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Environmental Regulation, Environmental Knowledge Spillover, and Regional Economic Growth in China: An Empirical Test Based on the Spatial Durbin Model

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Abstract: Considering the evolution of the spatial pattern of regional economic growth in China, this paper analyzes whether environmental regulation (ER) and environmental knowledge spillover (EKS) contribute to regional economic growth using panel data and the spatial Durbin model of China's 31 provinces and cities from 2005 to 2020. The findings indicate that (1) there are significant characteristics of economic agglomeration in the spatial distribution of economic growth in China's different provinces and cities according to the Moran's index; (2) the environmental regulation has a nonlinear "U"-shaped effect on the regional economic growth, which is first suppressed and then promoted, and the spatial effect presents the same "U" shape as that of the local effect; (3) the environmental knowledge spillover, as measured by the number of green patents, shows a positive contribution on the economic growth and is significantly active in terms of both the local spillover and inter-regional spillover; (4) Eastern China enjoys a larger ER dividend than the central and western regions, and EKS shows a significant positive contribution to economic growth in the eastern, central, and western regions; (5) other factors also influence the regional economic growth besides the core explanatory variables, including the research and development expenditure (RD), human capital (Edu), urbanization level (Urb), government intervention (Gov), and opening-up level (Open), all of which show a positive effect on the economic growth, whereas the science and technology expenditure (Ti) has not played a positive role in promoting economic growth.

Keywords: environmental regulation; environmental knowledge spillover; regional economic growth; spatial Durbin model

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1. Introduction

As the largest developing country, China's resource constraints and environmental pollution problems are becoming increasingly prominent. The carrying capacity of the natural environment on which human beings depend for existence has a certain upper limit. The development mode of stimulating economic growth at the cost of consuming resources and polluting the environment has a greater binding force on sustainable economic development [1]. Under the new global situation in which the United Nations formulates their Sustainable Development Goals (SDGs), environmental innovation has become a realistic problem facing the government and enterprises in China, and its impact on corporate performance is the most important issue in the current economic research [2]. Environmental products are public goods with negative externalities, often being derived from scarce resources and involving unclear property rights and high transaction costs. It is difficult to achieve emission reduction targets by relying solely on the market mechanisms. The government-implemented environmental regulation (ER) approach has emerged to compensate for market failures [3,4].

Neoclassical economists believe that, under the condition of market equilibrium, enterprises will choose the point of cost minimization for production, and the government implementation of ERs will inevitably increase the pollution management costs for the enterprises, thereby weakening the competitiveness of the enterprises and reducing their innovation ability [5]. Differing from the former, one idea for defending environmental protection is that ER will not only increase the production cost to the enterprises but also stimulate innovation in these enterprises [6], change the profit maximization conditions under the change constraint, and improve the production enterprises' efficiency [7]. More stringent environmental legislation will indeed lead to innovation. From a regional perspective, enterprises subject to ER also have problems related to relocation, the transfer of sewage, and the evasion of supervision [8].

Knowledge spillover (KS) has a beneficial impact on developing countries in achieving SDGs [9]. Based on the case study and context of China, this paper calls the knowledge spillover caused by environmental innovation "environmental knowledge spillover" (EKS) [10,11]. There are different definitions of environmental innovation according to the source and purpose [12]. It is generally believed that environmental innovation is "any innovation conducive to sustainable development", as defined by the European Ecological Innovation Commission. However, when measuring the EKS caused by environmental innovation, a problem still exists: how to distinguish environmental innovation from non-environmental innovation? Therefore, this paper uses the green patent data to measure the environmental innovation related to green development and generate the EKS variable instead of the general KS variable.

Although the research on KS and economic growth has achieved good results, the effect of EKS on China's economic growth is still not strongly supported by empirical research [13,14]. Spatial factors are crucial to understanding EKS, but are seldom considered [15]. This paper will try to study this problem. In addition, most of the research focuses on the two–two impacts of ER and economic growth and KS and economic growth and seldom discusses these three factors within a framework, especially regarding the role of knowledge spillover in green innovation. The primary contributions of this paper can be shown as follows: (1) This work describes the effect of ER on economic growth from the perspectives of the "following cost theory" and "innovation compensation theory", adds the quadratic term of ER, and empirically tests the nonlinear impacts between ER and regional economic growth in China. (2) Under the current trend of developing green economies, the study of the impact of EKS, rather than general KS on regional economic growth in China makes up for the lack of empirical research on how EKS can promote economic growth in China, and it also provides policy inspiration and empirical evidence for promoting sustainable economic development. (3) Based on the existing research, this paper expands on several topics. First, from the spatial perspective, we bring ER, EKS, and economic growth into a united analysis framework for active theoretical exploration. Second, we pay attention to the possible nonlinear spatial effect of ER—the local effect and neighborhood effect—and explore the spatial impact of EKS on China's economy growth caused by environmental innovation.

The remainder of this paper is organized as follows. Firstly, we summarize the relevant theories and existing studies in Section 2, then makes assumptions about the research issues discussed in this paper. Secondly, we show the space–time evolution process and basic characteristics of the economic center of gravity in the spatial pattern of China's economic growth. Thirdly, we describe the empirical framework, data sources, and calculation methods, as well as the spatial correlation testing of variables and the selection of spatial measurement models used in this paper. Fourthly, we evaluate the impacts of ER and EKS on regional economic growth and analyze the empirical results. We divide China into three regions—the east, the central, and the west—to analyze the impact of the regional heterogeneity further. Then, it is the discussion part, and points out the limitations of this paper. Finally, it is Section 7 of this paper.

2. Literature Review

There are two completely different viewpoints on the research into the connection between ER and regional economic growth in academic circles: the "following cost theory" and "innovation compensation theory". It will be an important supplement to the current literature to explore the nonlinear relationship between the inhibition of the cost effect and the promotion of the innovation compensation effect. The positive impact of KS on economic growth has been widely confirmed, while the empirical evidence of the impact of KS on the economic growth generated by environmental innovation still needs to be strengthened.

2.1. Environmental Regulation and Regional Economic Growth

From a static perspective, the carrying out of ERs objectively mandates that enterprises pay for pollution management; increase the environmental expenses and "compliance costs" of businesses; reduce the competitiveness, production effectiveness, and profit margins of enterprises; and expand to a macro level, which may hinder the expansion of the economy and represents the "following cost theory" [16]. From this view, increasing the intensity of the ER does not increase the profit of the enterprises [17]. Enterprises may face cost pressure from two aspects: one is the direct cost consumption brought about by reducing pollution discharge, and the other is the increasing cost of some production factors due to ER [18]. On this basis, to achieve short-term benefits, enterprises may reduce the development of innovative projects, reduce their investment in pollution projects, or even transfer to areas with less stringent environmental regulations, resulting in environmental deterioration in another area [19,20]. Based on data from five U.S. polluting industries, Barbera and McConnel proposed that ER has led to a 30% decrease in productivity in these industries, which has had a negative impact on industry development [21]. Chintrakarn's conclusion also indicates that the tightening of ERs has significantly reduced the technological efficiency of the manufacturing industry in 48 U.S. states [22]. In most cases, the purpose of ERs is to limit outcomes rather than production. The data from the carbon emissions trading pilot in China project confirmed that ERs can inhibit innovation in both regulated and unregulated businesses, thereby reducing the efficiency in production [23]. Pollution problems also exist in underdeveloped countries or regions. Aryal et al. evaluated Nepal's environmental policy, but the lack of coordination between the government and nongovernmental organizations has hindered the achievement of the expected policy results, which has eventually led to the failure of their environmental policies [24].

