The Construction of Linear Regression Model Based on the Index Evaluation Method to Account Green GDP

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Abstract. With the popularization of sustainable development, the traditional GDP index is discussed to be revised to build a new green GDP (hereinafter referred to as GGDP) to meet the needs of sustainable development. At present, there are many methods of calculating GGDP in the academic circle, but due to the complex and diverse environmental factors and the large differences in different countries, these methods fail to achieve the feasibility and simplicity of GGDP accounting operation while pursuing the theoretical accuracy. For this problem, this paper tries to start from the perspective of Value quantity accounting and uses pollution loss method for reference, establishes accounting method which can not only achieve the purpose of GGDP accounting, but also relatively simple, and easy to calculate. First, this paper constructs environmental cost variables through four indicators: Coal, Oil, Gas and Carbon dioxide. Next, to emphasize the importance of "green", a coefficient is introduced to increase the weight of environmental costs in the accounting of GGDP. Then, a linear regression model based on the index evaluation method is established where GGDP is calculated by subtracting the environmental cost of a certain weight from GDP. To justify the model effectiveness, a benefit prediction model is established to predict the environmental cost over the next 50 years under the conditions in which GDP and GGDP are adopted, respectively. The results prove the effectiveness of the linear regression model based on the index evaluation method constructed in this paper. Under the background that the current GGDP accounting methods proposed in the academic circle pursue accurate theory while ignoring the difficulties in practical accounting, the accounting model established in this paper, which is relatively simple and easy to calculate, will provide practical application value for the implementation of GGDP accounting in the future.

Keywords: Indicator Evaluation Method; Linear regression model; Green GDP.

1. Introduction

GDP is the core indicator in the national economic accounting system, which is often applied to determine a country’s purchasing power and ability to obtain loans. However, as a composite measurement that predominantly emphasizes economic dimensions, GDP does not fully consider resource and environmental factors of economic growth, such as water pollution, climate crisis, and resource exhaustion, etc. [1]. With the popularization of sustainable development, revising traditional GDP indicators and constructing a new green GDP adapted to the needs of sustainable development strategies have become hot research topics today [2].

In the field of academic research, many scholars have studied the measurement method of GGDP. Nawapanan et al. [3] used Life Cycle Assessment, which is a technique used to assess the environmental impact of sugar industry from raw materials, distribution, production, and waste management. Yan et al [4] mentioned that GGDP can be obtained through the adjustment of environmental costs on the basis of traditional GDP: including the removal of environmental asset depreciation, environmental damage prevention costs, resource and environmental restoration costs, etc. Zeng [5] considered the energy value method can be used to calculate GGDP, which calculates the total energy value, the energy value currency ratio and the energy-currency value by classifying and converting the original data. Specifically, GGDP is equal to GDP minus the energy value of non-renewable environmental resources in the system, the sum of the energy-currency value of the non-renewable resources consumed in the system, and the sum of energy-currency value of the waste discharged in the system. Tong [6] proposed that GGDP should be calculated by introducing the concept of negative output, the reconstruction of input and output indicators, and the accounting principles of consistency of input and output, and calculating resource input and environmental pollution from the perspective of flow, then an accurate green GDP index that reflects the effect of environmental governance can be obtained. Sun [7] reckoned that GGDP accounting needs to combine the theoretical ideas of self-organization, order parameters, comprehensive concept, system, technology, mechanism and other aspects, and explore the implementation path of cross-department coordination of green GDP accounting.

However, due to the complex and diverse environmental factors and the large differences in different countries, these methods fail to achieve the feasibility and simplicity of GGDP accounting operation while pursuing the theoretical accuracy. In view of this problem, this paper tries to use several indicators to simplify the accounting process and establish a relatively simple, accurate and easy to calculate model on the basis of pollution loss method from the perspective of Value quantity accounting. First, in this paper, the environmental cost variables are constructed through four indicators: Coal, Oil, Gas and Carbon dioxide. Next, to emphasize the importance of "green", a coefficient is introduced to increase the weight of environmental costs in the accounting of GGDP. Then, a linear regression model based on the index evaluation method is established where GGDP is calculated by subtracting the environmental cost of a certain weight from GDP. In order to verify the rationality of the model, a benefit prediction model is built to prove the effectiveness of the linear regression model constructed based on the index evaluation method.

