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Study on the Calculation Method of Green GDP to Measure the Economic Health

Yixin Zhong *, Zhanpeng Tian, Yuxuan Zhu

College of Electrical and Mechanical Engineering, Hohai University, Changzhou, China

Abstract. This paper discusses the replacement of conventional GDP with green GDP (GGDP) as the main measure of economic health. Based on data on annual average temperature, annual precipitation, annual sunshine hours and annual average relative humidity for country C over the past decade, a multiple regression model is used to demonstrate that the linear effect of GGDP is positive for green growth. Further considering the differences in economic power between developed, developing and lagging countries, an infinite iterative game model of green GDP and conventional GDP is constructed based on the mutual constraints of long-term and short-term interests. Finally, considering the resistance to replacing GDP with green GDP, and in order to fully reflect the tortuous and complex relationship between climate change and social costs, an integrated model that will be embedded in the economic system, the DICE-2013R model, is constructed in order to achieve a shift from a single energy model to an integrated climate model. Normalising the data based on the model calcglobal scale.

1. Introduction

GDP is a valid indicator of the speed and level of a country's economic ulations, it is concluded that replacing GDP with green GDP is feasible on a development, but it does not reflect the resource and environmental costs, social costs and sustainability of a country's economic development and has limitations. For early developing and backward countries, rapid economic development in the early years also exposed the problems of resource depletion and environmental pollution. While localised economic growth may appear to be a sign of national prosperity, its far-reaching effects and irreversible costs are in fact incalculable. Therefore, with an eye on green GDP, we should focus on the current state of economic development in country C while taking into account the costs of natural resources and environmental protection, and use green GDP as an indicator pointer for future development.

2. Models

2.1 Multiple regression model

2.1.1 Building a multiple regression analysis model

For the calculation method of green GDP, domestic and foreign scholars have made a lot of research on it, due to the present economic state, the calculation of the economy is more complicated, countries do not make clear regulations on the calculation of green GDP. However, green GDP is inseparable from environmental conditions, and nowadays we use green GDP = traditional GDP - total value of natural resource losses - total value of environmental pollution losses + total value of comprehensive waste use[1]. We collected the average temperature, precipitation, sunshine hours and average relative humidity of a certain region for the years 2000-2010 to represent the climate change of the region in the last decade We have developed a multiple regression analysis.

We developed a mathematical and statistical method of multiple regression analysis to seek associations between green GDP and a number of climate-related variables in the region. We took the logarithm of green GDP as the dependent variable, set as LNG, and average temperature, precipitation, sunshine hours and relative humidity as independent variables, denoted as T, W, S and H, respectively.

$$LNG=\beta_0+\beta_1 T+\beta_2 W+\beta_3 S+\beta_4 H$$

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[*] Corresponding author: 2417185958@qq.com.

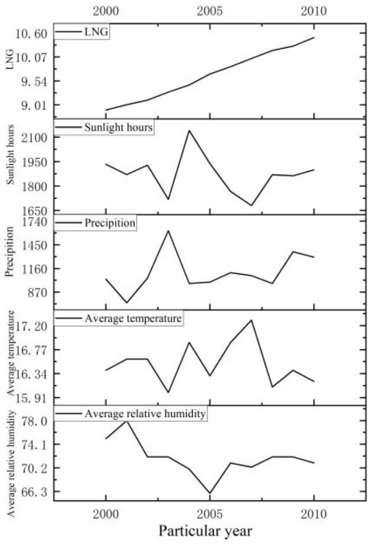

Figure 1. The interannual variability of climate indicators and LNG (left)

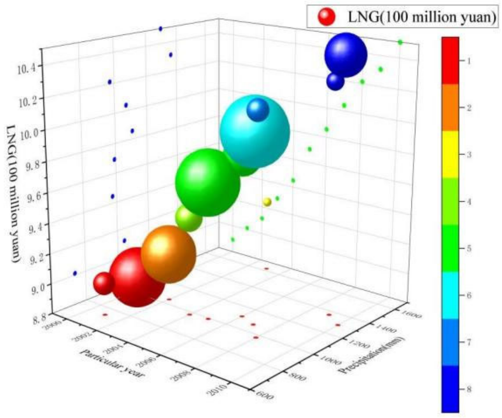

Figure 2. 3D model of climate indicators and LNG (right)

To solve for the parameters, we collected data and used partial derivatives to find the final result.For this multiple regression equation, we used the least squares method to solve for its parameters.