From a dynamic perspective, reasonable ERs not only increase the production costs to enterprises, but also force enterprises to carry out environmental innovation. When the production efficiency improvement brought about by innovation offsets or exceeds the loss of cost effect, it also results in knowledge spillovers and structural upgrading to reach a win–win scenario where both environment and economic benefit, which is the "Porter hypothesis" or "innovation compensation theory" of environmental regulation [25,26]. Porter believes that ER should not be restricted to the best performance under static limits. Instead, ER is regarded as an incentive source for enterprises to innovate, enhance their competitive advantage via technological innovation, and promote their economic growth [27]. Later, scholars tested the "Porter hypothesis". Lanjouw and Mody used data of the United States, Japan, and Germany in the 1970s and 1980s to prove that the degrees of ER and environmental technology innovation are strongly correlated, and the purpose of developing countries importing environmental patents is mostly to adapt to local technology innovation [28]. Telle and Larsson used Norwegian industrial data and found that the impact of ERs on the growth of the industrial total factor productivity is significant and brings an active influence on the economy [29]. Scholars have also carried out research on "innovation compensation theory" in recent years. Using China's urban data, Gu et al. discovered that the implementation of ER policies promotes energy conservation and emission reductions and shows a good trend on sustainable development [30]. Starting from the theory of institutional regulation, Cai et al. discovered that direct ER owns a large and considerable incentive impact on the development of green technology innovation in developing countries [31]. Based on the push–pull–mooring (PPM) theory, Dou et al. examined the motivating elements of the advanced manufacturing industry in the Guangdong–Hong Kong–Macao Greater Bay Area and believed that the environment was the driving factor, the economy was the pulling factor, and technology was the core factor. Technology is also the manufacturing sector's internal development environment, which may support the sector's intelligent development [32]. It is well-known that corrupt regulations will bring bad influence or harm the economy [33]. Zhou and Li considered the government's anti-corruption work in the green economy, and the research found that when the anti-corruption intensity exceeded a certain threshold, the implementation effect of the ER increased significantly [34]. Bayramoglu discussed the environmental policies of three developing countries (Argentina, Tunisia, and India) and found that ERs do not necessarily hinder national development and can provide incentives to modernize production [35]. Murshed et al.'s research on four South Asian countries (Bangladesh, India, Pakistan, and Sri Lanka) concluded that ERs will reduce the negative influence of economic expansion on the environment [36].

Based on the above positive and negative impacts of ERs on economic growth, there is not necessarily a simple causal or linear relationship between ERs and economic growth [37]. Therefore, some scholars have proposed that the "U"-shaped relationship can offer a better logical justification for the two theories of ER and economic development—the "following cost theory" and "innovation compensation theory" [38,39]. When the ER is at a low level, there is a growth inhibition effect. When the growth inhibition effect exceeds the threshold of the ER, the innovation compensation effect begins to appear [40]. Liu et al. concluded that the investment-based ER effect displays a "U"-shaped curve, while the impact of fee-based ER is an inverted "U"-shaped curve, and controlling the proportions of the secondary industry, foreign direct investment, and fiscal decentralization can directly promote an improvement of the environmental quality [41]. To sum up, this essay contends that there are two aspects in which ERs affect economic growth at the same time: one is the inhibition of cost effect, the other is the promotion of innovation compensation effect. Therefore, this paper puts forward the following assumptions:

Hypothesis 1a (H1a). *The effect of ER on regional economic growth is nonlinear.*

Hypothesis 1b (H1b). *Short-term ER has a negative impact on regional economic growth.*

Hypothesis 1c (H1c). *Long-term ER has a positive impact on regional economic growth.*

2.2. Knowledge Spillover and Regional Economic Growth

Classical economics generally regards knowledge as an exogenous variable of economic development. During the period of new economic growth theory, scholars began to focus on the influence of KS on economic growth, but it fails to examine KS from a spatial perspective and ignores the role of spatial factors in KS and economic growth. After the rise of the new economic geography, scholars began to incorporate KS into the spatial framework. In the research on the spatial proximity of KS, Anselin et al. found that the source of KS is the absorption and reference of patent achievements [42]. The scarcity of knowledge determines that it has the characteristics of diffusion and flow, resulting in the phenomenon of knowledge overflow [43]. Knowledge is also condensed into technology and experience through the production process, thereby resulting in spillover effects [44,45]. Economists such as Almeida and Kogut have put forward the idea that the regional flow of patent holders among enterprises affects the spatial diffusion of knowledge, and when individuals or organizations move under their social networks, such knowledge shows externalities [46].

The mobilization of talent brings regional KS and spatial agglomeration [47] and reduces production costs, while KS promotes further regional innovation, improves enterprise production efficiency, and promotes industrial transformation and upgrading and real economic growth [15,48]. Many scholars have come to the conclusion that KS plays a positive role in promoting economic growth [49]. For example, the research results based on Italian samples showed that KS has a good driving force for economic activities [50]. Mukhamediyev et al. used Kazakhstan's data and endogenous growth model and found out KS shows a good significance for regional economic growth [51]. Aldieri et al., based on data from Russia, proved the important role of KS in productivity through spatial econometrics [52]. Indonesia's evidence also shows that the spillover effects of government spending and education are significant for regional economic growth [53]. Some scholars have come to the conclusion—contrary to the mainstream view—that KS may lead to widening of the economic gap between the two regions [54]. Based on the enterprise data from Zambia, an African country, Bwalya estimated via GMM that there is little evidence to support the spillover effect of horizontal channels, i.e., there is a lack of intra-industry spillover [55]. The studies into KS mostly concentrate on the number of traditional patents or the degree of R&D, and there is a lack of in-depth research on the types of KS, especially the environmental innovation knowledge spillover seen in developing countries [56].

There is little research literature about the association of EKS and economic growth, however, there have been some noteworthy research conclusions. Aldieri et al. emphasized the important role of KS in environmental innovation based on patent data from 240 European companies [57]. Long et al. assessed the impact of environmental innovation in achieving sustainable economy in G7 economies from 1980 to 2020, and a positive facilitation was detected between economic sustainability and environmental innovation [58]. KS from environmental innovation is beneficial to the introduction of environmental innovation [59,60]. On the whole, it has a positive impact on corporate productivity and environmental sustainability, forming an environmentally friendly economy [14,61]. Anser et al. aggregated global data to assess global economic growth, which also proved that KS significantly reduced carbon emissions and had a positive impact on improving corporate productivity [62]. However, Aldieri and Vinci, based on the three regions of the United States, Japan, and Europe, reached opposite conclusions when examining the impacts of environmental spillover effects on corporate productivity from the spatial perspective [63].

On the whole, there is lots of research on the positive promotion of KS and economic growth and parts of the literature also introduce spatial factors to consider the spatial effect of KS on economic growth. However, the spatial impact of EKS on economic growth is less involved. Similarly, this paper holds that EKS and general KS have similar positive promotion effects. Combining spatial factors, this paper holds that EKS has similar effects to general KS on economic growth in terms of the spatial direct effects and spatial indirect effects. Therefore, the following assumptions are made:

Hypothesis 2a (H2a). *EKS has a positive effect on regional economic growth.*

Hypothesis 2b (H2b). *The direct effect of EKS can directly promote local economic growth.*

Hypothesis 2c (H2c). *The indirect effects of EKS can positively promote economic growth in the neighboring areas.*

To sum up, the theoretical framework of the impacts of ER and EKS on regional economic growth is shown in Figure 1.

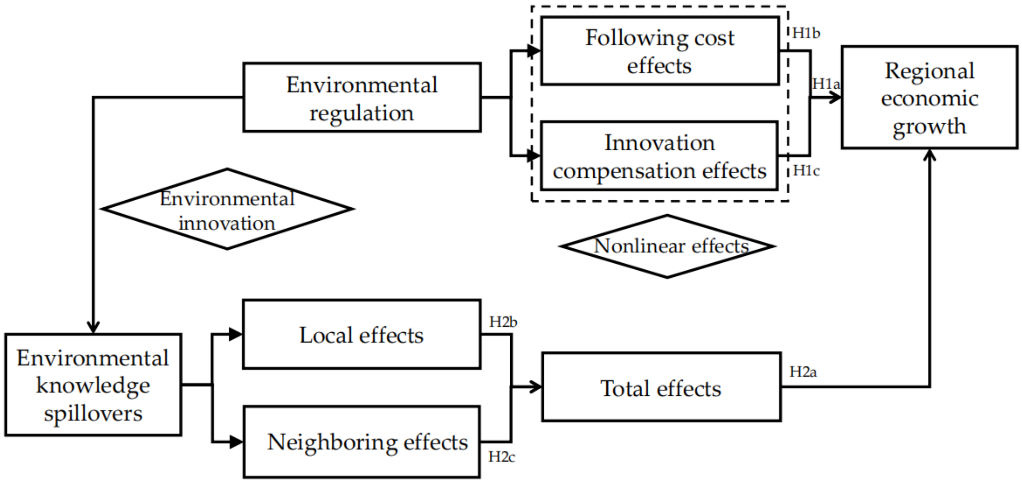

Figure 1. Theoretical framework of environmental regulation (ER), environmental knowledge spillover (EKS), and regional economic growth.

