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How does environmental regulation promote the eco-efficiency? exploration on the role of industrial transfer in the driving mechanism

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Abstract: How does the environmental regulation act on the ecological efficiency? What is the role of industrial transfer in the mechanism of action? Relations and interactions between the three determine the economic quality when ecological performance is concerned. Empirical studies in this paper are based on samples of the Yangtze River economic belt in China, which contributes nearly half of China's GDP. By measuring the environmental regulation, industrial transfer and ecological efficiency, data and indexes are prepared for investigation of the driving mechanism of environmental regulation and illustration of the role of industrial transfer. Applying the Markov process to model the industrial transfer between regions, the dynamic of transfer is simulated and facilitate further study on the effects of industrial transfer. Finally, this paper concludes that, targeting on the improvement of ecological efficiency, environmental regulation releases its utility through industrial transfer. The highlights may include three aspects. Theoretically, it illustrates driving mechanism of improving the eco-efficiency by environmental regulation. Technically, it pioneers a methodology of describing the regional industrial transfer by modeling it with Markov process. Practically, the conclusion supplies insights into the inherent law of sustainable development for policy makers.

Keywords: Environmental regulation; Industrial transfer; Ecological efficiency; Markov process

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1. Introduction

The Yangtze River economic belt is the most important inland river economic belt in China. It gathers 42.8% of China's population and 44.1% of GDP with only 21.4% of its land area. As the focus and vitality of China's economy, the Yangtze River Economic Belt will become a demonstration of regional high-quality development. Over the past decade, the state and local governments have guided the orderly transfer of resource and labor-intensive and domestic demand-oriented capital and technology intensive industries to the middle and upper reaches. It cannot be ignored that the related industries in the eastern coastal areas have also been transferred to the central and western regions due to problems such as labor and raw materials, which is also in line with the theory of industrial gradient transfer. As mentioned in the pollution shelter theory, the pollution industry is transferred to underdeveloped areas with the improvement of environmental regulation in developed areas, and the pollution industry is transferred upstream to the middle and upper reaches of the Yangtze River economic belt. The Environmental Kuznets curve

also puts forward that there is an inverted U-shaped relationship between eco-environmental quality and economic development level, and the industrial gradient transfer in the Yangtze River Basin is just in line with this objective law, but the pollution brought by the clip is more hidden. Therefore, the relationship and interaction among environmental regulation, industrial transfer and ecological efficiency has become an important economic research topic.

The research perspective of this paper on the mechanism of environmental regulation, industrial transfer and ecological efficiency focuses on the impact of the first two on ecological efficiency. Intuitively, both environmental regulation and industrial transfer will promote the improvement of ecological benefits, and this paper is mainly committed to revealing the impact of environmental regulation on ecological efficiency by promoting industrial transfer. Firstly, this paper measures the environmental regulation, industrial transfer and ecological efficiency of provinces and cities in China's Yangtze River economic belt. Because the data of industrial transfer is only limited to the amount of industrial transfer in and out of provinces and cities, there is a lack of specific values of industrial transfer between provinces and cities. Therefore, this paper introduces Markov process to simulate the dynamics of industrial transfer between provinces and cities, and on this basis, numerically estimate the effect of industrial transfer on ecological efficiency, so as to reveal the role of environmental regulation in promoting ecological efficiency through industrial transfer and provide theoretical support for policy suggestions.

The remaining parts are arranged as follows. We review the exited researches on related theory and topics in Section 2. By Section 3, measurements of environmental regulation, industrial transfer and ecological efficiency are established after data collection and selection. Sections 4 constructs the model of industrial transfer driven by environmental regulation, based on which, we proceed the numerical implements of industrial transfer driven by environmental regulation in Section 5. Hence in Section 6, the eco-efficiency driving mechanism of environmental regulation is verified. All the established conclusions and managemental implications achieved in the above sections will be summarized in Section 7.

2. Literature review

Relevant researches on the three aspects and their correlations will be summarized and commented.

2.1. Researches on environmental regulation

In terms of environmental regulation tools, many experts generally divide them into command-and-control policy tools, market-oriented policy tools, voluntary environmental policy tools, etc. Some experts also divide them into formal and informal environmental policy tools according to the implementation mechanism of environmental policy tools. The World Bank divides environmental policy tools into four categories: market utilization, market creation, environmental regulation and public participation. The theory and practice of environmental policy tools originated from western developed countries. In recent years, many innovations have been made in environmental policy tools for specific problems, and a variety of environmental policy tools have been continuously integrated and used. (Xie et al., 2019) proposed green electricity price from the perspective of green consumerism, and investigated the participation intention and implementation possibility of the potential adopters of green electricity price in the UK. (Gusmerotti et al., 2012) mainly explored the role played by stakeholders through negotiation tools and the effectiveness of various types of environmental protection agreements in environmental governance. (Gregmar et al., 2018) proposed the quality control of environmental policy evaluation tools based on specific cases in the Netherlands and Denmark, and advocated that the government should be responsible for enhancing the effectiveness of environmental policy tool evaluation. (Banos et al., 2018) selected the sustainable tool of environmental

policy, namely the social ecological model, adopted sensitivity analysis and other system dynamics methods to consider environmental policy assessment as a whole, and emphasized environmental impact assessment as a powerful tool. (Tosun et al., 2019) took the integration of environmental policies as the entry point to explain multi-level governance issues at the EU level, explore how to transform abstract policy concepts into practical policy tools, and focus on knowledge creation and authorization in the multi-level system.

Many scholars also select different environmental regulation variables for different research objects to conduct relevant empirical studies, and mostly use relevant data in annual reports for some micro enterprises. (Greenstone M et al., 2014) collected relevant laws and regulations to evaluate India's environmental regulations from the perspective of air and water pollution and their corresponding environmental regulations, and verified the effectiveness of air control and water control respectively. (Rubashkina et al., 2015) adopted the indicator PACE, which is the expenditure of pollution reduction and control. It also defines the intensity of environmental regulation from the perspective of expenditure, which is different from some measures based on the achievements of environmental regulation. (Neves et al., 2020) adopted environmental taxes to represent the severity of environmental regulations on carbon emissions in the European Union.

2.2. Researches on ecological efficiency

Corporate carbon performance is a newly developed concept to measure the achievement effect obtained by carbon consumption. Traditionally the corporate carbon performance is defined in forms of a ratio between certain financial indicator (like the operation revenue) and the amount of carbon emission. Based on the principle of simplicity, one of the widely applied expressions of carbon performance for Chinese enterprises with carbon emission is a ratio of sales and carbon emission, as used in (He, et al., 2017). Other approaches input and output models with non-radial directional distance are available to calculate the carbon performance (Zhou, et al., 2018; Zhu et al., 2021; et al., Li, et al., 2022). From the perspective of corporate management, carbon performance is well applied to investigate the impact of carbon emission and green innovation on the financial performance. There are intensive researches on this relation and influences, as listed in Table 2.2 below.

Many scholars continue to develop and innovate the concept of ecological efficiency on the early basis, and also explore and improve the evaluation system of ecological efficiency, trying to be closer to the reality of ecological construction. (Marti et al., 2020) compared and analyzed the ecological efficiency presented by DEA in African countries based on the affirmation of ecological footprint and biocapacific capacity. (Zameer, et al., 2020) adopted the entropy weight method to measure provincial ecological efficiency in China, and used the coupling coordination degree model to evaluate the coordination relationship between ecological efficiency and natural resources and financial development. (Gulaliyev, et al., 2020) evaluated the economic-ecological efficiency of six regions in Azerbaijan based on solar energy resources, technology, economy, market and other factors. (Hickel, 2020) proposed sustainable development index to replace human development index, which was used to represent the ecological efficiency of human development. Key ecological variables such as carbon dioxide and material footprint should be retained in the calculation of the formula. (Kubacka, 2019) collected CLC data sets and used FRAGSTATS and Statistica to evaluate the ecological efficiency of Polish landscape conservation. (Kharrazi, 2016) used the cross-efficiency model of Shannon entropy index and data envelopment analysis DEA to rank the ecological efficiency of Italian cities.

Scholars extend the application scope of eco-efficiency to various fields, and also adopt different research methods and analysis models due to differences in application fields. (Flyud, 2010) proposed ecological efficiency of foreign trade to determine the advantages of Ukraine's foreign trade and how to form an effective trade structure in the future, (Hoang, et al., 2012) used input-oriented data envelopment analysis to measure

and decompose the economic, environmental and ecological efficiency levels of agricultural production in OECD countries. Starting from the ecological modernization of the electric power industry, (Sarkis, et al., 2012) selected 437 fossil fuel power plants in the United States to conduct an ecology-technical efficiency investigation, and evaluated whether their organizational and technological innovation could improve such joint efficiency. (Tu, et al., 2015) further embodied this application by selecting ecological engineering rice from Mekong Delta in Vietnam and using stochastic frontier method to estimate and compare the environmental efficiency of ecological rice and normal rice. (Korhonen, 2008) mainly considered the limitations and difficulties of the concept of ecological efficiency and reconsidered the economic logic of ecological modernization. (DiMaria, 2019) proposed a new indicator to evaluate the sustainable development of a country. The concept of ecological efficiency was put forward from the Angle of ecological footprint and ecological reserve, and the specific evaluation method of ecological efficiency was put forward.

2.3. Researches on industrial transfer

Studies on industrial transfer started earlier, and many mature and classic theories have been formed, from absolute advantage theory to relative advantage theory, from the perspective of international trade to the perspective of industrial development, such as goose shape theory, product life cycle theory, marginal industry expansion theory, international production compromise theory, etc. These classical theories will be highlighted in chapter 2. Since the 1990s, the research on industrial transfer has gradually turned to empirical research and started to face specific countries, specific industries and specific enterprises. (Haddad, et al., 1993) empirically proposed that international industrial transfer had no significant impact on the productivity of domestic enterprises by adopting the cross-sectional data of Moroccan enterprises. The empirical test conducted by (Aitken, et al., 1999) on Venezuelan enterprise data also supports this conclusion. Some experts mainly studied the spatial distribution of industrial transfer. (Peter, et al., 2000) empirically analyzed the spatial direction and geographical distribution of international industrial transfer of IT industry by taking electronic information industry as an example. (Peter, 2000) and (Biggiero, 2006) mainly investigated the transfer among regional systems. To explore the transfer strategies of industry and knowledge under the challenge of globalization and digitalization. (Kurata, et al., 2020) even explained industrial transfer from the perspective of vertical specialization in north-south trade, and proposed that the decline of trade costs in different production stages would encourage vertical specialization, and final product production would shift to southern countries under a certain threshold value.

In terms of the mechanism and driving factors of industrial transfer, domestic and foreign experts also give explanations from different aspects, and combine specific industries and micro enterprises to explain and test. (Andersen, 2006) explained the problem of industrial transfer from the perspective of regional clusters on a global scale, and proposed that more regional clusters are the potential driving force for the reorganization of global production activities caused by global outsourcing or overseas outsourcing. (Rupasingha, et al., 2020) proposed that the benefits brought by agglomeration economy promote the concentration of industries in cities from the perspective of business location selection and relocation decisions in the United States.

2.4. Correlation study of the three and summation of literature review

In terms of the relationship between environmental regulation and industrial transfer, although environmental regulation is intended to promote energy saving and emission reduction and industrial upgrading, it objectively causes inter-regional transfer of high energy consumption and high pollution industries. (Choi, et al., 2013) conducted a field study on environmental regulation and health protection in asbestos production in Japan,

Germany, Indonesia and South Korea, aiming at the process of asbestos industry transfer in Asia and the environmental health problems caused by it. (Milani, et al., 2017) believe that polluting industries will move to countries with less stringent environmental regulations, but pollution intensity and ease of relocation will affect the response of various industries to strict environmental regulations. (Hamhami, et al., 2020) conducted A case study of Industrial enterprises in Algeria to discuss the impact of market forces and environmental regulations on industrial pollution, especially the transfer of cleaner production technology between developed industrial countries and developing countries.

On the impact of industrial transfer on the ecological environment, the main theoretical hypothesis is the pollution paradise hypothesis. The pollution Paradise hypothesis or pollution refuge hypothesis was first proposed by (Walter, et al., 1979). This hypothesis has also been analyzed and verified in the process of industrial transfer between countries, and has also been applied to inter-regional transfer within countries. (Al-mulali, et al., 2013) used multivariate framework analysis to test the effectiveness of the gulf states' pollution haven hypothesis and found that energy consumption and GDP growth were still the main pollution sources in the Gulf states. (Terzi, et al., 2020) investigated the relationship between FDI inflow and CO2 emissions in Turkey by using data of more than 40 years, and proposed that such one-way effect supports the pollution refuge hypothesis in Turkey.