Under the background that the current GGDP accounting method pursues accurate theory while ignoring the difficulties in practical accounting, the relatively simple and easy to calculate accounting model established in this paper will provide reference value for the implementation of GGDP accounting in the future.

2. Data Collection

This paper chooses a set of panel data consisting over 200 countries from Asia, Africa, South America, North America, and Europe. To ensure the universality and representativeness of the analysis results, our sample includes both developed countries and developing countries. To improve the accuracy and rationality of the subsequent calculation, the panel data spans from 2001 to 2020. All data sources used in this article are shown in Table 1.

Table.1. Data source

Data Source	Website
World Bank Open Data	https://data.worldbank.org/
IEA	https://www.iea.org/
Statistical Review of World Energy 2022	https://www.bp.com
UNdata	https://data.un.org/Default.aspx
Forward Database	https://d.qianzhan.com/
OECD Data	https://data.oecd.org/

3. Model Preparation

3.1. Basic assumption

- Here this paper mainly explores the global climate impact of GGDP adoption, so this paper makes no assumptions about the quantitative impact of the economy.
- When the world begins to adopt GGDP as a measure, and GGDP affects a country's national image, international status, credit, and other factors, thus countries will more or less consider changing their policies to suit for the new measurement.
- The extent to which the countries change their policy depends on the difference betthis paperen their measurement of GDP and GGDP.

- Countries with lower GGDP compared to GDP produce greater environmental pollution and climate impacts per unit of GDP, and therefore these countries are the most vulnerable when new standards are adopted.

3.2. Symbols

All the symbols used in this paper and their descriptions are shown as Table 2.

Table.2. Symbol description

Symbols	Description
E_{ij}	Indicates the environmental cost of the i^{th} country at the j^{th} time node
t_{ij}	Indicates the ratio of GGDP to GDP in the i^{th} country at the j^{th} time node
GDP_{ij}	Indicates the GDP of i^{th} country at the j^{th} time node
$GGDP_{ij}$	Indicates the GGDP of i^{th} country at the j^{th} time node
GE_{ij}	Indicates the environmental cost of i^{th} country at the j^{th} time node under GGDP
ΔE	Indicates the percentage of environmental cost reduced when adopted GGDP within next 5 decades
P_{coal}	The cost of environmental protection for each unit of coal consumed
P_{oil}	The cost of environmental protection for each unit of oil consumed
P_{gas}	The cost of environmental protection for each unit of gas consumed
P_{CO_2}	The cost of environmental protection for each unit of carbon dioxide consumed
$C_{coal_{ij}}$	The coal consumption of the i^{th} country at the j^{th} time node
$C_{oil_{ij}}$	The oil consumption of the i^{th} country at the j^{th} time node
$C_{gas_{ij}}$	The gas consumption of the i^{th} country at the j^{th} time node
$C_{CO_{2ij}}$	The carbon dioxide consumption of the i^{th} country at the j^{th} time node

4. Construction of Linear regression model based on the index evaluation method

4.1. Comparison of two general accounting methods

The method given by academia is of great reference significance, thus this paper summarizes the following two levels of GGDP measurement methods:

- **Physical quantity accounting**

Physical quantity accounting is to establish physical quantity accounts at different levels on the basis of the framework of national economic accounting to describe the production, removal and emission of various pollutants corresponding to economic activities.

- **Value quantity accounting**

Value quantity accounting is to estimate the monetary value loss caused by various environmental pollution and ecological damage on the basis of physical quantity accounting. It is also the main measure of GGDP accounting, including the following aspects: water pollution value accounting, air pollution value accounting, industrial solid waste pollution value accounting, urban domestic waste pollution value accounting and pollution accident economic loss accounting of each region. Common accounting Scope of GGDP is shown in Figure 1.

