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Research on Global Innovative Green Development Efficiency Measurement Based on Dea Super Efficiency Model

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ABSTRACT. *Innovative green development has become the direction of global development. Based on the R&D-driven theory, this paper builds an innovative green development efficiency index, and uses the super-efficient DEA-SBM model to measure the innovative green development efficiency and green total factor productivity of 18 countries around the world from 2008 to 2017. Through empirical findings: (1) Globally, technological innovation is not obvious for the efficiency of green economic development; (2) Green discovery efficiency varies greatly between countries; (3) Technological progress is again confirmed as the main factor that promotes the growth of green economic efficiency in various countries power.*

KEYWORDS: *Green development, R&d investment, Green economic efficiency, Total factor productivity*

1. Introduction

"Green economy" refers to the basis of ecological economy and knowledge economy, market orientation, the harmony and sustainable development of economy and environment as the goal, and the maintenance of human living environment, reasonable protection of resources and energy, and beneficial to human health. Features of a sustainable and balanced economic development model[1]. In 2008, the United Nations Environment Program (UNEP) proposed the "Green New Deal" and "Green Economy" initiatives to promote green transformation of the economy and promote green development has become an important way for sustainable development in various countries. In 2010, the European Commission announced the European Union's economic development plan for the next ten years, namely the "EU 2020 Strategy", focusing on technological innovation, research and development, education, clean energy and labor market liberalization, and formulated a series of green development goals[2]. At present, many governments in the United States, Britain, France, Japan, South Korea, and China have taken corresponding green actions.

The US Green New Deal was first proposed by Obama in the 2008 election campaign. He advocated long-term investment in new energy, leading the new

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generation of global industrial competitiveness, and proposed the mid- and long-term energy conservation and emission reduction goals in the United States. , Social and ecological coordinated and sustainable development[3].

British Prime Minister Blair published a white paper "Our Future Energy-Creating a Low-Carbon Economy" in 2003, which proposed that by 2050, the United Kingdom will become a green country, get rid of the current economic recession through green development, and promulgate a series of laws and regulations[4].

France put forward the "Grenelle de l'environnement" in 2007,establishing a long-term policy for solving environmental problems and promoting sustainable development. Laws 1 and 2 of the "New Environmental Protection Act" (Grenelle 1 and Grenelle 2) were promulgated in 2009 and 2010 respectively, which clearly stipulate that each French city must incorporate ecologically meaningful green infrastructure into the urban development plan, which makes French green Urbanization and sustainable development have entered a new stage of development[5].

Japan has mainly formed two models in the long-term green development: one is the "Utsu model" and the other is the circular economy model. The Yudu model relies on the participation of the whole people to supervise pollution, and through its "production, official, academic, and civilian" organization team, it makes urban governance more democratic and transparent. The circular economy model is mainly about the participation of consumers, enterprises and society to form a green development model. Through vigorous publicity, consumers fundamentally change their development concepts; through the vigorous development of green markets, they guide the transformation and upgrading of enterprises; through the promulgation of laws and regulations, strict market regulations[6].

South Korean President Li Mingbo pointed out in 2008 that low-carbon green growth is a new national development model that creates new growth drivers and job opportunities with green technologies and clean energy. In September 2008, the South Korean government issued the "Low-Carbon Green Growth Strategy", indicating the future development direction. A major development direction for South Korea's green growth is a sound transition to a low-carbon green economic system, and by 2020 it will become the world's top five green technology and green industry powerhouses. The main objectives of the green growth strategy: first, energy independence and building a low-carbon society; second, green technologies and industries as new growth drivers; third, the construction of green culture and green infrastructure; and fourth, the creation of green jobs [7].

The Chinese government put forward the scientific development concept in 2003, "Insist on people, establish a comprehensive, coordinated and sustainable development concept, and promote the comprehensive development of economy, society and people." The party's "17th National Congress" further put forward the strategic goal of building an ecological civilization. The "Twelfth Five-Year Plan for National Economic and Social Development" clearly states that the theme of scientific development should be the main line to accelerate the transformation of

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economic development mode, achieve green development, and take the construction of resource-saving and environment-friendly society as an accelerated transformation. An important focus of the economic development mode, improve the level of ecological civilization, and take the road of sustainable development [8].