Q=∑(LNGi- $\overline{\text{L}}$NGi) 2

Q=∑(LNG- $\overline{\text{L}}$NGi)=∑(LNG-β0-β1T-β2S-β3W-β4H)=min

Taking the partial derivatives of Q with respect to β0, β1, β2, β3 and β4 respectively, we get:

$$\frac{\partial Q}{\partial \beta_0} = \sum(LNG_i - \beta_0 - \beta_1 T - \beta_2 W - \beta_3 S - \beta_4 H)(-1) = 0$$

$$\frac{\partial Q}{\partial \beta_1} = \sum(LNG_i - \beta_0 - \beta_1 T - \beta_2 W - \beta_3 S - \beta_4 H)(-T) = 0$$

$$\ldots\ldots$$

$$\frac{\partial Q}{\partial \beta_4} = \sum(LNGi - \beta_0 - \beta_1 T - \beta_2 W - \beta_3 S - \beta_4 H)(-H) = 0$$

From the above equations we can solve for the specific values of β1, β2, β3, β4 and β0 to obtain a multivariate linear relationship between climate conditions and green GDP.

LNG=18.97607+(-0.08347T)+0.00198W+(-0.00104S)+(-0.0865H)

2.1.2 *Analysis of multiple regression equations for green GDP and climate indicators*

Our analysis of this calculation shows that green GDP growth has a positive effect on precipitation and a dampening effect on the rise in sunshine hours, average relative humidity and temperature. Due to the complexity and diversity of the influences on climate, we have inevitably overlooked some influences in our modelling process.

The above model initially shows the positive impact of GGDP on the environmental climate. Based on the realistic need for green GDP and green development and its influencing factors, we then use game theory to further design the model.

2.2 Repeated game model

2.2.1 *Establishing green GDP and GDP duplication game model*

Green GDP takes into account the damage to the natural environment and the cost of environmental management when compared to traditional GDP. However, in practice, compared to developed countries, for developing countries and economically backward countries, when calculating economic strength, green GDP is used exclusively as a measure of a country's economic health, and the accelerated growth of green GDP will lead to stagnant GDP growth in the region, bringing great disaster to the region's economy. However, the complete denial of the positive effects of green GDP on the ecological environment will lead to serious damage to the region's natural environment.

Economic development and environmental protection should be assessed from a long-term perspective. Based on the mutual constraints of long-term and short-term interests, and considering the possible outcomes of the different scenarios described above, we construct an infinite iterative game model of green GDP and conventional GDP, requiring both immediate and long-term benefits for economic development and environmental protection. We take the potential ecological gains as R and the potential negative losses as P when both sides play the game.

2.2.2 *The solution of green GDP and GDP duplication game model*

1. Both parties adopt a cooperative strategy.

This scenario means that we place green GDP on an equal footing with traditional GDP when considering the health of a country's economy. Both sides choose to cooperate and continue to do so for an indefinite period of time afterwards. In this state of the game, traditional GDP, which previously held 100%, is weakened by 50%.

$$\mathbf{R} = \sum(\boldsymbol{\alpha}\mathbf{ln}(\mathbf{W_i} - \mathbf{W_{i-1}})^2 + \boldsymbol{\beta}\mathbf{ln}(\mathbf{T_i} - \mathbf{T_{i-1}})^2 + \boldsymbol{\gamma}\mathbf{ln}(\mathbf{S_i} - \mathbf{S_{i-1}})^2) + \sum\frac{(\mathbf{H_{i-1}} - \mathbf{H_i})^2}{\mathbf{2}}$$

where α ,β ,γ represent the correlation coefficients of precipitation, average temperature, and sunshine hours on the value of potential ecological and economic benefits, respectively, and α, β, γ belong to [0,1]. n represents the year.

$$\mathbf{P} = \left[\int_{-\infty}^{\infty}\mathbf{L}^{\mathbf{x}^2}\mathbf{dx}\int_{-\infty}^{\infty}\mathbf{ln}(\mathbf{B}^{\mathbf{y}^2})\mathbf{dy}\right]^{\mathbf{1/2}}$$

Where L represents the environmental damage cost and B represents the environmental treatment cost. x and y represent the floor factors of environmental damage cost and environmental treatment cost on the potential negative loss, respectively.