Figure 1. Accounting Scope of GGDP

As to physical quantity accounting method, data is often difficult to obtain. Moreover, given that GGDP measures loss caused by various environmental pollution and ecological damage, this method cannot well fulfill this mission. In contrast, value quantity accounting is easier to calculate by selecting key indicators, which can simplify the calculation process and also better complete the task of GGDP accounting. Therefore, value accounting method is adopted in this paper.

4.2. Comparison of two specific accounting methods

Pollution control cost method and pollution loss method are the two methods to calculate the environmental value quantity.

- **Pollution loss method**

Pollution loss method refers to the damage based environmental value assessment method. This method calculates the damage caused by environmental pollution with the help of certain technical means and pollution loss survey, such as the impact on agricultural production, human health, ecological service functions, etc., and uses certain pricing techniques to assess the economic loss of pollution. This method reflects the harm of pollution, but it is technically difficult and difficult to evaluate, thus is less feasible for this paper.

- **Pollution control cost method**

The pollution control cost method is a cost-based valuation method that calculates the cost of avoiding environmental pollution from the perspective of "protection". The cost of pollution control approach is based on the simple idea that if all pollutants are treated, environmental degradation will not occur, and therefore the economic value of the environmental degradation that has occurred should be the cost of treating all pollutants.

4.3. Preparation prior to model establishment

The thinking map for accounting methods and indicator selection is shown in Figure 2. The pollution control cost method is a cost-based valuation method that calculates the cost of avoiding environmental pollution from the perspective of "protection". The cost of pollution control approach is based on the simple idea that if all pollutants are treated, environmental degradation will not occur, and therefore the economic value of the environmental degradation that has occurred should be the cost of treating all pollutants [8]. The characteristics of the pollution control cost method, which is the physical amount of pollution, multiplied by the treatment cost of unit pollutant, lie in the simplicity and easy to understand of its value accounting process and the objectivity of the accounting basis. Therefore, it is easier to be used by environmental protection departments and statistical departments. This method will also be used in this paper as a way for GGDP accounting.

Based on this method, Coal, Oil, Gas and Carbon dioxide are selected to construct linear regression model based on the index evaluation method [9].

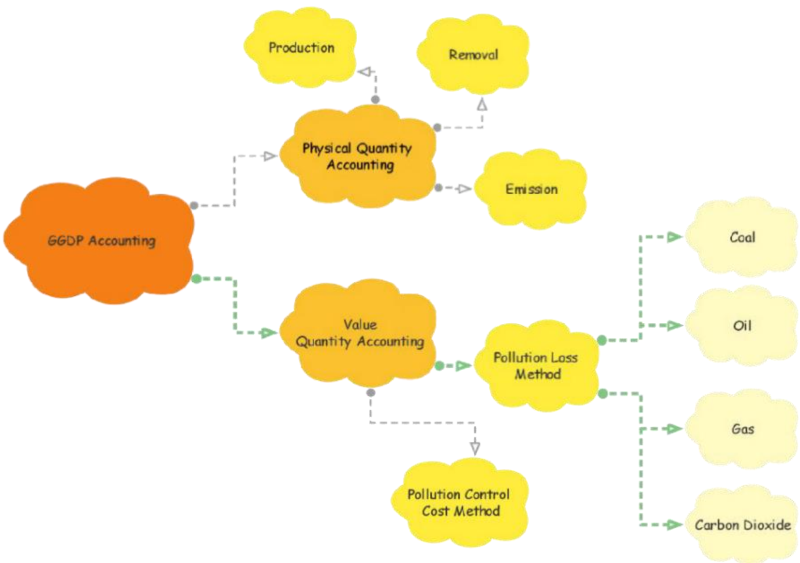

Figure 2. Thinking Map for Accounting Methods and Index Selection

4.4. Model establishment

Firstly, linear equations will be constructed by linear regression to the unit price of coal, oil, natural gas and carbon dioxide, shown as (1):

$$E_{ij} = P_{coal} \times C_{coal_{ij}} + P_{oil} \times C_{oil_{ij}} + P_{gas} \times C_{gas_{ij}} + P_{CO_2} \times C_{CO_{2ij}} \tag{1}$$

Then GGDP calculation is shown as (2):

$$GGDP_{ij} = GDP_{ij} - 10E_{ij} \tag{2}$$

The coefficient of E_{ij} comes from the proportion of our model allocated to environmental cost.