The green economy model will inevitably drive the rise of various green industries such as new energy, environmental protection, energy efficiency improvement technologies, cleaner production processes, and the development of related traditional industries. It will also inevitably lead to a substantial increase in the employment rate and create sustainable economic growth in various countries. point. Therefore, the green economy is not only a new development path to solve the current economic development dilemma and promote economic growth under the multiple global crises, but also a fundamental strategy for achieving sustainable development. It is also a hot field of global research.

2. Literature Review

The term “green economy” is derived from the book “Green Economy Blueprint” published by British Pierce Pierce in 1989, which incorporates green economy into the theoretical framework of environmental economics[9]. Green economy has experienced different research stages such as industrial ecology, ecological efficiency, ecological design, and innovative green development in the formation of sustainable development ideas[10].

Western scholars tried to incorporate resource and environmental factors into performance measurement for research and made breakthrough progress; Chung et al. [11]introduced the directional distance function when measuring the total factor productivity of Swedish pulp mills, and proposed Malmquist-Luenberger (ML) production Index, which can measure the total factor productivity with “unexpected output”. Solow [12]believes that total factor productivity growth rate is the remaining output growth rate due to technological changes and cannot be explained by input growth, while green total factor productivity is total factor productivity that incorporates environmental factors.

Chinese scholars have also conducted relevant research on China's economic development efficiency and total factor productivity. Wang Xiaoyun (2007) et al. [13]based on the data of 285 prefecture-level cities and used the DEA model research to find that technological progress is the main driving force leading to the improvement of urban green development efficiency. Hou Chunguang et al. (2017) [14]studied the impact mechanism of Chinese technological innovation on greening, and proposed that technological innovation played a significant positive role in regional greening. Most of the researches on economic development efficiency and total factor productivity are carried out without considering the economic development may cause greater environmental losses, such as Wang Zhigang et al [15]Zhu Chengliang et al[16], Yang Ru[17], Their research has drawn many valuable conclusions, but the biggest problem is that the constraints of resources and environment are not considered, which will affect the objectivity and accuracy of the

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measurement.

With the continuous development of the economy, the role of R&D investment in economic growth is increasingly important. Romer[18], Grossman & Helpman[19] and other scholars pointed out that R&D promotes technological progress, and accelerates the transformation of scientific research results to realize the upgrading of products and methods, thereby promoting economic growth. Foreign scholars tend to study it from a micro-enterprise perspective. For example, Sueyoushi & Goto[20] found that R&D investment can improve the value of Japanese IT and manufacturing companies. This result is also suitable for other industrial countries.

There have been studies on green development efficiency and green total factor productivity, which are more based on traditional factors, but the core driving force for optimizing the efficient allocation of green development resources and improving green total factor productivity in the new period is technological innovation capability. Therefore, based on the R&D driving theory, this paper constructs a DEA-SBM model that includes R&D investment. The traditional input factors include capital input, labor input, and energy input. The innovative input elements include R&D personnel and R&D funds. Further analysis of the evolutionary laws and regional differences of innovative green development efficiency and green total factor productivity in 18 major countries from 2008 to 2017.

3. Research Methods and Data Sources

3.1 Dea Model

Data Envelopment Analysis (DEA) is based on the concept of relative efficiency. It is a systematic analysis method for relative effectiveness or benefit rating of the same type of decision-making unit based on multi-index input and multi-index output. The advantages of using the DEA analysis method are as follows: fewer indicators required; high sensitivity and reliability; analysis of indicators that cannot be priced and difficult to determine weights; there is no need to unify indicator units, which simplifies the measurement process and guarantees the original information The completeness of the software also avoids the subjective influence of artificially determining the weights; the comprehensive evaluation of evaluation units with common characteristics does not require function assumptions for variables.