3. The Spatial Pattern Evolution of Regional Economic Growth in China

China has different regional resource conditions and development bases. In addition, due to the role of a series of regional economic development strategies and policies, the levels of economic and social development are quite different among the different provinces and cities in China, and the economic spatial pattern has shown many changes [64]. An understanding of the evolution of the spatial pattern of economic growth is helpful in order to rationally plan the spatial layout and make correct economic decisions, thereby accelerating the pace of economic growth. This paper uses the evolution of the center of gravity to present various changes in the spatial pattern of China's regional economic growth from 1997 to 2020.

The center of gravity of a region is the weighted average center of the region, which refers to the weighted geometric coordinates of spatial objects, taking various attributes of spatial objects (economic indicators, population indicators, labor indicators, and land use indicators) into consideration and obtaining the weighted average center of each spatial object. If an area consists of n small units, and the coordinate of the ith small unit is (X_i, Y_i), M_i is the attribute quantity value of the ith unit, and the calculation formula of the geographical coordinate $(\overline{x}, \overline{y})$ of the gravity center of an attribute in the area is $\overline{x} = \frac{\sum M_i X_i}{\sum M_i}, \overline{y} = \frac{\sum M_i Y_i}{\sum M_i}$. In this paper, the GDP value, population value, and GDP per capita value of each small unit are selected as the M_i values, respectively. The basic idea of the calculation is to take the prefecture-level cities as the small units of the study first find out the coordinates of their geographical centers and then use the M_i values of each prefecture-level city as the attribute values and directly calculate the national center of gravity coordinates of this attribute after weighting the average using the formula.

3.1. Migration of Economic Center of Gravity Based on GDP

In this paper, the GDP values of each year are weighted according to the gravity calculation formula, and the coordinates of the national economic center of gravity (ECG) are calculated each year. Using ArcGIS software (version number: 10.7; creator: ESRI; location: CA, USA), the migration map of the national ECG measured by GDP is drawn, which can be seen in Figure 2. The ECG of China's GDP moved to the junction of Henan and Anhui provinces from 1997 to 2020, and the general trend of regional economic development was that the ECG continued to move southward. According to the trajectory of the ECG, it can be roughly divided into three stages. In the first stage (1997–2004), the ECG shifted from southwest to northeast by 15.47 km; in the second stage (2004–2012), the ECG moved from southeast to northwest by 38.37 km, and the trend of the ECG moved obviously westward; in the third stage (2012–2020), the ECG moved from the northeast to the southwest by 122.73 km, and the ECG moved more southward than westward at this stage.

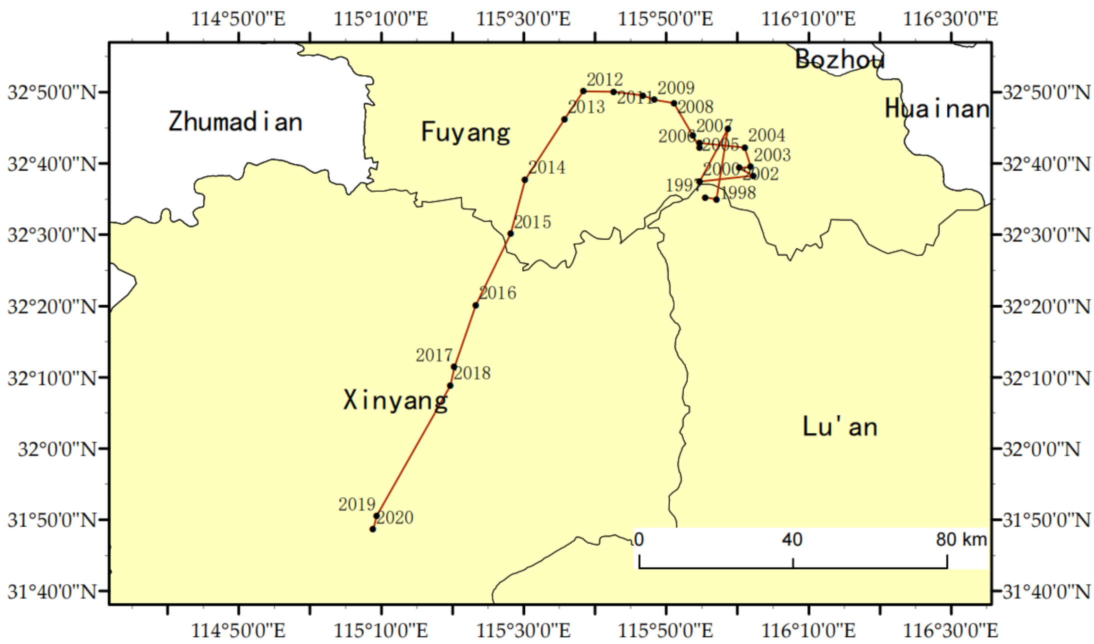

Figure 2. Migration of the economic center of gravity (ECG) based on the GDP.

The moving speed of the ECG in China from 1997 to 2020 showed a trend of first slowing and then quickening. In the first stage, the moving speed of the ECG was relatively slow at about 2.21 km/year. The speed in the second stage was accelerated with a speed of 4.79 km/year moving rapidly to the northwest. In the third stage, the ECG moved to the southwest at a faster speed of 15.34 km/year.

3.2. Migration of Population Center of Gravity Based on Population Size

Figure 3 shows a migration map of the center of gravity based on the population size of each region. From 1997 to 2020, the population center of gravity (PCG) was basically concentrated in Zhumadian City, Henan Province. After 2016, it entered Xinyang City, and the PCG shifted to the southwest by 68.17 km. Judging from the movement direction of the PCG and the ECG, the PCG has always been located on the west side of the ECG, and the evolution direction of the two is not a convergence relationship, indicating that China's ECG and the PCG have deviated to a certain extent. In general, the PCG will move to the southwest with the shift of the ECG. The transfer of the PCG can be divided into four stages, where, in the first stage (1997–2005), the PCG was mainly transferred to the southwest; in the second stage (2005–2008), it began to turn around to a certain extent, and the PCG slowed down its moving speed and even shifted to the northeast; in the third stage (2008–2014), the PCG shifted to the southwest again; and in the fourth stage (2014–2020), the PCG shifted to the southeast.

In the first stage (1997–2005), the PCG moved to the southwest. The year 2000 was the time when the country had just put forward the policy of developing the western region. At this time, the national policy began to tilt to the western region. Many resources were also infiltrating into the western region. A large number of people responded to the national call and rushed to Midwest China to support the construction. In the second stage (2005–2008), the ECG shifted slightly to the northwest, which was due to the impacts of policies, as well as objective reasons such as the migration of the labor force to economically developed areas, which caused the migration speed of the PCG to the southwest to slow down during this period, while the ECG moved to the west and slowed down under the influence of national policies. In the third stage (2008–2014), with the rapid development of industries in the central and western regions, a large number of labor-intensive enterprises appeared, resulting in a large amount of labor demand. Meanwhile, due to the impact of the financial crisis on the eastern coastal areas in 2008, and with the labor cost being relatively high, this led to a decrease in wages in the eastern regions. There were comprehensive reasons for the PCG shifting to the southwest again. In the fourth stage (2014–2020), as the economic requirements changed, and the country began to emphasize the use of comparative advantages to enhance the level of development, meaning the eastern economic development once again gained the upper hand. The attraction of the midwest regions for personnel began to decrease, and the PCG began to show a new trend of development toward the southeast, but its transfer speed was not rapid.

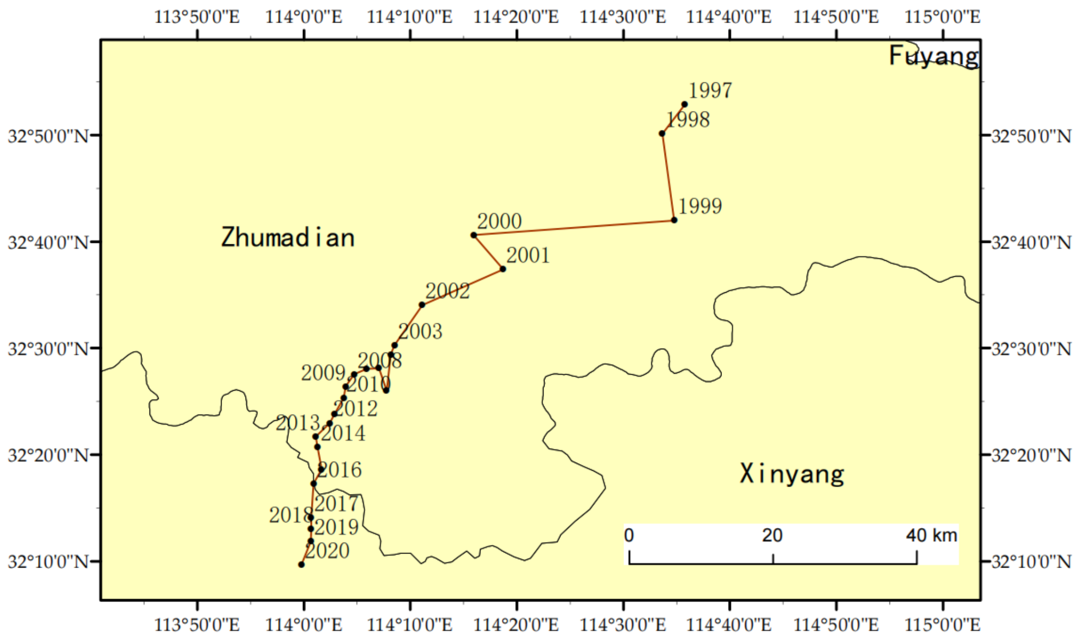

Figure 3. Migration of the population center of gravity (PCG) based on the population size.

