|---------|---------|
|            |         |         |

Figure 5 1995-2013 EU’s innovation rotation of SDE
The regional innovation efficiency of EU member states from 2002 to 2012.

| Country        | 2002   | 2003   | 2004   | 2005   | 2006   | 2007   | 2008   | 2009   | 2010   | 2011   | 2012   |
|----------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Belgium        | 0.798  | 0.790  | 0.781  | 0.772  | 0.763  | 0.753  | 0.743  | 0.733  | 0.722  | 0.711  | 0.699  |
| Bulgaria       | 0.734  | 0.724  | 0.713  | 0.701  | 0.690  | 0.678  | 0.665  | 0.652  | 0.639  | 0.626  | 0.612  |
| CzechRepublic  | 0.473  | 0.457  | 0.440  | 0.423  | 0.406  | 0.389  | 0.372  | 0.355  | 0.338  | 0.321  | 0.304  |
| Denmark        | 0.593  | 0.578  | 0.563  | 0.548  | 0.533  | 0.517  | 0.501  | 0.485  | 0.468  | 0.452  | 0.435  |
| Germany        | 0.941  | 0.938  | 0.935  | 0.932  | 0.929  | 0.926  | 0.923  | 0.919  | 0.916  | 0.912  | 0.908  |
| Estonia        | 0.659  | 0.646  | 0.632  | 0.619  | 0.605  | 0.591  | 0.576  | 0.561  | 0.546  | 0.530  | 0.515  |
| Ireland        | 0.651  | 0.637  | 0.624  | 0.610  | 0.596  | 0.581  | 0.567  | 0.552  | 0.536  | 0.520  | 0.505  |
| Greece         | 0.493  | 0.477  | 0.461  | 0.444  | 0.427  | 0.410  | 0.393  | 0.376  | 0.359  | 0.342  | 0.325  |
| Spain          | 0.691  | 0.679  | 0.667  | 0.654  | 0.641  | 0.627  | 0.614  | 0.599  | 0.585  | 0.570  | 0.555  |
| France         | 0.945  | 0.942  | 0.940  | 0.937  | 0.934  | 0.931  | 0.928  | 0.925  | 0.922  | 0.918  | 0.914  |
| Croatia        | 0.426  | 0.409  | 0.392  | 0.375  | 0.357  | 0.340  | 0.323  | 0.306  | 0.290  | 0.273  | 0.257  |
| Italy          | 0.834  | 0.827  | 0.820  | 0.812  | 0.804  | 0.796  | 0.787  | 0.779  | 0.769  | 0.760  | 0.750  |
| Cyprus         | 0.552  | 0.537  | 0.521  | 0.505  | 0.489  | 0.473  | 0.456  | 0.439  | 0.423  | 0.406  | 0.389  |
| Latvia         | 0.536  | 0.520  | 0.504  | 0.488  | 0.472  | 0.455  | 0.438  | 0.421  | 0.404  | 0.387  | 0.370  |
| Lithuania      | 0.533  | 0.517  | 0.501  | 0.485  | 0.468  | 0.452  | 0.435  | 0.418  | 0.401  | 0.384  | 0.367  |
| Luxembourg     | 0.319  | 0.302  | 0.285  | 0.268  | 0.252  | 0.236  | 0.220  | 0.205  | 0.190  | 0.176  | 0.162  |
| Hungary        | 0.824  | 0.817  | 0.809  | 0.801  | 0.792  | 0.784  | 0.775  | 0.765  | 0.756  | 0.746  | 0.736  |
| Malta          | 0.568  | 0.553  | 0.537  | 0.521  | 0.506  | 0.489  | 0.473  | 0.456  | 0.440  | 0.423  | 0.406  |
| Netherlands    | 0.945  | 0.943  | 0.940  | 0.938  | 0.935  | 0.932  | 0.929  | 0.926  | 0.922  | 0.919  | 0.915  |
| Austria        | 0.632  | 0.618  | 0.604  | 0.590  | 0.575  | 0.560  | 0.545  | 0.529  | 0.513  | 0.497  | 0.481  |
| Poland         | 0.819  | 0.812  | 0.804  | 0.795  | 0.787  | 0.778  | 0.769  | 0.759  | 0.749  | 0.739  | 0.729  |
| Portugal       | 0.485  | 0.469  | 0.452  | 0.436  | 0.419  | 0.402  | 0.385  | 0.367  | 0.350  | 0.333  | 0.316  |
| Romania        | 0.852  | 0.846  | 0.839  | 0.832  | 0.825  | 0.818  | 0.810  | 0.802  | 0.794  | 0.785  | 0.776  |
| Slovenia       | 0.461  | 0.445  | 0.428  | 0.411  | 0.394  | 0.377  | 0.359  | 0.342  | 0.325  | 0.308  | 0.292  |
| Slovakia       | 0.625  | 0.611  | 0.597  | 0.582  | 0.567  | 0.552  | 0.537  | 0.521  | 0.505  | 0.489  | 0.473  |
| Finland        | 0.728  | 0.717  | 0.706  | 0.694  | 0.682  | 0.670  | 0.657  | 0.644  | 0.631  | 0.617  | 0.603  |

Note: ***,**,* means significant at 1%, 5%, 10% level, respectively. LR is the likelihood ratio test for the null hypothesis ($\gamma = 0$), which is subject to Mixed chi-squared distribution for likelihood ratio test statistics.

**Table 2.** The regional innovation efficiency of EU member states from 2002 to 2012.
4. Conclusion
By panel data of the member in European Union, we use SDE and SFA to estimate Spatial evolutionary pattern and regional innovation efficiency of European Union, finding that:

(1) EU’s innovation SDE generally moves eastward with expanding trend obviously as a whole. In central and eastern Europe, such as Hungary, Slovenia, Estonia and other countries are pulling influence on innovation activities of EU, and the market aggregation effects in the Western Europe in weakened;

(2) Innovation SDE are mainly located in Germany, France, the Netherlands, Belgium and Denmark, whose yet effect on EU are weakening, making the innovation SDE generally moves toward the southeast, the rotation of SDE is reducing, and the short/long axis ratio drops, the shape of SDE is becoming flat.

(3) Compared with economy SDE, the spatial evolution of EU’s innovation SDE keeps pace with economic changes basically with the temporal differences and both SDE tend to move eastward with expanding scope. Specifically, after Britain leave EU, this trend will also be strengthened. The driving role of western developed countries are stronger in terms of innovation activities than in terms of economic development. There is more furtherly space to improve the innovation performance under the influence of central and eastern Europe driver. Accordingly, it is wise to increase the invest in innovation and economic support for central and eastern Europe, not only can effectively promote innovation in EU, but also help reduce the gap among the members, promote balanced development of regional innovation and EU integration process.

(4) The elasticity of R&D investment fund and R&D personnel play positive role in regional innovation efficiency and the role R&D investment fund is dominant. From 2002 to 2012, the average regional innovation efficiency of EU member states is 0.607 with dropping trend and there are 12 members are above the whole average efficiency of EU.

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