3.2 Sbm Directional Distance Function Model

This paper uses the non-radial, non-angle SBM directional distance function to measure the Malmquist-Luenberger (ML) productivity index, and uses this to measure the TFP level of each country. The basic idea is to use each country as a decision-making unit, and each decision-making unit includes input, “good” output and “bad” output. Suppose each country uses M kinds of inputs x=(x1,...,xm,...xM)

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∈Rm+ to produce N kinds of "good" output y=(y1,…,yn,…yN)∈RN+, and emits J kinds The "bad" output b=(b1,...,bj,...bJ)∈RJ+. The production possibility set reflecting environmental technology is Pt(x)={(xt,yt,bt,):xt}, and meets some basic assumptions of the production possibility set: ①closed set and bounded set; ② input and expectation Free disposability, zero integration and weak disposability of output. Therefore, the use of data envelopment analysis (DEA) can express environmental technology as:

$$P(x) = \left\{ \left(y^t, b^t\right) : \sum_{i=1}^{I} Z_i^t y_{im}^t \geq y_{in}^t, \forall_n; \sum_{i=1}^{I} Z_i^t b_{ij}^t = b_{ij}^t, \forall_j; \sum_{i=1}^{I} Z_i^t x_{im}^t \leq x_{im}^t, \forall_m; \sum_{i=1}^{I} Z_i^t = 1; Z_i^t \geq 0, \forall_i \right\}$$

(1)

Among them, i=1, 2, ..., I represents the corresponding countries; t=1, 2, ..., T represents the period; Zit represents the weight of each cross-sectional observation value. According to the SBM model processing method proposed by Fukuyama & Weber, the directional distance function considering environmental factors can be constructed under the condition of variable scale returns:

$$S_V^t\left(x^{t,i'}, y^{t,i'}, b^{t,i'}, g^x, g^y, g^b\right) = \max_{s_x \cdot s_y \cdot s_b} \frac{\frac{1}{M}\sum_{m=1}^{M}\frac{S_m^x}{g_m^x} + \frac{1}{N+J}\left(\sum_{n=1}^{N}\frac{S_n^y}{g_n^y} + \sum_{j=1}^{J}\frac{S_j^b}{g_j^b}\right)}{2}$$

(2)

The constraints are:

$$\sum_{i=1}^{I} z_i^t x_{im}^t + s_m^x = x_{i'm}^t, \forall_m$$

$$\sum_{i=1}^{I} z_i^t x_{in}^t - s_n^y = y_{i'n}^t, \forall n$$

$$\sum_{i=1}^{I} z_i^t x_{ij}^t + s_j^b = b_{i'j}^t, \forall_j$$

$$\sum_{i=1}^{I} z_i^t = 1, z_i^t \geq 0, \forall$$

$$s_m^x \geq 0, \forall_m; s_n^y \geq 0, \forall n; s_j^b \geq 0, \forall_j$$

(3)

Among them, the input and output vector of country i′ is (xt,i′, yt,i′,bt,i′,), and the direction vector whose positive output expansion, undesired output and input compression take positive values is (gx, gy, gb), the relaxation vector of input and output is (sx, sy, sb).

The index derived from the SBM model and the Malmquist model including undesired output is the Malmquist-Luenberger Productivity Index (ML), and the ML productivity index of period t+1 with period t as the base period is:

$$ML_t^{t+1} = \left\{ \frac{\left[1 + \overrightarrow{D_0^t}\left(x^t, y^t, b^t; g^t\right)\right]}{\left[1 + \overrightarrow{D_0^t}\left(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1}\right)\right]} \frac{\left[1 + \overrightarrow{D_0^{t+1}}\left(x^t, y^t, b^t; g^t\right)\right]}{\left[1 + \overrightarrow{D_0^{t+1}}\left(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1}\right)\right]} \right\} \quad (4)$$

When the ML value is greater than 1, it represents productivity growth; when ML. is less than 1, it represents productivity decline. The ML productivity index can be divided into a technological progress index (TECH) and an efficiency change index (EFFCH).