This paper hope to increase the importance of environmental cost in the calculation of GGDP, so that GGDP can better influence the policy direction of various countries and provide practical environmental benefits.

It should be noted that GGDP measurement may be less than 0, which means that the value of GDP created by the country is lower than to compensate for the irreversible environmental resource damage caused by the country's economic development in this standard, though the data this paper calculated are far from the case.

The index selected in this paper to measure the environmental cost mainly contains two aspects: one is the pollutant treatment cost, namely the emission cost and treatment cost, the other is the use of fossil energy and the theoretical compensation for resource use [10].

The amounts of GDP as well as the GGDP and Environment cost in various countries are shown in figure 3, figure 4 and figure 5.

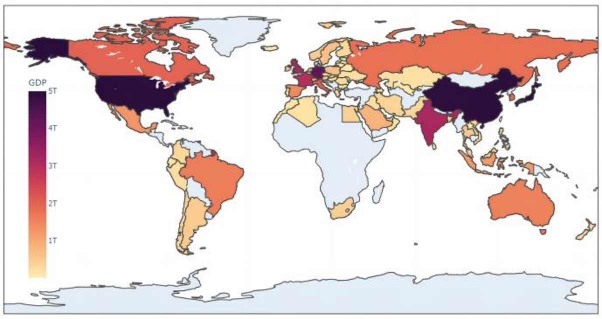

Figure 3. 2020 GDP Heat Maps (Current $)

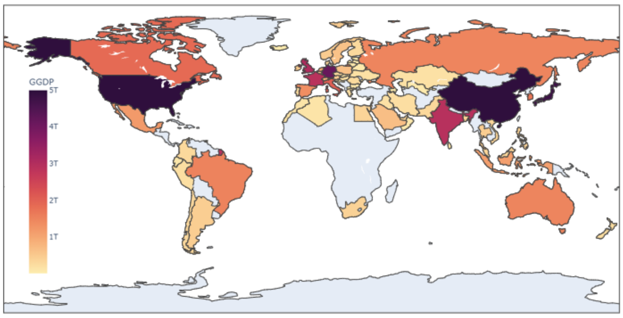

Figure 4. 2020 GGDP Heat Maps (Current $)

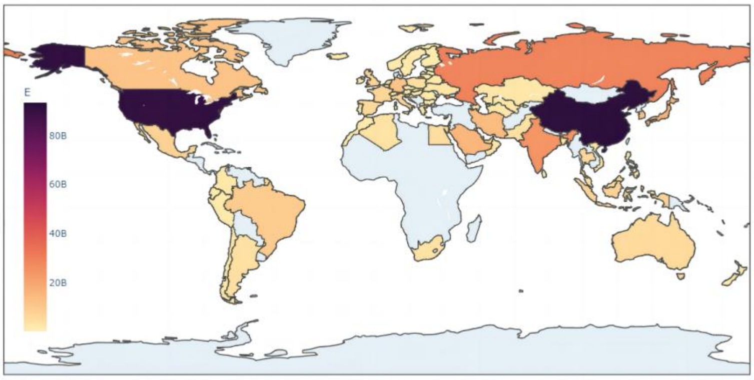

Figure 5. Environment cost in various global countries in 2020

5. Results

This paper will establish a benefit prediction model to explore the impact of GGDP Index Evaluation Model on environmental costs in various countries. The rationality and robustness of model construction are reflected by predicting the expected changes in environmental costs in various countries over the next 50 years.