3.3. Migration of Economic Center of Gravity Based on GDP per Capita

When the attribute value is changed into the GDP per capita, the migration map of China's economic center of gravity based on per capita GDP (ECGP) is as shown in Figure 4. With the per capita GDP as an attribute value, the ECGP of China from 1997 to 2020 falls in Xinyang City, Zhoukou City, and Zhumadian City in Henan Province. Among them, China's ECGP was in the territory of Xinyang City from 1997 to 2001, it was in the territory of Zhumadian City from 2002 to 2005, and then the ECGP moved to the territory of Zhoukou City from 2006 to 2012. It moved in the opposite direction and returned to Zhumadian City again from 2013 to 2020, then entered Xinyang City after 2019, with a trend of going north in 2020.

Compared with the movement trajectory calculated by using the GDP as the attribute value, the movement trajectory calculated by using GDP per capita as the attribute value also basically conformed to the characteristics of the three stages. However, the moving speed of the ECGP was obviously different. In the first stage (1997–2004), the ECGP moved to the northeast at a speed of 12.20 km/year; in the second stage (2004–2012), the moving speed slowed down slightly, moving to the northwest at a speed of 9.66 km/year; in the third stage (2012–2020), the ECGP shifted to the southwest at a high speed of 16.78 km/year.

The changes in direction and speed of the ECGP indicate that the spatial pattern of China's regional economy has undergone tremendous changes in recent years. In the first stage, due to the country's vigorous promotion of the reform and opening-up policy, the ECGP began to shift to the Yangtze River Delta region and the Bohai Sea region. In this stage, the ECGP shifted from southwest to northeast. In the second stage, against the background of the country advocating the development, many investments poured into the western region, industries took root and sprouted, and the economies of the midwest regions developed vigorously, which caused the shift of ECGP to the west. In the third stage, the economic development began to enter the new normal, with the development rate tending to be gentle, while the global economy also appeared to be weak. The economy in eastern China was greatly affected compared to the midwest regions for its obvious outward-looking characteristics. At the same time, due to its large base stock, the development speed has been insufficient, so the economic development trend in the eastern region has slowed down and the growth rate has decreased. However, the midwest regions have still obtained massive dividends from national policies, and their own development potential has been stimulated at the same time, making their economic development more prosperous. Compared with the northern region where the structural upgrading of economic development is blocked, and the southern region where high-tech industries and new service industries are rising strongly, the southern region's economic development is significantly higher. Therefore, the above-mentioned comprehensive reasons have led to the shift of the national ECGP to the southwest.

Figure 4. Migration of the economic center of gravity based on the GDP per capita (ECGP).

From the above migration track of China's ECG, PCG, and ECGP, the spatial pattern of China's economic growth has undergone tremendous changes in recent years. In comparison, the geographical center of gravity (Dongxiang Autonomous County in Gansu Province) shows larger deviation and imbalance characteristics. This paper will explore the differences in regional economic growth from the perspectives of ER and EKS.

4. Materials and Methods

4.1. Production Function

In this paper, we use the Cobb–Douglas knowledge production function (KPF) designed by Griliches-Jaffe to conduct an econometric analysis of regional economic growth [65,66]. We refer to the model used by Bode and add other factors to analyze the impact of spatial spillover [67]. The mathematical expression is:

$$INV_i = RD_i^{\alpha} Z_i^{\sigma} e^{\varepsilon_i} \tag{1}$$

In the mathematical expression, *INV* represents the innovation output, RD represents the research and development expenditure or human capital, Z represents other economic and social variables affecting the output, i represents the observation unit, α and σ are parameters, and e is a random error term.

In this paper, we mainly examine the impact of EKS on regional economic growth, so in addition to the innovation output, we should also consider the impact of the innovation output on the regional economic output. If the regional production function is set as $Y = F(K, L)$ and both sides are divided by L at the same time, the per capita production function after labor standardization to 1 is $\mathrm{y} = \mathrm{f}(\mathrm{k})$, and the specific per capita production function can be set as follows:

$$y_{it} = A_{it} K_{it}^{\beta} e^{\varepsilon_{it}} \tag{2}$$

where y_{it} is the total output per capita of region i in the t period, expressed as the per capita GDP here; A_{it} is the technological progress rate of region i of t period. Considering the KS from environmental innovation, the technology production function can be set as follows:

$$A_{it} = ER_{it}^{\beta 1} \cdot KS_{it}^{\beta 2} \cdot Z_{it}^{\beta 3} \tag{3}$$

Here, ER represents environmental regulation and KS represents environmental knowledge spillover. By substituting the above formula into the per capita production function, we get:

$$y_{it} = K_{it}^{\beta} \cdot ER_{it}^{\beta 1} \cdot KS_{it}^{\beta 2} \cdot Z_{it}^{\beta 3} \cdot e^{\varepsilon_{it}} \tag{4}$$

To reduce the potential heteroscedasticity problem, the logarithm on both sides of the above formula is taken to obtain the multiple regression equation for the spatial econometric analysis in this paper:

$$lny_{it} = \beta lnK_{it} + \beta_1 lnER_{i,t} + \beta_2 lnKS_{i,t} + \beta_3 lnZ_{i,t} + \varepsilon_{it} \tag{5}$$

Considering the mutual causality between current values, which may lead to endogenous problems, and because the knowledge production has certain time lag tables, this paper lags θ = 2 for all key variables and control variables. The following multiple regression equations can be obtained:

$$lny_{it} = \beta_0 + \beta lnK_{i,t-\theta} + \beta_1 lnER_{i,t-\theta} + \beta_2 lnKS_{i,t-\theta} + \beta_3 lnZ_{i,t-\theta} + \varepsilon_{it} \tag{6}$$

4.2. Variables and Data

4.2.1. Explained Variable

Regional economic growth (PGDP): The variable to be explained is measured by the per capita GDP of each province and city, and the per capita GDP for each year is converted into the actual per capita GDP data based on the year 2000. The data are taken from China Statistical Yearbook.

4.2.2. Explanatory Variables

Environmental regulation (ER): The indicators used to measure the intensity of the ER usually have a single indicator and a comprehensive indicator. This paper focuses on the impact of the intensity of the ER on the regional economic growth, drawing on previous practices and measuring the proportion of investment completed by using the industrial pollution control on the main business income for the industrial enterprises [68–70]. The data used are taken from the China Environmental Statistics Yearbook and China Industrial Statistics Yearbook publications from 2005 to 2020.

Environmental knowledge spillover (EKS): There are two commonly used indicators for measuring KS, namely the number of patents [71] and the R&D stocks [72]. In this paper, the perpetual inventory method (PIM) is used to calculate the initial knowledge stock in 2005 according to the formula $KS_0 = \frac{K_0'}{\delta' + g'}$, and the knowledge stock in each subsequent year is calculated according to the formula $KS_t = KS_{t-1}(1-\delta') + K'_t$. Here, K'_0 is the green invention patents obtained by the regions in 2005, and K'_t is the green invention patents obtained in the t period. KS is the green knowledge stock for the regions in each year. Here, δ' is the depreciation rate of green knowledge, and 15% is taken here; g' is the growth rate of the number of regional green invention patents, and it is constructed by the geometric growth rate of green invention patents from 2000 to 2020. The data are derived from the Chinese Research Data Services (CNRDS) database.

4.2.3. Control Variables

The control variables and detailed measurements are shown in Table 1, and the data are from the China Science and Technology Statistics Yearbook, the China Labor Economy Database, and the Economy Prediction System (EPS) data platform.

Table 1. Control variables and detailed measurements.