2. initial green GDP adopts offensive strategy, GDP adopts cooperative strategy

In the initial stage of the game, the proportion of green GDP is greater than GDP, but in the following time, GDP will adopt an offensive strategy, and at this time, the values of a and b keep changing with time change, and a+b=1[2].

$$\mathbf{R} = \sum\frac{\mathbf{a}}{\mathbf{50}}(\boldsymbol{\alpha}\mathbf{ln}(\mathbf{W_i} - \mathbf{W_{i-1}})^2 - \boldsymbol{\beta}\mathbf{ln}(\mathbf{T_i} - \mathbf{T_{i-1}})^2 - \boldsymbol{\gamma}\mathbf{ln}(\mathbf{S_i} - \mathbf{S_{i-1}})^2 + \sum\frac{\mathbf{a}}{\mathbf{50}}\frac{(\mathbf{H_{i-1}} - \mathbf{H_i})^2}{\mathbf{2}}$$

$$\mathbf{P} = \left[\int_{-\infty}^{\infty}\frac{\mathbf{b}}{\mathbf{50}}\mathbf{L}^{\mathbf{x}^2}\mathbf{dx}\int_{-\infty}^{\infty}\frac{\mathbf{b}}{\mathbf{50}}\mathbf{ln}(\mathbf{B}^{\mathbf{y}^2})\mathbf{dy}\right]^{\mathbf{1/2}}$$

3. Initially green GDP adopts a cooperative strategy and GDP adopts an offensive strategy.

In this scenario, we consider the economic health of a country and start with the proportion of GDP greater than 50% as b and the proportion of green GDP less than 50% as a. In the initial stage of the game, the proportion of GDP is greater than that of green GDP, but in the following time, green GDP will adopt an offensive strategy, and the values of a and b will change continuously over time, and a+b=1. The ecological potential gain R, and the potential negative loss P are calculated as in the second scenario.

4. Initial green GDP and traditional GDP both adopt offensive strategies

This scenario means that when we consider the economic health of a country, we initially consider placing green GDP on the same level of importance as conventional GDP[3]. That is, both parties cooperate and do so for an indefinite period of time thereafter, with the same calculation of potential ecological gains R and potential negative losses P as in the first scenario.

We collected the data of environmental damage loss and environmental treatment cost in a certain region in the past ten years, as well as the local climate indicators such as precipitation and sunshine hours, and analyzed and calculated the change pattern of environmental damage loss R and environmental treatment cost B when the ratio of green GDP to GDP is 50% each. Here, we set α,β,and γ to 0.3.

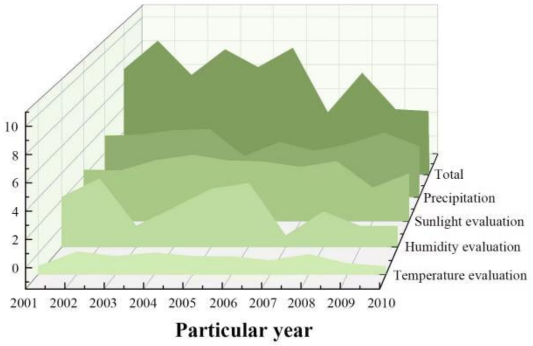

Figure 3. Map of ecological values and climate indicators changes(left)

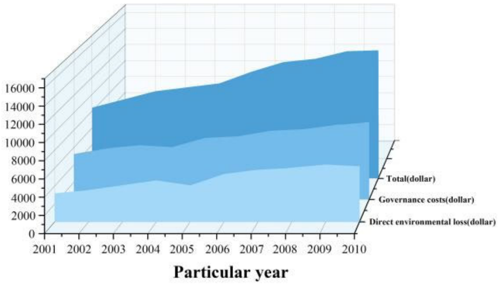

Figure 4. Interannual variations of potential losses and environmental damage(right)

2.2.3 Analysis of the results of green GDP and GDP duplicate game model

In the first and fourth scenarios, the two sides are in a state of cooperation in the game for a long time, and the values of potential ecological gain R and potential negative loss P[4] are calculated in the same way in each game. In the second and third scenarios, both parties start to cooperate and attack in the game, but the party that starts to cooperate also gradually changes to attack for its own benefit, and the proportion of both parties in the economic health evaluation is in dynamic change.