5.1. The establishment of benefit prediction model

To estimate the expected global impact on climate mitigation if GGDP is adopted as the primary measure of a country's economic health, this paper uses a simple model that takes into account the following factors:

- **The ability to influence the policy**

In order to estimate how quickly countries are adopting GGDP as the primary measure of economic health. For this model, let's assume that when the world begins to adopt GGDP as a measure, and GGDP affects a country's national image, international status, credit, and other factors. In order to keep the national economy as well as society as stable and reliable as when GDP is adopted as a measure, countries with large differences in GGDP and GDP will make large policy adjustments when the GGDP measurement is adopted, while countries with small differences will not even make policy changes for the new measure. This assumption is clearly conservative, since given the impact of the GGDP measure on countries, all countries will actually make more or less policy adjustments to the new measure to strive for higher scores.

- **Environmental cost**

Here this paper build a stepped model [11] and introduce the parameter t_{ij} as the ratio of GGDP to GDP in the i^{th} country at the j^{th} time node, shown as (3):

$$t_{ij} = \frac{GGDP_{ij}}{GDP_{ij}} \tag{3}$$

This paper makes the following conservative assumptions about the effect of GGDP accounting method on national policies on environmental costs. Assuming that in the next decade when GGDP is adopted as a measure, countries with a t_{ij} of 95%-100% make negligible policy adjustments to the new measure, countries with a t_{ij} of 85%-95% will reduce the environmental costs of the new policy by 10%, 75%-85% by 20% and 65%-75% by 30%. Considering that the country's ability to change the GGDP over a certain period of time is limited, regardless of the country's willingness to improve its policy, countries with a t_{ij} of less than 65% can at most reduce the environmental cost of the new policy by 35%, as shown in Table 3.

Table.3. Hypothetical data for stepped model

t	Predicted reduced environmental cost every decade
95%-100%	0%
85%-95%	10%
75%-85%	20%
65%-75%	30%
<65%	35%

The predicted reduced environmental cost every decade ΔE is shown as (4):

$$\Delta E = \begin{cases} 0 & 95\% < t < 100\% \\ 0.10E & 85\% < t < 95\% \\ 0.20E & 75\% < t < 85\% \\ 0.30E & 65\% < t < 75\% \\ 0.35E & t < 65\% \end{cases} \tag{4}$$

5.2. Benefit prediction

With these assumptions in mind, this paper can estimate the expected global impact on climate mitigation when GGDP is adopted as the primary measure of economic health using the following steps:

Step 1: Calculate the current E_{i0}

Step 2: Estimate the growth rate of based on global GDP growth rate [12] in the past 3 decades, shown as (5)

$$\widehat{r}_i = \sum \frac{GDP_{i(j+1)} - GDP_{ij}}{GDP_{ij}} \tag{5}$$

Step 3: Calculate expected $E_{i\ (j+1)}$ of each country using GDP as the main measure.

According to the result of step1, $E_{i\ (j+1)}$ can be calculated as (6):

$$E_{i(j+1)} = E_{ij} \times (1 + \widehat{r}) \tag{6}$$

Step 4: Calculate t_{i0} for each country and the expected reduced according to the assumption.

The calculated global t_{i0} can be shown in figure 6:

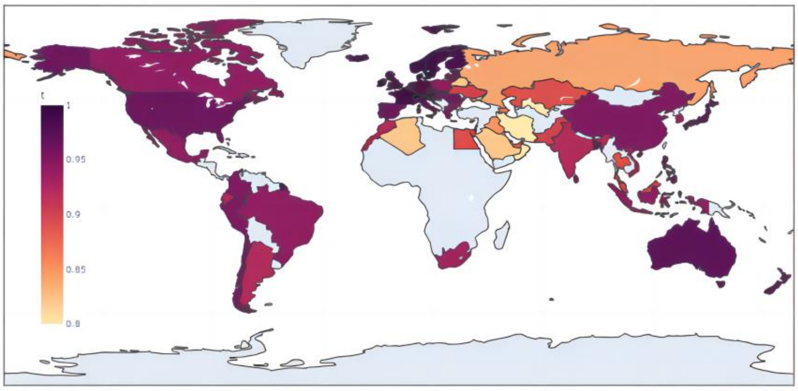

Figure 6. Ratio of GGDP to GDP in various global countries in 2020 (j=0)