Variables	Detailed Measurements
Research and development investment expenditure (RD)	The internal expenditure of R&D funds in each region.
Level of human capital (Edu)	The number of years of education per capita in each region. The calculation can be expressed as $H_t = \sum_{i=1}^{n} \frac{P_i * T_i}{P}$, with P_i representing the educated workforce at the *i*-th level, T_i representing the years of education at *i*-th level, and P representing the total workforce.
Level of science and technology (*Ti*)	The proportion of science and technology expenditure versus the general government budget expenditure.
Level of urbanization (Urb)	The proportion of the urban population.
Level of government intervention (Gov)	The general public budget revenue.
Level of opening to the outside world (Open)	The total import and export of goods in each region, and the data are adjusted to RMB based on the current exchange rate.

4.3. Spatial Correlation Tests

The common indicators used for testing the spatial correlation are the Moran index, Getis–Ord index, and Geary's C index [73]. This paper uses STATA software (version number: 16; creator: STATA crip; location: Texas, USA) to calculate the global Moran index of China's 31 provinces' economic growth from 2005 to 2020. Table 2 displays the index values results. The global Moran index values are between −1 and 1. If the value is positive, it indicates the existence of a positive autocorrelation for regional economic growth. If the value is negative, it indicates the existence of a negative autocorrelation. If the value is close to 0, it indicates the absence of an obvious spatial autocorrelation. The Moran index values from 2005 to 2020 are all greater than 0, showing that the growth presents a significant positive correlation in space. Therefore, the spatial effect of the economic growth should be considered in the empirical analysis.

The global Moran index only grasps the spatial autocorrelation of variables as a whole and cannot identify the spatial agglomeration of a region. With the help of Moran's I scatter plot, the spatial dependence of the economic growth in each province can be more intuitively presented [74]. Due to space limitations, in this paper, we selected the representative years as 2005, 2010, 2015, and 2020 to list Moran's I scatter plot of economic growth, as shown in Figure 5. According to the Moran scatter chart of each year, the economic growth of each region from 2005 to 2020 is more evenly located in the regions of the first and third quadrants, suggesting that the economic growth of most provinces and cities has a positive spatial spillover effect on the neighboring provinces.

Table 2. Moran's index of the GDP per capita for 2005–2020.

Year	The 0–1 Matrix			The Inverse-Distance Matrix		
	I	z	p	I	z	p
2020	0.390	3.776	0.000	0.130	4.847	0.000
2019	0.379	3.681	0.000	0.128	4.804	0.000
2018	0.378	3.669	0.000	0.128	4.785	0.000
2017	0.375	3.648	0.000	0.127	4.763	0.000
2016	0.370	3.608	0.000	0.127	4.762	0.000
2015	0.372	3.614	0.000	0.129	4.826	0.000
2014	0.376	3.647	0.000	0.133	4.923	0.000
2013	0.382	3.710	0.000	0.135	5.017	0.000
2012	0.389	3.778	0.000	0.138	5.111	0.000
2011	0.393	3.826	0.000	0.139	5.143	0.000
2010	0.400	3.898	0.000	0.139	5.178	0.000
2009	0.395	3.875	0.000	0.137	5.116	0.000
2008	0.388	3.846	0.000	0.132	5.006	0.000
2007	0.382	3.822	0.000	0.127	4.904	0.000
2006	0.377	3.799	0.000	0.124	4.845	0.000
2005	0.371	3.770	0.000	0.121	4.774	0.000

Source: The author used STATA software for the calculations.

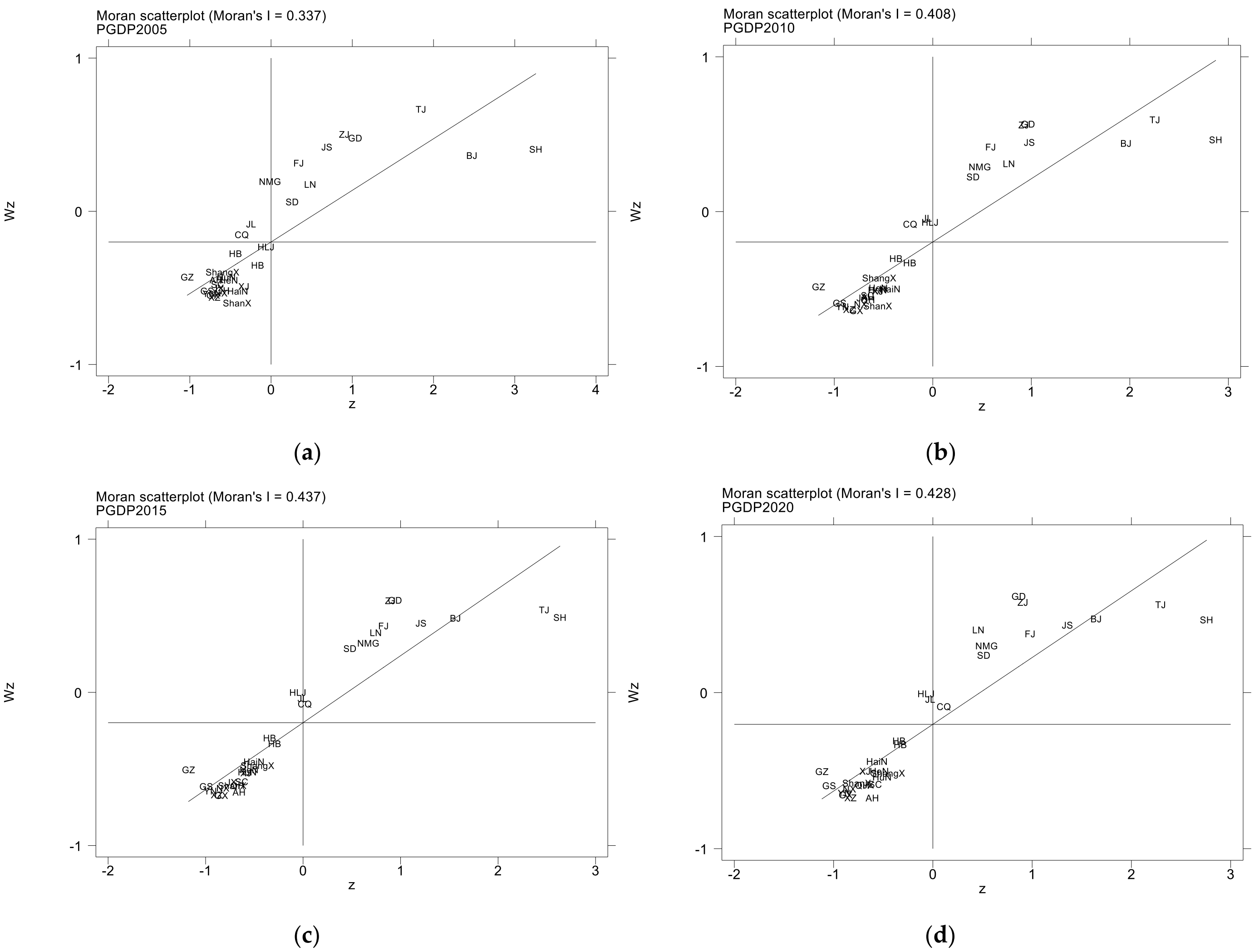

Figure 5. Moran's I scatter plot of regional economic growth. (**a**) Moran's I scatter plot in 2005; (**b**) Moran's I scatter plot in 2010; (**c**) Moran's I scatter plot in 2015; (**d**) Moran's I scatter plot in 2020. Source: The author used STATA software to draw.

4.4. Spatial Econometric Models

The results of the spatial correlation test show that there is a significant spatial correlation in China's regional economic growth, so the ordinary least squares (OLS) regression model will lead to deviation. This paper introduces the spatial relationship between the regions into the panel model. According to the different ways of introducing relationships, the spatial econometric model can be divided into the spatial lag model (SLM), the spatial error model (SEM), and the spatial Durbin model (SDM). The SLM is mainly used to study the spatial dependence of the explained variables and to analyze whether the explained variables have spillover or diffusion effects in a certain region. The SEM is mainly used to study the spatial correlation of the error terms. The SDM is based on the spatial lag model, in which the spatial lag effect of the independent variables is also included and is used to analyze the cross effect of the interpreted variables affected by the neighboring explanatory variables or other exogenous variables. Combining the selection of production functions and variables, the models are set as follows:

1. The spatial lag model:

$$\begin{aligned} lnPGDP_{it} = \ & \beta lnK_{i,t-\theta} + \lambda WlnPGDP_{it} + \beta_1 lnER_{i,t-\theta} + \beta_2 lnKS_{i,t-\theta} + \beta_3 lnZ_{i,t-\theta} \\ & + \varepsilon_{it},\ \varepsilon_{it} \sim N(0, \sigma^2 I_n) \end{aligned} \quad (7)$$

Here, Z is a series of control variables; λ is a spatial autoregressive lag coefficient; W is a spatial weight matrix, generally expressed by an adjacency matrix; Wy is a spatial lag-dependent variable; the parameter β reflects the influence of the explanatory variable on the explained variable; and ε is an error term.