$$ML_t^{t+1} = TECH_t^{t+1} \times EFFCH_t^{t+1} \quad (5)$$

3.3 Data Sources

In the national sample, 18 countries including China, Russia, India, Brazil, South Africa, the United States, Germany, Japan, South Korea, Australia, Canada, France, Greece, Israel, Italy, Spain, United Kingdom, and New Zealand are selected. In addition to the old developed countries, it also includes the newly industrialized countries, but also includes most of the countries in the OECD and the BRICS countries. It basically covers the main participating countries in various organizations and has a certain representation. In order to keep the statistical data consistent, the data in this article are all from the public data of the World Bank. Panel data of 18 countries from 2008 to 2017 are selected to build an innovative green indicator system. Among them, input factors include R&D researchers (per million people), R&D expenditure as a percentage of GDP (%), stock trading volume (as a percentage of GDP); output indicators include expected output and undesired output Among them, the expected output is the gross national income (GNI) trillion measured by purchasing power parity (PPP), the acceptance of intellectual property rights fees, and the undesired output is the total natural resource rent (% of GDP). In the selection of indicators, the traditional input elements generally include capital input, labor input, and energy input, while for the innovative input elements, we have selected R&D researchers, R&D expenditure as a percentage of GDP, and stock trading volume as a percentage of GDP. The input of scientific and technological personnel, the investment of scientific and technological capital, and the degree of economic prosperity are included. The traditional

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undesirable output factors generally include exhaust gas, wastewater, and solid waste emissions as a measurement standard, while for the innovative undesirable output, we use the World Bank's total natural resource rent indicator to represent our economic cost of natural resource destruction. The traditional expected output is the level of economic development, and the innovative expected output is not only expected to be efficient for economic development, but also for the income generation of intellectual property, so we choose the World Bank's gross national income (PPP) as measured by purchasing power parity (PPP) GNI) indicators and intellectual property usage fee indicators. The details are shown in Table 1:

Table 1 Innovative Green Development Efficiency Evaluation Index System

index	Type	Index composition
Input indicators	Elements of Traditional Input	Capital investment
		Labor input
		Energy input
	Innovative input elements	R&D researchers
		R&D expenditure as a percentage of GDP
Output indicators	Traditional expected output	The level of economic development
	Innovative expected output	The level of economic development
		Intellectual property royalties
	Traditional undesirable output	Exhaust emissions
		waste water disposal
		Solid waste discharge
	Innovative unexpected output	Total natural resource rent as a percentage of GDP

4. Efficiency Measurement and Empirical Analysis

Because the output contains undesired output indicators, the SBM model and Malmqusit considering the undesired output are used to calculate the efficiency, and the innovative green development efficiency value of each country from 2008 to 2017 is obtained.

Overall, the efficiency of innovative green development among countries showed a volatile upward trend. The efficiency value increased from 0.3797 in 2008 to 0.4620 in 2017, with an average annual growth rate of 2.20%, and it has obvious characteristics of stage changes. Among them, between 2008 and 2011 It fluctuated and declined, tending to rise slowly in 2011, which indicates that the efficiency of green economic growth among countries tends to increase, but the efficiency value is less than 0.5, and the overall value is small, indicating that there is still much room for improvement.

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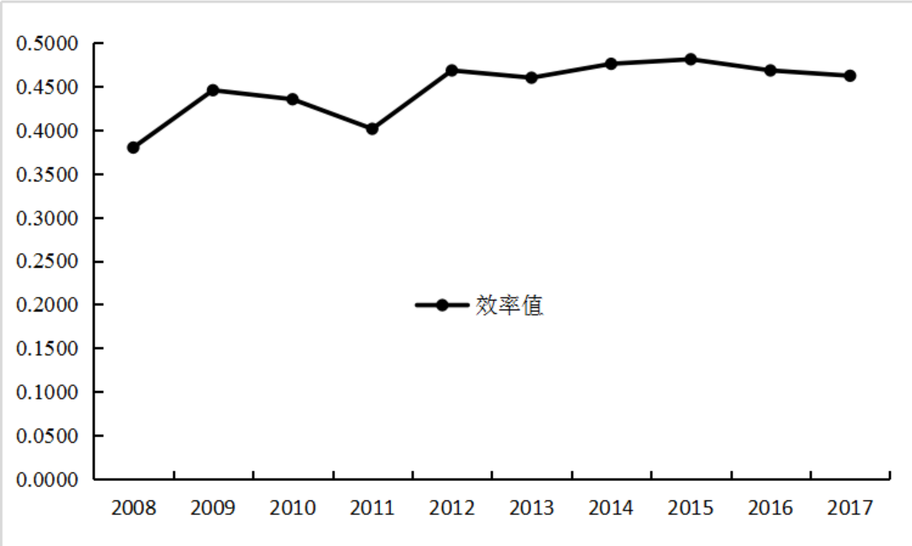