From the above analysis, we found that in either case, for the calculation of ecological potential gain R and potential negative loss P, the increase of precipitation in each stage is positively correlated with ecological potential gain R, while the increase of average temperature, sunshine hours and average relative humidity in each stage are negatively correlated with ecological potential gain R.

2.3 DICE-2013R model

In order to fully reflect the convoluted and complex relationship between climate change and social costs, we started with this aspect of PM2.5. We constructed an integrated model that embeds PM2.5 in the economic system, the DICE-2013R model[5], which achieves the transformation from a single energy model to an integrated climate model.

We use optimal path analysis [6] and assume that the $PM_{2.5}$ social cost is equal to the marginal price of $PM_{2.5}$

and, accordingly, to the marginal cost of reducing $PM_{2.5}$ concentrations and the present value of the air quality damage per unit of concentration. However, in reality many climate policies are not optimal, so the $PM_{2.5}$ social cost is a realistically derived marginal damage payment for $PM_{2.5}$.

2.3.1 Build a series of correlation models based on DICE design ideas

Based on the DICE design concept, the following correlation model was constructed.

1. **set preferences and welfare objective functions.** According to **the design principle of the Ramsey model**[7], the discounted value of consumption utility is assumed to be an optimal social welfare function under the consideration of intergenerational consumption, the value of intergenerational consumption in a given period is proportional to the population size, and the relative importance between different generations is influenced by two core criteria - the parameter pure social time preference rate (intergenerational discounting) and the marginal utility elasticity of consumption (consumption elasticity). We assume that these two parameters are consistent with the economic outcomes reflected by the interest rate and the self-return on investment, resulting in a standardized optimal utility model:

$$W = \sum_{t=1}^{T_{max}} U[c(t), L(t)]R(t)$$

$$R(t) = (1-\rho)^{-\tau}$$

$$U[c(t), L(t)] = L(t)[\frac{c^{1-\alpha}}{1-\alpha}] \; ln\, U[c(t), L(t)] = ln\, L(t) + (1-\alpha)\, ln\, c - (1-\alpha)$$

αis the consumption marginal utility elasticity, which is used to describe the degree of risk aversion and determines consumers' willingness to shift between periods. The closer αis to 1, the more averse the consumer is to intergenerational inequality; if α=1, the consumer is completely averse to intergenerational inequality. Accordingly, the above equation takes the logarithmic; if α=0, which indicates that consumers are not averse to intergenerational inequality at all, the above equation is linear.

2. construct **a model of economic variables assuming** that

there exists a single good that can be used for consumption, investment, and abatement;

consumption includes not only food and shelter but also non-marketed environmental facilities and services;

each city is given an initial stock of capital and labor and an initial level of technology;

population growth and technological progress are exogenous and specific.

The first model is to estimate net output. Based on the assumption that population or labor is an exogenous variable, define:

$$L(t) = L(t-1)[1+g_L(t)]$$

where gL(t)= population growth rate per period.

Set total output Y(t) to be a C-D function on population and capital, i.e.

$$Y(t) = A(t)K(t)^{\gamma}L(t)^{1-\gamma}$$

$$A(t) = A(t-1)[1+g_A(t)]$$

where A(t) is total factor productivity, A(t-1) is the initial value of gross product, K(t) is the capital stock, and gA(t) is the growth rate.

Apply the following standard equations of economic accounting:

$$Q(t) = C(t) + I(t)$$

$$c(t) = \frac{C(t)}{L(t)}$$

$$\mathrm{K} = \mathrm{I(t)} - \delta_k \mathrm{K(t-1)}$$

where δ_k is the capital depreciation rate.