2. The spatial error model:

$$lnPGDP_{it} = \beta lnK_{i,t-\theta} + \beta_1 lnER_{i,t-\theta} + \beta_2 lnKS_{i,t-\theta} + \beta_3 lnZ_{i,t-\theta} + \mu_{it} \quad (8)$$

Here, the disturbance term is $\mu_{it} = \rho W \mu_{it} + \varepsilon_{it}, \varepsilon_{it} \sim N(0, \sigma^2 I_n)$; ρ represents the spatial dependence of the error term.

3. The spatial Durbin model:

$$\begin{aligned} lnPGDP_{it} = \ & \beta lnK_{i,t-\theta} + \lambda WlnPGDP_{it} + \beta_1 lnER_{i,t-\theta} + \beta_2 lnKS_{i,t-\theta} + \beta_3 lnZ_{i,t-\theta} \\ & + \delta_1 WlnER_{i,t-\theta} + \delta_2 WlnKS_{i,t-\theta} + \delta_3 WlnZ_{i,t-\theta} \\ & + \varepsilon_{it},\ \varepsilon_{it} \sim N(0, \sigma^2 I_n) \end{aligned} \quad (9)$$

Here, the spatial lag term Wx represents the independent variable and δ is the spatial lag coefficient of the independent variable.

4.5. Spatial Weight Matrix

The definition of the spatial distance is the premise underlying the spatial econometric analysis. The distance is mainly reflected by the spatial weight matrix, which represents the form of influence between regions. Among them, the 0–1 adjacency weight matrix construction rule is used, where a value of 1 is assigned if there are adjacent boundaries and intersections in the geography of the adjacent areas, otherwise a value of 0 is assigned, and the matrix form is as follows:

$$w_{ij} = \begin{cases} 1 & \text{Region } i \text{ is adjacent to region } j \\ 0 & \text{Region } i \text{ is not adjacent to region } j \end{cases} \ (i \neq j) \quad (10)$$

Only when the two regions are adjacent can there be a mutual influence that is not entirely in line with reality. According to the first principle of geography, compared with things that are far away, things that are near are more closely related, and the inverse matrix of geographical distance can describe this feature. For the geographical distance N_{ij} between regions i and j, the setting of the inverse distance means that the closer the distance between the two regions, the greater the weight; on the contrary, the farther the distance, the smaller the weight:

$$w_{ij} = \begin{cases} 1/N_{ij} & i \neq j \\ 0 & i = j \end{cases} \quad (11)$$

5. Empirical Results

5.1. Selection of the Spatial Econometric Model

To select an appropriate model for estimation and carry out Lagrange multiplier (LM) test on the spatial econometric model, the LM (error) and robust LM (error) are selected to test the spatial dependence, and the LM (lag) and robust LM (lag) are selected to test the spatial hysteresis. Table 3 displays the test results. The results are substantial, showing that the SEM is more suited than the non-spatial model, as can be seen from the data, and the SLM is also more appropriate than the non-spatial model, i.e., there are both spatial error and spatial lag terms in the model.

Table 3. Results of LM test for spatial econometric models.

Statistics	Coefficient	*p*-Value
LM (lag)	135.3556	0.0000
Robust LM (lag)	3450.9540	0.0000
LM (err)	811.5765	0.0000
Robust LM (err)	4127.1750	0.0000

Source: The author used STATA software for the calculations.

The Hausman test can identify the choice of a fixed effect or random effect model [75]. The basic step is to observe the significance of the Hausman result, and if the original hypothesis is rejected at the 5% significance level, the alternative hypothesis of the fixed effect is accepted. Using STATA software to carry out the Hausman test, the chi-square value of the test result is 21.22, while the *p*-value is 0.0196, meaning the original hypothesis is rejected and the fixed effect model is selected for analysis.

Furthermore, the likelihood ratio (LR) test is carried out on the model to verify whether the SDM will change into the SLM or the SEM [76], and the test results are shown in Table 4. The results are all significant at 1%, indicating that SDM model is significantly better than the SLM and the SEM, so it is suitable to use the Durbin fixed effect for regression. The model controls both endogenous and exogenous interaction effects, is a spatial model for missing explanatory variables, and can simultaneously solve the endogeneity problem of the spatial lag term of the explanatory variables and the spatial lag term of the explanatory variables. In the goodness-of-fit test, the results are all significant; that is, the double fixed effect (Both) is significantly better than the time fixed effect (Time) and the individual fixed effect (Ind), so the double fixed spatial Durbin model is selected for regression.

Table 4. Results of LR test for the spatial Durbin model.

Statistics	Coefficient	*p*-Value
SDM vs. SLM	70.63	0.0000
SDM vs. SEM	98.61	0.0000
Both vs. Ind	116.08	0.0000
Both vs. Time	1404.56	0.0000

Source: The author used STATA software for the calculations.

5.2. Estimation of the Spatial Econometric Model

Table 5 reports the results of the SDM based on the 0–1 weight matrix. All of the models' *p*-values are larger than 0, which indicates that there is a spillover effect in China's regional economic growth, which acts on neighboring regions through the spatial effect. The coefficient of the linear term of ER is significantly negative at the level of 1%, and the coefficient of the quadratic term of ER^2 is significantly positive, which indicates that the impact of ER on the regional economic growth presents a "U" shape. In other words, China's enterprises can form a reverse mechanism under ER. With the increase in ER, the ER will change from the negative inhibition to positive promotion of economic growth, meaning Hypotheses 1a, 1b, and 1c are verified. The impact of ER on regional economic growth shows a certain time effect. In the short term, there may be regional differentiation. Some regions sacrifice the environment for economic growth due to undertaking polluting industries, while some regions are forced by ER to transform and upgrade their industrial structures, thereby achieving the high-quality growth of the regional economy. In the long run, regions that initially partake in polluting industries will eventually tend to transform and upgrade their industrial structures to improve the quality of their regional economy. EKS has a significant spatial spillover effect, which can significantly promote regional economic growth. This indicates that the higher the regional green knowledge stock, the more conducive to the improvement of the regional green technology innovation level, the stronger the knowledge production capacity, and the stronger the ability to transform the knowledge stock into the driving force of economic growth. Thus, Hypothesis 2a is verified.

Table 5. Estimation results of the spatial Durbin model.

Variables	Individual Fixation Effect	Time Fixation Effect	Individual Time Double Fixation Effect
ER	−0.0131 ***	−0.0723 ***	−0.0137 ***
	(0.0036)	(0.0132)	(0.0035)
ER^2	0.0023 ***	0.0097 ***	0.0021 ***
	(0.0008)	(0.0034)	(0.0008)
EKS	0.0136 **	0.0456 **	0.0257 ***
	(0.0055)	(0.0199)	(0.0055)
RD	0.0446 ***	0.0913 ***	0.0300 ***
	(0.0114)	(0.0204)	(0.0112)
Edu	0.2439 ***	0.4378 ***	0.2573 ***
	(0.0318)	(0.0339)	(0.0306)
Ti	−0.0191 ***	−0.0816 ***	−0.0201 ***
	(0.0048)	(0.0154)	(0.0044)
Urb	0.3969 ***	0.1742 **	0.3655 ***
	(0.0460)	(0.0862)	(0.0460)
Gov	0.1378 ***	0.1990 ***	0.1217 ***
	(0.0134)	(0.0369)	(0.0132)
Open	0.0043	0.1265 ***	0.0208 ***
	(0.0061)	(0.0139)	(0.0061)
Spatial rho	0.6994 ***	0.0722	0.3516 ***
	(0.0386)	(0.0747)	(0.0614)
sigma2_e	0.0009 ***	0.0193 ***	0.0007 ***
	(0.0001)	(0.0013)	(0.0001)

Note: ***, **, respectively, indicate that the estimated values of the parameters are significant at the statistical levels of 1%, 5%, and the values in brackets are standard errors. Source: The author used STATA software for the calculations.