In terms of the relationship between environmental regulation and ecological environment, the original intention of environmental regulation is to protect the ecological environment and other good intentions, but good intentions do not always bring good results, porter hypothesis or green paradox and other related theories have been constantly developed and tested by many empirical tests. (Schou, 2002) believed that environmental regulation itself was unnecessary, and pollution emissions would automatically decrease with the continuous consumption of natural resources. (Sinn, 2008) first proposed the concept of green paradox, which intended to restrict the implementation of climate change policies but led to accelerated exploitation of fossil energy and accelerated greenhouse gas emissions leading to environmental deterioration. (Van, et al., 2012) further divided the green paradox into the weak version and the strong version. The weak version emphasizes that imperfect climate policies increase short-term carbon emissions, while the strong version emphasizes on enhancing the net present value of future losses of climate change. (Porter, 1991) proposed Porter hypothesis, which is different from the green paradox, and believed that environmental protection policies in the true sense would not increase the cost of enterprises, but would also enhance competitiveness through the net income generated by innovation. However, some experts believe that Porter's hypothesis is not valid. Empirical studies of some countries or industries are selected, and they believe that the relationship between environmental regulation and technological innovation is uncertain, and the promoting effect and inhibiting effect coexist, so Porter's hypothesis is difficult to be supported by empirical evidence. (Farooq, et al., 2021) use empirical evidence from Asian economies to verify the negative impact of carbon tax rate on enterprises' investment decisions.

To sum up, scholars have conducted detailed discussions on the origin and development of environmental regulations. They can also conduct comparative analysis for different types of environmental regulations and conduct empirical analysis on environmental regulations by using single indicator or comprehensive indicator method. Existing studies have been able to sort out the causes and manifestations of industrial transfer in detail. Combined with several typical industrial transfers in the world, domestic scholars have also explored inter-regional industrial transfers in economic belts or urban agglomerations. In terms of ecological efficiency measurement, many experts use different measurement methods from their own fields to conduct empirical analysis in combination with specific regions, and obtain some spatio-temporal differentiation rules of ecological environmental efficiency. As for the internal relationship between environmental regulation,

industrial transfer and ecological efficiency, scholars have realized that the transfer of polluting industries caused by environmental regulation, the nonlinear relationship between environmental regulation and economic development stage, and the necessity and difficulty of collaborative environmental governance. But lacking research on the accurate definition of ecological efficiency, failed to accurately master the law of industrial transfer and pollution industry transfer, also failed to environmental regulation or comparing different types to choose from multiple evaluation system, failed to clarify how environmental regulation through cause pollution industry transfer will affect economic belt or the urban ecological environment, It also fails to fully recognize the ultimate impact of local government's measures to protect the ecological environment on ecological efficiency, which may be inconsistent with traditional theories. This paper hopes to reveal the impact of environmental regulation on ecological efficiency through industrial transfer through vivid depiction of industrial transfer, so as to make up for the gap of previous studies.

3. Index selection and data collection

3.1. Measurement of environmental regulation

The environmental regulation index is a relatively hidden latent variable. Generally, observation variables such as pollution control input and pollutant discharge are used to represent the intensity of environmental regulation. Some experts also divide it into cost-based environmental regulation and investment-based environmental regulation according to the nature of capital. According to the statistical caliber of China's relevant statistical yearbook, only the total investment in environmental pollution control is close to the real performance of environmental regulations. Of course, some experts test the policy effects of environmental regulations with the help of the dual difference model and other dummy variables before and after a specific environmental policy tool. Some experts have studied some environmental regulation policy tools, which can be divided into command-based environmental regulation, market-based environmental regulation, voluntary environmental regulation (public participation environmental regulation) and information-based environmental regulation. In general, scholars mainly observe and examine pollution control investment from the aspects of proportion, operating cost of pollution control facilities, per capita income level (endogenous environmental regulation intensity), times of inspection and supervision by environmental agencies, and pollution emissions. The proportion of total investment in industrial pollution control in industrial added value is used as a single indicator, because this indicator represents the efforts and governance determination of local governments in environmental regulation from the perspective of economic expenses, and then focuses on the development trend and spatial differentiation of environmental regulation in the Yangtze River Economic Belt from 2005 to 2018. Due to the slow updating of this block of data in the yearbook, some data of 2019 and 2020 cannot be obtained for the time being. In the empirical link of this paper, data of 2018 and previous years are uniformly adopted.

Table 3-1. Intensity of environmental regulation in provinces and cities of the Yangtze River Economic Belt: 2005-2018 Unit: percentage.

Region	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Shanghai	0.21	0.13	0.11	0.18	0.13	0.14	0.09	0.16	0.07	0.24	0.30	0.69	0.53	0.09
Jiangsu	0.42	0.25	0.22	0.26	0.16	0.10	0.14	0.16	0.23	0.18	0.22	0.25	0.13	0.22
Zhejiang	0.31	0.33	0.28	0.14	0.18	0.09	0.12	0.18	0.35	0.40	0.34	0.32	0.19	0.17
Anhui	0.25	0.25	0.20	0.33	0.27	0.11	0.13	0.16	0.46	0.19	0.19	0.41	0.24	0.17
Jiangxi	0.50	0.38	0.30	0.18	0.12	0.15	0.12	0.07	0.24	0.18	0.21	0.14	0.14	0.25
Hubei	0.61	0.51	0.43	0.37	0.54	0.41	0.11	0.15	0.24	0.24	0.14	0.29	0.13	0.10
Hunan	0.64	0.64	0.51	0.34	0.28	0.22	0.12	0.20	0.23	0.16	0.24	0.11	0.07	0.06

Chong-qing	0.38	0.30	0.23	0.48	0.24	0.21	0.11	0.08	0.15	0.10	0.11	0.06	0.09	0.08
Sichuan	0.79	0.65	0.52	0.39	0.17	0.10	0.18	0.10	0.16	0.20	0.11	0.10	0.11	0.13
Guizhou	0.83	1.18	1.00	0.82	0.71	0.45	0.72	0.56	0.73	0.59	0.32	0.15	0.13	0.16
Yunnan	0.57	0.67	0.55	0.50	0.45	0.41	0.46	0.57	0.63	0.63	0.56	0.33	0.15	0.22
Mean	0.50	0.48	0.40	0.36	0.30	0.22	0.21	0.22	0.32	0.28	0.25	0.26	0.17	0.15
SD	0.21	0.30	0.25	0.19	0.19	0.14	0.20	0.18	0.21	0.18	0.13	0.18	0.13	0.06
CV	0.41	0.62	0.63	0.53	0.65	0.64	0.95	0.81	0.65	0.63	0.53	0.69	0.74	0.43

Note: Data is calculated from the proportion of total investment in industrial pollution control in industrial added value.

3.2. Measurement of industrial transfer

According to the analysis of classical criteria, there are differences in resource endowment comparative advantages between eastern and western regions and unbalanced distribution of market size demand, and the central and local governments have also issued a series of policies to support industrial transfer. Of course, some empirical studies have shown that China has not seen large-scale industrial transfer so far, but inter-regional industrial transfer is different from international industrial transfer, and does not need to involve tariffs and labor mobility and other restrictions. Many scholars insist that industrial transfer is inevitable and happening, and accurate measurement of the scale of industrial transfer is the key to solve this problem. Some scholars use relative indexes such as regional output value or the proportion of added value to measure industrial transfer. For example, (Liu Z Y et al. 2010) used the change of the proportion of added value of regional industries to refer to industrial transfer. Some experts use Gini coefficient, Theil index, Herfindahl index and other measures to measure industrial transfer, which can effectively overcome the influence of relative measure on the size of administrative divisions and reflect the change of industrial value-added degree and the overall process of industrial transfer. The industrial gradient coefficient is also used to indirectly reflect the degree of industrial transfer, and the multi-regional input-output model based on inter-regional input-output is often introduced into the measurement process. However, the data of inter-provincial input-output is published only once every five years, so it is not suitable for the measurement of annual industrial transfer here.

To accurately reflect the industry difference before and after the transfer, here will use off shift share analysis method to measure the Yangtze river economic belt industry scale, because the country contains 34 provincial administrative region (including 23 provinces, five autonomous regions, four municipalities directly under the central government, two special administrative region), Taiwan, Hong Kong, Macao and other provinces and regions (SAR) data is not easy to collect, Only 31 provinces and cities in mainland China are investigated here, and 11 provinces and cities in the Yangtze River Economic Belt are separately listed from the final results for later research. Although the horizon cannot and should not be confined to the Yangtze river economic belt industrial relocation within the scope of research questions, industrial transfer phenomenon in China features the three major economic belt has, however, some countries have issued such as the Yangtze river economic belt industrial relocation policy, guide to the Yangtze river economic belt within the industry transfer become the main trend, will also accelerate the trend of development of the domestic large cycle, Therefore, the measured industrial transfer scale can be regarded as the industrial transfer in the Yangtze River Economic Belt. The deviation share analysis method regards the industrial transfer as an event. Before the transfer, the industrial development is relatively stable, while after the transfer, the industrial development is greatly changed, and the relative change before and after the transfer is the scale of industrial transfer. In general, shift-share analysis is a realistic way to measure industrial transfer according to share changes. It can decompose the changes of economic variables in specific regions and describe the transfer of industries or polluting industries across provinces as a whole.

Deviation share analysis generally decomposes regional increment into share component (national growth component), structural deviation component and competitiveness deviation component, etc. (see Formula 3-1 below), is the variable value in the early stage of the regional primary industry, is the variable value in the late stage of the industry, and its change value can be expressed as. National growth component refers to the study of industry of a region, in accordance with the industry growth rate should increase the amount of the whole nation, and industrial structure component refers to the industry growth rate and the state's overall growth rate difference caused by regional industry growth, competitiveness component refers to the actual growth differences of regional industry changes and the effect of component, and respectively in the nation's growth, industrial structure components, competitiveness. But deviates from the traditional analysis method is mainly used for industrial competitiveness or industrial structure analysis, even if combined with industry shift did not break through the traditional analysis method, such as extension of traditional dynamic deviation - share analysis model, quantitative analysis of industrial transformation of the regional units, this model will give full consideration to the national industry increment problem, From the change of industrial quantity in a single region to the measure of the change of industrial quantity across regions (formula 3-2). From theoretical analysis and the reality, the sum of all the regional industry transfer component should be 0, combined with the traditional deviation analysis model (3-1), regional industry growth in removing national growth components and sector structure, the rest is the measure of industry transfer, and is an area due to its reduction arising from the difference and the average development increased.

$$\Delta X_{ij} = X_{ij}^{`} - X_{ij} = X_{ij}r + X_{ij}(r_i - r) + X_{ij}(r_{ij} - r_i) \quad (3\text{-}1)$$

Among them, $r = \sum_{i=1}^{S}\sum_{j=1}^{R}(X_{ij}^{`} - X_{ij}) \Big/ \sum_{i=1}^{S}\sum_{j=1}^{R} X_{ij}$ ; $r_i = \sum_{j=1}^{R}(X_{ij}^{`} - X_{ij}) \Big/ \sum_{j=1}^{R} X_{ij}$;

$$r_{ij} = (X_{ij}^{`} - X_{ij}) \Big/ X_{ij}$$

$$\sum_{j=1}^{R}(X_{ij}^{`} - X_{ij}) = [X_{i1}r + X_{i1}(r_i - r) + X_{i1}(r_{i1} - r_i)] + [X_{i2}r + X_{i2}(r_i - r) + X_{i2}(r_{i2} - r_i)] + \cdots + [X_{iR}r + X_{iR}(r_i - r) + X_{iR}(r_{iR} - r_i)] \quad (3\text{-}2)$$

$$\sum_{j=1}^{R}(X_{ij}^{`} - X_{ij}) = \sum_{j=1}^{R}\Delta X_{ij} = \sum_{j=1}^{R}X_{ij}r + \sum_{j=1}^{R}X_{ij}(r_i - r) + \sum_{j=1}^{R}X_{ij}(r_{ij} - r_i) \quad (3\text{-}3)$$

Among them, $r = \sum_{i=1}^{S}\sum_{j=1}^{R}(X_{ij}^{`} - X_{ij}) \Big/ \sum_{i=1}^{S}\sum_{j=1}^{R} X_{ij}$ ; $r_i = \sum_{j=1}^{R}(X_{ij}^{`} - X_{ij}) \Big/ \sum_{j=1}^{R} X_{ij}$

$$r_{ij} = (X_{ij}^{`} - X_{ij}) \Big/ X_{ij}$$

$$CRIT = \sum_{j=1}^{R} X_{ij}(r_{ij} - r_i) = X_{i1}(r_{i1} - r_i) + X_{i2}(r_{i2} - r_i) + \cdots + X_{iR}(r_{iR} - r_i) \quad (3\text{-}4)$$

The industrial added value of 31 provinces and cities is selected here for measurement. The inter-regional industrial transfer is mainly manufacturing industry, so agriculture, construction industry and service industry are not considered here. The industrial added value comes from China Statistical Yearbook and the statistical yearbook of provinces and cities over the years. In this study, the measurement results are verified again to ensure that the sum of industrial transfer increment and industrial transfer reduction is 0, the data of the current year is the final variable value, and the industrial added value of the previous year is the initial variable value. The numerical results are presented in the Table 3-2 below.

Table 3-2. Increase and decrease of industrial transfer in 11 provinces and cities of the Yangtze River economic belt and other regions：2005-2018.