Assuming that the technical change is Hicks-neutral, the net production Q(T) considering PM2.5 damage with decreasing concentration factors can be expressed as:

$$Q(t) = \Omega(t)[1 - \Lambda(t)]Y(t) = C(t) + I\ \ (t)$$

$$\Omega(t) = \frac{D(t)}{1 + D(t)}$$

$$D(t) = \Psi_1 T_{AT}(t) + \Psi_2 [T_{AT}(t)]^2$$

$$\Lambda(t) = \xi(t)\mu(t)^{\theta}$$

Where D(t) is a reasonably approximate quadratic function of the mean value of all urban air quality change TAT(t), describing the impact or economic damage of air quality change; Λ (t)denotes the PM2.5 concentration reduction cost function and is a function proportional to the power function of the sectoral output ξ(t)and the PM2.5 concentration reduction ratioμ(t).

3. Finally, an economic model of PM2.5 concentration and resource constraints is set up according to the DICE model — a geophysical model. We correlate the atmospheric circulation, radiative forcing and climate change of PM2.5, which is represented at three levels of the atmosphere, sea level and biosphere by the following equation:

$$Z_j(t) = \varphi_j \sigma_t + \varphi_{ij} Z_j(t-1)$$

Zj(t) represents the cyclic values of PM2.5 concentrations at different levels, where j= AT, UP and LO, denoting the three levels of atmosphere, biosphere and deep ocean, and is the cyclic parameter between two levels at each stage.

Using multiple equations above, we define a social welfare function as W based on various exogenous policy variables, and then define the social cost of PM2.5 (SCP) at moment t as

$$SCP(t) = -\frac{\frac{\partial W}{\partial B(t)}}{\frac{\partial W}{\partial C(t)}}$$

Where the numerator is the marginal welfare impact of $PM_{2.5}$ concentration at time t and the denominator is the marginal welfare value of a unit of total consumption at time t. The ratio calculates the economic impact of one unit of $PM_{2.5}$ concentration based on the consumption at time t. Discrete approximations are made in the calculations, and because the damage and abatement are negative, we add negative signs to the model for computational convenience.

2.3.2 Data analysis of normalized processing and presentation of results

We collected data showing that the baseline value of the pure time preference rate ρ in country C is generally around 0.06, assuming α=1 and U in logarithmic form.

Table 1. Estimation of relevant indicators

particular year	R(t)	Log[U(C(t),L(t))]	W
2012	1.89	-2.31	-0.036
2013	2.56	-3.55	0.075
2014	4.10	-2.52	0.32
2015	6.55	-1.56	1.38
2016	10.49	-1.00	28.51

We share that since 2012, the resident population, per capita GDP, fiscal expenditure and fixed assets of city M have shown a rapid growth trend, but the increase is decreasing year by year. We normalize the data related to equation (5) to obtain the value of B(t).

Table 2. City Economic Indicators 2012-2016

Particular year	Population	GDP per capita	Fixed asset investment	Expenditure	$PM_{2.5}$ concentration reduction cost	B(t)
2012	531.37	59623.04	2227.28	467.28	11.13	0.045
2013	599.63	64951.02	2550.51	635.16	11,48	0.032
2014	675,08	70743.63	2941.59	750.55	15.29	0.261
2015	728.63	74116.81	3200.34	934.92	9.28	0,036
2016	786.32	77713.78	3521.17	10378.27	12.50	0.179

Based on the concentration of $PM_{2.5}$ the level of pollution is determined by the high or low AQI, the higher the AQI, the more serious the air pollution and the greater the risk to human health. Our statistical results show that the average annual decrease ratio of $PM_{2.5}$ concentration in the city reached 22.4 % on average, and the average annual air quality composite index ranged from 4.69 to 5.79 (see Table 2), and showed a seasonal variation of higher in winter and lower in summer.

Table 3. The city's PM2.5 concentration and air quality indicators from 2012-2016

Particular year	PM2.5 annual average Concentration($\mu g/m^3$)	Annual average concentration change rate of $PM_{2.5}$(%)	Average value of air quality composite index
2012	65.2	--	4.28
2013	70.2	7.69	4.69
2014	68.4	-2.5	5.79
2015	59.4	-13.16	4.48
2016	57.6	-3	4.76