Fig.1 Time Evolution of Innovative Green Development Efficiency

The efficiency of innovative green development varies greatly between countries. According to the SBM model, the growth efficiency of innovation and green development in various countries is shown in Table 2. As can be seen from Table 2, on the one hand, there is a large difference in innovation green development efficiency among countries. The value of the Gini coefficient of green development efficiency increased from 0.455 in 2008 to 0.507 in 2017; Large, green growth efficiency of China, Russia, India, the United States, Germany, Japan, Israel, and the United Kingdom generally fluctuated and increased, while Brazil, South Africa, South Korea, Australia, Canada, France, Italy, Spain, New Zealand, green growth efficiency generally fluctuated and declined However, the overall volatility of Greece has changed significantly, and the overall green growth efficiency tends to increase

Table 2 Innovative Green Development Efficiency of Various Countries in 2008-2017

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean	Rank
China	1.102	1.246	0.894	0.897	1.394	1.204	1.183	1.024	1.365	1.146	1.146	2
Russia	0.276	0.282	0.315	0.365	0.481	0.946	1.098	1.006	0.702	1.034	0.651	6
India	0.823	1.137	0.976	1.045	1.028	1.090	1.077	1.097	1.127	1.052	1.045	3
Brazil	0.466	0.341	0.327	0.318	0.291	0.294	0.296	0.292	0.232	0.236	0.309	9
South Africa	0.081	0.073	0.078	0.076	0.070	0.063	0.057	0.051	0.042	0.044	0.063	16
United States	0.874	1.172	1.003	0.959	1.254	1.102	1.187	1.945	1.004	1.055	1.155	1
Germany	0.286	0.511	0.770	0.640	0.807	0.867	0.976	0.713	1.190	0.761	0.752	5

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Japan	0.834	0.930	1.084	0.954	1.295	1.015	1.088	0.982	0.956	1.212	1.035	4
Korea	0.184	0.172	0.193	0.171	0.122	0.109	0.119	0.095	0.110	0.100	0.138	13
Australia	0.053	0.050	0.044	0.044	0.049	0.056	0.058	0.050	0.046	0.051	0.050	17
Canada	0.107	0.095	0.091	0.089	0.093	0.101	0.101	0.094	0.091	0.093	0.095	14
France	0.561	0.595	0.555	0.570	0.565	0.528	0.440	0.377	0.449	0.469	0.511	7
Greece	0.079	0.098	0.097	0.112	0.129	0.075	0.044	0.077	0.120	0.100	0.093	15
Israel	0.025	0.025	0.021	0.032	0.039	0.041	0.059	0.046	0.058	0.048	0.039	18
Italy	0.402	0.518	0.400	0.365	0.304	0.291	0.275	0.298	0.378	0.349	0.358	8
Spain	0.247	0.382	0.239	0.196	0.186	0.179	0.158	0.148	0.187	0.145	0.207	11
United Kingdom	0.266	0.246	0.242	0.241	0.224	0.239	0.270	0.291	0.301	0.352	0.267	10
new Zealand	0.168	0.146	0.502	0.148	0.095	0.073	0.078	0.069	0.067	0.070	0.142	12

In order to further understand the spatial heterogeneity of innovation green growth efficiency among various countries, it is divided into four categories according to the annual average value of innovation green growth efficiency of each country (Table 3). Among them, the first level is the high level of innovation green growth efficiency, the green growth efficiency value is significantly greater than 1, the second level is the higher level of innovation green growth efficiency, the green growth efficiency value is between 0.5-1; the third level is innovation The level of green growth efficiency is lower, and the value of green growth efficiency is between 0.1-0.5; the fourth level is the low level of innovative green growth efficiency, and the value of green growth efficiency is less than 0.1.

Table 3 Innovative Green Growth Efficiency Levels

Level	country	Interval efficiency
First level	United States, China, India, Japan	1-1.155
Second level	Germany, Russia, France	0.5-1
Third level	Italy, Brazil, United Kingdom, Spain, New Zealand, South Korea	0.1-0.5
Fourth level	Canada, Greece, South Africa, Australia, Israel	<0.1

The Malmquist index is further used to calculate the total factor productivity and its decomposition contribution of innovative green growth in each country (Table 4). It is known from Table 4 that from 2008 to 2017, the total factor production efficiency value of each country is greater than 1, which indicates that the innovation green growth rate of each country tends to rise; the innovation green growth efficiency is driven by technological progress and technical efficiency. Among them, technology The contribution rate of progress is obviously greater than the contribution rate of efficiency change, indicating that technological progress is the main driving force for promoting green efficiency growth in various countries, but there are differences between countries. The contribution rate of efficiency change in Russia, Japan, Israel, and New Zealand is greater than the contribution rate of technological progress It shows that the efficiency improvement of Russia, Japan, Israel and New Zealand from 2008 to 2017 is the main driving force for green

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economic growth.