The coefficient of the effect of RD on the economic growth passes the significance level test of 1%, which reveals that the RD expenditure is an indispensable and important factor for economic growth, and RD can promote technological innovation and economic growth. The EDU coefficient is positive and passes the significance test, which indicates that human capital is beneficial to knowledge spillover and is beneficial to enhancing the absorption and transformation capacity of the knowledge spillover, thereby promoting economic growth. In addition, regions with high reserves of capital and talent will also promote the economic growth of the neighboring regions through the "trickle-down effect". The impact of Urb on the regional economic growth is significant at 1%, showing that the promotion of urbanization has an active effect on the economic growth of local provinces, and the improvement of the urbanization level is beneficial to the local economic growth. The Gov does not play an adverse role in economic growth, indicating that under the existing public budget system, the government still relatively respects the independent decision-making ability of the enterprises and plays a guiding role in maximizing their productivity. The coefficient of the level of Open is positive overall, revealing that open areas promote the production of knowledge spillover and help to reduce barriers to industrial agglomeration [77], conducive to regional economic growth. It is worth noting that the Ti coefficient value is negative, indicating a recent decline in the contribution rate at which expenditures on Ti support economic development. The possible reasons are as follows: (1) There are opportunity costs in Ti, and the increase in Ti may squeeze out productive inputs, resulting in a slowdown in economic growth. (2) There is a certain time lag in the process of Ti from investment to innovation to promoting economic growth, which may have no substantial impact on the economic growth in a short term. (3) The conversion rate of scientific research achievements is low, the patent protection of scientific research achievements is insufficient, and the due economic benefits are not generated. (4) The overall planning of Ti is insufficient, and the scientific research achievements cannot be effectively implemented due to lack of channels or financial support. (5) In addition, if the Ti of the local finance is more focused on the role of capital growth and technological progress in the use structure, this will increase the production scale, but it will not be possible to achieve significant improvements in production efficiency and environmental protection in the production process, thereby affecting the sustainable economic development. It can be seen that it is not desirable for developing countries to pursue rapid economic growth by blindly increasing their Ti, and other policies and measures also need to be implemented.

Since the SDM contains spatial lag terms of explanatory variables and explained variables, the coefficients in the model cannot effectively explain the spatial spillover effect of the variables, and further effect decomposition is needed to accurately measure the spatial effect of each variable on the explained variable [78]. The decomposition effect of the estimation results of the SDM is shown in Table 6.

Table 6. Estimation results of effect decomposition for the spatial Durbin model.

Variables	Direct Effect	Indirect Effect	Total Effect
ER	−0.0157 ***	−0.0354 ***	−0.0511 ***
	(0.0038)	(0.0125)	(0.0145)
ER^2	0.0025 ***	0.0057 *	0.0082 **
	(0.0009)	(0.0030)	(0.0035)
EKS	0.0288 ***	0.0415 **	0.0703 ***
	(0.0056)	(0.0166)	(0.0197)

Note: ***, **, and *, respectively, indicate that the estimated values of the parameters are significant at the statistical levels of 1%, 5%, and 10%, and the values in brackets are standard errors. Source: The author used STATA software for the calculations.

From the perspective of the direct effect, the linear term coefficient of the ER on the local economic growth is positive, while the quadratic term coefficient is negative, and both pass the significance test of 1%, which further proves that the ER has a "U"-shaped impact on China's economic growth in space. In the initial stage of ER, the increase in ER increases the environmental cost to the enterprises and affects the regional environmental innovation, while the effect of the innovation compensation is not obvious in the initial stage, which leads to the negative impact of the ER on the economic growth. With the further strengthening of the ER, when the innovation compensation effect outweighs the cost effect, it will positively affect the economic growth. The direct effect of the EKS is 0.0288, which is significant at 1%, indicating that every 1% increase in EKS will lead to 0.0288% economic growth in the region, further confirming the positive correlation between EKS and regional economic growth, meaning Hypothesis 2b is verified.

From the indirect effect point of view, the ER will also gradually change from having a negative impact to a positive influence on the explained variable of the neighboring areas. In the short term, the increases in ER and government supervision in a certain region may force the local heavily polluting enterprises or industries to move to the neighboring areas, which will make the nearby areas' environmental contamination worse and adversely affect the economic growth. In the long run, although the transferred enterprises will cause pollution to the environment, they will indeed increase the income from industrial transfer in the neighboring regions, thereby promoting the development of their technological innovation capabilities, which will have a beneficial impact on the the nearby areas' economic growth. The indirect effect of the EKS is 0.0415, revealing that EKS will increase the economic growth of the neighboring regions by 0.0415% in every 1% increase, which is greater than the impact of the EKS on the local regions, meaning Hypothesis 2c is verified. Regarding the overall effect, the impact of the ER and EKS on the economic growth is consistent with the direct effect and indirect effect.

5.3. Robustness Test

This paper further uses the inverse matrix of geographical distance to estimate the effects of the ER, EKS, and regional economic growth. The results are shown in Table 7. The significance and sign of the direct effect, indirect effect, and total effect have not changed, which is consistent with the original estimation results. This shows that the change in spatial weight matrix does not affect the robustness between the ER, EKS, and regional economic growth, and the empirical results remain robust.

Table 7. Results of robustness test for the spatial Durbin model.

Variables	Direct Effect	Indirect Effect	Total Effect
ER	−0.0194 ***	−0.1446 ***	−0.1641 ***
	(0.0038)	(0.0407)	(0.0424)
ER^2	0.0030 ***	0.0293 ***	0.0324 ***
	(0.0008)	(0.0099)	(0.0102)
EKS	0.0433 ***	0.1963 ***	0.2396 ***
	(0.0063)	(0.0511)	(0.0545)

Note: ***, indicate that the estimated values of the parameters are significant at the statistical levels of 1%, and the values in brackets are standard errors. Source: The author used STATA software for the calculations.

5.4. Regional Heterogeneity Analysis

Considering the differences in the development of the ER and EKS among the different regions, China is further divided into the east, center, and west in this paper. Using panel data from these three regions, we conduct a spatial econometric analysis to discuss the spatial impact of the regional heterogeneity on the ER and EKS. Table 8 shows the specific estimation results.

From the standpoint of the total effect result, the ER in the eastern and western regions still presents a "U"-shaped feature in terms of economic growth. From the size of the estimation coefficient, it can be seen that the dividend of the ER in the eastern region is greater than in the central and western regions. From the perspective of the direct effect, the quadratic coefficient of the ER is not significant, indicating that this nonlinear effect is not obvious. The coefficient of the linear term of the ER in the eastern region is significantly negative, indicating that the ER in the eastern region is at the stage of the "following cost". The rising cost of the ER inhibits the economic growth and is bigger than compensation effect. Although the quadratic coefficient is not significant, the possibility that the impact of the ER will start to rise after reaching the lowest point is also considered. From the indirect effect, the implementation of the ER has regional heterogeneity on the economic growth of the neighboring regions. The quadratic coefficient of the ER on the economic growth is active in eastern China. Combined with the sign of the linear coefficient of the ER, it can be concluded that the innovation compensation impact of the ER on the surrounding regions in eastern China will spill over to neighboring provinces to promote economic growth. The spatial spillover effect of the ER in the central region is not very stable, and the implementation of the ER cannot boost the economics of the neighboring provinces and cities in the central region. The symbols of the coefficients of the linear term and the quadratic term of the ER in the western region conform to the "U" shape, which indicates that the carrying out of the ER policy has a better implementation effect on the neighboring provinces than on its own in western China. The phenomenon that the spatial effect of the ER in the western region being stronger than that in the central region is worth considering. The possible reason is that the western region's overall strength is lower than that of the central and eastern areas, is better at learning and imitating the economic policies of the surrounding regions, and has a stronger ability to absorb external knowledge spillover. However, the more developed eastern and central regions often have a larger industrial scale, and it is more difficult for high-pollution enterprises to migrate to the neighboring provinces, meaning it is more difficult to produce spatial spillover.

Table 8. Results of regional heterogeneity analysis for the spatial Durbin model.