	SH	JS	ZJ	AH	JX	HB	HN	CQ	SC	QZ	YN	External
2005	-294	292	-317	16	93	71	-41	-77	73	3	-124	305
2006	-203	-124	40	43	169	-16	68	26	128	-4	21	-148
2007	-314	-132	-11	112	75	83	134	-68	142	10	25	-56
2008	-523	-247	-469	149	48	140	243	-20	291	20	43	325
2009	-404	410	-380	331	138	569	234	165	445	25	-70	-1463
2010	62	-481	-144	462	452	502	440	-16	295	-70	116	-1618
2011	-532	-589	-412	577	349	574	548	220	147	68	-84	-866
2012	-598	-75	-515	364	10	567	312	309	305	224	246	-1149
2013	-374	129	56	312	267	-153	232	217	314	211	124	-1335
2014	-105	144	224	95	39	368	161	324	-188	164	-39	-1187
2015	-324	1269	612	-354	-1	347	461	177	-118	316	-97	-2288
2016	-120	476	232	255	76	393	-286	77	-322	193	-99	-875
2017	287	1063	-119	116	31	-50	-675	-167	-218	39	-67	-240
2018	196	110	265	260	-229	535	-628	-342	170	93	278	-708

3.3. Measurement of ecological efficiency

Jorgenson (1987) proposed KLEM model for the input-output relationship of water resources utilization in the process of economic growth, which decomposed input into labor, capital, energy and intermediate input. Output refers to the desirable output of economic significance. In the existing measurement studies of energy efficiency or carbon emission efficiency, only total energy consumption and total carbon dioxide emission are included in the model, while in the existing measurement studies of water efficiency, only total water consumption and total wastewater discharge are included in the measurement model. Paper considering the problems in the development of the Yangtze river economic belt ecological efficiency, ecological efficiency relates to the water resources and water environment problems, also involved in energy consumption and air pollution problems of selection of capital, labor, energy and water as input indicators, GDP, wastewater discharge, sulfur dioxide emissions, solid waste and so on as the purpose and the desirable output respectively, Due to data collection problems, other air pollution indicators are not applicable. The selection of major indicators is as follows.

① Capital investment. Research by zhang jun, gui-ying wu (2004), the calculation method of the perpetual inventory method, on the basis of new investment, considering the economic depreciation of the capital stock in the previous years, set the depreciation rate as 9.6%, due to technical innovation and capital waste, starting in 1992, for accounting year here, its calculating formula is $K_{it} = K^{*}_{i,t\text{-}1}(1\text{-}\delta_{it}) + I_{it}$, K_{it} and $K^{*}_{i,t\text{-}1}$ are capital stock for this year and last year, is the economic depreciation rate of the year, and the capital stock of each province from 2005 to 2018 is calculated by China Statistical Yearbook.

② Labor input. This article take the provinces at the end of the year the total number of workers (urban and rural) to represent the regional labor input, due to the current university graduates employment is the difficulty and the education level is also rising, the paper here no longer consider labor, human capital problems in past years related basic data from China statistical yearbook and China's population and employment statistics yearbook, Missing data for some years in individual provinces were calculated from other years according to the smoothing index, and some data were also obtained from provincial statistical bulletins.

③ Total amount of water used in the region. Regional economic growth studies generally choose total water consumption as the input index of water resources, including agricultural water, industrial water, domestic water and ecological water. The analysis here is not specific to specific industries, and domestic water and ecological water are also

considered as indispensable links of economic life. Relevant data come from China Statistical Yearbook and China Water Resources Bulletin over the years.

④Total energy consumption. The annual consumption of various types of energy in each province is converted into the total amount of standard coal for measurement. Natural gas, coal, oil, hydropower, etc. in energy consumption are not considered separately, and production energy consumption and domestic energy consumption are no longer distinguished. Relevant data come from China Statistical Yearbook and China Energy Statistical Yearbook, etc. In some years, some data also come from provincial statistical bulletins.

⑤ The desired output indicator -- real GDP. Excluding the influence of price changes in the study, the actual GDP of each province is chosen to represent the desired output, and the calculation method is $GDP_{it}^{R} = GDP_{it}^{N} \times I_{it}$, and GDP_{it}^{N} is the nominal GDP of the province in 2003, is the growth index relative to the base period of 2003, and is the actual GDP denominated in the base period of 2003, which is calculated according to the China Statistical Yearbook of past years.

⑥ Non - desirable output index - waste discharge. Total waste water discharge, total sulfur dioxide discharge and industrial solid waste production are selected here to represent the discharge of the three wastes. The total waste gas discharge is not selected here because of the availability of data, which also represents three specific types of environmental pollution, including water pollution, air pollution and land pollution. Relevant data come from China Statistical Yearbook and China Environmental Statistical Yearbook over the years, and part of the three wastes data also come from the statistical yearbook of provinces and cities.

Here, se-SBM model considering non-desirable output (discharge of three wastes) is used to measure the ecological efficiency of the Yangtze River Economic Belt. The research period is from 2005 to 2018. In order to reflect the dynamic comparison of ecological efficiency measurement, the selection window period is 14 years. Set the weight of waste water discharge, sulfur dioxide discharge and solid waste as 1/3 respectively. Accordingly, input-oriented ecological efficiency measurement results of the Yangtze River Economic Belt can be obtained:

Table 3-3. Measurement results of eco-efficiency in the Yangtze River Economic Belt (input-oriented) : 2005-2018.

Region	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Shanghai	0.58	0.61	0.70	0.65	0.66	0.70	0.73	0.78	0.80	0.83	0.87	0.91	0.95	1.00
Jiangsu	0.88	0.48	0.46	0.47	0.47	0.48	0.49	0.50	0.51	0.52	0.55	0.57	0.59	0.62
Zhejiang	0.61	0.50	0.51	0.52	0.53	0.55	0.55	0.57	0.58	0.60	0.62	0.65	0.67	0.71
Anhui	0.77	0.37	0.35	0.32	0.31	0.30	0.30	0.30	0.31	0.32	0.33	0.34	0.35	0.37
Jiangxi	0.45	0.37	0.36	0.35	0.34	0.34	0.33	0.34	0.37	0.36	0.36	0.36	0.38	0.39
Hubei	0.37	0.36	0.35	0.35	0.34	0.33	0.33	0.33	0.34	0.35	0.36	0.38	0.39	0.41
Hunan	1.02	0.77	0.45	0.37	0.35	0.34	0.34	0.34	0.33	0.35	0.36	0.37	0.39	0.40
Chong-qing	0.37	0.36	0.36	0.36	0.36	0.37	0.39	0.41	0.43	0.45	0.47	0.51	0.54	0.56
Sichuan	0.47	0.35	0.34	0.33	0.32	0.32	0.33	0.33	0.35	0.36	0.37	0.39	0.40	0.42
Guizhou	0.29	0.28	0.28	0.27	0.26	0.25	0.24	0.24	0.24	0.25	0.25	0.26	0.27	0.28
Yunnan	0.34	0.32	0.31	0.29	0.29	0.28	0.28	0.28	0.29	0.29	0.30	0.31	0.31	0.33

4. Model of industrial transfer driven by environmental regulation

In this section, we will reconstruct the dynamic model of industrial transfer in each region of the Yangtze River Economic Belt from 2005 to 2018 using the Markov process as the basic framework of the model. The driving mechanism of environmental regulation on industrial transfer will be reflected in the parameter setting of Markov transfer probability matrix. Due to the introduction of the influencing factors of environmental regula-

tion, the Monte Carlo simulation of industrial transfer will encounter a series of mathematical and technical difficulties (such as the need to prove the existence of a model that satisfies the assumptions). In order to achieve a more reasonable and accurate numerical simulation.

4.1. Establishment of Markov Model of Industrial Transfer

In order to study the correlation between the time series of HJ's green technology innovation investment and the time series of carbon performance in recent five years, based on the numerical results of carbon performance calculated in the previous chapter, this section first needs to obtain the time series of HJ's green technology innovation investment in recent five years.

In order to describe the dynamics of industrial transfer, the cumulative amount of industrial transfer between two provinces and cities from 2005 to 2018 will be a set of significant statistics. However, the author can only collect the final transfer volume of industries in each province and city in each year (a positive value indicates that all transfers in and out are a net transfer in, and a negative value indicates a net transfer out). Based on this, it is impossible to obtain every two provinces and cities in each year. The amount of industrial transfer between them. To this end, this paper uses the Monte Carlo simulation method to simulate the industrial transfer values between provinces and cities in each year based on the existing increase and decrease of industrial transfer in each province and city in each year and the geographical information of each province and city, forming 14 (2005-2018) The industrial transfer matrix between provinces and cities in each year.

The industrial transfer volume of each province and city in each year has been presented in Table 3-4 in Chapter 3, and in Table 3-5 in the same chapter, the increase and decrease of industrial transfer in each year of the 11 provinces and cities in the Yangtze River Economic Belt is extracted, but Table 3-5 the data processing of is based on considering the industrial transfer of the provinces and cities in the Yangtze River Economic Belt as a closed-loop transfer realized in the closed area of the Yangtze River Economic Belt, and this chapter introduces the 12th region, the national Non-Yangtze River Economic Belt regions, thus extracting the increase and decrease of industrial transfer in these 12 regions in each year from Table 3-2 in Chapter 3.

Behind the macro-process of industrial transfer is the micro-behavior of the cross-regional transfer of specific enterprises and industries in each region. The average probability of transferring enterprises or industries from i province and city to j province and city in the Yangtze River Economic Belt in a certain year t can be recorded as T(i, j,t), then for each fixed year t, T(i,j,t): i∈{1,2,...,12} constitutes a transition probability matrix, where {1,2,... ,12} represents 12 regions.

Since each value in Table 3-2 is the increase or decrease of the industry in the region in that year, a negative value indicates that the industry's transfer-out is greater than the transfer-in, and a positive value indicates that the industry's transfer-in is greater than the transfer-out. can not be obtained, denote O(i, j, t) as the industrial transfer from area i to area j in year t, and I(i, j, t) as the industrial transfer from area i from area j in t year, Then the increase or decrease of the industrial transfer in the region i in this year is I(i,j,t)-O(i,j,t) fixed (i,t), when j is taken over {1,2,...,12 } The sum of the items, that is, the existing values in Table 6 in Chapter 5; denote O(i,t) as the total industrial transfer out of area i in the t year, that is, O(i,j,t) is fixed and fixed (i, t), when j takes the sum of the items of {1, 2, ..., 12}; record I(i, t) as the total industrial transfer in area i in year t, that is, I (i,j,t) fixed (i,t), when i takes the sum of the terms of {1,2,...,12}; thus, I(i,t)-O(i,t) That is, the increase or decrease of industrial transfer in region i in year t, that is, the existing value in Table 5-6 in Chapter 5. The transition probability matrix T constructed above can be used to build the relationship between O(i, j, t) and O(i, t). Given the known values of O(i, t), O(i, j, t) For each value of different j, that is, for the distribution of O(i,t) in year t in region i among regions, multiply O(i,t) by the probability of transferring to region j T(i, j, t) to get an estimate of O(i, j, t).

For the construction and estimation of the transition probability matrix T, this paper mainly considers the influence of two aspects, one is the active role of environmental regulation on the transition probability, and the other is the geographical information between regions. According to the first law of geography, everything is spatially related, and things that are close to each other are more spatially related than things that are far away. By default, the amount of industrial transfer between adjacent areas will be more likely than non-adjacent ones. There is a large amount of industrial transfer between regions. Therefore, this paper will use the geographic information matrix, that is, the adjacent matrix {d(i,j)} between provinces and cities in the Yangtze River Economic Belt, and the element d(i,j) in the matrix expresses region i and region j Whether it is adjacent, it is recorded as 1 if it is adjacent, and it is recorded as 0 if it is not adjacent. For the distance between any area of the Yangtze River Economic Belt and the outside of the Yangtze River Economic Belt, it is considered to be weakly adjacent, and it is recorded as 0.1. The information of environmental regulation is reflected in Table 3-1, and the data in this table is recorded as a matrix A of the form n*m, where n=12 represents 12 areas, m=14 represents 14 years, and the last column That is, the intensity of environmental regulation outside the Yangtze River Delta, and its value is taken from the mean. This section characterizes the relationship between environmental regulation and transition probability matrix in the following expression: $T = C + k_1A + k_2Ad$. Among them, C is the coefficient matrix, which will reflect the influence of other variables on environmental regulation and transition probability, and k_1 and k_2 are coefficients. A*d constitutes the intersection term of environmental regulation and geographic information, thus constituting a nonlinear regression model. However, given the above description, the transition probability matrix and O(i,j,t), O(i,t) relationship, and O(i,j,t), O(i,t) and the quantitative relationship between the increase and decrease of the actual industry in each region in each year is constrained by the matrix A(:,:,t) (that is, the transition probability matrix in the t-th year). With O(:,t) representing the vector {O(1,t), O(2,t), ..., O(n,t)}, I(:,t) representing the vector {I(1,t)), I(2,t),...,I(n,t)},N(:,t) represents the vector {N(1,t), N(2,t),...,N(n, t)}, where N(i, t) represents the net value of the actual industrial increase or decrease in region i in year t. Then the following matrix relationship is obtained:

$$O(:,t) * T(:,:,t) = I(:,t) \quad (4\text{-}1)$$

$$N(:,t) = I(:,t) - O(:,t) \quad (4\text{-}2)$$

Obtained from the above matrix equation, O(:,t)*T(:,:,t)=N(:,t)+O(:,t), O(:,t)*(T(:,:, t)-E)=N(:,t) and O(:,t)=N(:,t)*inv(T(:,:,t)-E), I(:,t)=N(:,t)+O(:,t)=N(:,t)*(inv(T(:,:,t)-E)+E), where E is the identity matrix, and inv(T) represents the matrix T The inverse matrix of . Since all elements of O(:,t) and I(:,t) are positive, the following constraints are obtained:

$$N(:,t) * \text{inv}(T(:,:,t) - E) > 0 \quad (4\text{-}3)$$

$$N(:,t) * (\text{inv}(T(:,:,t) - E) + E) > 0 \quad (4\text{-}4)$$

In addition, T(:,:,t) as a transition probability matrix should satisfy the following two conditions:

$$T(i,j,t) \in [0,1] \text{ and } T(i,i,t) = 0 \text{ holds for any } i,j \in \{1,\ldots,n\} \quad (4\text{-}5) \quad (4\text{-}5)$$

$$T(i,i,t) * (1,\ldots,1)' = (1,\ldots,1)' \quad (4\text{-}6)$$

Therefore, in the above expression of the transition probability matrix constructed with $T = C + k_1A + k_2Ad$, the assignments of C, k_1, and k_2 are limited, and wrong assignments will make the above two equality constraints not satisfied , so the further Monte Carlo simulation of the model will encounter mathematical difficulties: the first thing to demonstrate is that, given any vector N(:,t) of the form 1*n, whether there is a condition that satisfies the above constraints (4-3), (4-4) and the matrix T(:,:, t) of its own conditions (4-5), (4-6) exists, whether it exists only or the linear space of the solution has a large degree of freedom. To this end, this paper completes the argument with the following lemma. In fact, this lemma can be accepted intuitively, but by randomly generating a large number (100,000 times) of matrices that satisfy the conditions (4-5) and (4-6), none of them satisfy the conditions (4-3) and (4-4), therefore, in order to achieve mathematical rigor, this

paper must eliminate the question of the existence of the T matrix satisfying the conditions through the lemma in the next section.

4.2. Matrix Analysis of Markov Model of Industrial Transfer

As Subsection 4.1 indicated, the impact of the company's green technology innovation investment on carbon performance is not immediate, and the impact effect gradually appears in half a year to one year. In order to quantitatively analyze the enhancement and attenuation law of the impact of HJ's green technology innovation investment on carbon performance over time, this subsection will mainly study the term structure of the impact of green technology innovation investment on carbon performance, that is, the law of the impact of green technology innovation investment on carbon performance over time. For the measurement of impact degree, this section calculates the impact degree based on the correlation analysis of time series.

In order to prove the existence of the matrix in the Markov model of industrial transfer established in Section 4.1, this section first considers the following lemma and proves it.

Lemma 1. For any vector N of the form 1*n, there exists a matrix T of the form n*n that satisfies the above (4-3), (4-4), (4-5), (4-6) , and T that satisfies the condition is not unique.

Proof: On the premise that t remains unchanged, the vectors I(:,t), O(:,t), N(:,t) in the form of 1*n are abbreviated as I_n, O_n, N_n. The equation that communicates the relationship between O_n, I_n, and T is:

$$O_n * T = I_n \quad (4\text{-}7)$$

The equation that reflects the connection between I_n, O_n, and N_n is:

$$N_n = I_n - O_n \quad (4\text{-}8)$$

Based on equations (4-7), the following two matrix equations are obtained:

$$(1,\cdots,1)\cdot\begin{pmatrix} O(1) & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & O(n) \end{pmatrix}\cdot T = \big(I(1),\cdots,I(n)\big) \quad (4\text{-}9)$$

$$(1,\cdots,1)\cdot T'\cdot\begin{pmatrix} O(1) & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & O(n) \end{pmatrix} = \big(O(1),\cdots,O(n)\big) \quad (4\text{-}10)$$

Observing the two formulas (4-9) and (4-10), it is found that the matrix should be defined

$$M:=\begin{pmatrix} O(1) & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & O(n) \end{pmatrix}\cdot T \quad (4\text{-}11)$$

So the formulas (4-9) and (4-10) become:

$$(1,\cdots,1) * M = I_n \quad (4\text{-}12)$$

$$(1,\cdots,1) * M' = O_n \quad (4\text{-}13)$$

Subtract the two equations (4-12) and (4-13) to get

$$(1,\cdots,1) * D = N_n \quad (4\text{-}14)$$

The above equations (4-8) are used here, where the matrix D is defined as follows:

$$D = M - M' \quad (4\text{-}15)$$

Obviously, matrix D is a symmetric matrix. Since the diagonal elements of matrix T are all 0, the diagonal elements of matrix M are also all 0, so the diagonal elements of matrix D are also all 0, and the matrix The elements of D can be positive or negative. So far, the existence of the solution of the original problem has been reduced to the existence of the solution of equation (4-14). By transposing, equation (4-14) is equivalent to D*(1,...,1)' = N_n', that is, a system of equations composed of n first-order equations, since matrix D has all 0 diagonal elements A symmetric matrix of order n, thus having n(n-1)/2 variable elements. Therefore, there are at least n(n-1)/2-n or n(n-3)/2 solutions for the system of equations (4-14). It can be verified that when n=3, the system of equations (4-14) may have no solution. But in this paper n=14, so there are at least 77 sets of solution vectors.

It can be seen that there is still a large degree of freedom when stochastic simulation of matrix D is performed.

After the matrix D is obtained, the matrix M can be further randomly determined, but it is necessary to ensure that each element of the matrix M is non-negative and the diagonal elements are all 0. It can be realized as follows: a real number r between 0 and 1 can be set as the import and export proportional coefficient. For the element d(i,j) in the matrix D, if it is 0, then let m(i,j)=m (i,j), can be any random positive number, the value of the same order of magnitude as N_n is suitable; if it is a positive number, then let m(i,j)=d(i,j)*(1+r),m(j,i)=d(i,j)*r, thus satisfying the condition; if the element d(i,j) is negative, then let m(i,j)=-d(i,j)* r,m(j,i)=-d(i,j)*(1+r), the condition can still be satisfied.

After the matrix M is obtained, use the formula (4-11) to perform linear row transformation, that is, multiply each row of M by 1/O(i), so that the sum of the rows of the resulting matrix T is 1, as long as each O(i) The value is the row sum of the i-th row of M. Note that each row of matrix M is positive except for the elements on the diagonal, so the row sum is not 0, thus avoiding O(i) being 0 or is a negative value. So far, the matrix T has been determined.

It can be seen from the above construction and discussion that a matrix T of the form n*n that satisfies the conditions (4-3), (4-4), (4-5), and (4-6) exists and is not unique, and the matrix T satisfying (4-3), (4-4), (4-5), (4-6) can be determined by a linear space with at least n(n-3)/2 degrees of freedom. Therefore, it is feasible to introduce a random fitting of the form $T = C + k_1A + k_2Ad$ to the matrix T and perform Monte Carlo simulation.

5. Numerical implements of industrial transfer driven by environmental regulation

Section 4 above constructs the model of dynamic simulation of industrial transfer driven by environmental regulation. This section will design and implement the numerical simulation of the dynamic model of industrial transfer driven by environmental regulation on this basis.

5.1. Numerical simulation of dynamic model of industrial transfer

In the following Code 5-1, first design and generate the matrix D with the least restrictive conditions in the previous Section 5 (i.e. M1 in the Code 5-1 below), and reflect the proportional relationship between elements determined by $T = C + k_1A + k_2Ad$ in the process of random assignment, Also satisfy that D is a symmetric matrix and ensure that the matrix equation (4-14) holds. The algorithm embodied in the code gradually realizes the transposed form of equation (4-14) for the matrix D from the upper left corner to the lower right corner: D*(1,...,1)' = N_n', because the D matrix is symmetric, it is determined When the elements of a certain row are selected, the corresponding elements of a certain column are also determined at the same time, but this will specialize the order of each region in the matrix, and the first region will reflect the ratio between elements defined by $T = C + k_1A + k_2Ad$ more. In order to eliminate the deviation caused by such specialization, the algorithm designs a random wrapping mechanism, and generates a random sequence through the function randperm that comes with Matlab, which is recorded as *in1*, and the recovery sequence obtained by calculating *in1* is recorded as *in2*, so that at the beginning of generating the random matrix, we wrap the line with the in1 sequence, and then use the sequence *in2* for column transformation and row transformation to restore the original order after generation, that is, in the code: M1=M1(in2,:); M1=M1(:,in2); In addition, In the process of determining the elements of matrix D, in order to make the sum of each column meet the requirements, the last three columns cannot be set randomly, and the three undetermined elements will be determined by solving the 3-dimensional 3-order inhomogeneous linear equation.

After the D matrix is obtained, follow the steps described in Section 6.1 to set a real number r between 0 and 1 as the import and export proportional coefficient. For the element d(i,j) in the matrix D, if it is 0, Then let m(i,j)=m(i,j), you can take any random positive

number, the value of the same order of magnitude as N_n is suitable; if it is a positive number, then let m(i,j)=d (i,j)*(1+r), m(j,i)=d(i,j)*r, thus satisfying the condition; if the element d(i,j) is negative, let m(i,j))=-d(i,j)*r,m(j,i)=-d(i,j)*(1+r), the condition can still be satisfied. Thus, the M matrix is obtained. After the matrix M is obtained, use the formula (4-11) to perform linear row transformation, that is, multiply each row of M by 1/O(i), so that the sum of each row of the resulting matrix T is 1, so let each O(i) The row sum of the i-th row whose value is M is sufficient.

There are two coefficients in the code that can be adjusted. One is the distance influence intensity coefficient, which is represented by pod in the code, and its value can be 0.8, 0.5, and 0.2, respectively indicating that the distance influence intensity factor has a strong, normal, and weak effect on industrial transfer. The second is the average coefficient of import and export ratio mentioned above, which is represented by oirate in the code, and its value is set to 0.2, and other values can be considered, such as 0.1 and 0.5. Specifically as shown in Code 5-1:

669

```
d=[1 1  1   0   0   0   0   0   0   0   0   0
1   1   1   1   0   0   0   0   0   0   0   0.1
1   1   1   1   1   0   0   0   0   0   0   0.1
0   1   1   1   1   1   0   0   0   0   0   0.1
0   0   1   1   1   1   1   0   0   0   0   0.1
0   0   0   1   1   1   1   1   0   0   0   0.1
0   0   0   0   1   1   1   1   0   1   0   0.1
0   0   0   0   0   1   1   1   1   1   0   0.1
0   0   0   0   0   0   0   1   1   1   1   0.1
0   0   0   0   0   0   1   1   1   1   1   0.1
0   0   0   0   0   0   0   1   1   1   1   0.1
0   0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 1
];
tr=[-294    -203    -314    -523    -404    62  -532    -598    -374    -105    -324    -
120    287 196
292 -124    -132    -247    410 -481    -589    -75 129 144 1269    476 1063    110
-317    40  -11 -469    -380    -144    -412    -515    56  224 612 232 -119    265
16  43  112 149 331 462 577 364 312 95  -354    255 116 260
93  169 75  48  138 452 349 10  267 39  -1  76  31  -229
71  -16 83  140 569 502 574 567 -153    368 347 393 -50 535
-41 68  134 243 234 440 548 312 232 161 461 -286    -675    -628
-77 26  -68 -20 165 -16 220 309 217 324 177 77  -167    -342
73  128 142 291 445 295 147 305 314 -188    -118    -322    -218    170
3   -4  10  20  25  -70 68  224 211 164 316 193 39  93
-124    21  25  43  -70 116 -84 246 124 -39 -97 -99 -67 278
305 -148    -56 325 -1463   -1618   -866    -1149   -1335   -1187   -2288   -875    -240
-708
];
[n,m]=size(a);aa=zeros(n,n,m); pod=0.8; MM=zeros(n,n,m); oirate=0.2;
MMR=MM;sp=100000; SSS=zeros(n,n);
for t=1:m
    for i=1:n
        for j=1:n
            aa(i,j,t)=a(i,t)-a(j,t);
        end
    end
end
for s=1:sp
    in1=randperm(n); in2=in1;
    for i=1:n
        in2(i)=find(in1==i);
    end
for k=1:m
C=rand(n,n)*0.2-0.1; pa=rand(); pb=rand()*pod;
A1=aa(:,:,k); B1=A1.*d; A1=A1(in1,:); B1=B1(in1,:);
M1=C+pa*A1+pb*B1;
    for ii=1:n
        M1(ii,ii)=0;
    end
M1=M1./repmat(sum(M1,2),1,n); M1=M1';
for i=1:(n-2)
    sum1=sum(M1(i+1:n,i)); sum2=tr(i,k)-sum(M1(1:i,i));
    for h=i+1:n
        M1(h,i)=sum2*M1(h,i)/sum1;
        M1(i,h)=M1(h,i);
    end
end
y1=tr(n-2,k)-sum(M1(n-2,1:n-3)); y2=tr(n-1,k)-sum(M1(n-1,1:n-3)); y3=tr(n,k)-
sum(M1(n,1:n-3));
M1(n-2,n-1)=(y1+y2-y3)/2; M1(n-1,n-2)=M1(n-2,n-1);
M1(n-2,n)=(y1+y3-y2)/2; M1(n,n-2)=M1(n-2,n);
M1(n-1,n)=(y2+y3-y1)/2; M1(n,n-1)=M1(n-1,n);
M1=M1(in2,:);M1=M1(:,in2);
MM(:,:,k)=M1; %ones(1,n)*M1-tr(:,k)'
MR=M1;
for i=1:n-1
    for j=i+1:n
        if M1(i,j)>0
            MR(i,j)=M1(i,j)*(1+oirate);MR(j,i)=M1(i,j)*oirate;
        elseif M1(i,j)<0
            MR(i,j)=-M1(i,j)*oirate;MR(j,i)=-M1(i,j)*(1+oirate);
        end
    end
end
MMR(:,:,k)=MR;
end
SS=zeros(n,n);
for i=1:m
SS=SS+MMR(:,:,i);
end
SSS=SSS+SS/m;
end
disp(SSS/sp);
```

5.2. Analysis of Numerical Results of Dynamic Model of Industrial Transfer

The following table 5-1 is the cumulative directional transfer of industries in the 11 provinces and cities in the Yangtze River Economic Belt directly generated by the above code. Note that the result is generated by Monte Carlo simulation, and each run will get a copy as shown in Table 5-1 There are differences in the value of the estimated results, but the relative relationship between the data is roughly the same.