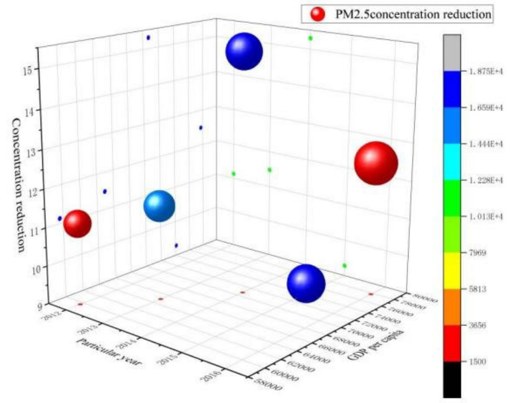

Figure 5. Interannual variation of PM2.5 and GDP(left)

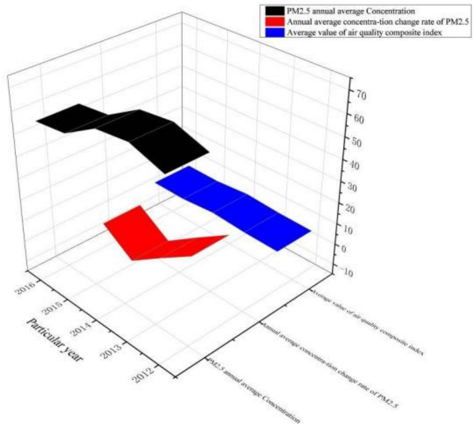

Figure 6. Visualisation of Table 3 data（right）

Due to the availability of data, we only analyze the health damage cost. First, we analyze the physical damage of $PM_{2.5}$ by using the "dose-response" relationship.The model is as follows:

Where $\ln(Y_0)$ represents the base-period mortality/ morbidity, σ_0 represents the base-period $PM_{2.5}$ concentration, β is the relationship parameter, and then the health damage of $PM_{2.5}$ is monetized using the wage-risk method (see Table), and the results show that the loss of premature death caused by $PM_{2.5}$ accounts for value of 55.5% to 66.1%, and chronic bronchitis accounted for about 28.2% to 30%.

Table 4. Value of per capital life damage caused by PM2s in city

Unit:10000 yuan

Particular year	Life value of residents	Premature death	chronic bronchitis	Cardiovascular treatment	Medical costs of asthma	Congestive pulmonary disease
2012	150	82	43	1.9	1.36	0.92
2013	181	100	51	2.3	1.87	1.24
2014	205	121	57	3.1	2.24	2.51
2015	229	140	62	3.5	3.62	3.82
2016	257	170	78	4.1	4.59	5.13

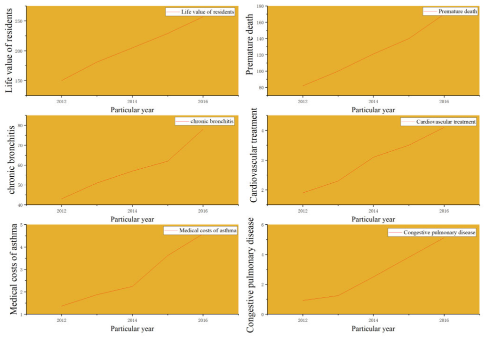

Figure 7. Visualisation of Table 4 data

3. Conclusion

GDP is an effective indicator to reflect the speed and level of a country's economic development. In considering the healthy development of the country's economy, and in the pursuit of comprehensive development and achieving a win-win situation between economic development and environmental protection, GDP accounting has also revealed problems such as resource consumption and environmental pollution, mainly in the following ways.

(1) The interrelationship between resources, the environment and the economy is not adequately reflected. The faster the resources are consumed and the faster the environment is degraded, the more GDP is generated, which to a certain extent promotes economic growth.

(2) The economic activities of resource recovery and environmental pollution management increase GDP again, which is reflected in economic growth. From the

perspective of natural and economically sustainable development, this double impact exaggerates GDP to a certain extent and causes a certain degree of ineffective economic growth.

Green GDP, on the other hand, refers to deducting from GDP the cost of resource consumption and environmental damage caused by economic development. Promoting the transition from a GDP accounting system to a green GDP accounting system is also an effective response to the current neglect of ecological and environmental issues in economic development.Only by focusing on the quality of GDP growth, reducing destructive and ineffective growth and establishing a green GDP accounting methodology that measures the circular economy pointer system can we ensure sustainable economic development and sustainable use of the environment. Only by establishing a green GDP accounting method that measures the indicators of the circular economy can we ensure the sustainable development of the economy and the sustainable use of the environment.

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