	Variables	**Eastern Region**	**Central Region**	**Western Region**
Direct effect	ER	−0.0272 ***	−0.0014	−0.0005
		(0.0065)	(0.0072)	(0.0037)
	ER^2	−0.0007	−0.0035	0.0003
		(0.0044)	(0.0023)	(0.0007)
	EKS	0.0167 ***	0.0745 **	0.0742 ***
		(0.0041)	(0.0340)	(0.0168)
Indirect effect	ER	0.0056	−0.0183	−0.0152 **
		(0.0088)	(0.0116)	(0.0070)
	ER^2	0.0195 ***	−0.0031	0.0028 **
		(0.0075)	(0.0046)	(0.0014)
	EKS	0.0254 ***	0.1712 **	0.2276 ***
		(0.0077)	(0.0761)	(0.0494)
Total effect	ER	−0.0216 **	−0.0197	−0.0157 **
		(0.0103)	(0.0150)	(0.0079)
	ER^2	0.0189 **	−0.0065	0.0031 **
		(0.0085)	(0.0061)	(0.0016)
	EKS	0.0421 ***	0.2458 **	0.3018 ***
		(0.0100)	(0.1063)	(0.0559)

Note: ***, **, respectively, indicate that the estimated values of the parameters are significant at the statistical levels of 1%, 5%, and the values in brackets are standard errors. Source: The author used STATA software for the calculations.

The EKS has contributed noticeably to economic growth regardless of the region. Among them, the EKS coefficients of the eastern and western regions are significant at 1%, while that of the central region is significant at 5%. This further shows that China's EKS is the direct driving force promoting regional economic growth, and its spatial spillover effect on the neighboring areas is also obvious. In the three regions, the coefficient of the indirect effect exceeds the coefficient of the direct effect; that is, the influence of EKS in the neighboring regions on this region is greater than that of this region itself.

6. Discussion

First, the ER approach is an important policy put forward by China to achieve sustainable economic development. Scholars have done a lot of research on this, but the existing literature mostly considers the linear influence of ER on economic growth. In order to make up for this deficiency, this paper considers the nonlinear influence of the ER, and the conclusion obtained further confirms the two theories of the "following cost theory" and "innovation compensation theory", which is helpful when choosing differentiated ER approaches according to different development stages. Second, the impact of the KS on the economic growth is a hot research topic. However, few scholars have defined the term "environmental knowledge spillover" (especially for the case of China). This paper offers a fresh viewpoint and adds to the knowledge on EKS and economic growth. In addition, the research on ER and KS in relation to economic growth often ignores the influence of spatial factors. This paper also pays attention to the possible spatial effects, including both local effects and neighboring effects.

However, the research of this paper still has the following limitations: Academically, knowledge is divided into explicit knowledge and implicit knowledge. Due to the limitation of obtaining data, the number of green patents obtained in this paper is the data after implicit knowledge has been converted into explicit knowledge, but there is a certain gap with the theoretical situation. The technological innovation performance includes both the quantity and economic value of innovation achievements. However, the number of patents cannot accurately reflect the innovation achievements number and economic value due to the influence of enterprises' willingness to apply for patents, restrictions of patent systems and policies, and difficulty in quantifying indirect income [79]. In addition, China defines invention patents, utility model patents and design patents as "patents", but there are differences in the classification and licensing standards of patents in different countries, for example, the United States, Britain and other countries do not have patents for utility model. Therefore, under the conditions of regional heterogeneity and different institutional scope, the horizontal comparability of analysis results between different countries may be insufficient. In terms of the types of ER, the impact of ER may be different according to the types of ER and the degree of implementation. Therefore, it is of certain significance to further study the subdivision types of ER.

7. Conclusions and Recommendations

7.1. Conclusions

Based on the panel data from 31 provinces and cities in China from 2005 to 2020, in this paper we used the Moran index and Moran scatter plot to analyze the spatial correlation and to construct the SDM to analyze the impacts of ER and EKS on regional economic growth. The following are this paper's primary conclusions.

First, the spatial pattern of economic growth in China has changed dramatically over recent years. The global Moran index and local Moran scatter plot show that the spatial distribution of the economic growth in different provinces and cities has significant characteristics of economic agglomeration. The *p*-value of the estimation results of the SDM indicates that a spillover impact on regional economic growth existing in China, which acts on neighboring regions through a spatial effect.

Second, the ER shows a "U"-shaped influence on the regional economic in the surrounding areas. Therefore, the impact of the ER on the regional economic growth first decreases and then increases. In the initial stage of ER, the increase in ER increases the environmental cost to the enterprises, and the effect of the innovation compensation is not obvious in the initial stage, resulting in a negative impact of the ER on the economic growth. With the increase in ER to a certain extent, when the innovation compensation effect exceeds the cost effect, it will have a positive impact on the regional economic growth.

Thirdly, the direct effect, indirect effect, and total effect of the EKS are all significantly positive, indicating that the EKS not only promotes the local regional economic growth significantly, but also has a spatial spillover effect on the economic growth in neighboring regions. The coefficient of the indirect effect exceeds that of the direct effect, indicating that the contribution of EKS to economic growth through neighboring regions is greater than the direct impact on the economic growth of local regions.

Fourthly, the regional heterogeneity analysis revealed that the dividends from ER obtained by the eastern region are greater than those obtained by the central and western regions, and ER in the eastern region has a spatial spillover effect on neighboring regions and promotes the economic growth of these neighboring regions. The spatial effect of ER in the western region is stronger than that in the central region. EKS in the eastern, central, and western regions has obvious direct and indirect effects on the economic growth.

Finally, in terms of the control variables, RD, Edu, Urb, Gov, and Open have positive impacts on the regional economic growth. Due to the opportunity cost of Ti, certain time lag in promoting economic growth, low conversion rate of scientific research achievements, insufficient overall planning of Ti, and the neglect of the production efficiency and green environmental protection in the production process, Ti does not play a positive role in promoting economic growth.

7.2. Recommendations

First, we recommend that the intensity of the ER be strengthened and the requirements for sustainable economic development be met. We should continue to strengthen the ERs, paying attention to the development of green scientific technologies, accurately implementing ER policies with focus and direction, and enhance the "innovation compensation effect". By strengthening these ER policies, enterprises will be forced to independently enhance their level of technological innovation and their digestion and absorption capacity, helping to improve productivity, reduce environmental pollution, support the development of green emerging industries, and build a coordinated development system of ER. In addition, we should also comprehensively investigate the implementation effects of environmental policies in local regions and neighboring regions, build a regional collaborative environmental governance system, and enhance the enforcement and effectiveness of ER policies.

Second, we should take note of the EKS between regions and cultivate a new impetus for economic growth. On the one hand, we should accelerate the realization of knowledge production, accumulation, and overflow. We should encourage increases in green technology research, development capital, development personnel, and green products to flow across regions to promote industry complementarity. On the other hand, we should build a knowledge exchange platform, strengthen the interaction and exchange of knowledge carriers, enhance the external learning absorption capacity between regions, and strengthen the formal and informal links between diversified innovation organizations to promote the spillover of knowledge between regions. We should also actively introduce advanced environmental protection technologies and equipment to achieve the re-innovation of green technologies and stimulate the production of regional environmental knowledge.

Thirdly, we should unblock the science and technology expenditure chain and improve the market for the transformation of technological achievements. We should optimize the investment structure regarding science and technology expenditure and should enrich the methods used to support enterprise innovation. We should set up platforms and markets for the transformation of achievements, and set up transfer services. We should pay attention to patent protection, strengthen the supporting policies of scientific and technological intellectual property rights, and reduce the risk of enterprise achievement transformation. We should set up specialized agencies or organizations; strengthen the coordination and communication among departments; improve the supervision of science and technology project funds; and increase the effectiveness with which science and technology funds are used. We should strengthen our ability to support green science and technology, pay attention to environmental protection in the production process.

Fourthly, we should optimize the innovation environment and facilitate the steady growth of factor inputs. We should increase the construction of knowledge infrastructure in the region, expand capital investment conducive to environmental innovation, improve the regional human resource reserve, and enhance the regional awareness toward innovation. Starting from development in the region and combined with the current situation in the region, we should encourage the appropriate distribution of the population and resources, explore the path of integrating environmental regulations with urbanization, improve the innovation level of enterprises with the diversity brought about by the level of urbanization, and promote the sound development of industries and economic growth.

Fifthly, we should strengthen the regional connectivity and build a pattern of mutual benefits and win–win results. On the one hand, we need to improve the way that transportation infrastructure is constructed; scientifically plan a basic transportation layout; accentuate the fundamental and overarching contributions that transportation infrastructure makes to societal and economic advancement; and achieve the smooth circulation of essential resources, commodity trading, and technological knowledge. On the other hand, we should improve the mechanism of cooperation and exchange between regions and make use of the region's strengths to achieve a more reasonable industrial division and collaboration. In addition, on the basis of strengthening the organic links between the various functional regions, the knowledge spillover between regions can be used to boost the economy of the neighboring provinces.

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