Table 4 Efficiency of Innovation and Green Development in Various Countries from 2008 to 2017

	All elements Productivity index	Effectiveness Change index	technology Progress index	Efficiency change Contribution rate (%)	skill improved Contribution rate (%)	Rank
China	1.183	1.036	1.135	87.590	96.018	5
Russia	1.396	1.255	1.203	89.901	86.131	1
India	1.056	1.003	1.103	94.966	104.448	10
Brazil	1.052	0.935	1.147	88.930	109.015	12
South Africa	1.016	0.910	1.118	89.532	109.993	18
United States	1.028	0.980	1.059	95.338	103.042	16
Germany	1.307	1.132	1.183	86.583	90.541	3
Japan	1.035	1.154	1.073	111.506	103.677	15
Korea	1.052	0.982	1.148	93.266	109.034	11
Australia	1.072	1.006	1.081	93.853	100.838	8
Canada	1.044	0.974	1.075	93.300	102.982	13
France	1.090	1.066	1.159	97.785	106.296	7
Greece	1.195	1.083	1.099	90.667	92.013	4
Israel	1.163	1.081	1.078	92.947	92.723	6
Italy	1.022	0.920	1.148	89.957	112.352	17
Spain	1.037	0.894	1.192	86.268	115.005	14
United Kingdom	1.060	1.014	1.052	95.695	99.300	9
new Zealand	1.350	1.254	1.180	92.897	87.439	2
average value	1.120	1.038	1.124	92.664	100.382	

According to the development dynamics of total factor productivity of innovative green growth in all countries from 2008 to 2017 (Table 5), the total factor productivity of innovative green growth in all countries in each year tends to fluctuate and change, efficiency changes slightly, and technological progress declines in a stepwise fluctuation . From the perspective of factors that affect total factor productivity growth, technological progress is the main factor that promotes green economic growth in various countries. Its annual average contribution rate is 100.72%, while the average annual contribution rate of efficiency changes is only 93.07%.

Table 5 Overall Factor Productivity of Innovative Green Growth in Various Years

Level	All elements Productivity index	effectiveness Change index	technology Progress index	Efficiency change Contribution rate (%)	skill improved Contribution rate (%)
2008-2009	1.117	0.994	1.181	88.914	105.697

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2009-2010	1.341	1.205	1.115	89.833	83.124
2010-2011	1.162	0.979	1.250	84.253	107.609
2011-2012	1.192	0.922	1.312	77.375	110.095
2012-2013	1.055	1.114	0.985	105.581	93.355
2013-2014	1.075	1.031	1.053	95.853	97.929
2014-2015	1.043	0.945	1.189	90.673	114.004
2015-2016	1.103	1.160	1.021	105.165	92.569
2016-2017	0.991	0.990	1.012	99.941	102.092

5. Conclusion

This paper builds an innovative SBM model that includes scientific and technological innovation input through R&D-driven theory, measures and analyzes innovative green development efficiency and total factor productivity in 18 countries from 2008 to 2017, and draws the following conclusions:

(1) Since 2008, the investment in science and technology in various countries around the world has shown a gradual upward trend in green development efficiency, but the growth effect is not obvious. Overall, the annual growth rate is only 2.20%. Technological innovation is not obvious for the efficiency of green economy development.

(2) The efficiency of innovation green development varies greatly among countries, and the fluctuation of innovation green growth efficiency in some countries varies greatly. For example, the highest US (1.155) and the lowest Israel (0.039) are nearly 30 times different.

(3) It is found through empirical evidence that the efficiency of innovation and green growth is jointly promoted by technological progress and technological efficiency. In most countries, the contribution rate of technological progress is significantly higher than the contribution rate of technological efficiency change, which once again confirms that technological progress promotes various The main force of national green efficiency growth.

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