Table 5-1. Cumulative directional transfer of industries in 11 provinces and cities in the Yangtze River Economic Belt: 2005-2018.

	SH	JS	ZJ	AH	JX	HB	HN	CQ	SC	QZ	YN
SH	0	2398	9862	2414	3888	1303	3442	2315	1853	4104	3273
JS	10626	0	3427	1793	2454	1384	13578	1229	2679	13211	2333
ZJ	2631	3844	0	2014	1407	3413	2908	1641	5822	1533	2430
AH	1696	4643	2136	0	9367	1792	2899	1987	1250	3318	3443
JX	1784	4737	1754	3116	0	2485	1965	2397	2639	1460	4284
HB	2521	2490	2417	1388	1664	0	2095	5613	2265	3135	2645
HN	1851	3467	10968	1517	4767	1218	0	3657	2074	4442	1624
CQ	4396	1527	1777	3492	2853	2582	4101	0	2371	3089	2656
SC	1690	4100	2691	1786	1936	3925	3782	2463	0	1426	4410
GZ	1871	3150	3894	15061	3335	3706	2400	1839	2581	0	2282
YN	5207	1827	3176	1515	2677	4503	3433	2164	1942	2549	0

The distance influence intensity coefficient in the model will have an impact on the final estimation result. Therefore, this paper calculates the cumulative transfer volume of the industry when the distance influence intensity coefficient is 0.5, 0.8, and 0.2 according to the situation, and obtains the following Figure 5 -1, Figure 5-2, Figure 5-3, the average in-out ratio coefficient is set to 0.2 in each case.

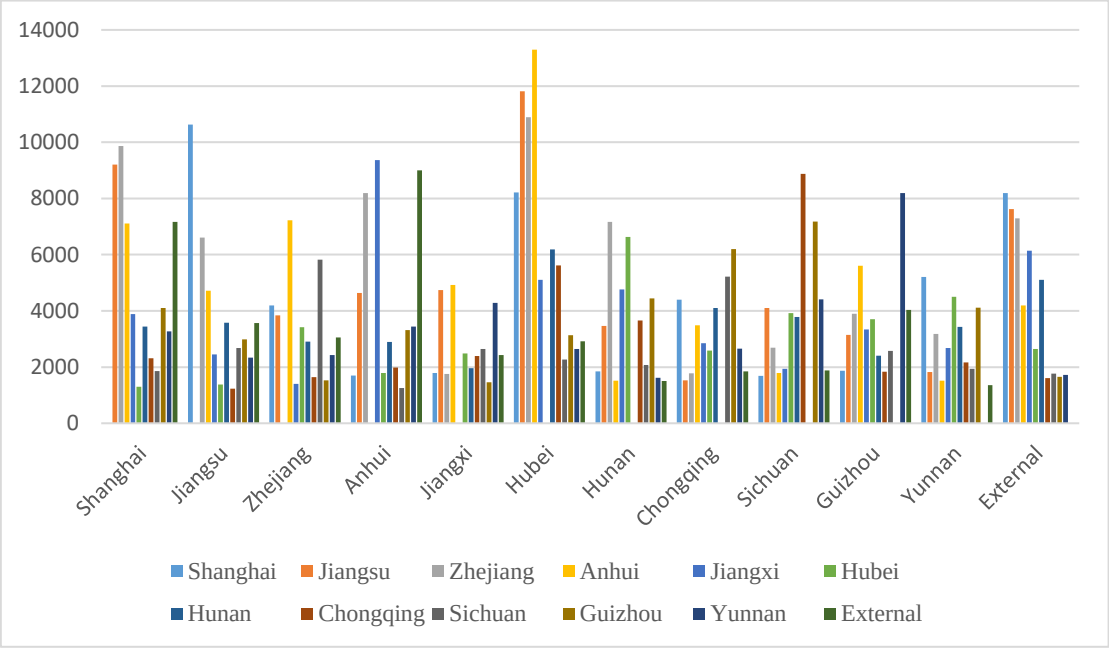

Figure 5-1. Cumulative directional transfer of industries in 11 provinces and cities in the Yangtze River Economic Belt.

Figure 5-1 shows that when the distance influence intensity coefficient is set to 0.5, the cumulative value of industrial transfer between regions in the Yangtze River Economic Belt reflects the influence of the relative strength of environmental regulation and whether the regions are adjacent. According to the environmental regulation intensity index of the 11 provinces and cities in the Yangtze River Economic Belt shown in Table 3-1 in Chapter 3, it can be seen that the environmental intensity of the 14 years from 2005 to 2018 varies among regions, among which Sichuan, Guizhou, and Hubei have higher environmental regulation intensity. As shown in Figure 5-1, Hubei's industrial transfer out volume to Shanghai, Jiangsu, Zhejiang, and Anhui is relatively high; Sichuan and Guizhou have higher industrial transfer out volume than Yunnan, Chongqing, Jiangxi and other provinces and cities. This shows that, the model's characteristics of the influence of environmental regulation on industrial transfer in the Yangtze River Economic Belt have been portrayed and reflected. The influence of geographical factors on the amount of industrial transfer between regions in the Yangtze River Economic Belt also has a certain performance in the quantitative comparison shown in Figure 5-1: if Jiangsu, Zhejiang and Shanghai are adjacent, the industrial transfer between these three provinces and cities is comparable. Large; note that there is always a vacancy in each cluster in the figure, and that vacancy is the amount of industry transfer from the region to the region, set to 0; through observation, it is found that the number of bars near each space is relatively high, which means that each Areas near each area have received relatively more industrial transfers.

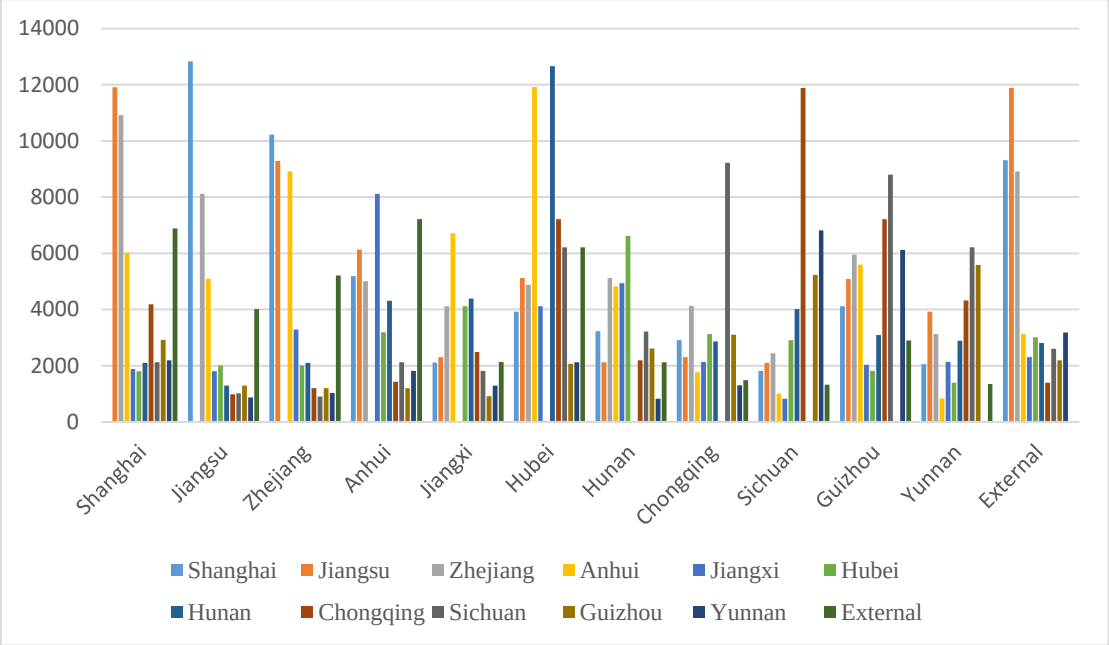

Figure 5-2. Cumulative directional transfer of industries in 11 provinces and cities in the Yangtze River Economic Belt.

In the case of increasing the distance influence strength coefficient to 0.8, the histogram of the cumulative directional transfer amount in each area shown in Figure 5-2 is obtained. Compared with Figure 5-1, it is found that the most obvious difference is that in Figure 5-2, the fluctuations in the amount of industrial transfer from different regions are more different. There are only 2 in 5-1. At the same time, in Figure 5-2, there are many more inter-regional industries whose one-way transfers are less than 2,000, and some are even less than 1,000. Obviously, this change is affected by the upward adjustment of the distance influence intensity coefficient. The maximum transfer amount visible in Figure 5-2 is the transfer out of Jiangsu to Shanghai. At the same time, the transfer out of Shanghai to Jiangsu is also close to 12,000; In comparison, the difference between Shanghai and

Jiangsu is not large, and the large amount of industrial transfer is due to the fact that the absolute number of industries in the two places is relatively large, and that the two places are adjacent to each other and have convenient transportation. In Figure 5-2, the smallest amount of industrial transfer out is the amount of industrial transfer from Hunan to Yunnan and Yunnan to Anhui. In fact, Hunan and Yunnan are separated by a province, and the distance is not particularly far, but the geographic information matrix in this model It only reflects whether it is adjacent or not, so the final estimated amount of industrial transfer is still small. In addition, it can be seen from Figure 5-2 that the amount of industrial transfer from Jiangsu and Zhejiang to the west is relatively small. On the one hand, due to the fact that the two provinces are not adjacent, more industries from Jiangsu and Zhejiang are allocated to neighboring provinces and cities. On the other hand, it is due to the high coefficient of environmental regulation intensity in western Sichuan, Guizhou and other places.

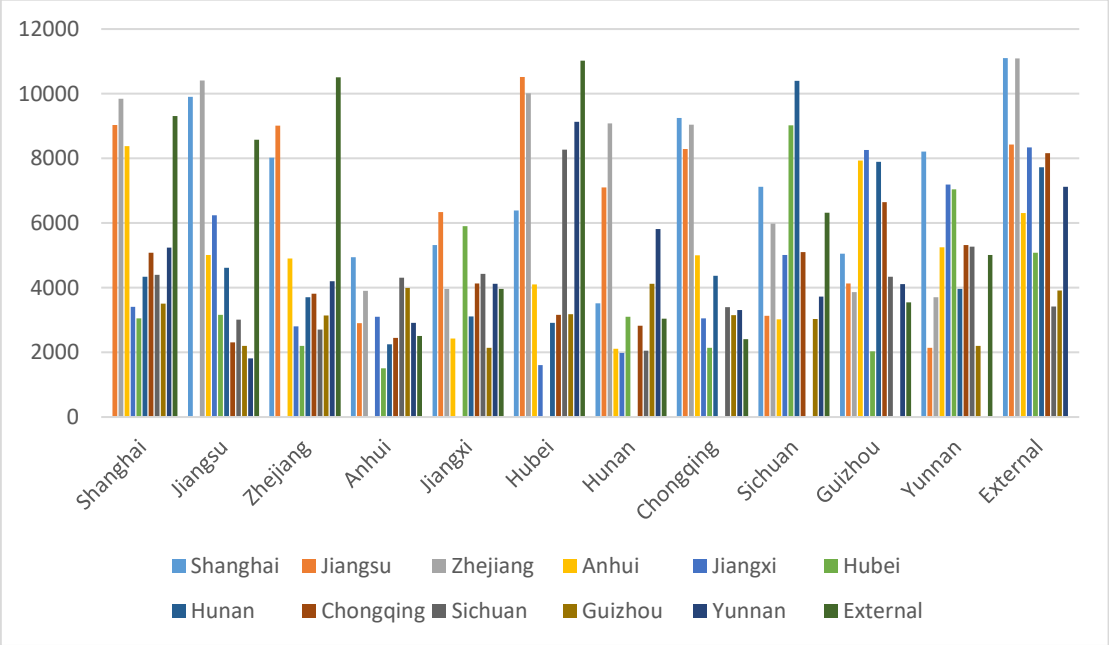

Figure 5-3. Cumulative directional transfer of industries in 11 provinces and cities in the Yangtze River Economic Belt.