Step 5: Calculate expected GE_{i1} of each country when using GGDP as the main measure, shown as (7):

$$GE_{ij} = E_{ij} - E(\Delta E_{ij}) \tag{7}$$

Step 6: Repeat step3, step4, until the next five time nodes are predicted, i.e.,,within the next 5 decades,. Therefore, if GGDP is adopted as the primary measure of economic health, following our assumptions, this paper estimate that it will contribute to reducing global environmental cost by up to 88.40%, calculated as (8). It should be emphasized that while the policy adjustment reduces environmental costs, the steady increase in environmental costs caused by the impact of inflation, population increase and so on still exists

$$\Delta E_{\max} = 1 - (1 - 35\%)^5 = 88.40\% \tag{8}$$

Step 7: Compare E_{ij} the expected GE_{ij} and of the next 5 decades, $1 \le j \le 5$. Here this paper takes the figures of next decade, three decades, and five decades due to space limitations for comparison, shown as figure 7-9.

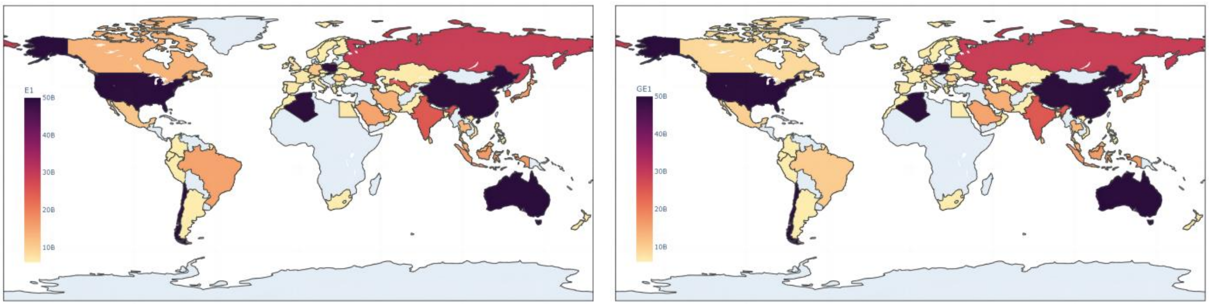

Figure 7. Predicted environmental cost by country in 2030 in adopting GDP and GGDP

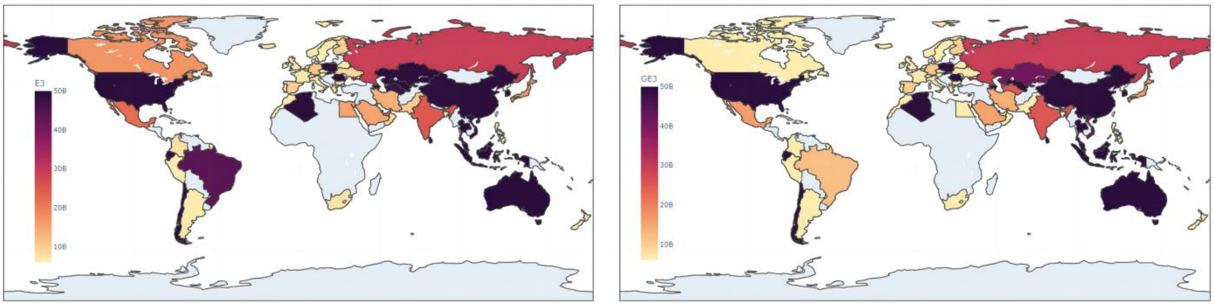

Figure 8. Predicted environmental cost by country in 2050 in adopting GDP and GGDP