In the case where the distance influence intensity coefficient is adjusted down to 0.2, the histogram of the cumulative directional transfer amount in each area shown in Figure 5-3 is obtained. Comparing with Figure 5-2, it is found that the most obvious difference is that the fluctuation difference of the industrial transfer volume in each region in Figure 5-3 is significantly smaller. In Figure 5-3, there is no industry transfer from one province or city to another province or city close to 12,000, while the industrial transfer volume between all provinces and cities exceeds 1,000; The geographical connection of the industrial transfer out of all regions has been significantly weakened, and the industrial transfer out and in transfer volume outside the Yangtze River Economic Belt have increased significantly. However, after the coefficient of the geo-information matrix is reduced, the effect of environmental regulation intensity on inter-regional industrial transfer will become obvious. As mentioned above, Hubei has a relatively high intensity of environmental regulation. In Figure 5-2, Hubei has become the province and city with the largest amount of industrial transfer.

From the analysis of the characteristics of the above three figures, it can be seen that the dynamic model of industrial transfer in the Yangtze River Economic Belt constructed in Section 4 and the numerical simulation demonstrated in this section can reflect the design intention of the model under the discussion of different scenarios where distance

affects different intensities. The law of influence on industrial transfer. In the sequel, we will construct the relationship between the cumulative industrial transfer out and ecological efficiency, so as to further examine the effect of environmental regulation intensity on environmental efficiency by driving industrial transfer

6. Verification of the eco-efficiency driving mechanism of environmental regulation

In order to establish the numerical correlation between the dynamics of industrial transfer and ecological efficiency, based on the industrial transfer volume between regions of the Yangtze River Economic Belt obtained in Section 5, the quantitative difference of each variable between each two provinces and cities was considered. The following table 6-1 shows the cumulative directional transfer of industries in the 11 provinces and cities in the Yangtze River Economic Belt (the distance influence intensity coefficient is set to 0.5, and the average entry and exit ratio coefficient is set to 0.2).

Table 6-1. Cumulative directional transfer of industries in 11 provinces and cities in the Yangtze River Economic Belt (the distance influence intensity coefficient is set to 0.5).

	SH	JS	ZJ	AH	JX	HB	HN	CQ	SC	QZ	YN	EX
SH	0	9211	9862	7109	3888	1303	3442	2315	1853	4104	3273	7170
JS	10626	0	6613	4718	2454	1384	3578	1229	2679	2991	2333	3562
ZJ	4192	3844	0	7221	1407	3413	2908	1641	5822	1533	2430	3059
AH	1696	4643	8192	0	9367	1792	2899	1987	1250	3318	3443	9004
JX	1784	4737	1754	4921	0	2485	1965	2397	2639	1460	4284	2422
HB	8212	11812	10891	13291	5102	0	6188	5613	2265	3135	2645	2917
HN	1851	3467	7170	1517	4767	6626	0	3657	2074	4442	1624	1499
CQ	4396	1527	1777	3492	2853	2582	4101	0	5218	6201	2656	1845
SC	1690	4100	2691	1786	1936	3925	3782	8871	0	7181	4410	1878
GZ	1871	3150	3894	5601	3335	3706	2400	1839	2581	0	8191	4034
YN	5207	1827	3176	1515	2677	4503	3433	2164	1942	4110	0	1352
EX	8191	7622	7291	4191	6143	2643	5103	1608	1769	1653	1724	0

Consider other control variables: economic development level, technological innovation level, external dependence, urbanization level, industrial structure, per capita education level, level of opening to the outside world, per capita water resources endowment, and energy structure. Accordingly, the regression analysis is still carried out with the difference model.

$$\Delta E_c = k_0\Delta T_r + k_1\Delta X_1 + k_2\Delta X_2 + k_3\Delta X_3 + k_4\Delta X_4 + k_5\Delta X_5 + k_6\Delta X_6 + k_7\Delta X_7 + k_8\Delta X_8 + k_9\Delta X_9 + \varepsilon \quad (6\text{-}1)$$

Among them, ε is the random error term, Tr represents the proportion of industrial transfer to local GDP, Δ represents the variable difference between two regions, such as ΔT_r will no longer be a column vector of 11 values, but 55 (ie 11* (11-1)/2) value column vector, which lists all the values in the upper half of the matrix in Table 2: {9211,9862,…7170,6613,…3562,7721,…1352}.

In addition, when using the data in Table 1, divide it by the 14-year average GDP of each region, and the order of regions in the table is: 279880.94, 726910.95, 463102.45, 226151.21, 170745.42, 294842.58, 288557.36, 153615.71, 311049.93, 99.812.41, 138745.42, 294842.58, 288557.36, 153615.71, 311049.93, 99.812.41 The ratio of the export volume to the local GDP. Code 6-1 implements all of the above steps:

Code 6-1

```
a=[
0     9211  9862  7109  3888  1303  3442  2315  1853  4104  3273
10626 0     6613  4718  2454  1384  3578  1229  2679  2991  2333
4192  3844  0     7221  1407  3413  2908  1641  5822  1533  2430
1696  4643  8192  0     9367  1792  2899  1987  1250  3318  3443
1784  4737  1754  4921  0     2485  1965  2397  2639  1460  4284
8212  11812 10891 13291 5102  0     6188  5613  2265  3135  2645
1851  3467  7170  1517  4767  6626  0     3657  2074  4442  1624
4396  1527  1777  3492  2853  2582  4101  0     5218  6201  2656
1690  4100  2691  1786  1936  3925  3782  8871  0     7181  4410
1871  3150  3894  5601  3335  3706  2400  1839  2581  0     8191
5207  1827  3176  1515  2677  4503  3433  2164  1942  4110  0
];
gdp=[
279880.94  726910.95   463102.45   226151.21   170745.42   294842.58   288557.36
153615.71   311049.93   99812.41    137834.14
];
b=[
1.0000  11.3648 4.5655  0.9842  0.6060  37.7071 10.6690 0.1007  172.8895    0.1935
0.6200  10.9833 2.2922  0.5127  0.4332  50.9357 8.9591  0.0843  564.1280    0.3971
0.7100  10.9464 2.3067  0.5200  0.4579  49.9143 8.6774  0.0617  1970.0617   0.2394
0.3700  10.0387 0.8632  0.1310  0.3814  45.1643 8.0671  0.0690  1264.4850   0.5361
0.3900  10.0654 0.2116  0.1240  0.3626  50.4529 8.5021  0.0807  3565.6351   0.5500
0.4100  10.3490 0.7756  0.0863  0.4143  45.0643 8.8673  0.0426  1682.0958   0.5268
0.4000  10.2059 0.5465  0.0644  0.4240  43.0907 8.7604  0.0536  2565.7517   0.5518
0.5600  10.3423 0.8273  0.2217  0.4344  44.9643 8.4158  0.0434  1808.0222   0.4497
0.4200  10.0732 0.6058  0.1517  0.3995  43.9000 7.9837  0.0421  3030.1286   0.4135
0.2800  9.6768  0.2526  0.0374  0.4451  38.9271 7.4156  0.0121  2683.6337   0.6485
0.3300  9.8330  0.2500  0.1006  0.4246  38.7436 7.4439  0.0207  4108.3857   0.5757
];
[n,m]=size(b);
for i=1:n
    for j=1:n
        a(i,j)=a(i,j)/gdp(i);
    end
end
bigm=zeros(n,n,m+1); bigm(:,:,2)=a; bigm1=zeros(n,n,m);
for k=1:m
    for i=1:n
        for j=1:n
            bigm1(i,j,k)=b(i,k)-b(j,k);
        end
    end
end
bigm(:,:,1)=bigm1(:,:,1); bigm(:,:,3:end)=bigm1(:,:,2:end);
disp(bigm);
h=n*(n-1)/2;regm=zeros(h,m+1);
for i=1:m+1
    vec=bigm(1,2:end,i);
    for j=2:n
    vec=[vec,bigm(j,j+1:end,i)];
    end
    regm(:,i)=vec';
end
disp(regm);
[b,bint,r,rint,stat]=regress(regm(:,1),[regm(:,2:end),ones(h,1)]);
b
stat(1)
stat(2)
stat(4)
```

The following regression expression is obtained from the running result of the program:

$$\Delta E_c = -0.0672\Delta T_r + 0.1121\Delta X_1 - 0.2062\Delta X_2 + 0.5714\Delta X_3 + 1.8610\Delta X_4 - 0.0006\Delta X_5 + 0.0075\Delta X_6 + 1.5840\Delta X_7 + 0.0000\Delta X_8 - 0.6932\Delta X_9 + 0.0062 \quad (6\text{-}2)$$

stat(1)=0.9954, stat(2)=943.8971, stat(4)=3.07E-04. That is, the fitting degree of the regression model is 0.9954, the F value is 943.8971, and the error sum of squares is 3.07E-04. It can be seen from the above running results that the fitting degree of the regression model is 0.9954, which is a very high degree of fitting; the F value is 943.8971, which is very high, again indicating that the regression fitting is significantly credible; Also within the acceptable error range. Therefore, the significant establishment of the above regression

equation shows that the cumulative amount of industrial transfer between the two provinces and cities in the 14 years from 2005 to 2018 generally significantly affected the comparison value of the ecological efficiency between the two provinces and cities in 2018, thus indicating that the provinces and cities in the Yangtze River Economic Belt Industrial transfer does change the eco-efficiency of provinces and cities.

As far as the regression coefficient is concerned, the coefficient of ΔT_r is negative, indicating that the transfer of industries between provinces and cities will promote the improvement of ecological efficiency. Under the goal of minimizing the sum of squared errors, perform regression tests on the defaults of different variables in the model multiple times, and run Code 6-2 on the basis of Code 6-1:

Run the results of Code 6-1 to get the expression for the regression fit:

$$\Delta E_c = -0.0222\Delta T_r + 0.1167\Delta X_1 + 0.5268\Delta X_3 + 2.0207\Delta X_4 + 1.7691\Delta X_7 + 0.0000\Delta X_8 - 0.6899\Delta X_9 + 0.0044 \quad (6\text{-}3)$$

Code 6-2

```
a=regm;
[a1,a2]=size(a); co=3:a2; n=length(co); m1=zeros(2^n-1,n); rec=0.01;
for i=1:2^n-1
    b=dec2bin(i); len=length(b);
    for j=1:len
        m1(i,end-j+1)=str2num(b(len-j+1));
    end
end
for i=1:2^n-1
    inx=zeros(0,0);
    for j=1:n
        if m1(i,j)==1
            inx=[inx,j+2];
        end
    end
    [b,bint,r,rint,stat]=regress(a(:,1),[a(:,[2,inx]),ones(a1,1)]); st=stat(4);
    if st<rec
        rec=st; best=[2,inx];
    end
end
[b,bint,r,rint,stat]=regress(a(:,1),[a(:,best),ones(a1,1)]);
b
stat(1)
stat(2)
stat(4)
best
```

Also shows stat(1)=0.9953, stat(2)=1213.9, stat(4)=2.9854E-04. That is, the fitting degree of the regression model is 0.9853, the F value is 1213.9, and the error sum of squares is approximately 0. The result shows that the regression fitting result is acceptable. The variables ΔX_1 economic development level, ΔX_2 scientific and technological innovation level, ΔX_3 external dependence, ΔX_4 Urbanization level, ΔX_7 level of opening to the outside world, ΔX_9 energy structure are significant control variables. Other control variables have little effect on the mechanism of environmental regulation affecting ecological efficiency.

The following table 6-2 shows the cumulative directional transfer of industries in the 11 provinces and cities in the Yangtze River Economic Belt (the distance influence intensity coefficient is set to 0.8, and the average in-exit ratio coefficient is set to 0.2).

Table 6-2 Cumulative directional transfer of industries in 11 provinces and cities in the Yangtze River Economic Belt (the distance influence intensity coefficient is set to 0.8).

	SH	JS	ZJ	AH	JX	HB	HN	CQ	SC	QZ	YN	EX
SH	0	11912	10921	6019	1882	1809	2102	4192	2122	2920	2188	6891
JS	12829	0	8122	5102	1802	2012	1288	981	1022	1291	871	4022
ZJ	10229	9290	0	8910	3291	2013	2102	1201	910	1199	1031	5210
AH	5192	6131	5002	0	8122	3201	4310	1429	2122	1202	1821	7219

JX	2109	2313	4121	6722	0	4121	4391	2491	1822	921	1292	2131
HB	3921	5121	4882	11921	4121	0	12661	7219	6212	2071	2128	6210
HN	3233	2129	5121	4829	4941	6626	0	2199	3219	2618	821	2125
CQ	2914	2313	4129	1772	2134	3129	2871	0	9218	3102	1302	1489
SC	1819	2102	2441	1004	823	2910	4014	11892	0	5233	6821	1332
GZ	4121	5089	5952	5601	2031	1822	3092	7219	8802	0	6128	2901
YN	2055	3921	3129	839	2139	1396	2890	4329	6219	5592	0	1352
EX	9316	11890	8912	3129	2303	3019	2811	1399	2600	2191	3186	0

Consider other control variables: economic development level, technological innovation level, external dependence, urbanization level, industrial structure, per capita education level, level of opening to the outside world, per capita water resources endowment, and energy structure. Accordingly, the regression analysis is still carried out with the difference model.

$$\Delta E_c = k_0\Delta T_r + k_1\Delta X_1 + k_2\Delta X_2 + k_3\Delta X_3 + k_4\Delta X_4 + k_5\Delta X_5 + k_6\Delta X_6 + k_7\Delta X_7 + k_8\Delta X_8 + k_9\Delta X_9 + \varepsilon \quad (6\text{-}4)$$

Among them, ε is the random error term, Tr represents the proportion of industrial transfer to local GDP, and Δ represents the variable difference between two regions. Similar to the case above for the distance effect strength factor of 0.5, running the same code yields:

$$\Delta E_c = 0.1838\Delta T_r + 0.1218\Delta X_1 - 0.2001\Delta X_2 + 0.5423\Delta X_3 + 1.8727X_4 - 0.0005\Delta X_5 - 0.003\Delta X_6 + 1.6722\Delta X_7 + 0.0000\Delta X_8 - 0.6857\Delta X_9 - 0.0004 \quad (6\text{-}5)$$

stat(1)=0.9954, stat(2)=952.0613, stat(4)=3.0454e-04. That is, the fitting degree of the regression model is 0.9954, the F value is 952.0613, and the error sum of squares is 3.0454E-04. It can be seen from the above running results that the fitting degree of the regression model is 0.9954, and the fitting degree is very high; the F value is 952.0613, which is very high, again indicating that the regression fitting is significantly credible; the error sum of squares is 3.045E-04 (ie 0.000307), Also within the acceptable error range. Therefore, the above regression equation is significantly established.

But note that the regression coefficient 0.1838 of the ΔT_r term is positive, which is opposite to the sign of the regression coefficient of the ΔT_r term above for the case where the distance influence strength coefficient is 0.5. This is due to the increase of the distance influence intensity coefficient to 0.8 (due to the fact that the determination of the distance influence intensity coefficient cannot be supported by empirical evidence, the quantitative verification process below will be verified separately in the three cases of strong, medium and weak inter-provincial distance influence), so that Geographical information becomes the dominant factor in determining the ratio of transition probability among variables, making it difficult to reflect differences in environmental regulation. Therefore, the actual meaning of the positive regression coefficient of the ΔT_r term is not credible. Similarly, when the distance influence intensity coefficient is 0.2, the influence of environmental regulation is prominent. Repeat the above process to obtain:

$$\Delta E_c = -0.0392\Delta T_r + 0.0173\Delta X_1 - 0.7141\Delta X_2 + 0.9170\Delta X_3 + 0.0781\Delta X_4 + 4.3131\Delta X_7 + 0.0000\Delta X_8 - 1.8003\Delta X_9 + 0.0312 \quad (6\text{-}21)$$

This result is consistent with the above analysis. If, as predicted above, the influence of environmental regulation becomes dominant, the regression coefficient of the ΔT_r term returns to a negative value. In the following chapters, the research on environmental regulation-driven industrial transfer and eco-efficiency will discuss the above three situations respectively.

As set before, we have the assumed relationship between environmental regulation and transition probability matrix: $T = C + k_1A + k_2Ad$. The numerical simulation in Section 5 basically verifies the significant existence of this correlation. This section will further reveal that environmental regulation is in the driving mechanism of industrial transfer on ecological efficiency. Recalling the simulation steps in Section 4: first determine the matrix D from Equation (4-14), then determine the matrix M, and then determine the matrix T in Equation (4-11), namely

$$\begin{pmatrix} O(1) & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & O(n) \end{pmatrix} \cdot T. \quad (872)$$

The environmental regulation intensity matrix A is reflected in the process of simulating the matrix T; considering that it cannot form a linear relationship with ΔTr, the relationship between the matrix T and ΔEc is also nonlinear. Therefore, the linear relationship expression between the environmental regulation intensity matrix A and ecological efficiency cannot be obtained based on the above model. In order to verify the indirect effect of environmental regulation on ecological efficiency, and quantitatively show the relationship between the environmental regulation intensity matrix A and the ecological efficiency value, this paper will perform various forms of numerical perturbation on the environmental regulation intensity matrix A, so as to observe how the corresponding ecological efficiency changes. To this end, following the commonly used Greeks value definition form of sensitivity analysis, this paper first defines the gradient (ie the rate of change) Λ(ε): When the intensity matrix A is disturbed with a difference of ε, it acts on the industrial transfer matrix and eventually causes If the magnitude of environmental efficiency is$|\Delta E_c^{\varepsilon} - \Delta E_c|$, the value of gradient Λ(ε) is defined as$|\Delta E_c^{\varepsilon} - \Delta E_c|/\varepsilon$.

For this reason, this section considers the form of perturbing the environmental regulation intensity matrix A. Since each row of the environmental regulation intensity matrix A represents the environmental regulation intensity of different provinces and cities, the perturbation of the A matrix is carried out by row transformation. Considering that the matrix transformation can be divided into three These three elementary transformations will be used in this paper to act on the environmental regulation intensity matrix A: line-by-line scaling transformation, two-line overall exchange, and line-by-line doubling transformation. In actual operation, each elementary transformation will only change one row (the first and third transformations) or two rows (the second); in this paper, in order to realize that all rows are perturbed globally at one time, the same elementary transformation is carried out. Multiplicative superposition (that is, decomposed into the product of multiple elementary row transformations of the same kind). The disturbance difference is represented by ε, then the first type of table exchange is defined as: $\Gamma_1 A := M_1 A$ (defined for any n-row matrix A), where

$$M_1 = \begin{pmatrix} 1+\varepsilon & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & 1+\varepsilon \end{pmatrix} \quad (901)$$

is an n*n square matrix, the first type of transformation multiplies all elements in the A matrix by 1+ε, and the simulation realizes the overall strengthening of environmental regulation; the second type of transformation is defined as: $\Gamma_2 A := M_2 A$ (for any n row of matrix A definition), where:

$$M_2 = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & \ddots & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \end{pmatrix} \quad (906)$$

is an n*n square matrix, the second type of transformation will realize the exchange of environmental regulation strength values of two adjacent regions such as (1,2), (3,4)...(n-1,n), If n is an odd number, the last field value does not participate in the swap. The third type of transformation is defined as: $\Gamma_3 A := M_3 A$ (defined for any n-row matrix A), where

$$M_3 = \begin{pmatrix} 1 & 1+\varepsilon & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & \ddots & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1+\varepsilon & 0 \end{pmatrix}. \quad (912)$$

It is an n*n square matrix, which is formed by arranging several 2*2 small square matrices on the diagonal, in which 1+ε randomly appears in the lower left corner or upper right corner of the small square matrix. When 1+ε appears in the lower left corner, Will

realize that in the corresponding two rows in the A matrix, the previous row is multiplied by 1+ε and added to the next row; when 1+ε appears in the upper right corner, the following row is multiplied by 1+ε and added to the previous row.

Code 6-3 implements three row transformations with the number of rows in the environmental regulation intensity matrix A:

Code 6-3

```
p1=0.02; p1=1+p1;
[n,m]=size(A); tran1=eye(n)*p1;
tran2=zeros(n,n);
for i=1:6
    i1=2*i-1;i2=2*i;
    tran2(i1,i1+1)=1; tran2(i2,i2-1)=1;
end
tran3=eye(n);
for i=1:6
    i1=2*i-1;i2=2*i;
    if rand()>0.5
        tran3(i1,i1+1)=p1;
    else
        tran3(i2,i2-1)=p1;
    end

end
disp(tran1);
disp(tran2);
disp(tran3);
```

Note that the disturbance parameter set in the first and third transformations is p1=0.02, a positive value means that the disturbance is positive, which is to consider the situation that environmental regulation becomes stronger, and then the following will reset p1=-0.02 to indicate that environmental regulation weakened situation. After multiplying the three transformation matrices obtained by the above codes on the environmental regulation intensity matrix A (see Table 3-1 in Chapter 3), the environmental regulation intensity matrix A after three disturbances (the disturbance coefficient is 0.02) is obtained, as shown in the following Table 6-3, Table 6-4, Table 6-5:

Table 6-3. Environmental regulation intensity matrix A after perturbation by the first type of transformation.

0.21	0.13	0.11	0.18	0.13	0.14	0.09	0.16	0.07	0.24	0.31	0.70	0.54	0.09
0.43	0.26	0.22	0.27	0.16	0.10	0.14	0.16	0.23	0.18	0.22	0.26	0.13	0.22
0.32	0.34	0.29	0.14	0.18	0.09	0.12	0.18	0.36	0.41	0.35	0.33	0.19	0.17
0.26	0.26	0.20	0.34	0.28	0.11	0.13	0.16	0.47	0.19	0.19	0.42	0.24	0.17
0.51	0.39	0.31	0.18	0.12	0.15	0.12	0.07	0.24	0.18	0.21	0.14	0.14	0.26
0.62	0.52	0.44	0.38	0.55	0.42	0.11	0.15	0.24	0.24	0.14	0.30	0.13	0.10
0.65	0.65	0.52	0.35	0.29	0.22	0.12	0.20	0.23	0.16	0.24	0.11	0.07	0.06
0.39	0.31	0.23	0.49	0.24	0.21	0.11	0.08	0.15	0.10	0.11	0.06	0.09	0.08
0.81	0.66	0.53	0.40	0.17	0.10	0.18	0.10	0.16	0.20	0.11	0.10	0.11	0.13
0.85	1.20	1.02	0.84	0.72	0.46	0.73	0.57	0.74	0.60	0.33	0.15	0.13	0.16
0.58	0.68	0.56	0.51	0.46	0.42	0.47	0.58	0.64	0.64	0.57	0.34	0.15	0.22
0.51	0.49	0.41	0.37	0.31	0.22	0.21	0.22	0.33	0.29	0.26	0.27	0.17	0.15

Table 6-4. Environmental regulation intensity matrix A after perturbation by the second type of transformation.

0.42	0.25	0.22	0.26	0.16	0.10	0.14	0.16	0.23	0.18	0.22	0.25	0.13	0.22
0.21	0.13	0.11	0.18	0.13	0.14	0.09	0.16	0.07	0.24	0.30	0.69	0.53	0.09
0.25	0.25	0.20	0.33	0.27	0.11	0.13	0.16	0.46	0.19	0.19	0.41	0.24	0.17

0.31	0.33	0.28	0.14	0.18	0.09	0.12	0.18	0.35	0.40	0.34	0.32	0.19	0.17
0.61	0.51	0.43	0.37	0.54	0.41	0.11	0.15	0.24	0.24	0.14	0.29	0.13	0.10
0.50	0.38	0.30	0.18	0.12	0.15	0.12	0.07	0.24	0.18	0.21	0.14	0.14	0.25
0.38	0.30	0.23	0.48	0.24	0.21	0.11	0.08	0.15	0.10	0.11	0.06	0.09	0.08
0.64	0.64	0.51	0.34	0.28	0.22	0.12	0.20	0.23	0.16	0.24	0.11	0.07	0.06
0.83	1.18	1.00	0.82	0.71	0.45	0.72	0.56	0.73	0.59	0.32	0.15	0.13	0.16
0.79	0.65	0.52	0.39	0.17	0.10	0.18	0.10	0.16	0.20	0.11	0.10	0.11	0.13
0.50	0.48	0.40	0.36	0.30	0.22	0.21	0.22	0.32	0.28	0.25	0.26	0.17	0.15
0.57	0.67	0.55	0.50	0.45	0.41	0.46	0.57	0.63	0.63	0.56	0.33	0.15	0.22

938

939 **Table 6-5.** Environmental regulation intensity matrix A after perturbation by the first type of trans-
940 formation.