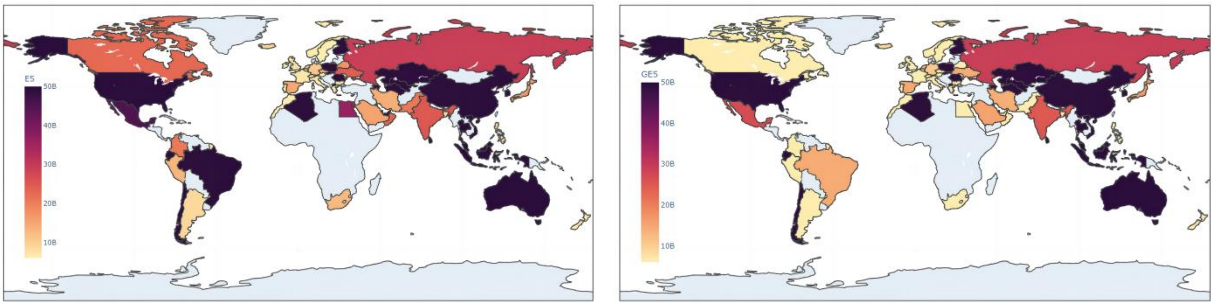

Figure 9. Predicted environmental cost by country in 2070 in adopting GDP and GGDP

As can be seen from the above figures, most countries in the Americas and some countries in Europe, Asia and Africa showed significant changes in environmental costs after adopting GGDP. While other countries have relatively insignificant changes over the next 50 years due to higher environmental costs or very low costs. From these figures, global environmental benefits of GGDP adoption can be easy seen. Over the next 100 to 1,000 years, these changes will be more pronounced.

The adoption of this GGDP accounting method has a significant effect in reducing the environmental cost, which can reduce environmental costs by 88.4% in fifty years, which will benefit a lot to climate mitigation.

5.3. Sensitivity Analysis of the benefit prediction model

Although the quantitative data of the model partially depends on subjective judgment, in the process of logical deduction, this paper reduces the expectation of GGDP adoption affecting the policy formulation of various countries, thus the model data is biased to be conservative. If the model quantification data are improved, the results will still support the conclusion of GGDP adoption, and the impact of GGDP on environmental costs will be even higher. For example, suppose the countries with $t<65\%$ are expected to reduce environmental costs by 40% per decade, the adoption of GGDP will enable a country to reduce environmental costs by up to 92.22% in five decades.

6. Conclusions

First, this paper introduces the concept of environmental cost as a variable, which includes the cost of actual treatment and the compensation of environmental damage value, and is composed of four indicators: Coal, Oil, Gas and Carbon dioxide. Next, to emphasize the importance of "green", a coefficient is introduced to increase the weight of environmental costs in the accounting of green GDP. This paper establishes a linear regression model based on the index evaluation method where GGDP is calculated by subtracting the environmental cost of a certain weight from GDP.

To test the robustness of this model, this paper establishes a Step Model to evaluate the benefit of the proposed GGDP accounting method. In order to eliminate the influence of inflation, population growth and other factors, this paper first uses linear regression to obtain the GDP growth rate. In the prediction process, considering the different willingness of countries to change policies after GGDP, t value is introduced as the ratio of GGDP to GDP, establishes reasonable assumptions about the impact of policy changes on environmental costs based on the value of t, then the environmental costs of each country in the next 50 years under the adoption of GDP and GGDP are predicted respectively. The conclusion is as follows:

(1) GGDP can be obtained by subtracting GDP from a certain weighted environmental cost, including actual expenditure and compensation for environmental damage and is composed of four indicators: Coal, Oil, Gas and Carbon dioxide. This GGDP accounting method is highly operable and effective

(2) The adoption of GGDP accounting method in this paper has a significant effect in reducing the environmental cost. This paper conservatively predicts to reduce environmental costs by 88.4% in fifty years, which will benefit a lot to climate mitigation.

In the short term, the adoption of GDP does have its own economic benefits. However, in the long term, the adoption of GGDP is not only beneficial to the environment, thus affecting the climate and living environment, but also is effective in promoting the sustainable development of the economy. While in the long run, the adoption of GDP will also lead to an economic downturn and damage to national interests due to the unsustainable development caused by resource shortage and environmental damage. This is also the significance and value of our study of Green GDP accounting method. While this paper focuses more on the simplicity and operability of GGDP accounting method, it also abandons the accuracy of GGDP accounting theory. We will continue to optimize the accounting model in the future, hoping to find a better balance in the simplicity and accuracy of GGDP accounting methods in the future.

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