0.64	0.39	0.33	0.45	0.29	0.24	0.23	0.32	0.30	0.42	0.52	0.95	0.66	0.31
0.42	0.25	0.22	0.26	0.16	0.10	0.14	0.16	0.23	0.18	0.22	0.25	0.13	0.22
0.57	0.59	0.48	0.48	0.46	0.20	0.25	0.34	0.82	0.59	0.53	0.74	0.43	0.34
0.25	0.25	0.20	0.33	0.27	0.11	0.13	0.16	0.46	0.19	0.19	0.41	0.24	0.17
1.12	0.90	0.74	0.56	0.67	0.57	0.23	0.22	0.48	0.42	0.35	0.44	0.27	0.35
0.61	0.51	0.43	0.37	0.54	0.41	0.11	0.15	0.24	0.24	0.14	0.29	0.13	0.10
0.64	0.64	0.51	0.34	0.28	0.22	0.12	0.20	0.23	0.16	0.24	0.11	0.07	0.06
1.03	0.95	0.75	0.83	0.53	0.43	0.23	0.28	0.38	0.26	0.35	0.17	0.16	0.14
1.64	1.85	1.54	1.23	0.89	0.56	0.91	0.67	0.90	0.80	0.44	0.25	0.24	0.29
0.83	1.18	1.00	0.82	0.71	0.45	0.72	0.56	0.73	0.59	0.32	0.15	0.13	0.16
1.08	1.16	0.96	0.87	0.76	0.63	0.67	0.79	0.96	0.92	0.82	0.60	0.32	0.37
0.50	0.48	0.40	0.36	0.30	0.22	0.21	0.22	0.32	0.28	0.25	0.26	0.17	0.15

941 Substitute the new environmental regulation intensity coefficient matrix under the
942 three transformations presented before and repeat the steps in Section 5 to obtain the cor-
943 responding industrial cumulative directed transfer volume matrix (the distance influence
944 intensity coefficient is set to 0.5): For Table 6-6, the environmental regulation intensity
945 matrix is taken from Table 6-3, the distance influence intensity coefficient is set to 0.5, and
946 the average in-out ratio coefficient is set to 0.2; For Table 6-7, the intensity matrix is taken
947 from table 6-4, the distance influence intensity coefficient is set to 0.5, and the average
948 entry and exit ratio coefficient is set to 0.2.

949 **Table 6-6.** Cumulative directional transfer of industries in 11 provinces and cities in the Yangtze
950 River Economic Belt.

	SH	JS	ZJ	AH	JX	HB	HN	CQ	SC	QZ	YN	EX
SH	0	8996	10109	6509	2967	1489	2810	3057	2133	3524	2751	6909
JS	11338	0	7114	4784	2131	1620	2544	1100	1929	3209	1672	3683
ZJ	5612	6054	0	7785	2170	2756	3019	1423	3642	1362	1793	3901
AH	3130	5175	6688	0	8656	2347	3433	1712	2011	2362	2692	7923
JX	1884	3624	2713	5579	0	3122	2944	2388	2243	2020	2941	2251
HB	6245	7912	8149	12449	4587	0	8782	6175	3877	2625	3078	4129
HN	2394	2499	7212	2877	4744	6493	0	2971	2513	3587	1254	1731
CQ	3685	1826	2729	2699	2493	2760	3502	0	6793	4775	2034	3819
SC	2101	3178	3013	2044	2067	3420	3803	9962	0	6219	5334	1611
GZ	2778	4066	4680	5488	2720	2287	2642	4061	5142	0	7160	3477
YN	4019	2669	3092	1200	2397	3108	3136	3030	3699	4650	0	1009
EX	5101	6691	7826	3661	4407	2748	2873	1488	1031	2171	3012	0

951 **Table 6-7.** Cumulative directional transfer of industries in 11 provinces and cities in the Yangtze
952 River Economic Belt.

	SH	JS	ZJ	AH	JX	HB	HN	CQ	SC	QZ	YN	EX
SH	0	9751	10073	6891	3486	1404	3174	2690	1906	3867	3056	7114
JS	11066	0	6914	4794	2323	1509	3120	1179	2347	2651	2040	3654

ZJ	5399	4933	0	7558	1783	3133	2746	1553	4839	1466	2150	3489
AH	2395	4940	7554	0	9118	2073	3181	1875	1424	2894	3118	8647
JX	1849	4252	2227	5281	0	2812	2450	2415	2475	1352	3685	2363
HB	7353	10473	9689	13017	4905	0	7482	5934	3054	2922	2541	3575
HN	2127	3199	6760	2179	4801	6626	0	3365	2303	4077	1463	1624
CQ	4099	1684	2247	3148	2709	2691	3855	0	6018	5581	2385	1773
SC	1715	3700	2641	1629	1713	3722	3828	9475	0	6791	4892	1768
GZ	2321	3537	4305	5601	3074	3329	2538	2915	3825	0	7778	3807
YN	4576	2245	3166	1379	2569	3881	3324	2597	2797	4406	0	1352
EX	8416	8475	7615	3978	5375	2718	4644	1566	1935	1760	2016	0

Table 6-8. Cumulative directional transfer of industries in 11 provinces and cities in the Yangtze River Economic Belt. 953 954

	SH	JS	ZJ	AH	JX	HB	HN	CQ	SC	QZ	YN	EX
SH	0	8941	9699	8317	3200	1190	4061	3192	2089	3994	3811	6982
JS	9868	0	9772	6198	3290	2319	3033	1329	2515	3012	3144	2791
ZJ	5129	4021	0	9712	2432	3866	2791	1822	4795	1990	2719	4080
AH	2103	5311	8517	0	8869	1913	3160	2233	2069	2991	4012	8277
JX	1909	5229	2319	5672	0	3001	1734	2619	2388	1913	3709	3081
HB	7812	12017	10033	12660	3921	0	4612	6712	6102	3129	4924	2371
HN	2134	3913	4901	3216	3912	4551	0	5182	3328	3235	2048	2190
CQ	5013	1203	2301	2846	3011	3398	3921	0	4961	7392	3014	2051
SC	2181	3917	3081	2781	3012	4013	3191	10212	0	9123	4910	2301
GZ	3001	2889	3891	4981	4239	4166	2188	2161	3078	0	7731	3977
YN	4129	2008	2969	1867	3081	4227	4062	3757	2810	4671	0	2775
EX	6879	8170	7305	4710	5003	3035	4912	1558	1914	1992	2048	0

Reverse this regression expression to find the $\Delta E_{c\varepsilon}$ value in each case, and subtract it from the original ΔE_c value, as shown in Code 6-4 (where a is the industry transfer matrix in each case): 955 956 957

Code 6-4

```
gdp=[
279880.94  726910.95   463102.45   226151.21   170745.42   294842.58   288557.36
153615.71   311049.93   99812.41    137834.14
];
b=[
1.0000  11.3648 4.5655  0.9842  0.6060  37.7071 10.6690 0.1007  172.8895    0.1935
0.6200  10.9833 2.2922  0.5127  0.4332  50.9357 8.9591  0.0843  564.1280    0.3971
0.7100  10.9464 2.3067  0.5200  0.4579  49.9143 8.6774  0.0617  1970.0617   0.2394
0.3700  10.0387 0.8632  0.1310  0.3814  45.1643 8.0671  0.0690  1264.4850   0.5361
0.3900  10.0654 0.2116  0.1240  0.3626  50.4529 8.5021  0.0807  3565.6351   0.5500
0.4100  10.3490 0.7756  0.0863  0.4143  45.0643 8.8673  0.0426  1682.0958   0.5268
0.4000  10.2059 0.5465  0.0644  0.4240  43.0907 8.7604  0.0536  2565.7517   0.5518
0.5600  10.3423 0.8273  0.2217  0.4344  44.9643 8.4158  0.0434  1808.0222   0.4497
0.4200  10.0732 0.6058  0.1517  0.3995  43.9000 7.9837  0.0421  3030.1286   0.4135
0.2800  9.6768  0.2526  0.0374  0.4451  38.9271 7.4156  0.0121  2683.6337   0.6485
0.3300  9.8330  0.2500  0.1006  0.4246  38.7436 7.4439  0.0207  4108.3857   0.5757
];
[n,m]=size(b);
for i=1:n
    for j=1:n
        a(i,j)=a(i,j)/gdp(i);
    end
end
bigm=zeros(n,n,m+1); bigm(:,:,2)=a; bigm1=zeros(n,n,m);
for k=1:m
    for i=1:n
        for j=1:n
            bigm1(i,j,k)=b(i,k)-b(j,k);
        end
    end
end
bigm(:,:,1)=bigm1(:,:,1); bigm(:,:,3:end)=bigm1(:,:,2:end);
h=n*(n-1)/2;regm=zeros(h,m+1);
for i=1:m+1
    vec=bigm(1,2:end,i);
    for j=2:n
    vec=[vec,bigm(j,j+1:end,i)];
    end
    regm(:,i)=vec';
end
plist=[-0.0672
0.1121
-0.2062
0.5714
1.861
-0.0006
0.0075
1.548
0
-0.6932
0.0062
];
re=abs(sum([regm(:,2:end),ones(h,1)]*plist-regm(:,1)))
```

Run the code separately to get the difference values of 2.1109, 2.1118, and 2.1168. Based on the above definition of the gradient $\Lambda(\varepsilon)$ value: $|\Delta E_c^{\varepsilon}-\Delta E_c|/\varepsilon$, it can be obtained that under the disturbance of the above three linear transformations to the environmental regulation intensity matrix, The gradients are 105.55, 105.59, and 105.84 respectively. Strictly speaking, the $|\Delta E_c^{\varepsilon}-\Delta E_c|/\varepsilon$ values obtained under the second transformation cannot be called gradients, because the transformation only uses line breaks and does not use the ε value. As far as the numerical results are concerned, the first transformation has the least impact on ecological efficiency, because the first transformation makes each value of the environmental regulation intensity matrix multiplied by 1.02 times, and the relative strength of the inter-regional environmental regulation intensity changes the least; The gradient obtained under the third transformation is the largest, because some rows of the environmental regulation intensity matrix are numerically improved, and some rows remain unchanged, which obviously affects the relative strength of environmental regulation between regions.

Correspondingly, considering the weakening of environmental regulation, we can set p1=-0.02 and repeat the above process to run the code to obtain the gradients of 105.56, 105.59, and 105.79 under the disturbance of the above three linear transformations to the

environmental regulation intensity matrix, respectively. Obviously, the value of $|\Delta E_c^{\varepsilon} - \Delta E_c|/\varepsilon$ obtained under the second transformation will not change; while the gradient obtained under the first and third transformations changes slightly, it can be seen that the value of the environmental regulation intensity matrix The impact of overall scaling is not significant enough, and the driving effect of environmental regulation is mainly reflected in the difference in the strength of environmental regulation between regions.

The results in this section indicate that changes in the value of environmental regulation intensity will significantly affect the final value of eco-efficiency. Through the demonstration in this section, the application constructed in this chapter through the regression expression of the relationship between industrial transfer and eco-efficiency shows that the realization process of environmental regulation-driven eco-efficiency improvement is indirectly promoted through the intermediate link of industrial transfer. Changes in the value of environmental regulation intensity will significantly affect the final value of eco-efficiency. In the process of demonstration, the application of the regression expression of the relationship between industrial transfer and ecological efficiency constructed in this chapter shows that **the process of environmental regulation driving the improvement of ecological efficiency is indirectly promoted through industrial transfer.**

7. Summation and conclusion

It can be seen that the improvement of the ecological efficiency of the Yangtze River Economic Belt through the path of environmental regulation significant affects or drives the transfer of industries. For carbon-green transition, we believe that further relevant policy measures can be taken. First, based on the laws revealed by the quantitative verification of industrial transfer by environmental regulation, we should further guide the rational transfer of industrial groups in the Yangtze River Economic Belt with differentiated environmental regulations. Based on the Markov process model of industrial transfer established in this chapter, it conducts real-time research and judgment on the trend of industrial transfer between provinces and cities in the Yangtze River Economic Belt, and conducts Monte Carlo analysis on the industrial transfer situation caused by changes in the relative strength and weakness of inter-regional environmental regulation. Secondly, the quantitative results indicate that a stable and sustainable environmental regulation should exert a long-term cumulative effect of environmental regulation. The numerical simulation and regression analysis in this chapter show that the cumulative amount of environmental regulation has the effect of driving industrial transfer and improving ecological efficiency, while the comparative analysis in this paper has shown that the final impact of immediate environmental regulation on ecological efficiency is not significant, so it can be inferred from this Its driving effect is also weak. In conclusion, in order to achieve the promotion of eco-efficiency by strengthening environmental regulation, emphasis should be placed on the long-term robustness and sustainability of environmental regulation. Finally, based on the significance analysis of the control variables discovered in the regression analysis, it is concluded that optimizing the structure of foreign investment as a catalyst for the driving effect of environmental regulation. According to the numerical results of regression fitting in this chapter and the previous chapter, it can be seen that the two control variables of external dependence and the proportion of foreign direct investment have always been significant. It is indispensable in the characterization of the law of action of ecological efficiency. It can be seen from the regression expression that foreign investment has played a positive role in the direct effect of industrial transfer on ecological efficiency. Therefore, optimizing the structure of foreign investment will help to give full play to the driving effect of environmental regulation. However, the convenience of foreign direct investment in different regions in the upper, middle and lower reaches of the Yangtze River Economic Belt is significantly different. Thereby, other inland areas should strengthen their ability to absorb the radiation effect of foreign trade resources along the coast and rivers, and speed up the construction of inland transportation,

so as to better undertake the assistance and thrust of foreign investment in the low-carbon and green transformation of the industry.

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